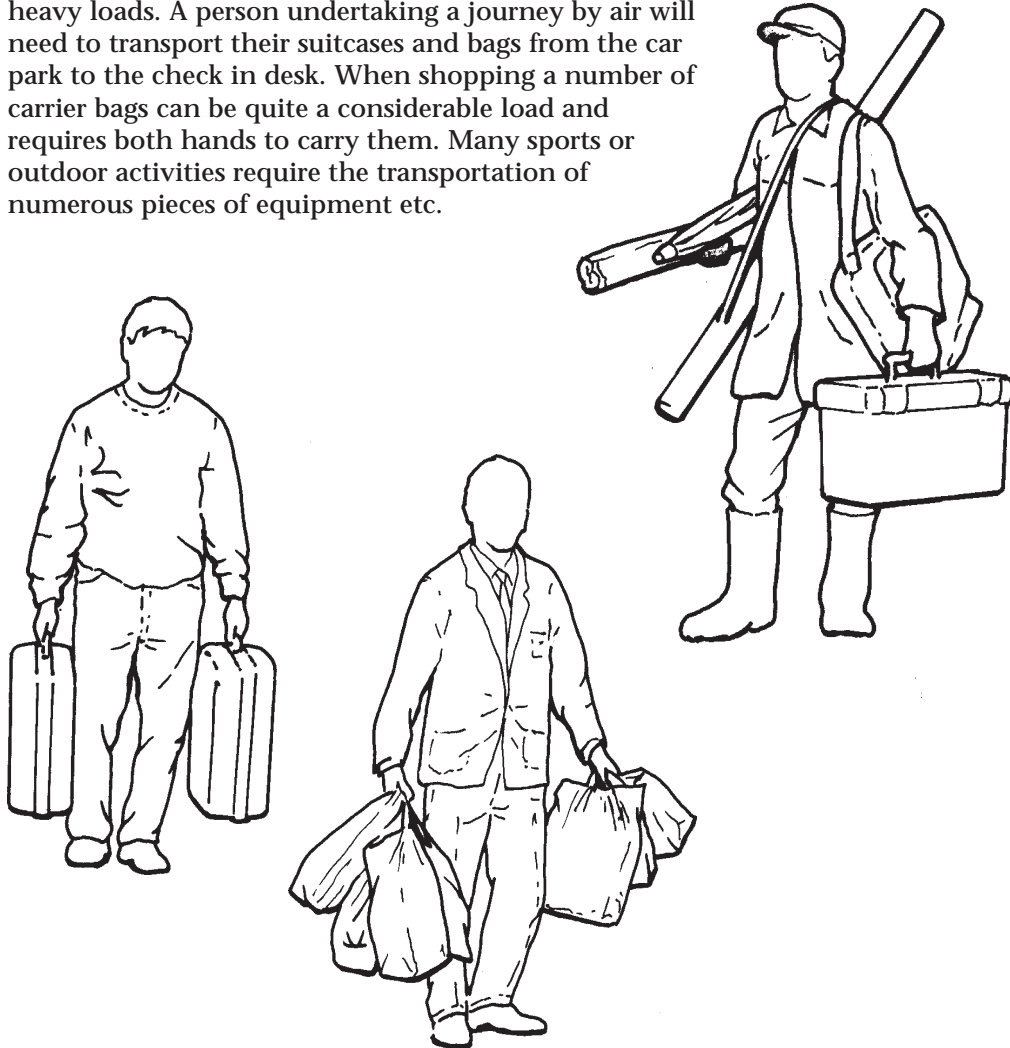


DESIGNING AND MAKING A LIGHTWEIGHT FOLD-DOWN CARRYING UNIT

It is often necessary when undertaking some activities, or when in some situations, for a single person to carry relatively heavy loads. A person undertaking a journey by air will need to transport their suitcases and bags from the car park to the check in desk. When shopping a number of carrier bags can be quite a considerable load and requires both hands to carry them. Many sports or outdoor activities require the transportation of numerous pieces of equipment etc.



These situations, and no doubt some others, present a design opportunity: assisting in the transportation of a load. A carrying aid or unit would need to be as light as possible or it would simply add to the burden. The unit's ability to fold-down to a smaller size when not in use would improve its performance as it could be stored or transported easily when not in use. The structural integrity, or strength, of the unit would have to be as high as possible within the limits set by the optimum weight.

DESIGN BRIEF

Design and make a lightweight fold-down carrying unit that will be used in a situation that has been identified, described and investigated by you. The unit must be as light and as structurally robust as possible. It must fold-down to a convenient size for easy transportation and storage. The folding mechanism should be quick and easy to operate and must be secure when the unit is in use.

