DET: Technological Studies

Structures and Materials

Higher

4517

Spring 1999

HIGHER STILL

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Structures and Materials

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Support Materials

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TEACHER'S GUIDE

Support Materials - Overview

The support materials for Technological Studies courses in Higher Still have been created to specifically address the outcomes and PC in each unit at the appropriate level. These support materials contain a mixture of formal didactic teaching and practical activities.
The support materials for each unit have been divided into outcomes. This will facilitate assessment as well as promoting good teaching practice.

The materials are intended to be non-consumable, however it is at the discretion of each centre how to use these materials.

Each package of support materials follows a common format:

1. Statement of the outcome.
2. Statement of *what the student should be able to do* on completion of the outcome.
3. Learning and teaching activities.
4. Sequence of structured activities and assignments.
5. Formal Assessment
    - NAB - assessing knowledge PC.
    - Computer simulation - assessing simulation PC.
    - Practical assignments - assessing practical PC.

It is important to note that the National Assessments have been designed to allow assessment either after each outcome has been completed or as an end of unit assessment when all outcomes have been completed depending on the needs of the centre.

The use of SQA past external paper questions has been used throughout the materials and the further use of these questions is encouraged.

Using past questions provides the opportunity for students to:

1. Work at the appropriate level and rigor
2. Prepare for external assessment.
3. Consolidate teaching and learning.
4. Integrate across units.

Homework is a key factor in effective teaching and learning. The use of resources such as P & N practice questions in Technological Studies is very useful for homework activities and also in preparation for external assessment.

The use of integrated questions across units is essential in preparation of students for External Assessment.

Support Materials - Content

Outcome 1 - Apply the conditions of static equilibrium in solving problems on concurrent force and non-concurrent force systems.

The purpose of this unit of work is to introduce students to concurrent and non-concurrent force systems, conditions of static equilibrium and free body diagrams. Resolution of forces and the principle of moments are other areas that are investigated.

When students have completed this unit of work they should be able to -

- Resolve a force into its horizontal and vertical components
- Find the resultant force in concurrent force system
- Apply the principle of moments to a simple lever system
- Draw free body diagrams of a force system
- Apply the conditions of static equilibrium to solve non-concurrent force systems.

Outcome 2 - Apply the conditions of static equilibrium in solving problems on simple structural systems.

The purpose of this unit of work is to introduce students to frame structural systems and the nodal analysis method of solving frame structural problems.

When students have completed this unit of work they should be able to -

- Recognise how ties and struts behave in a frame structure
- Understand that a node in a frame structure is in equilibrium
- Apply the conditions of static equilibrium at a frame structures node
- Use the nodal analysis method to determine the loads in members
- Determine the support reactions for a frame structure.

Outcome 3 - Use and interpret data from a tensile test in studying properties of materials.

The purpose of this unit of work is to introduce students to the properties of materials. This is achieved through analysis of tensile test data. Calculations of Young's Modulus, stress, strain and the interpretation of graphs are integral to this outcome.

When students have completed this unit of work they should be able to -

Plot a load extension graph from given test data
Identify important points on the graph
Describe the effect of increased loading on a test piece
Calculate Young's Modulus, stress and strain

- Describe the properties of a material from test data

Outcome 4 - Produce a specification for a structural component.

The purpose of this unit of work is to introduce students to component and structural specifications. Factor of safety, loading, the environment are issues that are addressed in this outcome.

When the students have completed this unit of work they should be able to -

- Use tabulated and graphical data to select materials
- Calculate factor of safety
- Consider the effect of the environment on structures

TECHNOLOGICAL STUDIES

HIGHER

STRUCTURES AND MATERIALS

SECTION 1

OUTCOME 1

OUTCOME 1

Apply the conditions of static equilibrium in solving problems on concurrent force and non-concurrent force systems.

It is recommended that the learning outcomes for the Structures and Materials unit are presented to the students in the sequence they are listed in the arrangements document.

