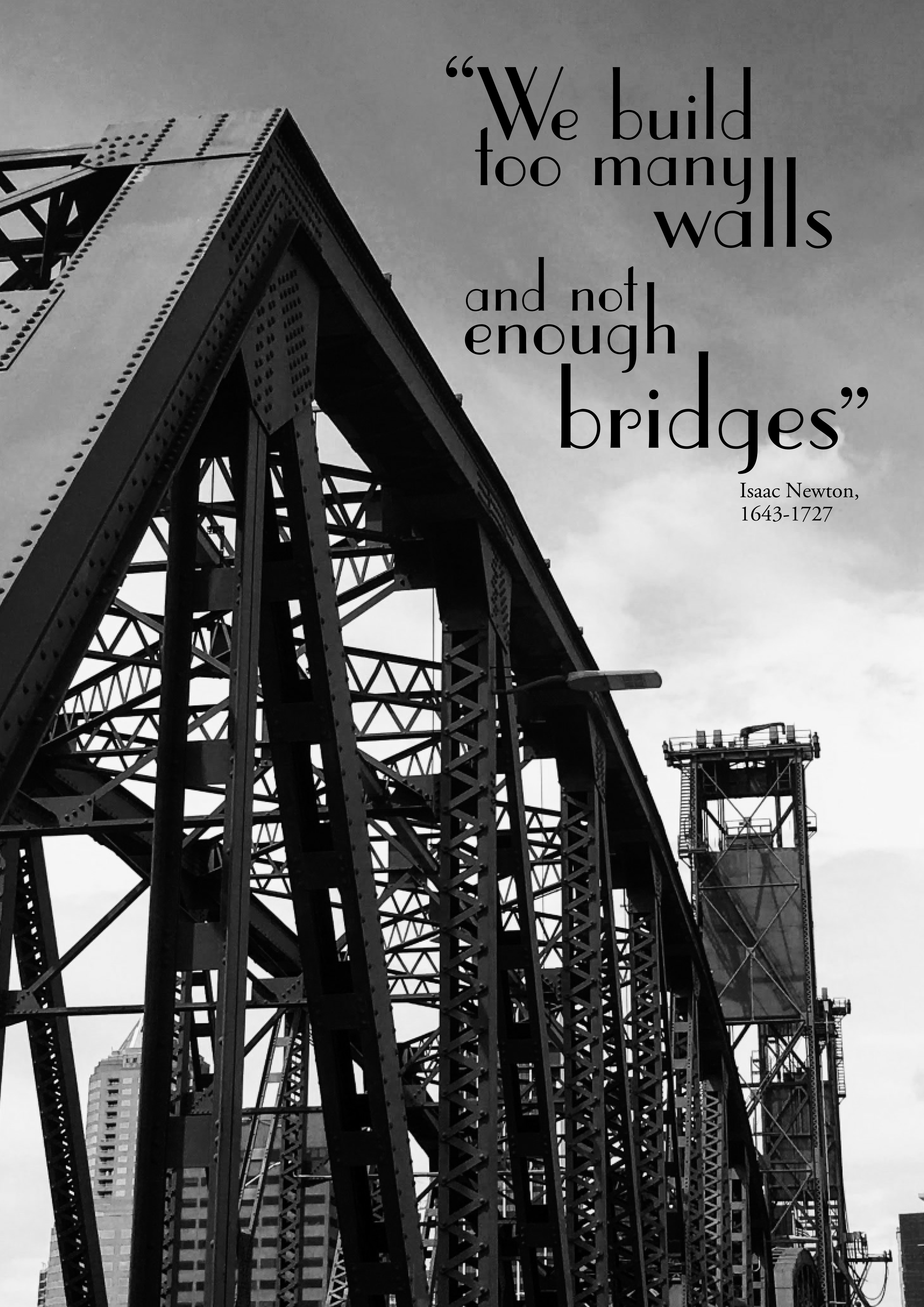

"We build
too many
walls
and not
enough
bridges"
Isaac Newton,
1643-1727

What shall we learn?

All forms of civil engineering, mechanics or architecture requires the designers and engineers to have an understanding of materials, forces and structures.

The complex world of making structures relies on understanding the mathematics of forces.

In this unit, you will learn the basics of structural engineering and how engineers use this to create the built environment around us.

You will know you are ready for your exam when you are able to

- ○ I can describe what a force is.
- ○ I can explain the term ‘tensile’.
- ○ I can explain the term ‘compressive’.
- ○ I can describe a ‘concurrent force’.
- ○ I can explain ‘equilibrium of forces’.
- ○ I can use free-body diagrams.
- ○ I can describe a ‘non-concurrent force’.
- ○ I can calculate moments of a force.
- ○ I can calculate the forces in a beam.
- ○ I can select and justify a material choice.
- ○ I can calculate stress, force and area.
- ○ I can calculate strain in a material.

In your National 5 exam you will be expected to answer questions about structures, forces and materials.

The exam will have between:

7 - 12 marks on structures and forces
and
6 - 10 marks on materials

What is a Force?

A force is a push or pull upon an object resulting from the object's interaction with another object. This is typically kinetic or potential energy, but not always!

Whenever there is an interaction between two objects, there is a force upon each of the objects. When the interaction ceases, the two objects no longer experience the force. Forces only exist as a result of an interaction.

‘Contact forces’ are those types of forces that result when the two interacting objects are perceived to be physically contacting each other. Examples of contact forces include frictional forces, tensional forces, air resistance forces, and applied forces. In fig 1.0, the force of the finger must overcome the opposing force of the friction to move the block forward. If the finger stops pushing, the force of friction will stop the block moving.

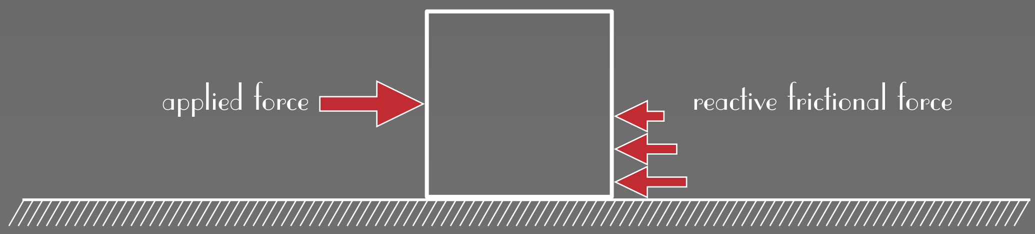


fig 1.0

When a force is applied to an object or structure it will move, even if only slightly. If the force is too great, an object or structure can be come deformed (fig 1.1) or eventually break.

Sometimes when forces are applied to a structure it may be almost impossible to see changes happening. For example, a bridge will sag slightly when a vehicle drives over it, but this is not visible to the human eye.

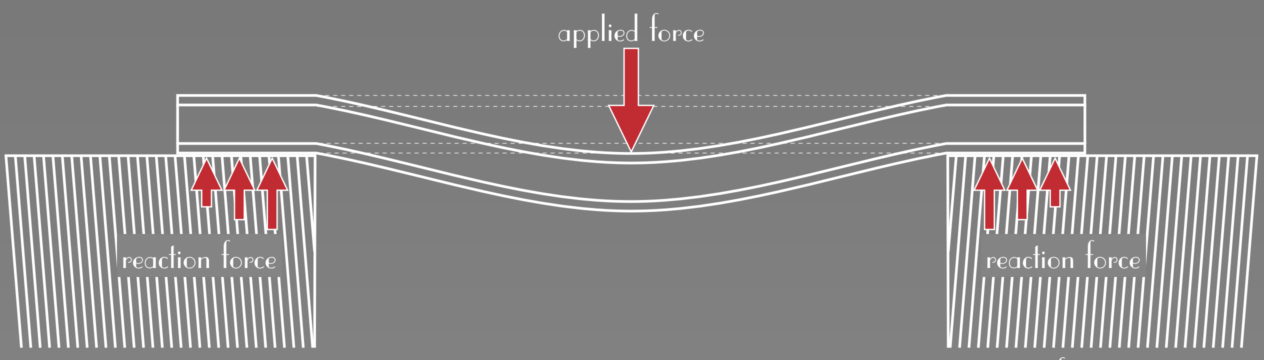


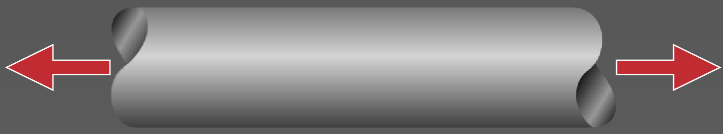
fig 1.1

How do we describe force?

Force is a quantity that is measured using the standard metric unit known as the Newton.

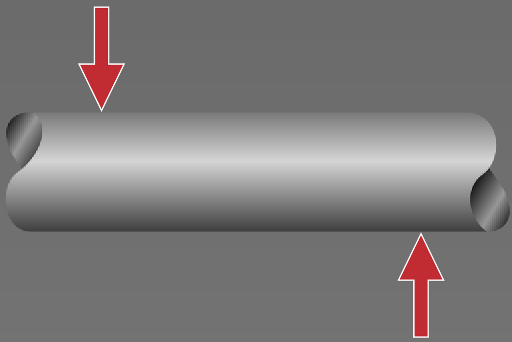
A Newton is abbreviated by an "N." "10.0 N" means 10 Newton of force.

One Newton is the amount of force required to give a 1kg mass an acceleration of 1 m/s^2.



Tension is the term used to describe the act of forces pulling on a piece of material in at-least two directions. Tension can result in a piece of material becoming stretched to the point where it will snap. Some materials are better with tensile forces than others.

Compression is the term used to describe the act of forces pushing or squeezing a material. Compressive forces act to squash a material. Some materials can withstand compressive forces better than others. Materials undergoing too great a compressive force will squash, bend or buckle.



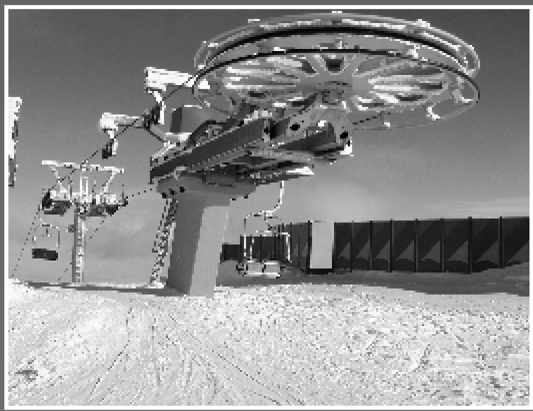
Shearing is the term used to describe forces that act perpendicular - 90^{o} degrees - to the material. Shearing forces can be useful; aeroplane wings rely on the shearing force of air to give the wings lift. Some shearing forces can result in the material breaking.

Static forces

Static forces as their name suggest means the force does not move. This is move commonly used where objects are placed under a force to stop them from moving. A good example is a g-cramp, which applies force to grip materials together. Other examples include scaffolding used in construction or electricity pylons.

Dynamic forces

Dynamic forces are ones that move. Whilst these are common used in levers to move objects, they can be found in a range of devices where one mechanism moves another one, often of greater mass. Winches, cranes



Bending forces

Bending forces is referred to as a '*bending moment*'. It is the reaction induced in a structural material when an external force is applied to the material, causing it to bend. The most common or simplest structural element subjected to bending moments is a beam, such as those used in bridges, which will bend under load.

Torsion forces

Torsion forces are best described as a twisting or turning force. The same principle of leverage applies; the longer the lever, the less effort is required to move the load. Examples of torsion forces include spanners, wrenches and screwdrivers.

Forces & Levers

Levers are simple machines designed to help move heavier loads using a smaller force. There are three parts to a leaver; a beam, a fulcrum and applied loads, see figure 2.0. As a designer or engineer, you must understand how levers work and calculate the sizes and forces involved.

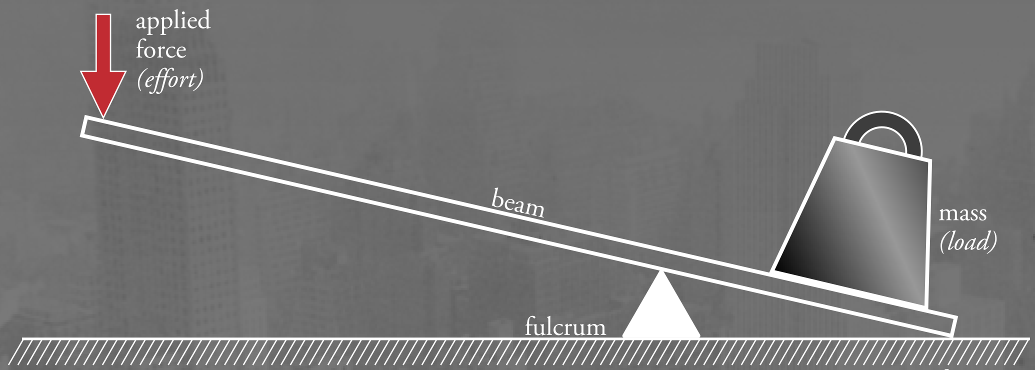


fig 2.0

The point that a lever pivots about is called a fulcrum. On one side of this fulcrum is the mass to be moved. This mass is called the 'load'. On the other side of the fulcrum is the applied force, called the 'effort'. The greater the distance between the fulcrum and effort, the easier it becomes to move the load. This is one of the most simple machines created by humans.