DESIGN CONSIDERATIONS

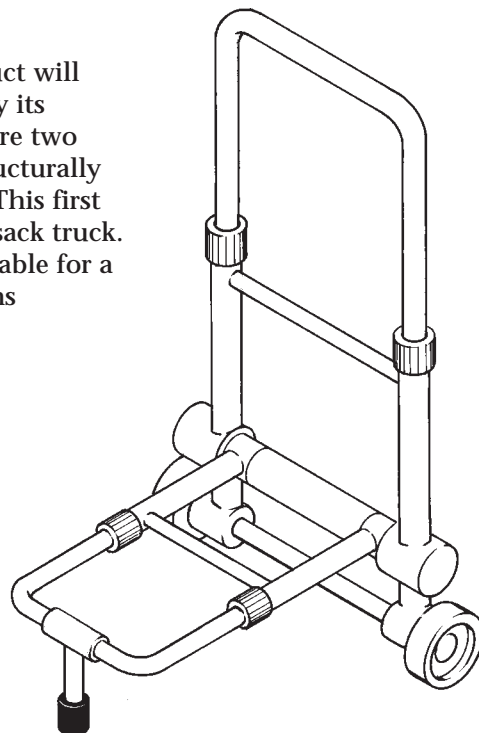
Once you have chosen the context for your product you will need to begin to think about how to develop your design. The success of the product will depend upon how well it satisfies the factors identified in the design brief and those which you list in your own specification. Perhaps the two major considerations will be the structural strength and lightness and the folding mechanism.

STRUCTURE

The two major factors that will affect the structural strength and the lightness of your product will be the form of the structure and the materials that you choose to use. It is most likely that your product will be some form of frame structure. It is possible to carry out simple structural analysis of your design ideas which will help you to make reasoned decisions about the quality of your design.

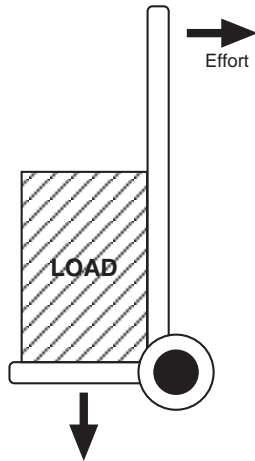
FORM

The form of your product will obviously be affected by its function. Shown here are two examples of how to structurally analyse simple forms. This first idea is based upon the sack truck. The form would be suitable for a number of the situations identified.

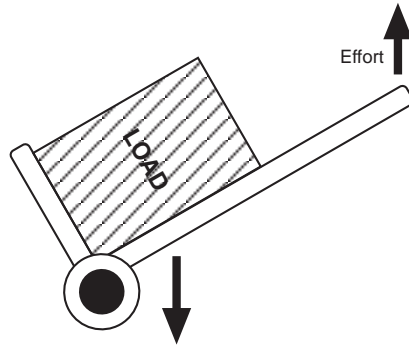


When in use this design has two major functions. The first is to lift the load and the second is to support it.

When lifting the load the structure acts as a first class lever.
 When carrying the load the structure acts as a second class lever.

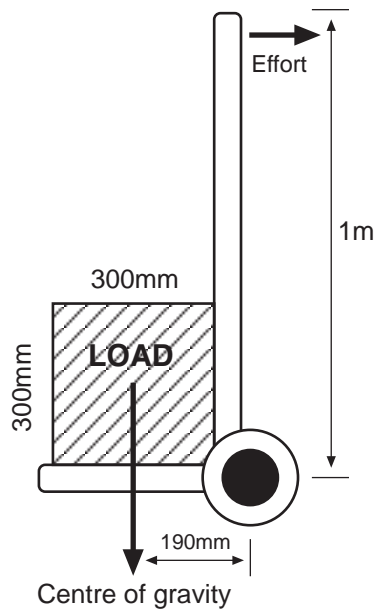


Structure acting as 1st class lever



Structure acting as 2nd class lever

Using *moments* it is possible to calculate what loads are present in different parts of the structure. When initially lifting the load a turning force is applied to the top of the handle. The magnitude of this force is calculated using moments.



The anticlockwise moment (ACWM) applied by the load is first calculated thus:

$$\begin{aligned} \text{ACWM} &= \text{Force} \times \text{distance from fulcrum} \\ &= 200 \text{ N} \times 190\text{mm} (0.19\text{m}) \\ &= \underline{38\text{Nm}} \end{aligned}$$

(The distance from the fulcrum is 190mm as we assume that the force created by the load acts at its central point, i.e. the centre of gravity.)