When the students have completed this unit they should be able to:

- resolve a force into its horizontal and vertical components.
- find the resultant force in concurrent force system.
- apply the principle of moments to a simple lever system.
- draw free body diagrams of a force system.
- apply the conditions of static equilibrium to solve non-concurrent force systems.

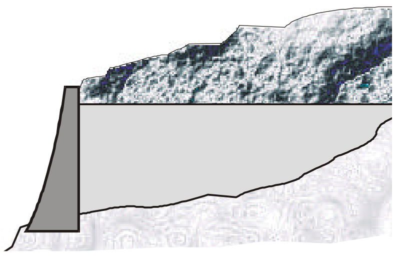
For this learning outcome unit it is assumed that students have no previous experience with force systems. It would, however, be useful if the students had a working knowledge of basic trigonometry and can find an unknown dimension or angle in a right angled triangle.

There are no separate homework sheets in this learning outcome unit. It is envisaged that tasks could be started in class and finished at home. This will probably be necessary due to the number of tasks to be done in the time available.

STRUCTURES

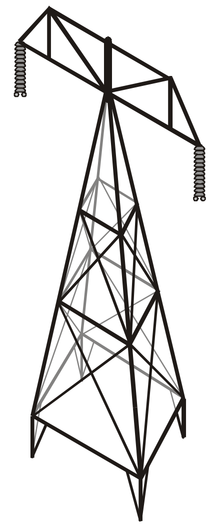
There are three main types of structure - mass, framed and shells.

Mass structures perform due to their own weight.
An example would be a dam.



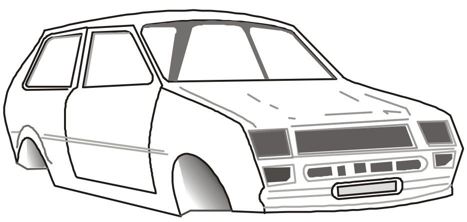
SM H O.1 fig1

Frame structures resist loads due to the arrangement of its members. A house roof truss can support a load many times its own weight. A two dimensional frame such as this is known as a plane frame. The Eiffel Tower is an example of a three dimensional frame structure, known as a space frame. Electricity pylons are good examples of frame structures.



SM H O.1 fig2

Shells are structures where its strength comes from the formation of sheets to give strength.
A car body is an example of a shell structure.



SM H O.1 fig3

It is very important with any structure that we can calculate the forces acting within it so that a safe structure can be designed. Early structures where found to be successful due to the fact that they stayed up and many early structures are still with us, but many are not. The science of structures has been progressively improving over the centuries and it is now possible to predict a structures behaviour by analysis and calculation. Errors can still be made, some times with catastrophic results.

In this course we are generally going to consider frame structures. We shall learn to recognise the effect a load will have on a body and what happens if several forces are acting on a structure. When a force acts on a body we have to be able to calculate the effect on the different members. We shall by the end of this unit be able to calculate the force acting in any member in a simple structure and, from this determine, a suitable material and cross section needed to carry this load.

FORCES

All structures are loaded or exerted upon by external forces.

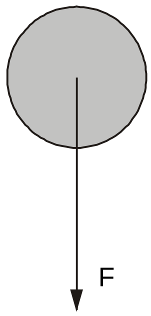
The many different physical quantities you will encounter in the field of engineering and science may be split into two different groups. The first group contains those quantities that have no direction; e.g. mass and volume are examples of scalar quantities.

The second group of physical quantity posses a direction as well as a magnitude and are known, as a vector quantity examples of vector quantities are displacement, velocity and force.

Vectors

A vector quantity can be represented by a straight line drawn in the direction its acting. The length of the line is proportional to the magnitude.

The diagram below shows the vector for the force produced by gravity acting on a 10Kg force.



$$F = mg$$

$$F = 10 \times 9.81$$

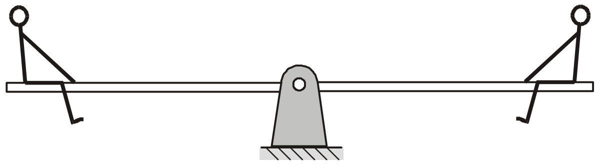
$$F = 98.1N$$

SM H O.1 fig4

In most situations you will encounter two or more vector quantities acting on an object or structure at the same time.