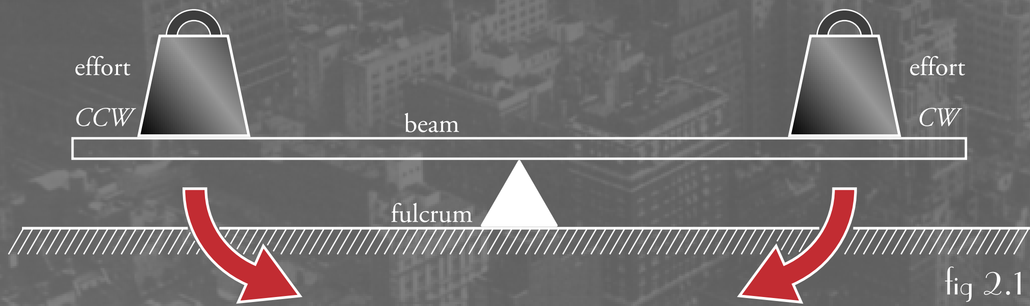


fig 2.1

The type of lever shown is called a *'type 1 lever'*, with countering efforts on either side of the fulcrum.

Effort applied to either side of a fulcrum will have a different turning effect on the beam. Effort applied on the right of the fulcrum will try to move the beam clockwise. Effort applied to the left of the fulcrum will try to move the beam counter-clockwise. To stop the beam moving, the effort on both sides of the fulcrum needs to be equal in its' turning effect.

This turning effect is called a *'moment'*.

Give me a moment...

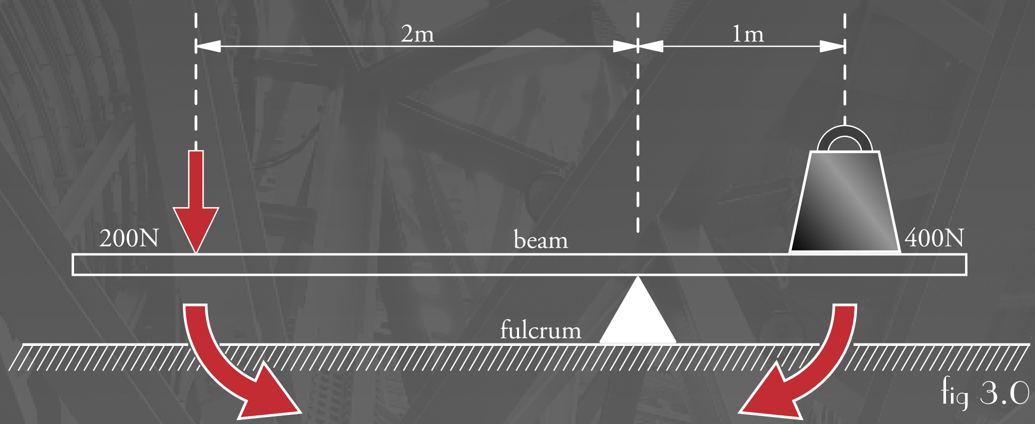


fig 3.0

The lever system in figure 3.0 shows a lever that is in a state of balance, called 'equilibrium'. The input force is tending to turn the lever counter-clockwise; the load is tending to turn the lever clockwise.

The forces on each end of the lever are exerting a moment: one clockwise, the other counter-clockwise. If the beam (lever) is in equilibrium, both of these moments must be equal.

The principle of moments states that the sum of the moments must equal zero or the sum of the clockwise moments must equal the sum of the anticlockwise moments. The Greek letter ∑ (epsilon) is used by designers, engineers and mathematicians for *'the sum of'* and are used as a shorthand way of writing the principle of moments:

$$\sum CWM = \sum CCWM$$

$$F1 \times d1 = F2 \times d2$$

The force (F) multiplied by the distance (d) turning the lever clockwise is equal to the force multiplied by the distance turning the lever anticlockwise.

Moments are measured in *newton-metres*. It can be seen that the moment on one side of the lever is equal to the moment on the other side. (Work done = force x distance in the direction of motion.)

A moment is a force multiplied by a distance:

The load is exerting a clockwise moment; that is, it is tending to make the lever turn clockwise.

Clockwise moment = 400N x 1m = 400Nm

The effort is exerting a counter-clockwise moment; that is, it is tending to make the lever turn counter-clockwise.

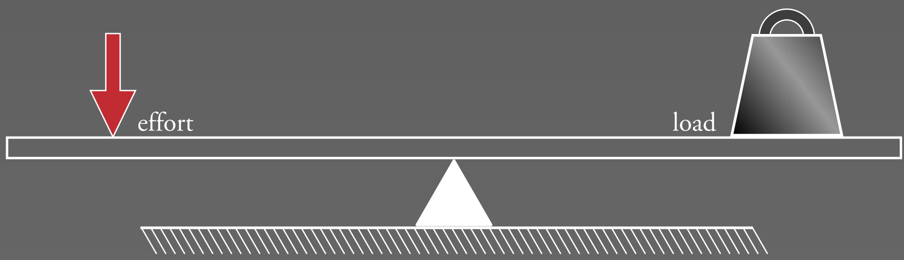
Anticlockwise moment = 200N x 2m = 400Nm

Therefore, $\sum CWM = \sum CCWM$

Types of lever

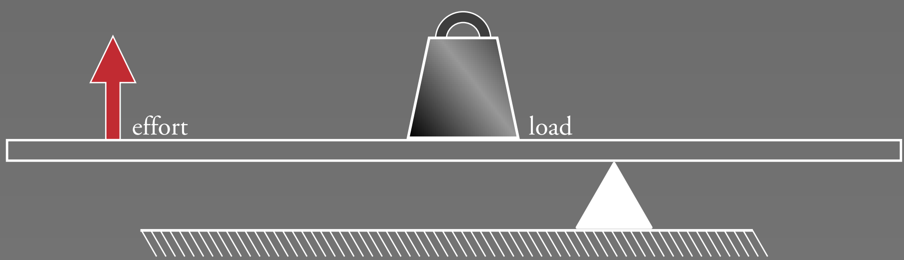
There are different types of lever used in different in conditions.

Class one



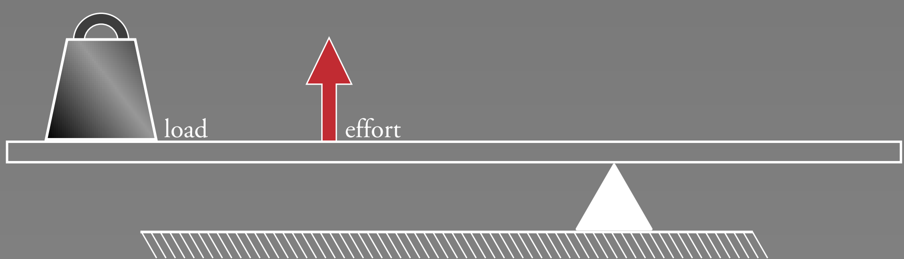
'Class One' levers are the easiest to understand. On one side of the fulcrum is the effort and on the opposite side, the load. A lever amplifies an input force to provide a greater output force, which is said to provide *'leverage'*.

Class two



'Class Two' levers have the load in or near the middle: the effort is applied on one side of the resistance and the fulcrum is located on the other side, for example, a wheelbarrow, a nutcracker, a bottle opener or the brake pedal of a car.

Class three



'Class Three', the effort in the middle: the resistance (or load) is on one side of the effort and the fulcrum is located on the other side, for example, a pair of tweezers

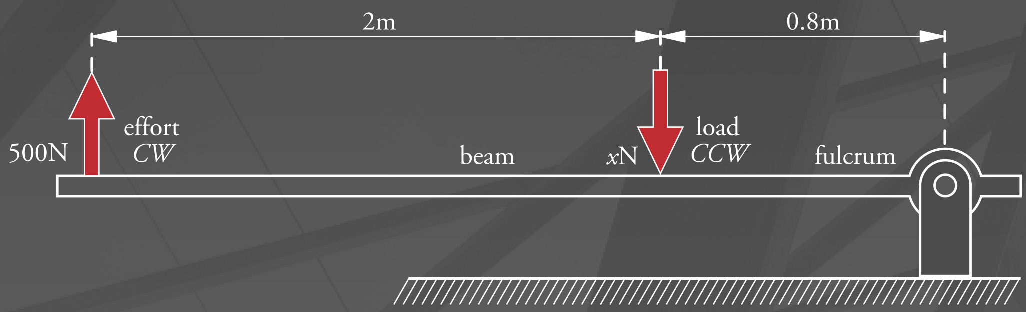


fig 3.1

The lever shown in figure 3.1 is a 'class 2' lever, where both load and effort are on one side of the fulcrum. Class 2 levers are often used to amplify forces in a system.

In the example, the effort acting counter-clockwise is 3m from the fulcrum with the reaction, clockwise effort, 1m from the fulcrum.

Take moments about the fulcrum to find the force on the system.

The principle of moments states that:

$$\sum CWM = \sum CCWM$$

$$F1 \times d1 = F2 \times d2$$

$$500N \times 3m = F2 \times 0.8m$$

$$F2 = \frac{500N \times 3m}{0.8m}$$

$$F2 = 1{,}875N \text{ (or } 1.875kN)$$

This means that the 500N force will create a 1,875N force at point F2.

Force multipliers

Class 2 levers are often called *'force multipliers'*. This means the lever will lift a load with either the same or less force required. Class 1 levers can sometimes act as force multipliers, depending on how they are set up.

Class 3 levers are not force multipliers.

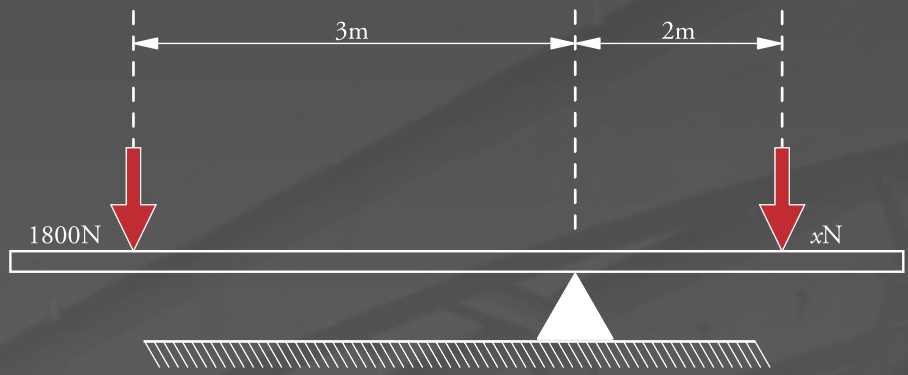
Force multipliers work like below:

Find the force-multiplier ratio for the lever in figure 3.1. Note, there are no units to the ratio!

$$\text{Force-multiplier ratio} = \frac{\text{load}}{\text{effort}} = \frac{1875N}{500N} = 3.75$$

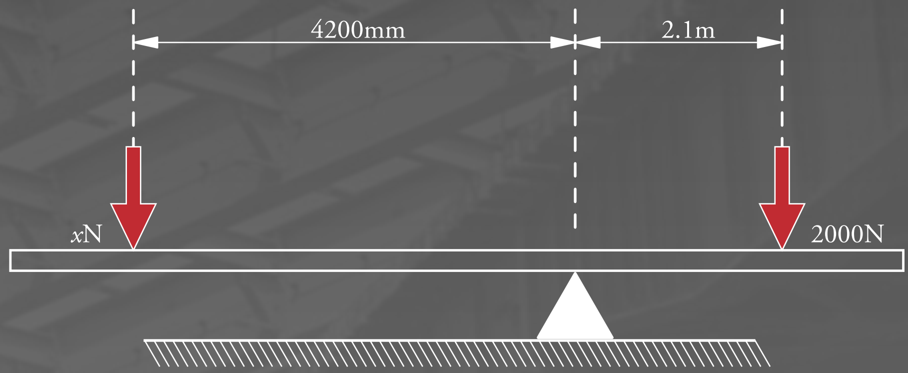
Practice 1

In this simple class 1 lever you are challenged to calculate the load at 'x'.



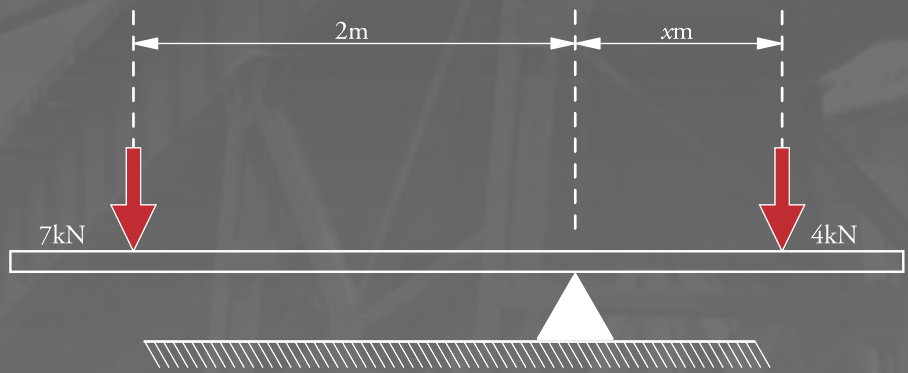
Practice 2

In this simple class 1 lever you are challenged to calculate the load at 'x'. Check the units used in the question!



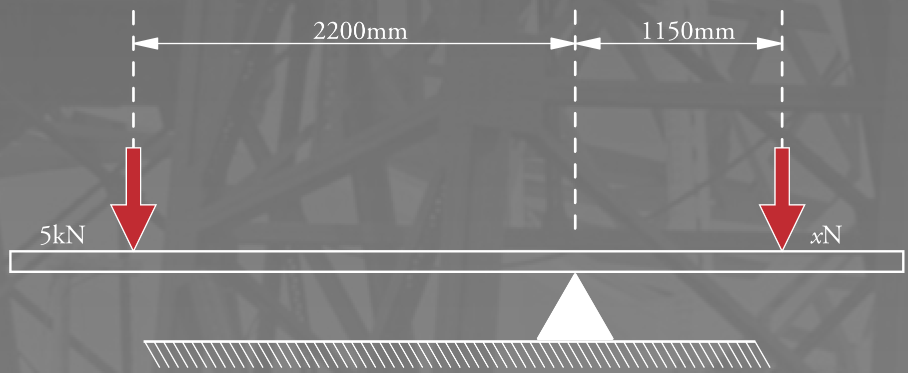
Practice 3

In this simple class 1 lever you are challenged to calculate the load at 'x'. Check the units used in the question!