To lift the load, a clockwise moment that is greater than the anticlockwise moment must be applied to the structure. To calculate the magnitude of the force needed to apply this moment:

$$\text{CWM} > \text{ACWM}$$

$$\text{Force} \times 1\text{m} > 38 \text{ Nm}$$

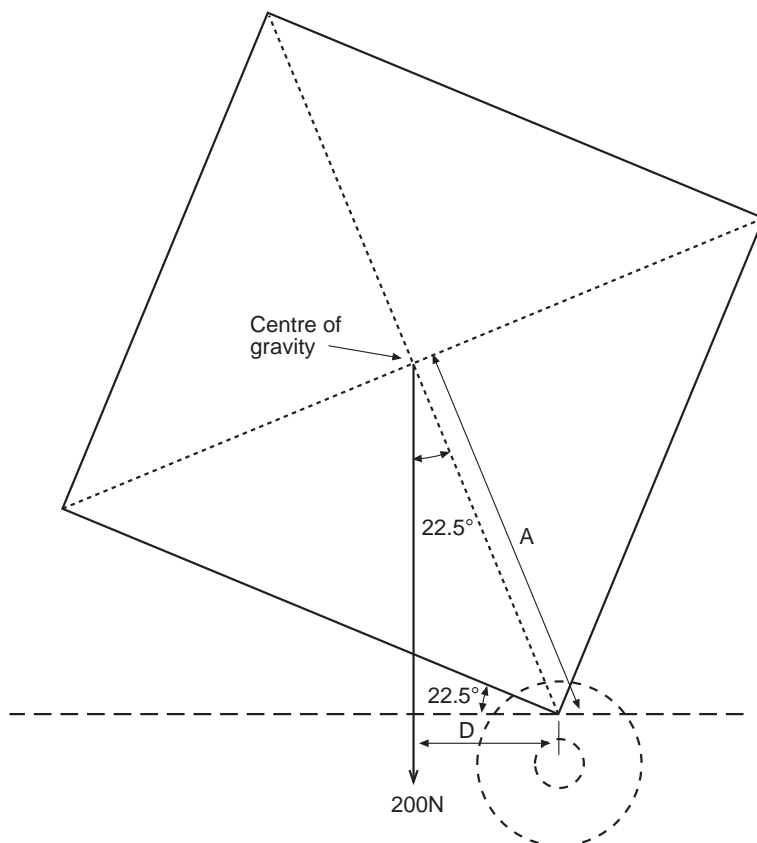
$$\text{Force} > \frac{38 \text{ Nm}}{1\text{m}}$$

$$\text{Force} > \underline{38 \text{ N}}$$

As the load is lifted the moments and, hence, the applied forces will change. This is because a moment is calculated as **the magnitude of the force multiplied by the perpendicular distance of the point from its line of action.**

When the structure turns to lift the load the perpendicular distance of the forces from the fulcrum changes. The load force acts vertically as gravity is pulling it downwards. Therefore the perpendicular distance is measured horizontally from the fulcrum.

With the structure now at 22.5° the moments and, hence, the applied lifting force can be calculated.



STRUCTURES POST 16 UNIT 3

ACWM = Force \times perpendicular distance

$$\text{Force} = 200 \text{ N}$$

Perpendicular distance = D

$$A = \text{Diagonal of load} \div 2$$

Using Pythagoras:

$$\begin{aligned} \text{Diagonal of load} &= \sqrt{100^2 + 100^2} \\ &= 141.42 \text{ mm} \end{aligned}$$

$$\begin{aligned} \text{So, } A &= 141.42 \div 2 \\ &= \underline{70.7 \text{ mm}} \end{aligned}$$

Calculating perpendicular distance D:

$$\begin{aligned} \sin 22.5^\circ &= \frac{D}{70.7} \\ D &= 70.7 \sin 22.5^\circ \\ &= \underline{27 \text{ mm}} \end{aligned}$$

Therefore,

$$\begin{aligned} \text{ACWM} &= 200 \text{ N} \times 0.027 \text{ m} \\ &= \underline{5.4 \text{ Nm}} \end{aligned}$$