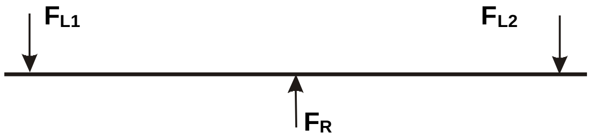
Adding Vectors

In the structure below, three forces are acting on it.



SM H O.1 fig5

The diagram shown below can represent the forces in the above diagram.



SM H O.1 fig6

$\mathbf{F_{L1}}$ and $\mathbf{F_{L2}}$ represent the force exerted due to the mass of the people. $\mathbf{F_R}$ is the reaction force. This type of diagram is known as a free-body diagram.

The reaction load $\mathbf{F_R}$ is found by adding the two downward forces together.

In any force system the sum of the vertical forces must be equal to zero.

$$\Sigma F_v = 0$$

$$F_R = F_{L1} + F_{L2}$$

$$F_R = 810N + 740N$$

$$F_R = 1550N$$

$\Sigma F_v = 0$ - this is one of the conditions of static equilibrium.

There are two other conditions of static equilibrium -

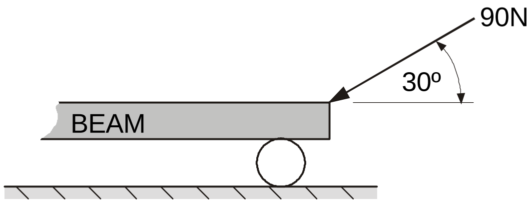
$\Sigma F_x = 0$ - this states that all forces acting horizontally must be equal to zero.

We shall meet the other condition of static equilibrium later in the course.

Resolution of a force

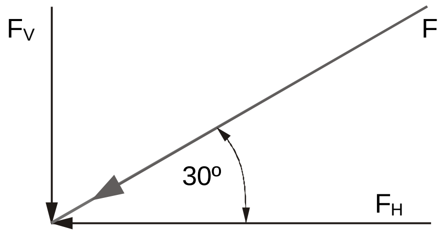
In some cases the loads may not be acting in the same direction, and can not therefore be added together directly.

In the situation shown below the force is acting down at an angle.



SM H O.1 fig7

This force can be split into two separate components. A vertical component $\mathbf{F_V}$ and a horizontal component $\mathbf{F_H}$.



SM H O.1 fig8

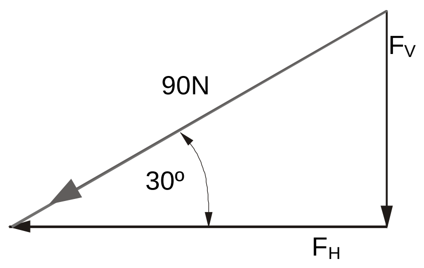
To resolve a force into its components you will have know two things, its magnitude and direction.

Trigonometry is used to resolve forces.

$$\sin a = \frac{opp}{hyp} \qquad \cos a = \frac{adj}{hyp}$$

Where - hyp = force (F)
opp = vertical component (F_V)
adj = horizontal component (F_H)

The diagram above can be redrawn as below.



SM H O.1 fig9

To find the horizontal force (F_H)

$$\cos 30° = \frac{F_H}{90}$$

$$F_H = 90 \times \cos 30°$$

$$= 77.94N$$

Horizontal force = 77.94 N

To find the vertical force (F_V)

$$\sin 30° = \frac{F_V}{90}$$

$$F_V = 90 \times \sin 30°$$

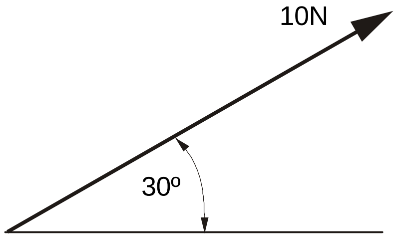
$$= 45N$$

Vertical force = 45 N

Task - Resolution of Forces

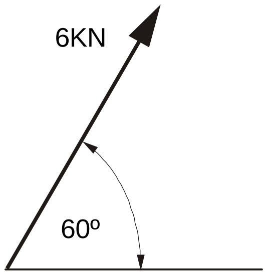
1. Resolve the following forces into their horizontal and vertical components.