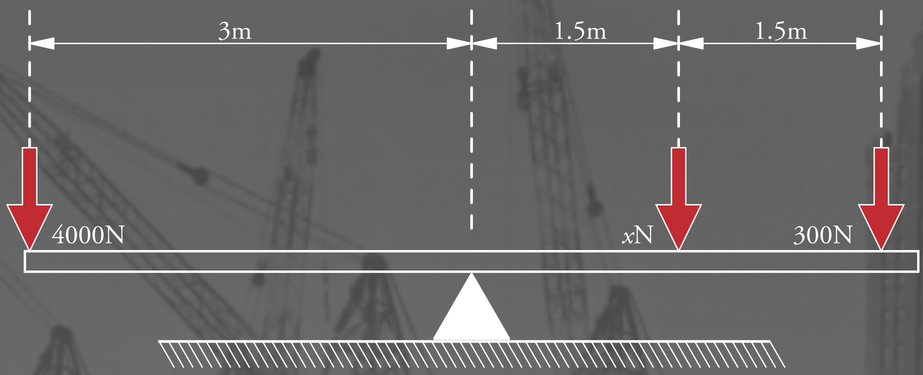
Practice 4

In this simple class 1 lever you are challenged to calculate the load at 'x'. Check the units used in the question!



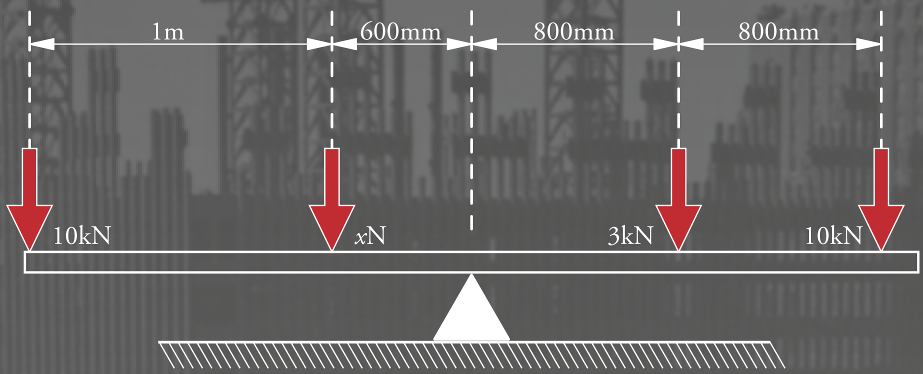
Practice 5

In this class 1 lever you are challenged to calculate the load at '*x*'. Check the direction the forces are acting and consider these in your calculations…



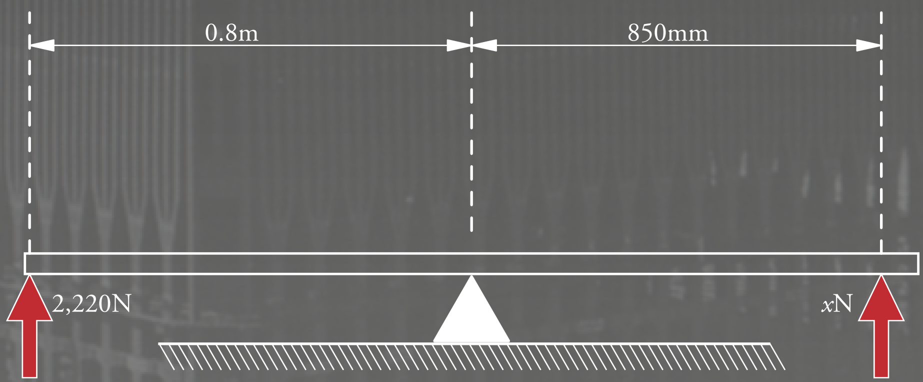
Practice 6

In this simple class 1 lever you are challenged to calculate the load at '*x*'. Check the units and the direction the forces are acting and consider these in your calculations…



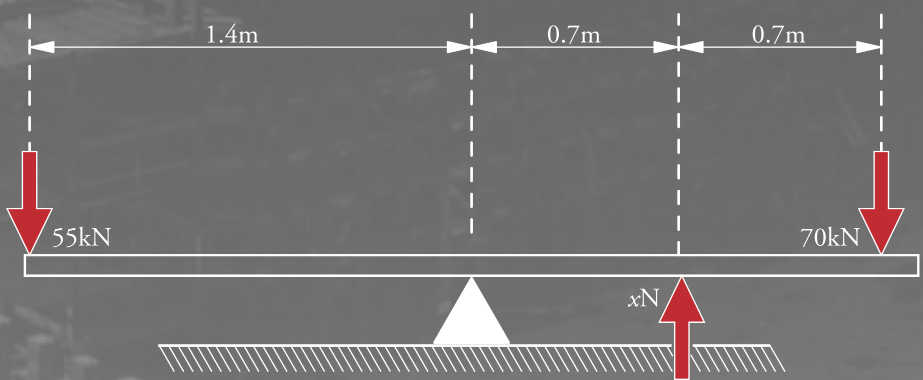
Practice 7

In this class 1 lever you are challenged to calculate the effort at '*x*'. Check the units and the direction the forces are acting and consider these in your calculations…

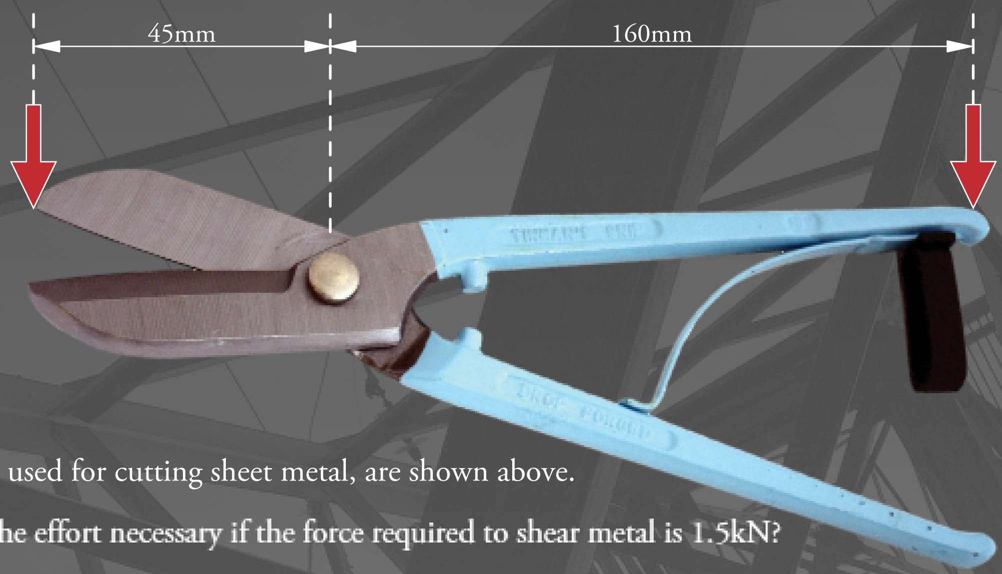


Practice 8

In this difficult class 1 lever you are challenged to calculate the effort at '*x*'.



Engineering problems : moments

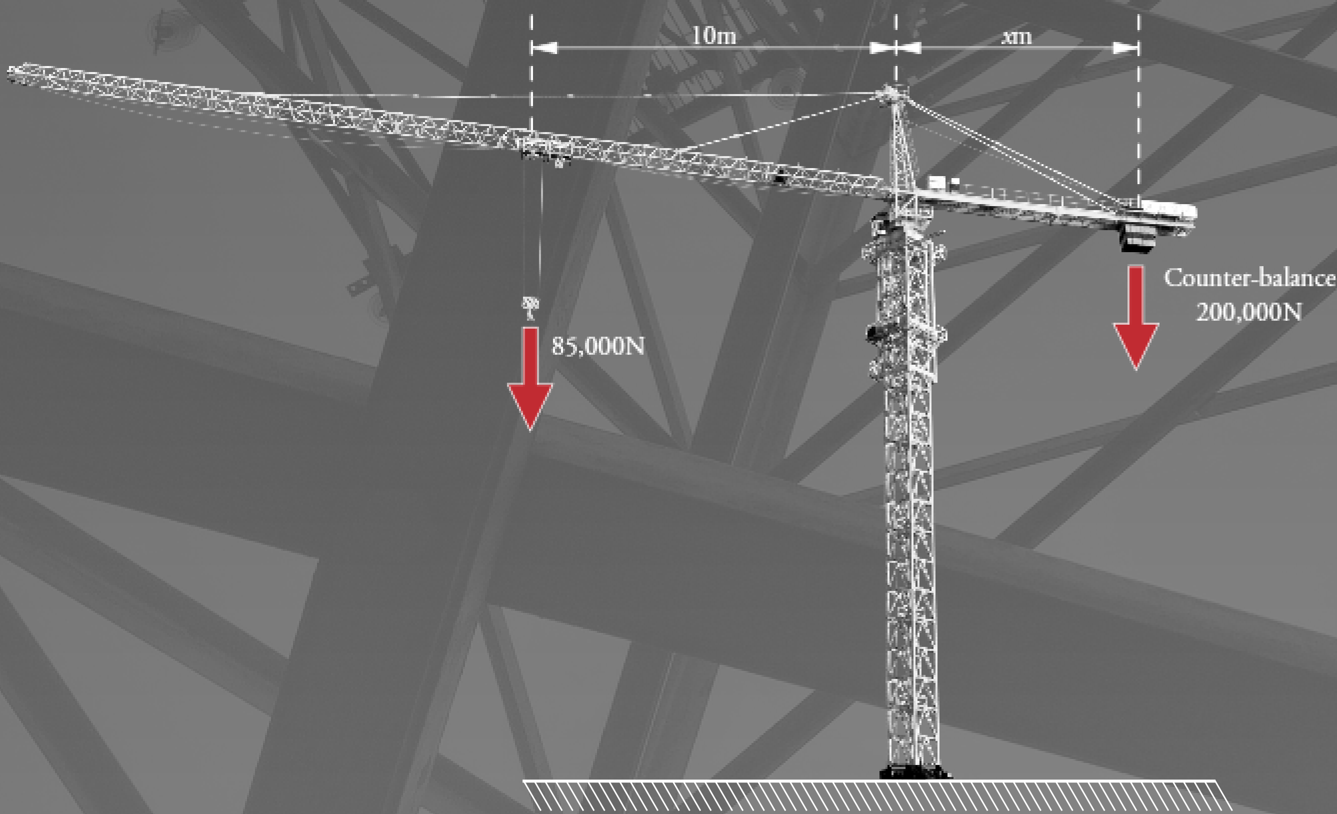


1.

A pair of tin-snips, used for cutting sheet metal, are shown above.

i) Calculate the effort necessary if the force required to shear metal is 1.5kN?

ii) Describe one change that could be made to the tin-snips to make it easier to cut the sheet metal by hand.



2.

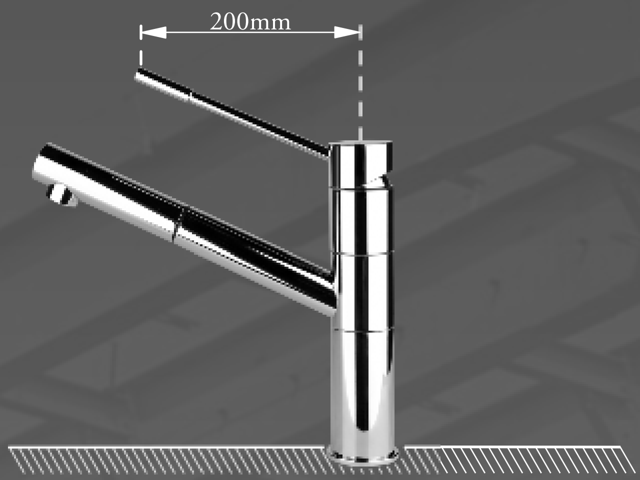
A heavy lifting tower crane is shown above. Tower cranes have a movable counter-balance.

i) Calculate the distance required at *x* to maintain equilibrium?

ii) Explain why a counter-balance is required with a tower crane.

ii) Explain why it is advantageous that the counter-balance can be moved.

Engineering problems : moments

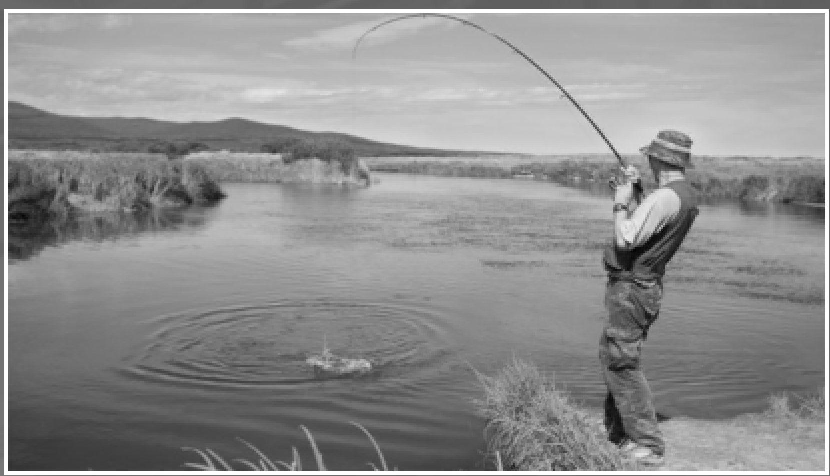


3.