To lift the load,

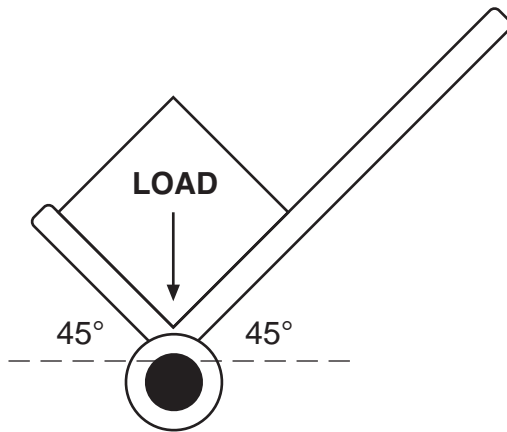
$$\text{CWM} > \text{ACWM}$$

$$\text{Force} \times 1 \text{ m} > 5.4 \text{ Nm}$$

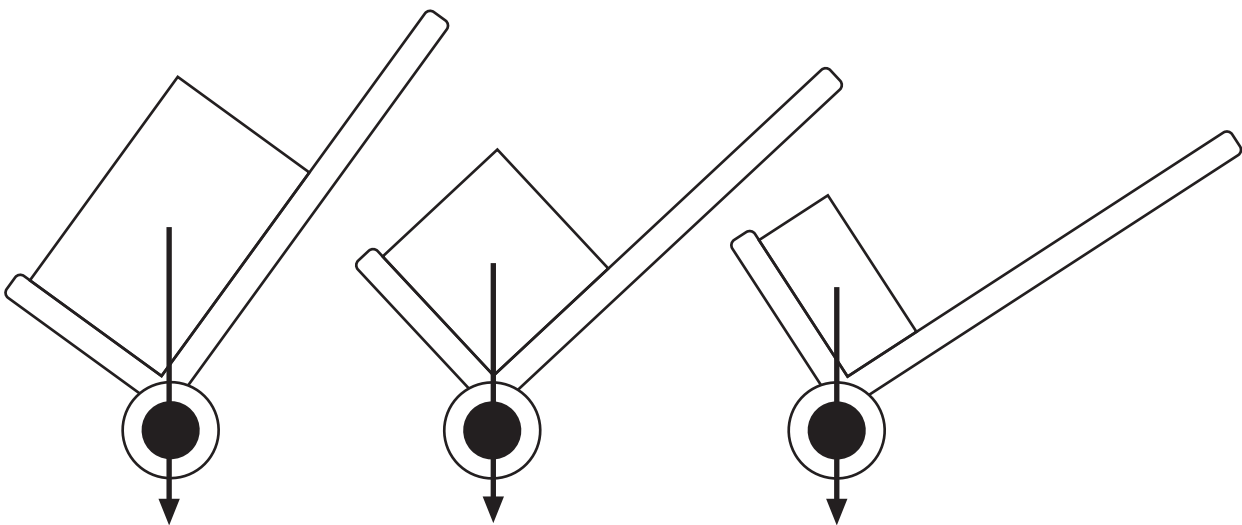
$$\text{Force} > 5.4 \div 1$$

$$\text{Force} > \underline{5.4 \text{ N}}$$

So, as the structure turns the force that is applied to the handle to lift it reduces. This force will continue to reduce until the force applied by the load is directly above the fulcrum. At this point The ACWM and the CWM will be zero and, hence the lifting force will be zero.



This point of no lifting force occurs when the structure is in equilibrium, or balanced. This is obviously the best angle for the structure to be at when transporting the load. In the example shown the angle will be at 45°. This is because the load is square. If the load were rectangular then its centre of gravity would be at a different point and, therefore, the perpendicular distance to the fulcrum would alter at a different rate. This means that the optimum carrying angle, or balance point, will change for different loads. You will need to investigate this further if you choose to use this form of structure.