a)



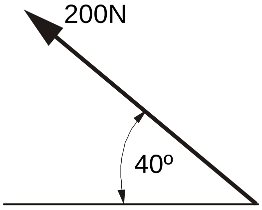
SM H O.1figs10

b)



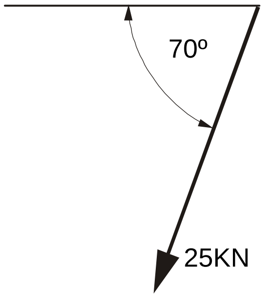
SM H O.1figs11

c)



SM H O.1figs12

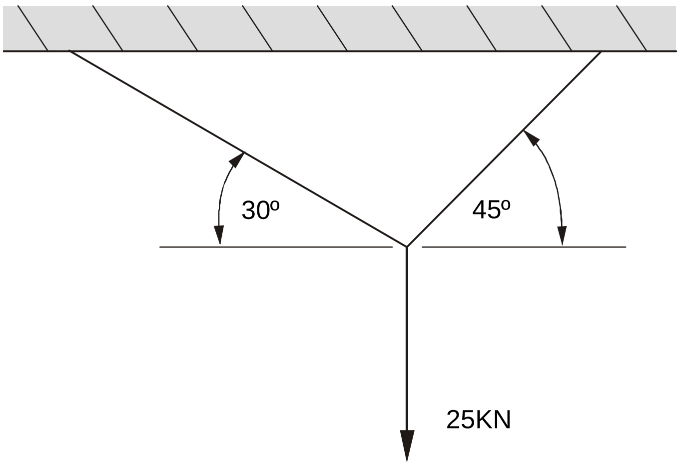
d)



SM H O.1figs13

Sometimes the components are known and it is the force that is to be calculated.

2. Determine the tension in the two cables.
   Note - the vertical component of the two cables will be the same.

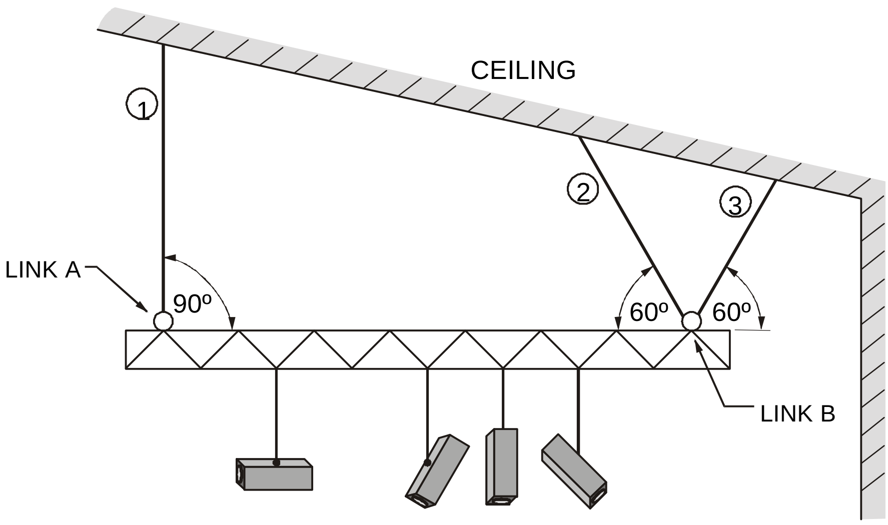


SM H O.1fig14

3. A lighting gantry in a small theatre is fixed to a sloping ceiling by three independent wire ropes as shown below.

When the lamps are set in position, the vertical loading on link A and link B are 2.5KN and 5KN respectively.