A pair of tin-snips, used for cutting sheet metal, are shown above.

i) Calculate the effort necessary if the force required to shear metal is 1.5kN?

ii) Describe one change that could be made to the tin-snips to make it easier to cut the sheet metal by hand.



4.

When a fish has been hooked, the pull from the fish is 22 Newtons at right angles to the fishing rod. The pivot is at the end of the rod, which is 2.4 metres long. The angler applies an effort at 0.4 metres from the end of the rod.

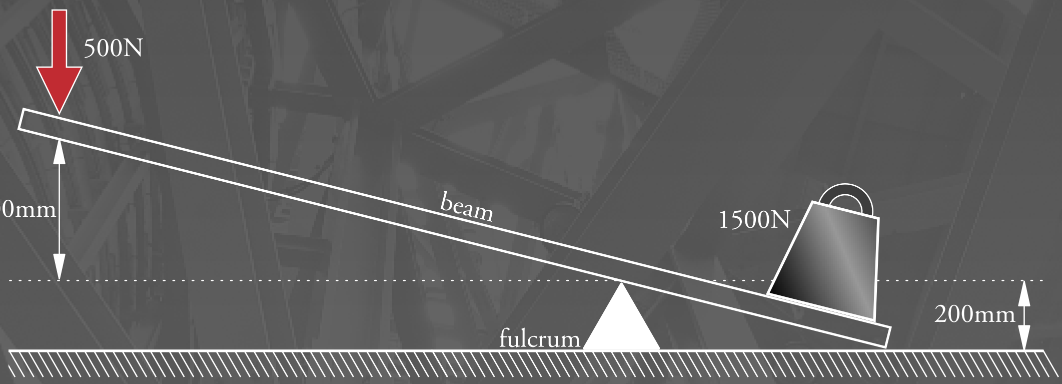
i) Sketch a line diagram with dimensions, loads, pivots, etc.

ii) Calculate the counter-clockwise turning moment applied by the fish.

iii) Calculate the effort the angler must apply to stop the rod from turning anticlockwise.

iv) The angler has to exert a greater effort than the load applied by the fish to maintain equilibrium. Is this an advantage or disadvantage to the angler?

How efficient are levers?



The load being lifted is three times more than the effort being applied. The load divided by the effort gives a ratio. This ratio is a force multiplier, or how much more load can be lifted compared to the effort.

'Force-multiplier ratio': $\frac{\text{load}}{\text{effort}} = \frac{900\text{ N}}{500\text{ N}} = 1.8$

The force multiplier ratio appears to give the user something for nothing. The user is only applying a third of the force to move the load. However, it can be seen above that the effort side of the lever has to move much further than the load side. The ratio of the distance moved by the effort, divided by the distance moved by the load, is known as the distance-multiplier ratio.

'Movement-multiplier ratio': $\frac{\text{distance moved by the effort}}{\text{distance moved by the load}} = \frac{400\text{ mm}}{200\text{ mm}} = 2$

No machine can ever be 100% efficient. Some energy is lost overcoming inertia, is converted into sound and even some heat. If your calculations ever show 100% (or above), you know you have made a mistake somewhere.

The efficiency of a lever system is found by dividing the *'force-ratio'* by the *'movement-ratio'*, with the efficiency given as a percentage.

'Efficiency': $\frac{\text{force ratio}}{\text{movement ratio}} = \frac{1.8}{2} \times 100 = 90\%$

Free body diagrams

Engineers use *'free body diagrams'* as a graphic to visualise the forces, movements, and resulting reactions on an item in a given condition.
They depict a body with all of the applied forces and moments, as well as reactions, that act on that body.

The body may consist of multiple parts, for example, a bridge, or be a simple beam. Sometime a series of free bodies and other diagrams may be necessary to solve complex problems.

Free body diagrams explained...

Freebody diagrams allow designers and engineers to represent real-life scenarios in a more simplistic way. It also allows the engineer to remove information that will have no impact on the calculation that they need to make.

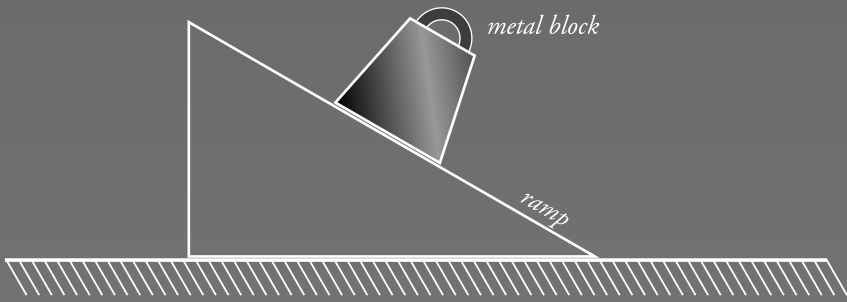


fig 5.0

In figure 5.0, a mass has been placed upon a ramp. There are lots of different forces working in this scenario and it can be difficult to isolate each one and work out what effect it is having overall.

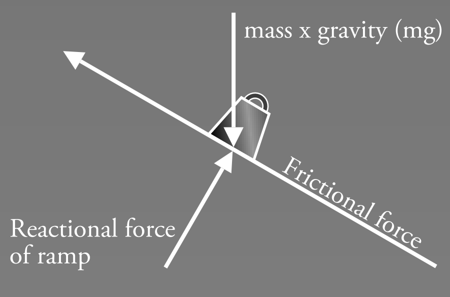


fig 5.1

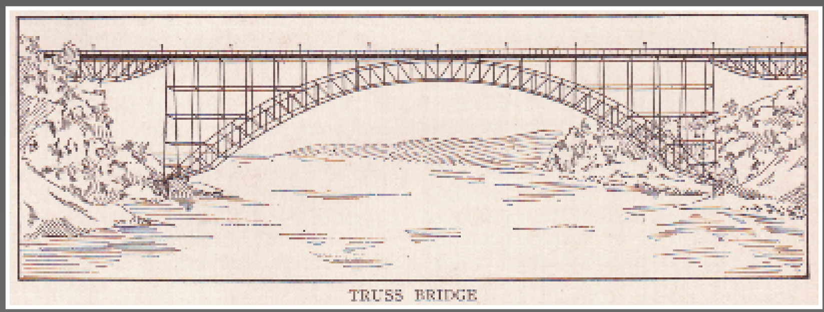
In figure 5.1, each of the forces have been isolated and identified. At this stage it may be possible to identify the force that is working in the system, for instance, the metal block is influenced by the mass of the block, multiplied by the gravity working upon it.
To stop the block from falling straight down, the ramp is acting against the block, holding it up. This force is 90° (perpendicular) to the surface of the ramp. The ramp surface is providing friction that can stop the stop the block moving.

Calculating free body diagrams

Free body diagrams allow designers and engineers to isolate all the forces working within a system.

These diagrams can then be used, applying the principle of *'moments'* to the calculations

photograph of bridge



designer sketch of bridge

A truss bridge is a complex piece of engineering. A photograph of the bridge, including a car about to drive across is shown above. A complex designer sketch of the bridge has also been included. These two images can be difficult to use when calculating the forces acting on the structure.

If all the visual components acting on the structure or body were removed and replaced with their force value, a simplified diagram would allow a better understanding of how the forces are affecting the structure.

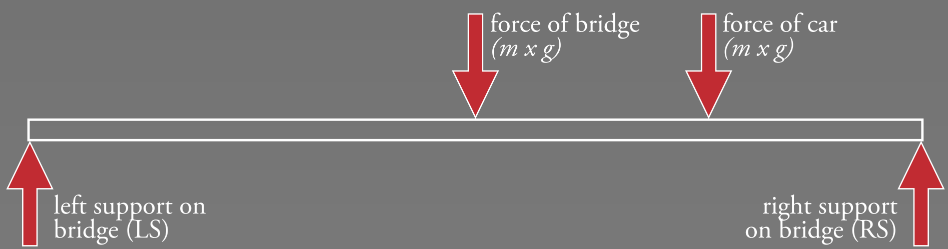


fig 5.2

In figure 5.2, a simplified free-body diagram of the photograph and sketch is shown.

The forces representing the car and the weight of the bridge act downwards and are taken through the centre of the car and the middle of the bridge. The arrow for the car is shown in the centre, between the front and back wheels.

The forces LS and RS represent the forces that the supports the structure.

We could be more detailed and draw the angled support for the bridge in the rock face, but that would make the example very complicated.

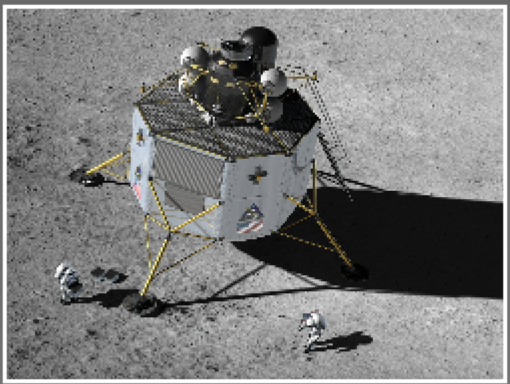
Practice
free body diagrams

In the following examples, you are tasked with sketching free body diagrams that may represent the objects in each of the scenarios.

1.

A child's see-saw is shown above.

i) Draw a free-body diagram of the see-saw indicating the downward force and reactions with arrows.

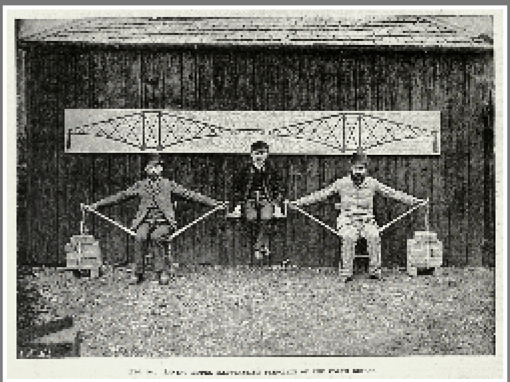


2.

A computer rendering of the proposed ALTAIR lunar lander is shown above.

i) Draw a free-body diagram of the car indicating the downward force and reactions with arrows.

ii) Explain any specific considerations need to be made with forces acting upon the lander that would affect calculations.



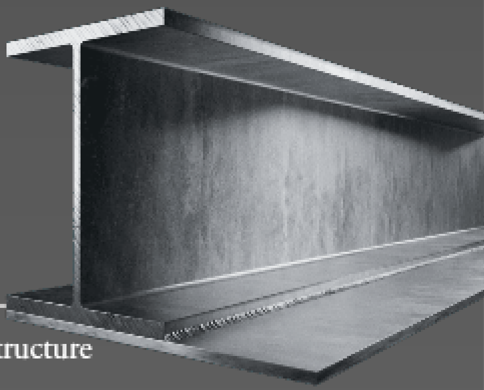
3.

A historic photograph used to explain the *'cantilever'* principle for the Forth Bridge is shown above.

i) Draw a free-body diagram of the car indicating the downward force and reactions with arrows.

ii) Explain any specific considerations need to be made with forces acting upon the bridge that would affect calculations.

Building structures - Beams



Many buildings use structural *'beams'* - usually made of steel or wood - to give the structure strength to stand-up, hold multiple floors or take extreme weights, such as multi-story car-parks.

Structural beams are also affected by forces and turning moments. For a horizontal structure to be stable (in equilibrium) when affected by vertical forces, the following conditions must be satisfied:

1.

The sum of the forces acting upwards must equal the sum of the forces acting downwards.

$$\sum \text{upwards forces} = \sum \text{downwards forces}$$

$$\sum f \Uparrow = \sum f \Downarrow$$

2.

The sum of the clockwise moments must equal the sum of the anticlockwise moments about the same point.

$$\sum \text{clockwise moments} = \sum \text{counter-clockwise moments}$$

$$\sum m ↻ = \sum m ↺$$

At the points of support, the downwards forces acting on the beam are resisted by the forces acting upwards. These upward forces are known as *'beam reactions'* (or simply, *'reactions'*).

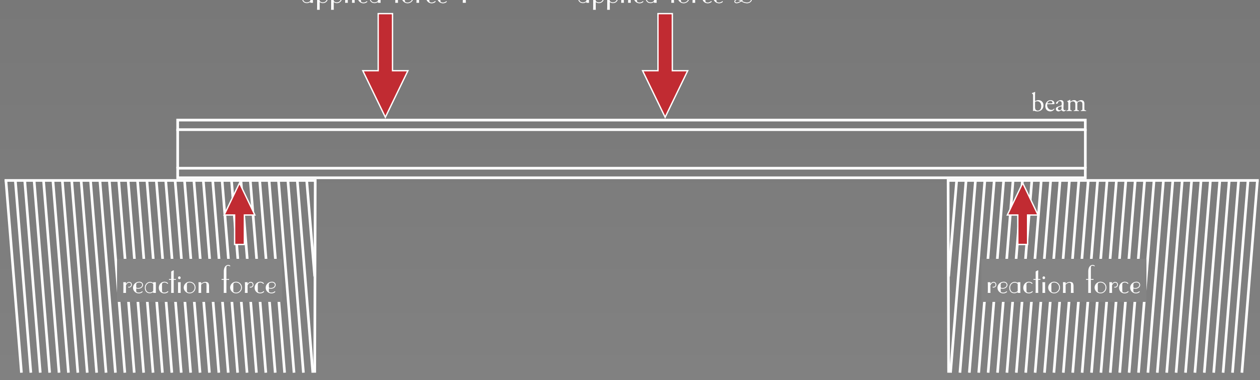


fig 5.3

Example beam calculations

A simple beam, resting on two points is shown below (figure 5.4). There are three loads working on this beam, in different positions and at different magnitudes.