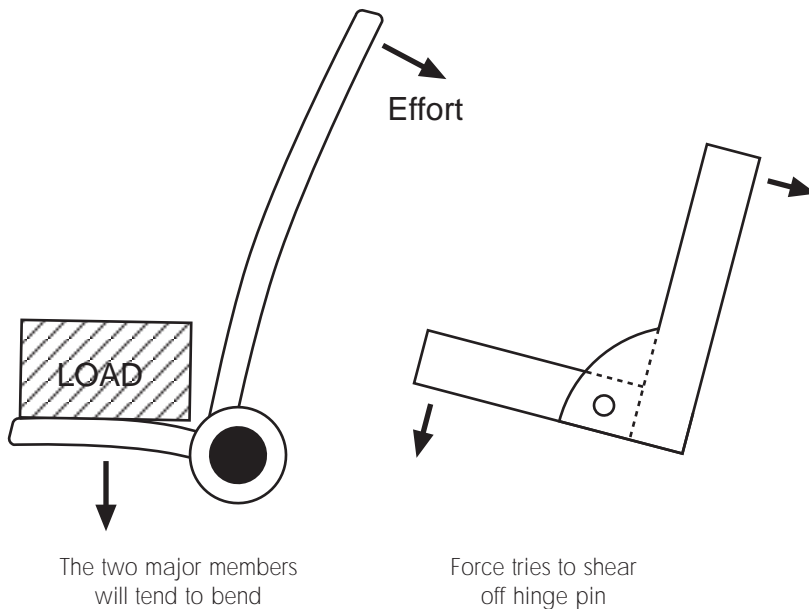
Balance points for different load sizes

When the balance point is exceeded the structure will now act as a second class lever.

The force that needs to be applied to lift the handle can be calculated in a similar way. When calculating this remember that it is the perpendicular distance to the fulcrum that is used and not the actual distance.

From the above calculations, and any subsequent ones that you carry out, you will see that the structure is under maximum load when the load is initially lifted. The forces will act upon the structure to attempt to deform it. Its rigidity will resist these forces.

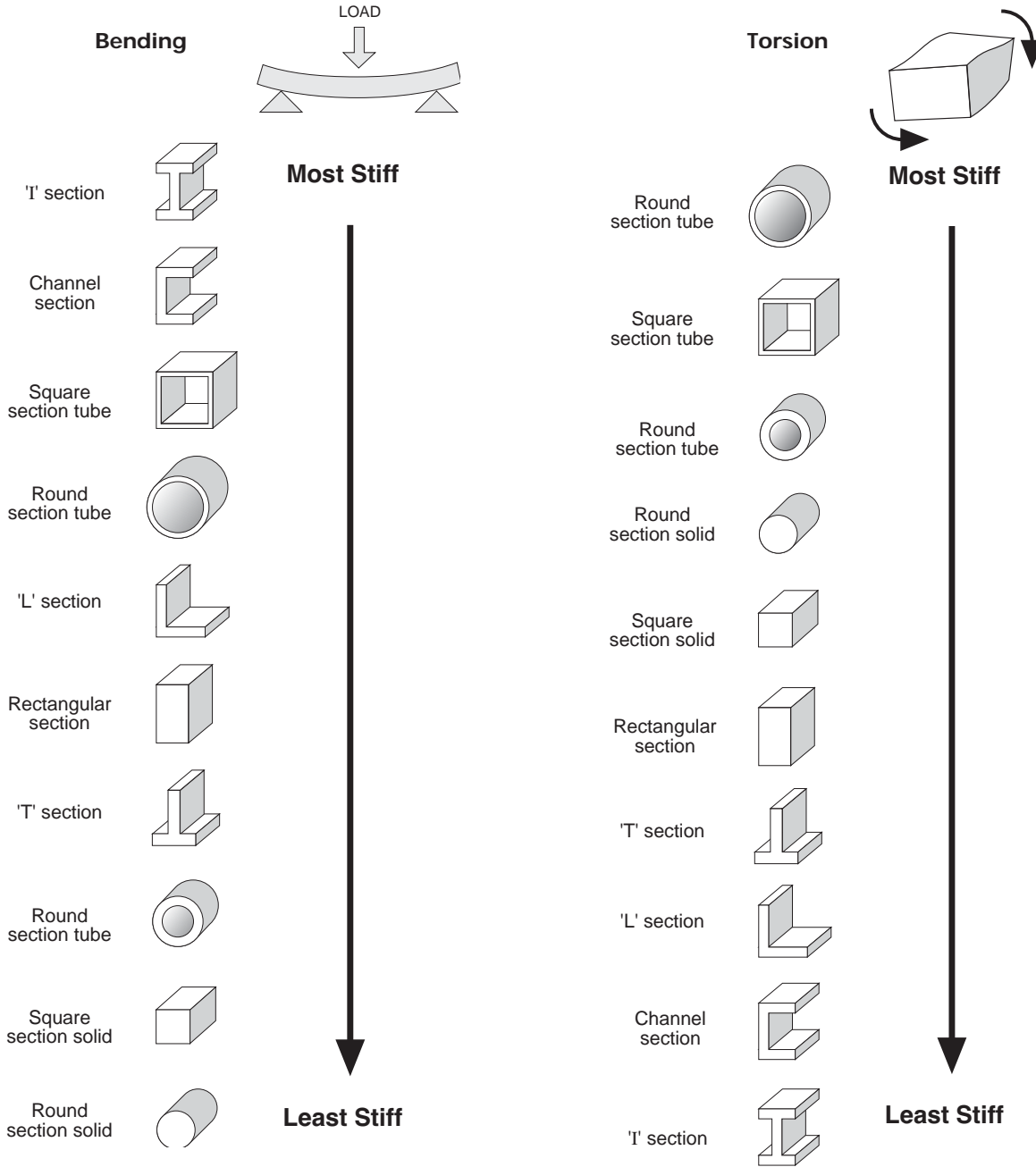
The two major members will have bending forces applied by the load and the lifting force. The joint at the fulcrum will have a turning force applied to it which will translate into a shear force at the joint.