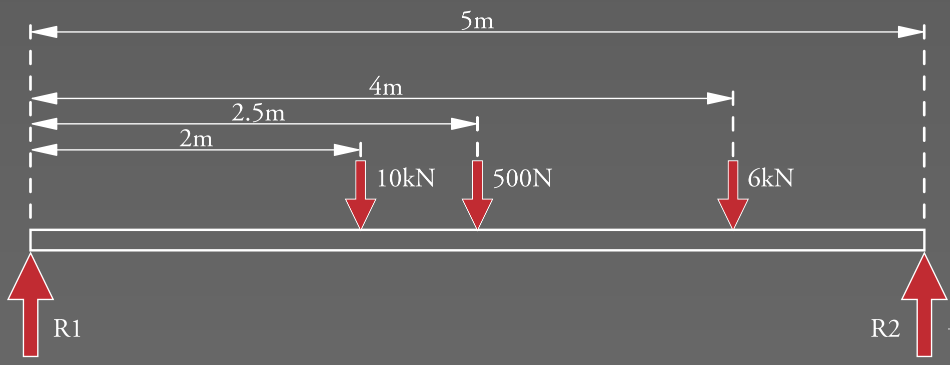


fig 5.4

When trying to resolve reaction forces, using the principles of moments:

Taking moments around R1:

$$\sum \text{clockwise moments} = \sum \text{counter-clockwise moments}$$

$$(10{,}000\text{N} \times 2\text{m}) + (500\text{N} \times 2.5\text{m}) + (6000\text{N} \times 4\text{m}) = \text{R2} \times 5\text{m}$$

Therefore:

$$\frac{20{,}000\text{Nm} + 1250\text{Nm} + 24{,}000\text{Nm}}{5\text{ m}} = 9050\text{N}$$

$$\underline{\text{R2} = 9050\text{N}}$$

Also:

$$\sum \text{upwards forces} = \sum \text{downwards forces}$$

$$\text{R1} + \text{R2} = 10{,}000\text{N} + 500\text{N} + 6000\text{N}$$

$$\text{R1} = 16{,}500\text{N} - \text{R2}$$

Therefore:

$$\text{R1} = 16{,}500\text{N} - 9050\text{N}$$

$$\text{R1} = \underline{7450\text{N}}$$

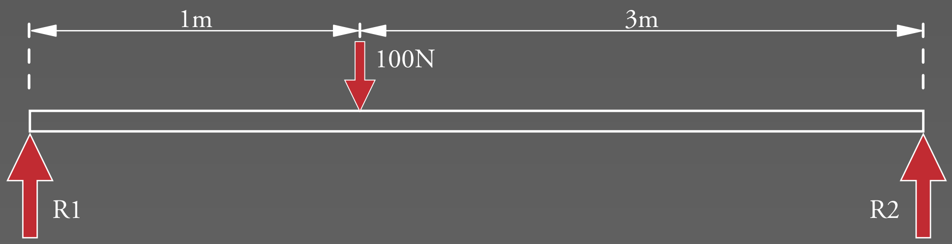
Therefore the reactions for the beam supports are:

$$\underline{\text{R1} = 7450\text{ N and R2} = 9050\text{ N}}$$

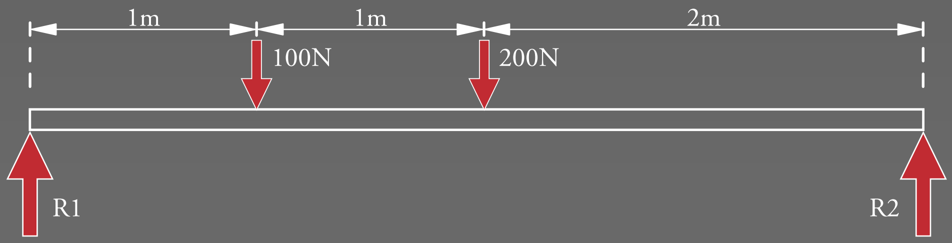
Practice beam calculations

Remember, $\sum f \Uparrow = \sum f \Downarrow$
$\sum m \circlearrowright = \sum m \circlearrowleft$

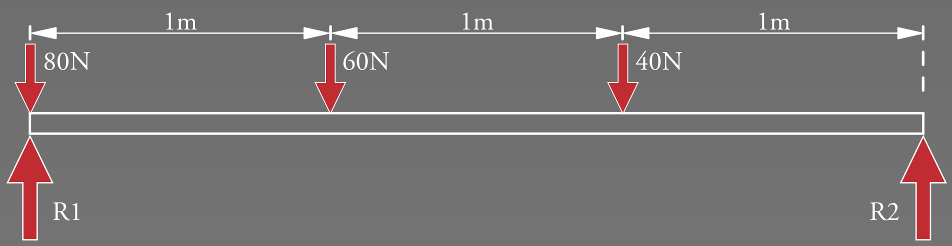
Practice 1



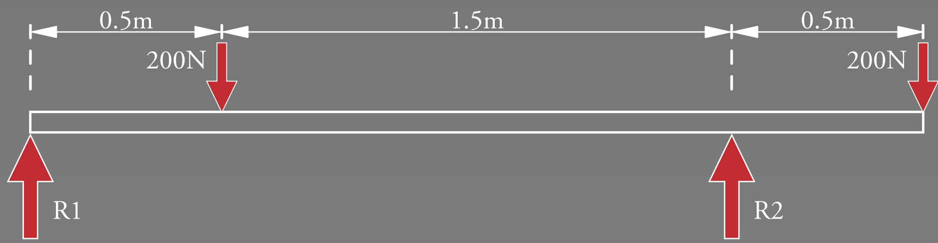
Practice 2



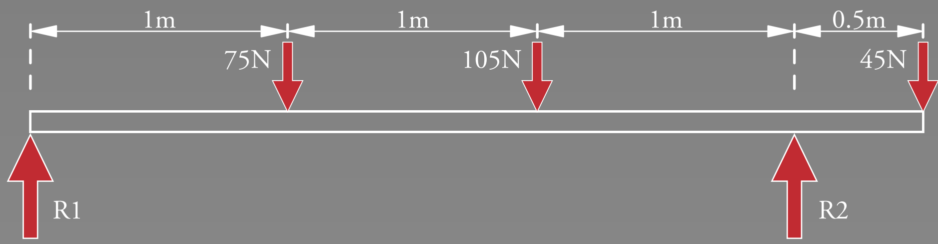
Practice 3



Practice 4



Practice 5

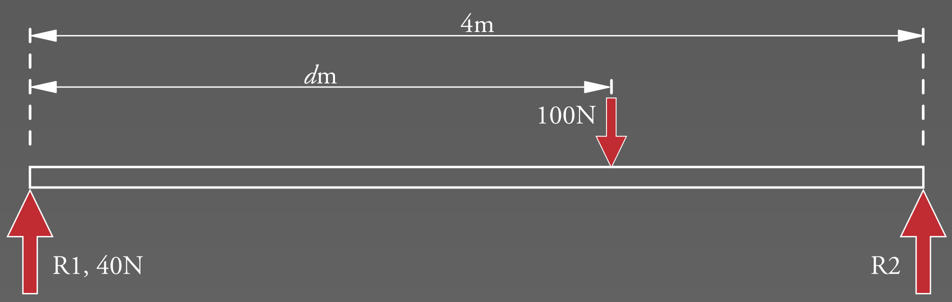


Practice beam calculations

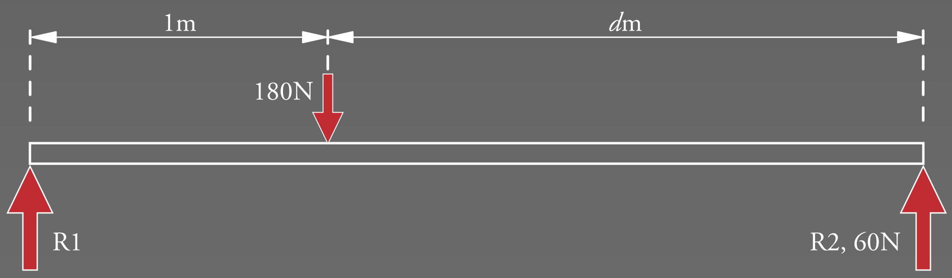
Remember,

$$\sum f \Uparrow = \sum f \Downarrow$$
$$\sum m \circlearrowright = \sum m \circlearrowleft$$

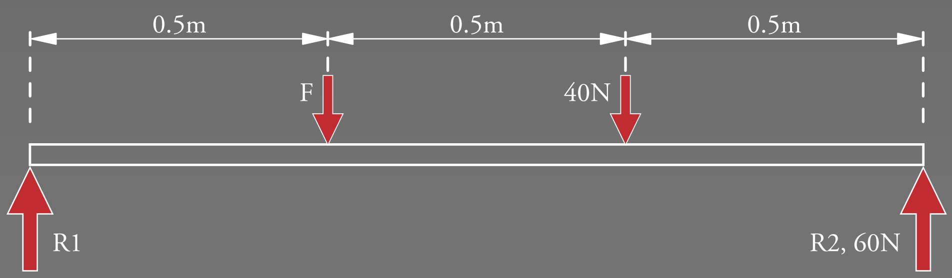
Practice 6



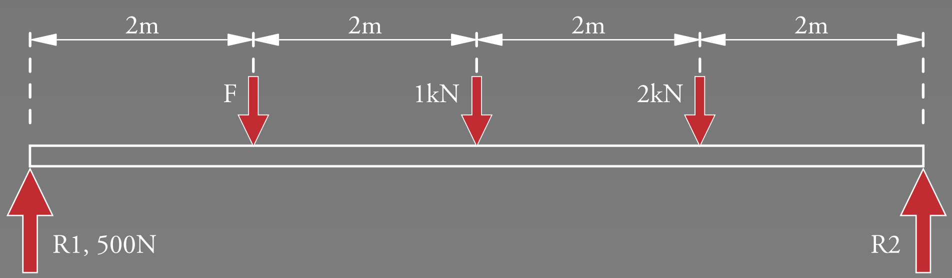
Practice 7



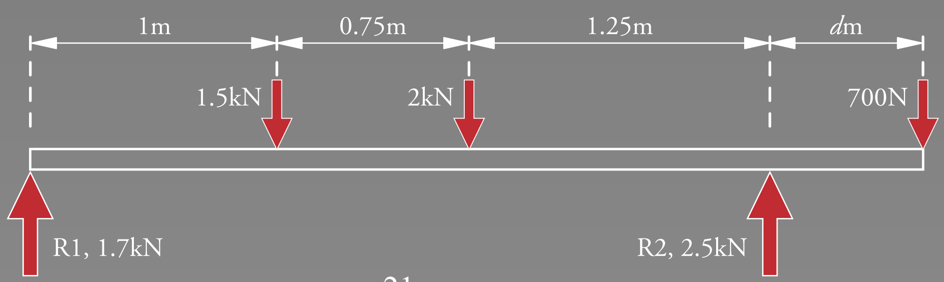
Practice 8



Practice 9

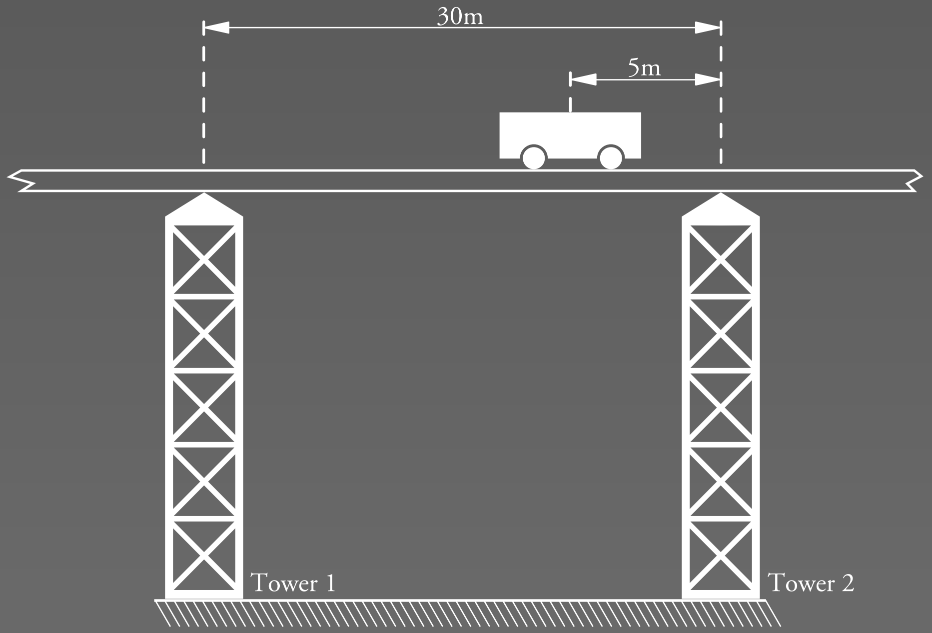


Practice 10



Practice beam calculations

Remember, $\sum f \Uparrow = \sum f \Downarrow$
$\sum m \circlearrowright = \sum m \circlearrowleft$



11.

A gantry rail system is shown above. The rail should be treated as a beam. The beam is simply supported at each end with a span of thirty metres. The beam carries a cart, having a weight of 5kN.

i) Complete a suitable free-body diagram.

ii) When the cart is positioned at the mid-point of the beam and carrying an additional weight of 3kN, what are the reactions at R1 and R2?

iii) When the lifting device is positioned one metre from one end and carries an additional weight of 6kN, what are the reactions at R1 and R2?

12.

The engineer that designed the gantry rail system considered making the towers from either wood or metal.

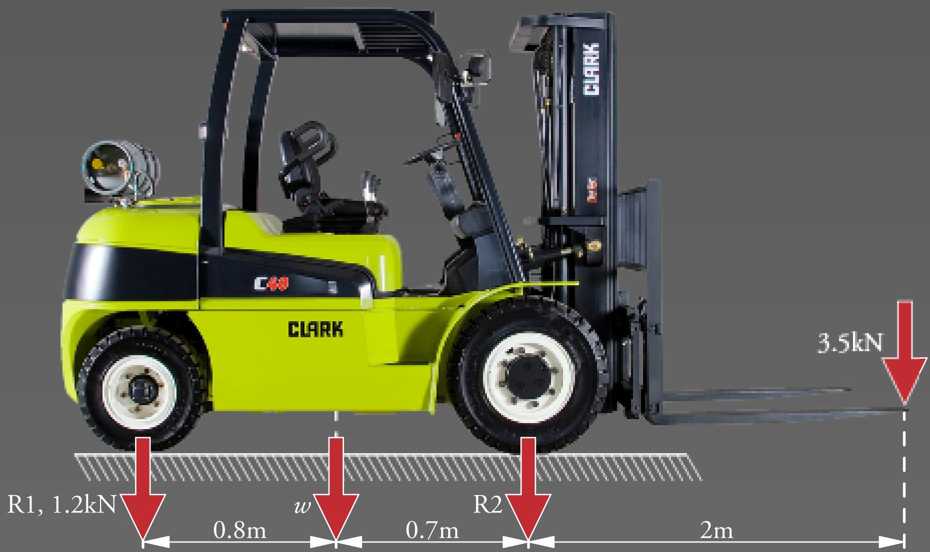
i) Describe the advantages and disadvantages of using either wood or metal.

When designing the gantry rail system, the engineer had to consider more loads than those shown.

ii) Describe any other loads that may affect the system.

Practice beam calculations

Remember, $\sum f \Uparrow = \sum f \Downarrow$
$\sum m \circlearrowright = \sum m \circlearrowleft$



13.

A forklift truck must have a minimum downward force of 1200N acting through the rear wheels to remain stable.

i) Draw an appropriate free-body diagram.

ii) Calculate the weight required to balance the load on the lift with R1 = 0N.

iii) Find the additional weight acting through the centre of gravity of the truck to produce 1200N at the rear wheels.

Feeling stressed & strained?

Choosing the right material for the job is essential for any designer or engineer; wood, steel, iron, or plastic.

Whether a material is strong enough is one of the most important questions. When determining whether a material is strong enough, it is important to consider the force that will be applied. Some materials are strong under compression and others are better with tension.

When a force is applied to a material it will undergo '*stress*' and '*strain*'.

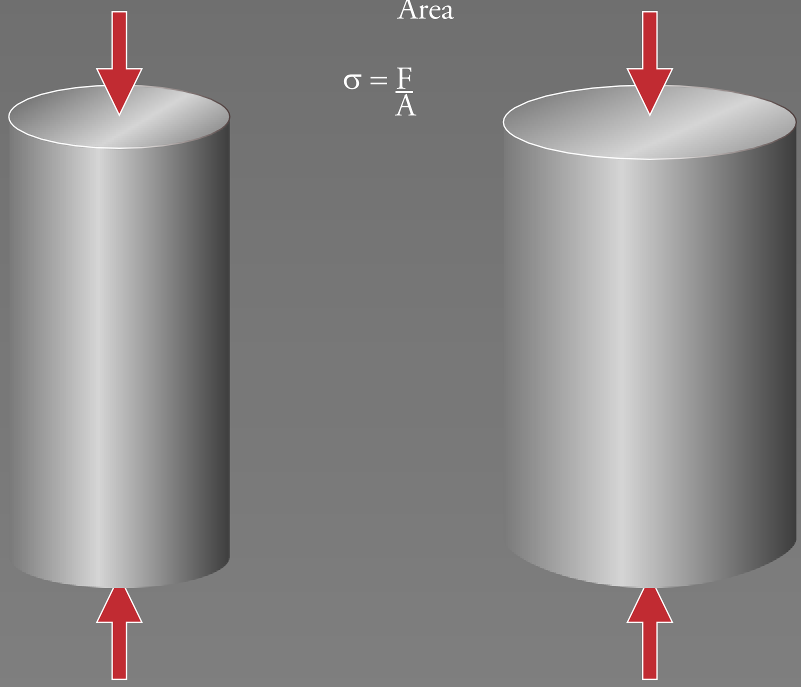
When a force is applied to a part of a structure it will experience stress. A high level of stress will result in the part failing (breaking).

To calculate stress, you need to know the magnitude of the force being applied and the cross-sectional area of the material. Cross-sections describe the end-face, or a face of the material if cut. This cross-section is 90^{o} (perpendicular) to the force applied.

As we know, force is represented in Newtons, N. Area is measured in mm^2. Stress is represented by the Greek letter, σ, sigma. The formula used is:

$$\text{Stress} = \frac{\text{Force}}{\text{Area}}$$

$$\sigma = \frac{F}{A}$$



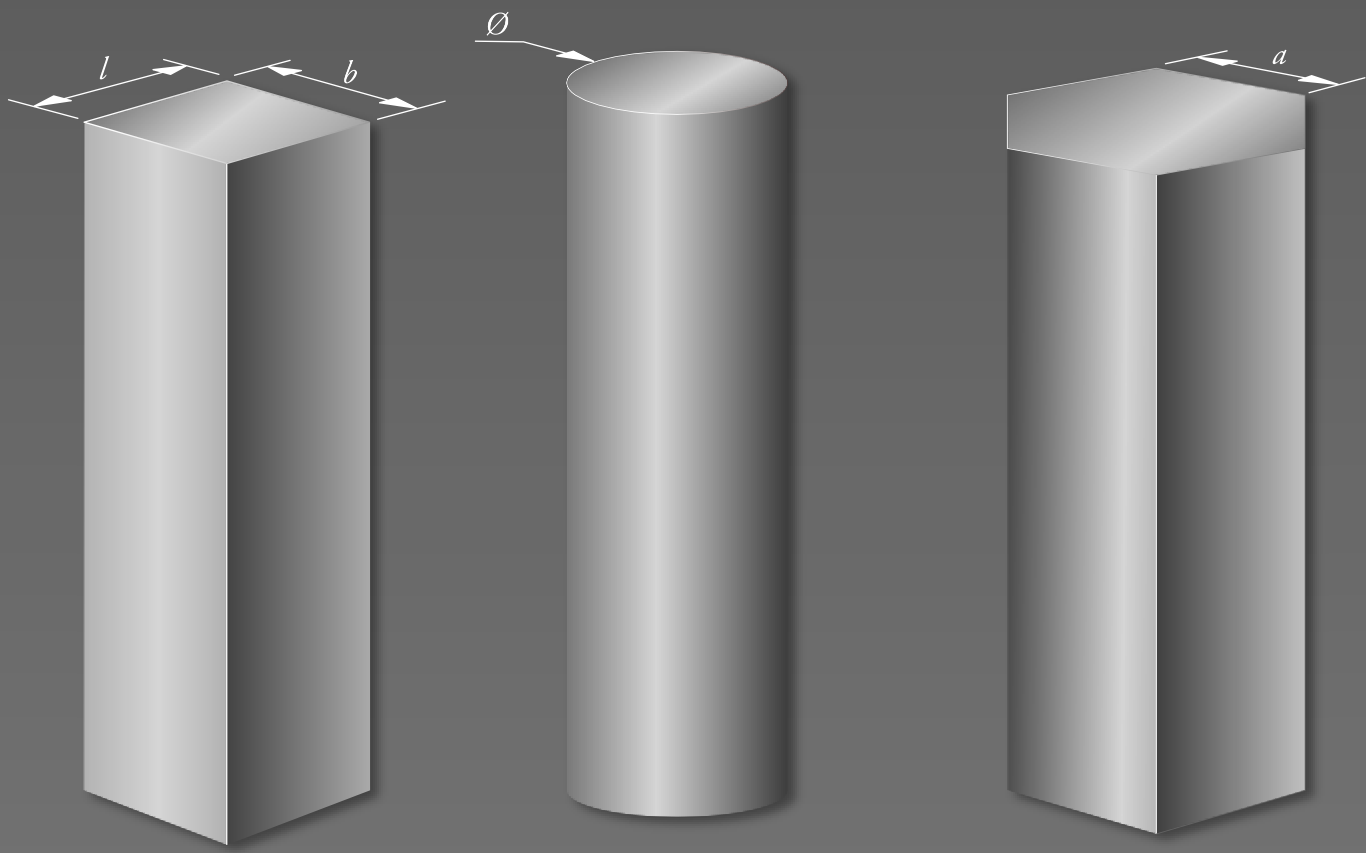
Column 1 Column 2

fig 6.0

Two cylindrical columns are shown in figure 6.0. Column 1 will be more likely to fail when the force is applied. This is because it has a smaller cross-section area so will experience more stress. However, it is also smaller and lighter, and more likely to be less expensive.

Calculating area

Structural members can come in a variety of shapes. It is important that a designer or engineer is confident in calculating the cross-sectional area of different profiles. You will learn more about this in mathematics. However, below is a few different shapes and their corresponding formulae for calculating area.



$A = l \text{ x } b$

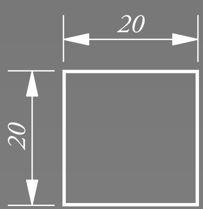
$A = \frac{\pi d}{4}$ Or $A = \pi r^2$

$A = \frac{3\sqrt{3}}{2} a^2$

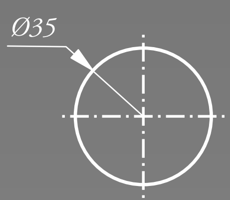
Practice calculating area

Calculate the area of the following cross-sections. All units are in mm.

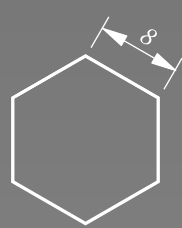
i)



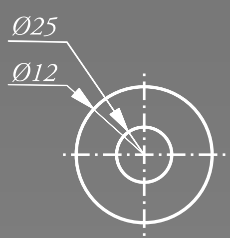
ii)



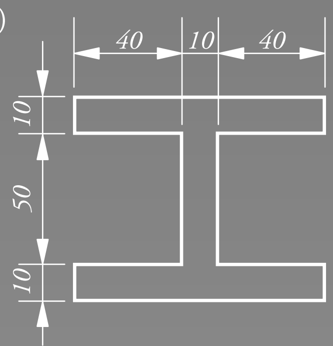
iii)



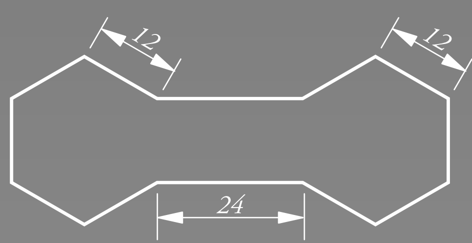
iv)



v)



vi)



Example stress calculations

A square bar of 20mm x 20mm cross-section is subjected to a tensile load of 500N.

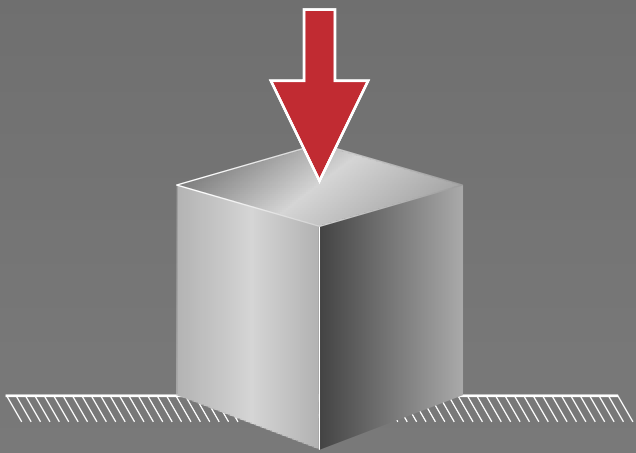
Calculate the stress in the bar.

$$\text{Stress} = \frac{\text{Force}}{\text{Area}}$$

$$\sigma = \frac{F}{A}$$

$$\sigma = \frac{500}{400}$$

$$\sigma = 1.25\text{mm}^2$$



A column of section 0.25m^2 is required to act as a roof support. The maximum allowable working stress in the column is 50Nmm^2.

Calculate the maximum compressive load acting on the column.

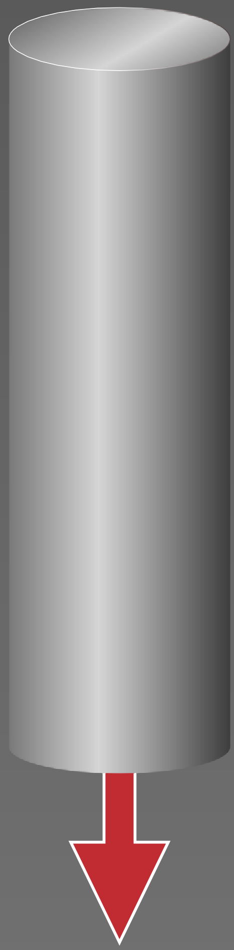
$$\text{Stress} = \frac{\text{Force}}{\text{Area}}$$

$$\text{Force} = \sigma \text{ x } A$$

$$\text{Force} = 50 \text{ x } 0.25\text{x}10^6$$

$$\text{Force} = 12.5\text{MN}$$

Example stress calculations



The stress in a steel wire supporting a load of 8kN should not exceed 200N/mm2.