The ability of the structures form to resist the bending forces will be mainly affected by the stiffness of the members. The stiffness of the members is affected by the material that they are made from and also their cross-sectional shape. The table on the following page shows a simple way of comparing the inherent stiffness of different cross sections. You can use this to select appropriate cross-sections for the major members of your structure.

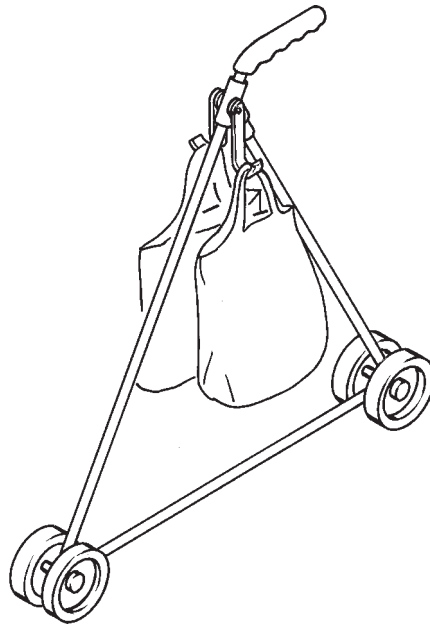
STIFFNESS OF SECTIONS

Comparative stiffness of sections with the same cross-sectional area.



The shear force can be reduced by spreading the load at the hinge points. This is done by increasing the contact point to a maximum acceptable area.

This next idea is based upon a simple 'A' Frame. The load is supported at the apex of the frame.



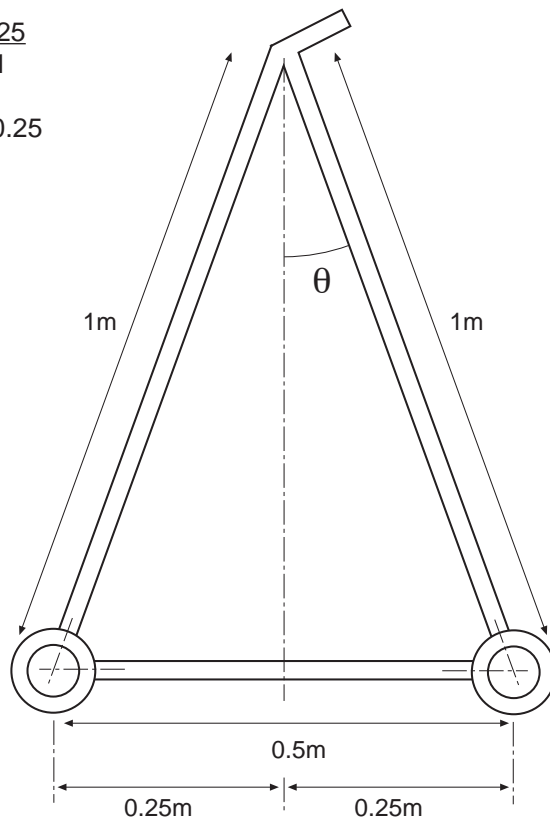
To analyse the behaviour of this structure you could calculate the magnitude of the compressive and tensile forces in the structure's members.

To do this you first need to calculate the angle at the apex of the frame.

$$\sin \theta = \frac{0.25}{1}$$

$$\theta = \sin^{-1} 0.25$$

$$= \underline{14.47^\circ}$$



Next you need to draw a force vector diagram and then use Bow's Notation to establish the magnitude of the forces in the supporting members.

In triangle ADC calculate the length dc (tie force magnitude).

$$\tan \theta = \frac{\text{Tie force}}{50}$$

$$\text{Tie force} = 50 \tan 14.47^\circ$$

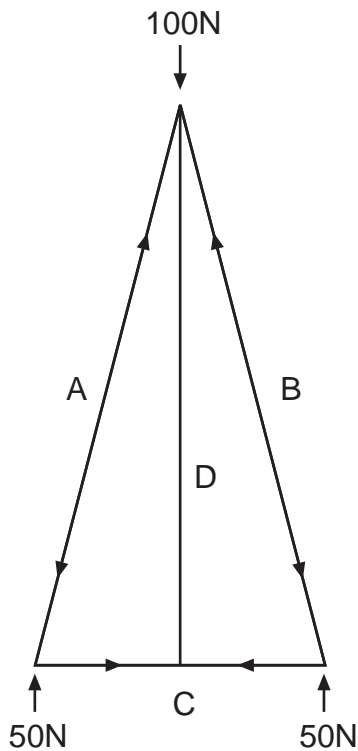
$$= \underline{12.9 \text{ N}}$$

Calculate length ad = bc (strut force magnitude)

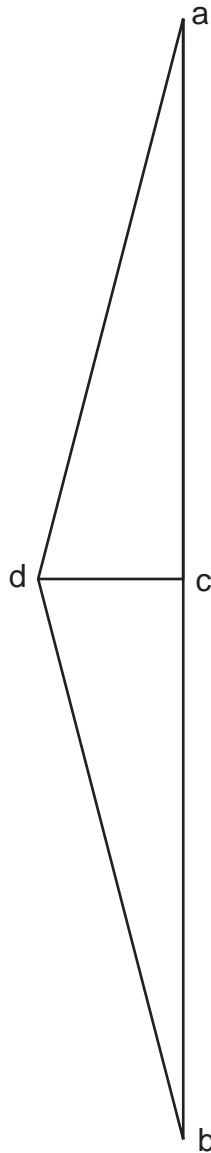
$$ad = bc = \frac{50 \text{ N}}{\cos 14.47}$$

$$= \frac{50 \text{ N}}{0.968}$$

$$= \underline{51.6 \text{ N}}$$

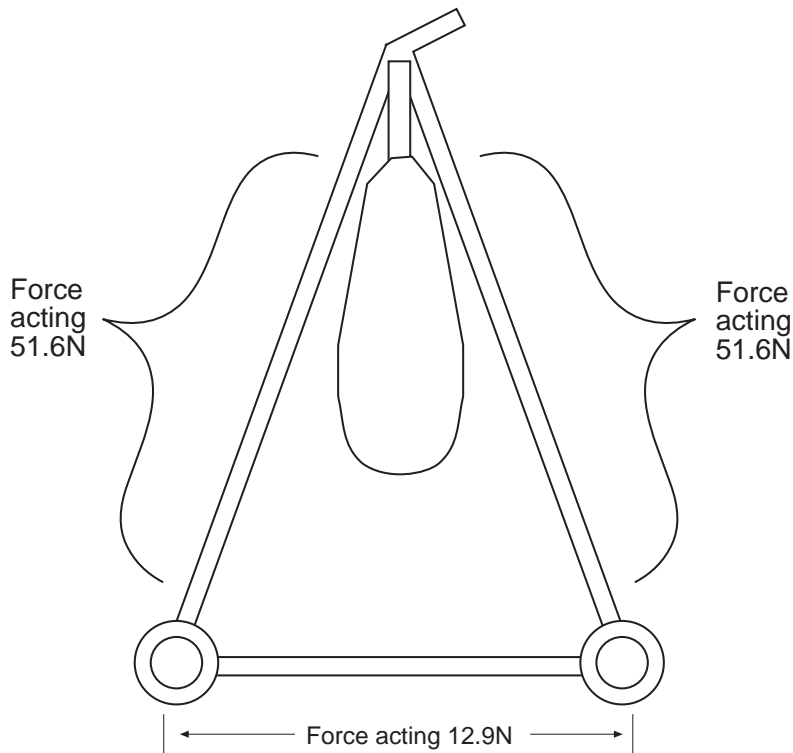


Force diagram



Bow's Notation diagram

So each strut will have 51.6 N of compressive force acting upon it.



Again the cross-section of the members will affect their ability to resist bending forces, i.e. stiffness. The struts will need to be able to resist these forces whereas the tie will not be subjected to them. You can use the above table of comparative stiffness to aid you in selecting the appropriate cross-section for your design.

MATERIALS

The materials that you choose to use will affect the lightness and the strength of your structure. Once you have chosen the material for its physical properties you can calculate what the minimum cross-sectional area must be to resist the forces in your structure.

The tables shown on the next page list various figures for the structural properties of a variety of materials.

The proof or yield stress (σ_y) gives a typical range of figures for the amount of stress that a material can be subjected to before it permanently deforms. It is normal practice to take the lowest figure for reasons of safety.