Calculate the minimum diameter of wire required to support the load.

$$\text{Stress} = \frac{\text{Force}}{\text{Area}}$$

$$\text{Area} = \frac{\text{Force}}{\text{Stress}}$$

$$A = \frac{\text{Force}}{\sigma}$$

$$\text{Area} = \frac{8000}{200}$$

$$\text{Area} = 40\text{mm}^2$$

$$\varnothing = \sqrt{\frac{4A}{\pi}}$$

$$\varnothing = \sqrt{\frac{4 \times 40}{\pi}}$$

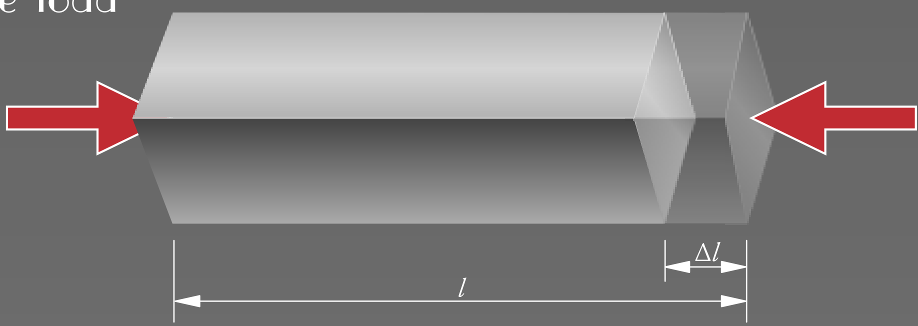
$$\varnothing = 7.14mm$$

Example strain calculations

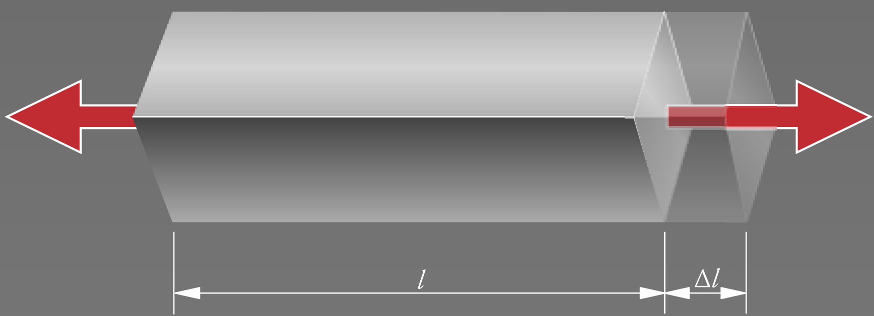
Applying a load or force to a structural member will cause it to change in length. Every material changes shape to some extent when a force is applied, although this is sometimes difficult to see in materials such concrete. With many materials we need special equipment to detect these changes.

If a compressive load is applied to a structural member, then the length will reduce. If a tensile load is applied, then the length will increase. This is shown in the diagrams below.

Compressive load



Tensile load



Calculating strian

The result of applying a load to a structural member is called *'strain'*. This is calculated using the formula:

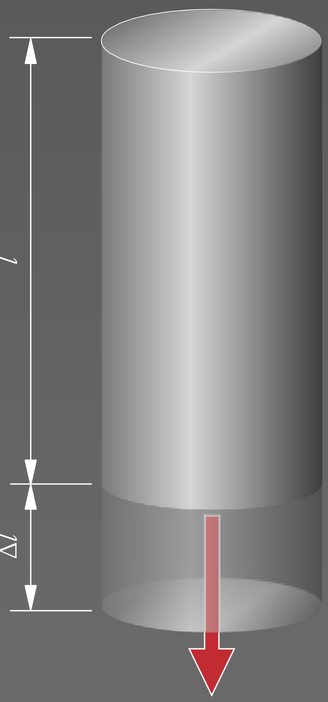
$$\text{Strain} = \frac{\text{change in length}}{\text{original length}}$$

$$\varepsilon = \frac{\Delta l}{l}$$

Length is measured in the same units, either m or mm. As the units cancel each other out, strain is dimensionless. This means that there are no units of strain.

Strain is a ratio that describes the proportional change in length in the structural member when a direct load is applied. Strain is denoted by the Greek letter *'epsilon'* (ε).

Example strain calculations



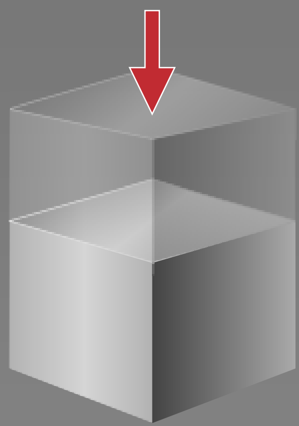
A steel wire of length 5m is used to support a tensile load. When the load is applied, the wire is found to have stretched by 2.5mm.

Calculate the strain for the wire.

$$\varepsilon = \frac{\Delta l}{l}$$

$$\varepsilon = \frac{\Delta 2.5}{5000}$$

$$\varepsilon = \underline{0.0005}$$



The strain in a concrete column must not exceed 5×10^{-4}. The column is 3m high

Calculate the maximum reduction in length produced when the column is loaded.

$$\varepsilon = \frac{\Delta l}{l}$$

$$\Delta l = \varepsilon \times l$$

$$\Delta l = (5 \times 10^{-4}) \times 3000$$

$$\Delta l = 1.5\text{mm}$$

Practice
stress & strain calculations

i. A bar of steel 500mm long has a cross-sectional area of 250mm2 and is subjected to a force of 50kN. Calculate the stress in the bar.

ii. A wire 4 mm in diameter is subjected to a force of 300N.
Calculate the stress in the wire.

iii. A round steel bar is required to carry a tensile force of 10kN and the stress is not to exceed 14.14N/mm2. Calculate the diameter.

iv. A wire 10m long stretches 5mm when a force is applied at one end.
Calculate the strain produced.

v. A tow bar, 1.5m long, is compressed by 4.5mm during braking.
Calculate the strain.

vi. The allowable strain on a bar is 0.0075 and its length is 2.5m.
Calculate the change in length.

vii. During testing, a shaft was compressed by 0.06mm. The resulting strain was 0.00012.
Calculate the original length of the shaft.

viii. A piece of wire 6m long and diameter of 0.75mm stretched 24mm under a force of 120N.
Calculate stress and strain.

ix. A mild steel tie-bar, of circular cross-section, lengthens 1.5mm under a steady pull of 75kN. The original dimensions of the bar were 5m long and 30mm in diameter.
Calculate the intensity of tensile stress in the bar and determine the strain.

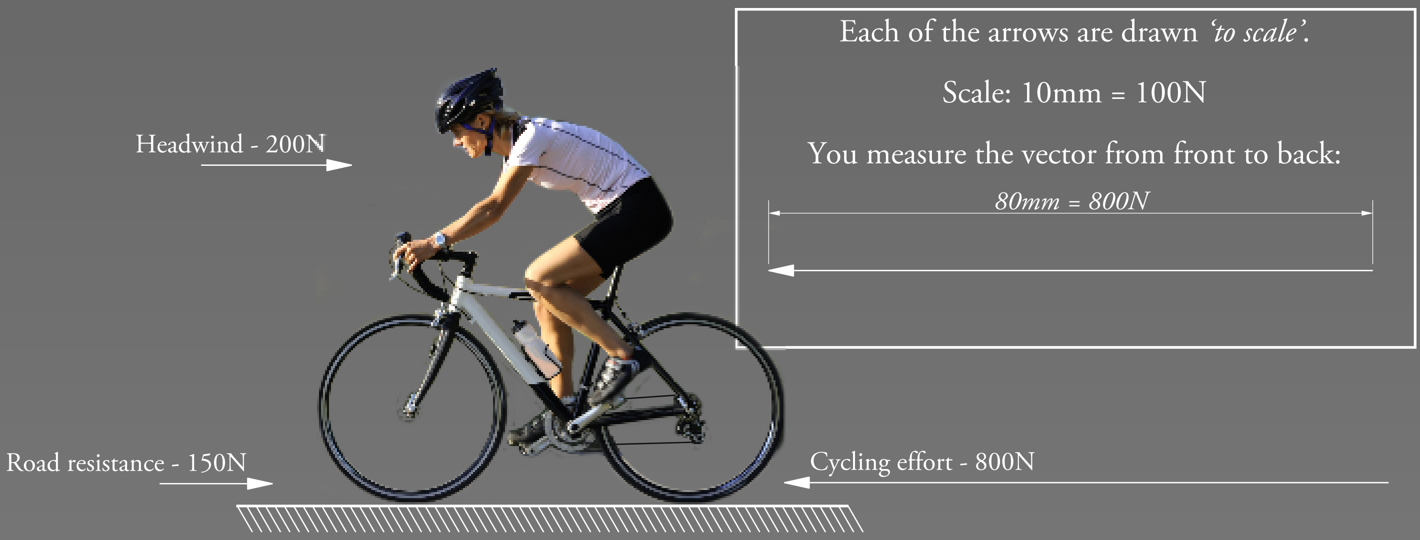
x. A mass of 2500kg is hung at the end of a vertical bar, the cross-section of which is 75mm x 50mm.
A change in length in the bar is detected and found to be 2.5mm. The original length of the bar is 0.5m
Calculate the stress and strain in the bar.

Vectors & scalars

In mathematics there are two groups of descriptive terms for forces and motion. These are called *'vectors'* and *'scalars'*.

Vectors have magnitude and direction, scalars only have magnitude. The fact that magnitude occurs for both scalars and vectors can lead to some confusion.

Force is a vector quantity and has both magnitude and direction. This means it is often convenient to represent a force by a line, which is sometimes easier to understand visually. The direction of the force may be indicated by an arrow-headed line, with the length of the line drawn to scale to represent the size of the force. This line is a vector.



The overall effect will be 800N - 200N - 150N = 450N.

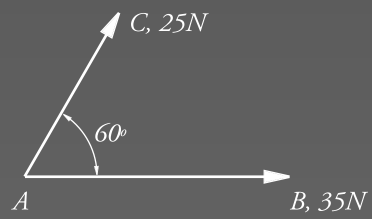
A suitable scale would be selected - possibly 10mm to represent 20N - and using this scale each force is drawn in turn, one following on from the other.

When the three forces are added together, they can be replaced by a single force that has the same effect, called the *'resultant'*. This is also drawn to scale:

The direction the arrow is pointing is also very important, as this represents the direction of the force.

Vectors & scalars

Vectors can also used to find the resultant of two forces that are inclined at an angle to each other.



Scale: 10mm = 10N

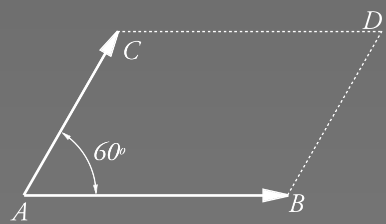
In figure 7.0, the resultant of the two forces can be found by drawing two vectors. First choose a suitable scale and draw the two vectors AB and AC.

A to C = 25mm = 25N

A to B = 35mm = 35N

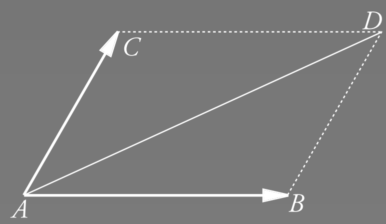
The bigger the scale the easier to draw and the more accurate the vectors.

Scale: 10mm = 10N



Instructions:

1. *From C draw a line parallel to AB*
2. *From B draw a line parallel to AC.*
3. *Call the point where the two lines intersect point D.*



4. *Draw a line from A to D.*
5. *A line drawn from A to D is the resultant of the two forces AB and AC.*

If you measure line AD, the resultant has a magnitude of 51N.

Drawing and measuring the vectors accurately is extremely important. Using grid paper can help.

---

stay balanced:

Equilibrium

Stability is important with all structures. To stay stable, certain conditions must apply.

When calculating vectors, the resultant is made up of the combined forces that are trying to move an object or structure in a set direction.

If such a force were applied without an opposing force then major problems could occur - the building or structure could move or collapse! Structures have to remain in a stable or balanced state called *'equilibrium'*, which simply means *'balanced'*.

There are three types of balancing that must exist if structures, bodies, objects, etc. are to remain in equilibrium:

horizontal forces
vertical forces
rotational forces

must all balance.

Remember:

$$\sum f \Uparrow = \sum f \Downarrow$$
$$\sum f \Leftarrow = \sum f \Rightarrow$$
$$\sum m \circlearrowright = \sum m \circlearrowleft$$

Consider these…

1. Study the following statements and explain whether they are true or false.

   i. *"A body that is accelerating is in a state of equilibrium."*

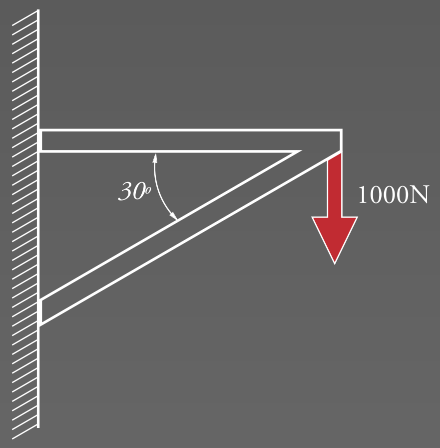
   ii. *"For a body to be in a state of equilibrium it is necessary only for the vector sum of the forces acting on it to be zero."*

   iii. *"A resultant force is a single force that can replace two or more forces."*

   iv. *"If two or more forces are replaced by a resultant force, the effect on the body is changed."*

2. Explain two conditions necessary for a structure or body to be in equilibrium.

stay balanced:
Equilibrium



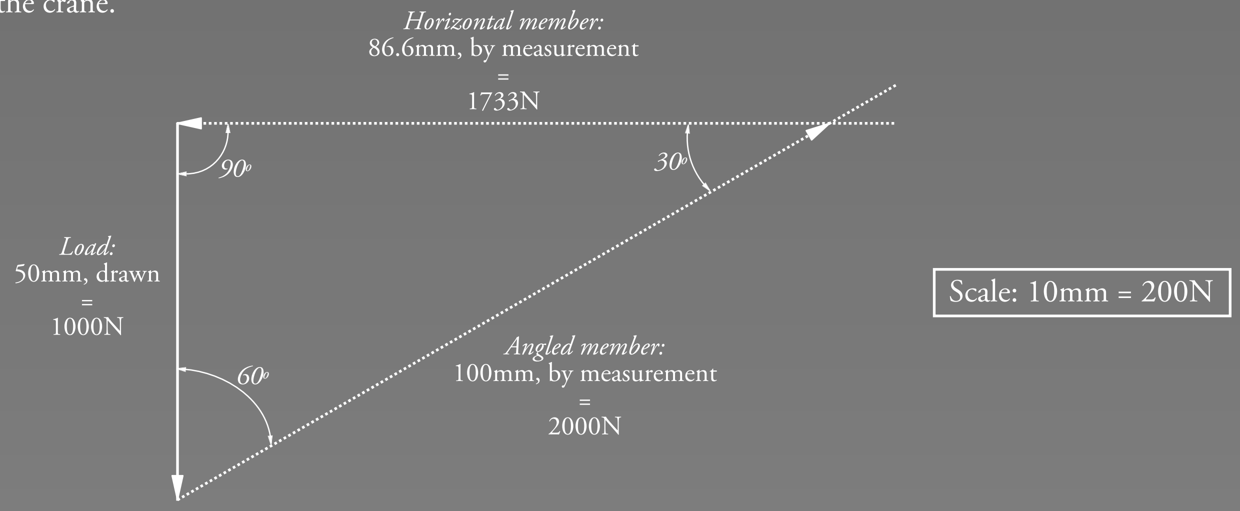
A crane is fixed against a wall, as shown above.

Determine the forces in the compression and tension members.

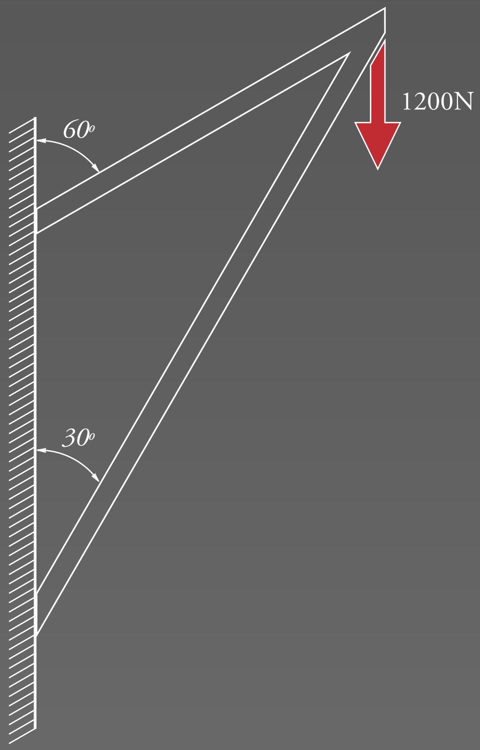
To determine the forces in all the members you will need a protractor and ruler.

Select a suitable scale for your drawing. In this case, 10mm = 200N.

To find the forces created in the tension and compression members by the 1000N load, draw a triangle representing the crane.

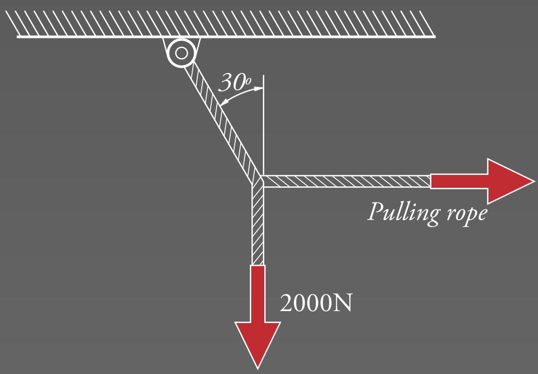


1. *Draw a line representing the direction of the load force. The length of this must be to the chosen scale.*
2. *Draw a line perpendicular to the load force, representing the horizontal member. Do not worry about the length.*
3. *Draw a line representing the angled member. Use a protractor to get the angle correct. This line should cross the horizontal line.*
4. *Measure the length of each line and use the scale to determine the force within each member.*



A small crane is used on a fishing trawler to lift cases of fish to the dock. The weight of the lift is 1200 N. Determine the size and direction of the forces in each of the crane members.

Scale: 1 block = 100N

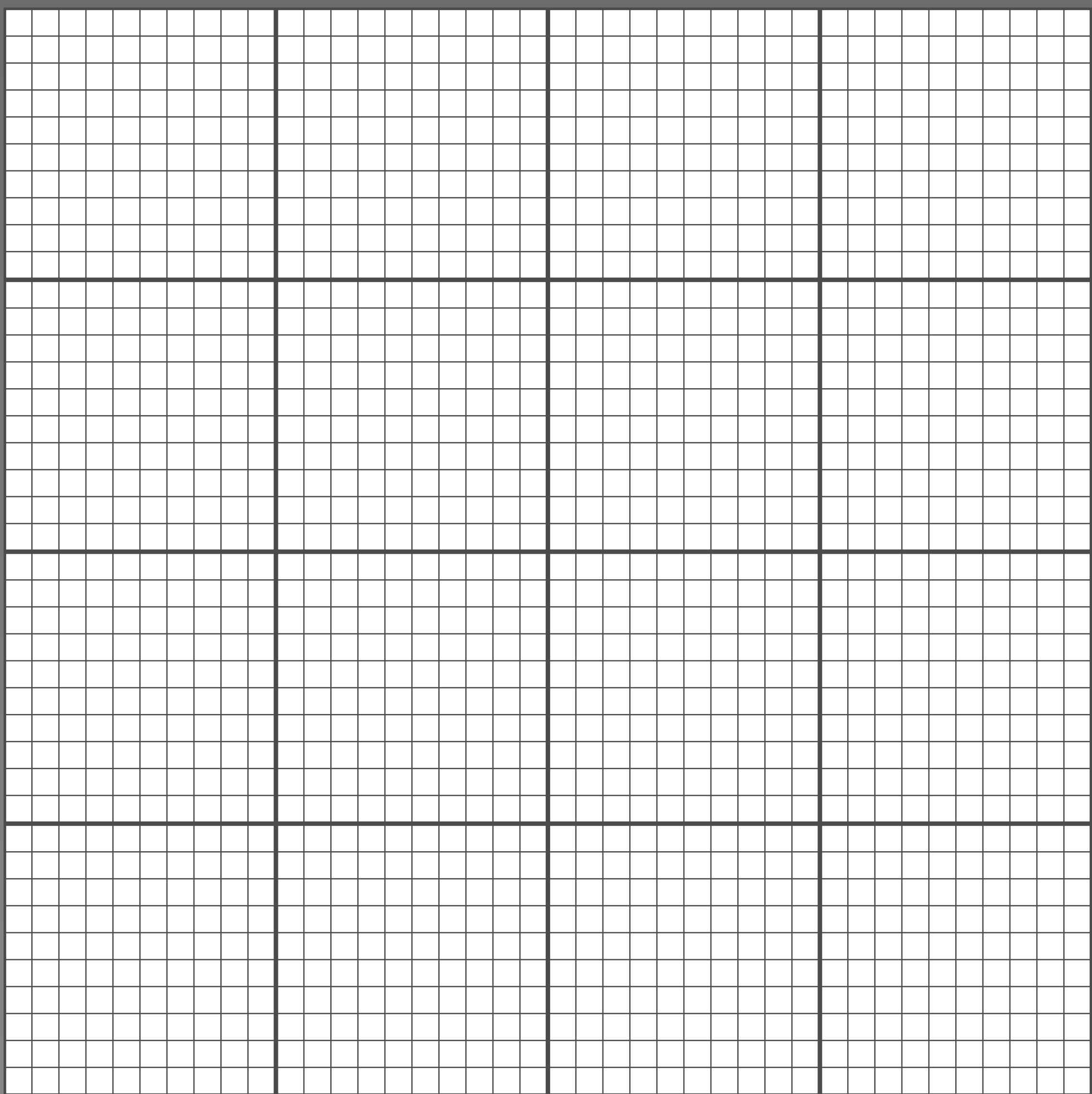


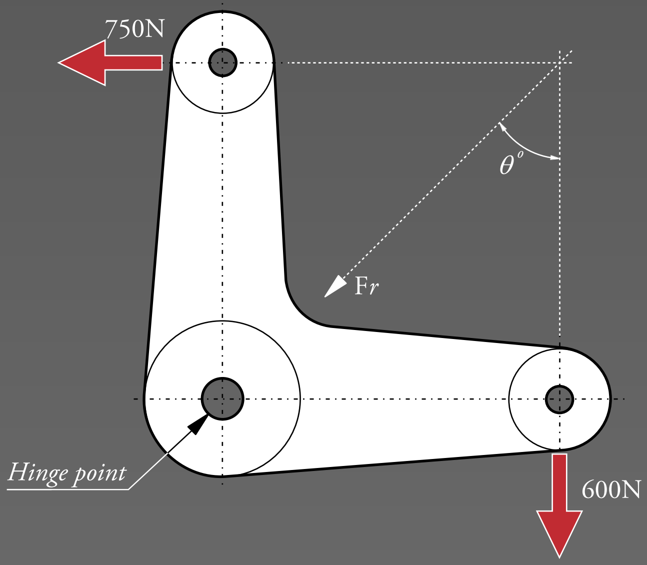
A weight of 2000 N is suspended by a rope attached to a hook firmly fixed to a roof joist.

A second rope is attached to the vertical rope and pulled horizontally until the rope makes an angle of 30° to the vertical.

Determine the horizontal pull on the rope and the force on the hook.

Scale: 1 block = 100N

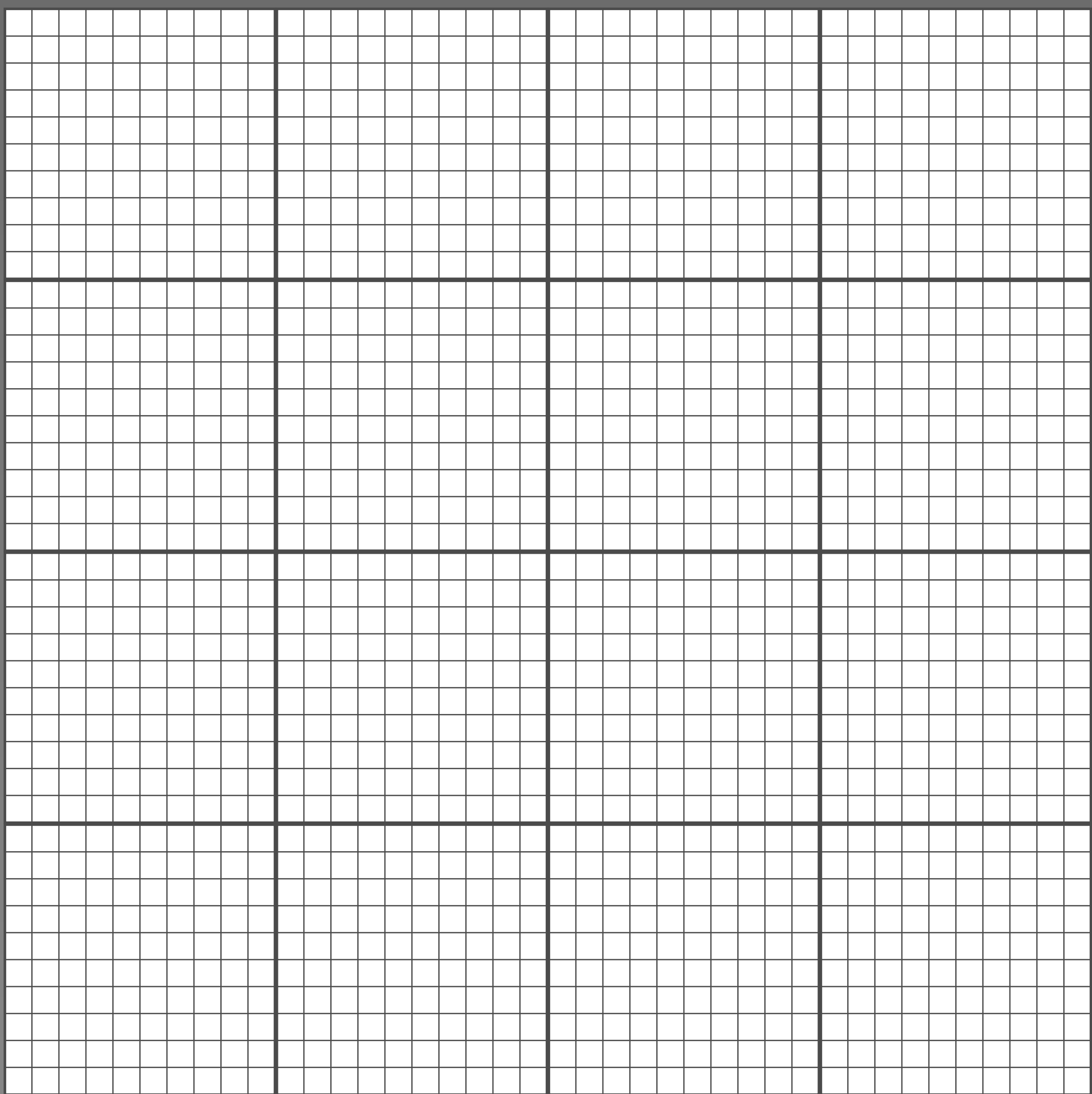




The diagram above shows a cranked lever that is part of a gear-change mechanism.

Determine the resultant force F*r* acting on the hinge pivot and the angle .

Scale: 1 block = 100N



Course Notes v2.0, June 2017

Some may question why these notes look the way they do. Well, simply put, the explosion of construction and the adoption of Art-Deco design of the 1920's is simply inspirational. Post World-War 1, New York adopted steel to create monstrously huge buildings that only 50 years before would be impossible to create.

Understanding forces, materials and structures is a science that designers and engineers have developed over thousands of years, and with the invention of new materials, this wisdom could be applied in new ways.

What materials of the future will build our world?

DESIGN CLASS