Here is an example of how to use these figures. Using the results of the calculations on the 'A' frame you can see that the force acting on one side member (strut) is 51.6N.

If you choose to use aluminium then the table shows a figure of 30 - 140 for σ_y .

Stress is the amount of force acting upon the cross-sectional area of the material.

So,

$$\text{Stress} = \frac{\text{Force}}{\text{Cross-sectional area}}$$

To calculate the minimum Cross-sectional area,

$$\begin{aligned} \text{Area} &= \frac{\text{Force}}{\text{Stress}} \\ &= \frac{51.6 \text{ N}}{30 \text{ N / mm}^2} \\ &= \underline{1.72 \text{ mm}^2} \end{aligned}$$

This seems very small. But remember if you simply use a square section bar of this size it will remain within the maximum stress loading but it will not be resistant to bending forces and so the structure will fail. If, however you were to use a much stiffer cross-section, such as square section tubing then the same cross-sectional area could be used but would be far more resistant to the bending forces.

SOME MECHANICAL PROPERTIES OF METALS

- E Young's modulus (kN/mm²) - (linear stress)/(linear strain)*
- G Shear modulus (kN/mm²) - (shear stress)/(shear strain)* *within the elastic limits
- ν Poisson's ratio - (lateral strain)/(longitudinal strain)*
- σ_y Proof or yield stress (N/mm²)
- σ_f Ultimate (failure) stress (N/mm²)

Values of σ_y and σ_f usually depend strongly on the preparation and condition of a material. The ranges given are typical but not necessarily exhaustive and, unless otherwise stated, those for metals refer to drawn or wrought rather than cast material of commercial purity.

| | σ_f | σ_y | E | G | ν |
|--------------------------|------------|------------|-----|-----|-------|
| <i>Metallic elements</i> | | | | | |
| Aluminium | 60-160 | 30-140 | 70 | 26 | 0.34 |
| Copper | 200-350 | 47-320 | 124 | 46 | 0.35 |
| Gold | 110-230 | 0-210 | 80 | 28 | 0.42 |
| Iron (wrought) | 350 | 160 | 195 | 76 | 0.29 |
| Iron (cast) | 140-320 | | 115 | 45 | 0.25 |
| Lead | 15-18 | | 16 | 6 | 0.44 |
| Nickel | 480-730 | 140-660 | 205 | 79 | 0.31 |
| Platinum | 125-200 | 15-180 | 168 | 61 | 0.38 |
| Silver | 140-380 | 55-300 | 76 | 28 | 0.37 |
| Tantalum | 340-930 | | 186 | | |
| Tin | 15-200 | 9-14 | 47 | 17 | 0.36 |
| Titanium | 250-700 | 200-500 | 110 | 41 | 0.34 |
| Tungsten | 1000-4000 | | 360 | 140 | |
| Zinc | 110-200 | | 97 | 36 | 0.35 |

Alloys

| | σ_f | σ_y | E | G | ν |
|--------------------|------------|------------|-----|----|-------|
| <i>Alloys</i> | | | | | |
| Brass (65/35) | 330-530 | 62-430 | 105 | 38 | 0.35 |
| Constantan (60/40) | 400-570 | 200-440 | 163 | 61 | 0.33 |
| Dural (4.4% Cu) | 230-500 | 125-450 | 70 | 27 | 0.33 |
| Manganin (84% Cu) | 465 | | 124 | 47 | |
| Mumetal (77% Ni) | 540-910 | | 220 | | |
| Nichrome (80/20) | 170-900 | | 186 | | |
| Phosphor-bronze | 330-750 | 110-670 | 100 | | 0.38 |
| Steel mild | 480 | 240 | 210 | 81 | 0.30 |
| Steel high yield | 600 | 450 | 210 | 81 | 0.30 |

FOLDING MECHANISM

There are many and varied mechanisms and locking devices already in use on folding structures. The type that you choose to use will depend very much on the function of your product and the method of folding. Remember that if the product is to be successful then it needs to fold to a convenient size for easy storage and transportation and also needs to be stable and secure when in use.

A very good source for researching these folding and locking mechanisms would be to analyse some existing products. Perhaps the most ingenious and 'high-tech' of the possible examples would be the modern 'baby buggy'. These products have been subjected to many years of design effort and have now reached a considerably advanced state. A few simple actions can fold the full-size buggy into a very compact space without the use of any tools. When unfolded they lock securely in position, usually automatically, and provide a very stable and safe environment.

The success of your product will be dependent 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, lock securely in both states and be both ergonomically sound and aesthetically pleasing.