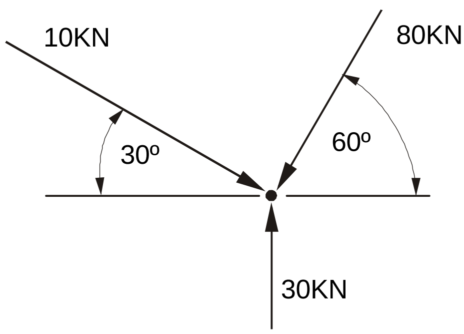
Calculate the magnitude of the force in each of the three ropes.



SM H O.1fig15

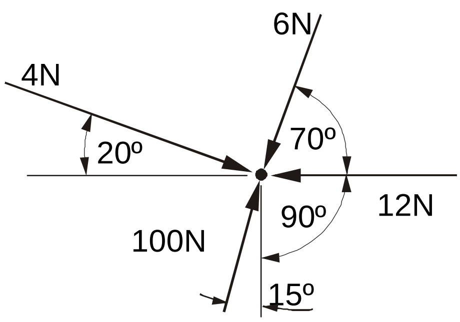
4. Find the resultant for these force systems. Find the horizontal and vertical components of each - add them up to find the overall component forces and then find the resultant.

a)



SM H O.1figs16

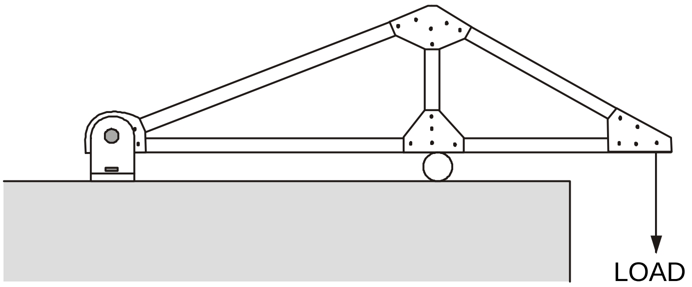
b)



SM H O.1figs17

MOMENT OF A FORCE

The moment of a force is the turning effect of that force when it acts on a body



The load acting on the frame structure above will have a turning effect on the structure and cause the supports to support different loads.

Principles of Moments - Revision

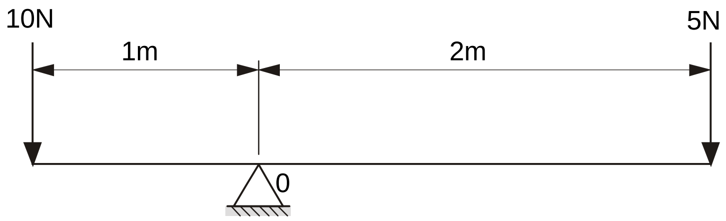
The Principle of Moments states that if a body is in Equilibrium the sum of the clockwise moments (given positive sign) is equal to the sum of anti-clockwise moments (negative sign). This can be written:

$$\Sigma M_O = 0$$

This is the third condition of static equilibrium.

Worked Examples

Example 1



SM H O.1fig19

$$\Sigma M_O = 0$$

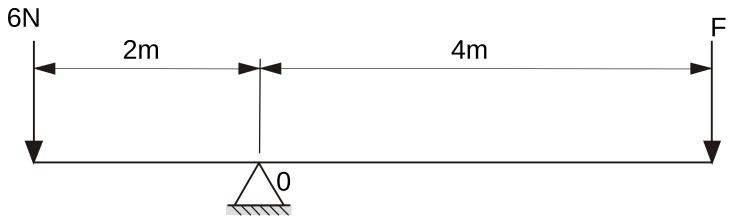
$$(5 \times 2) - (10 \times 1) = 0$$

$$10 - 10 = 0$$

THE ABOVE EXAMPLE IS IN EQULIBRUIM

We can use this principle to find an unknown force or unknown distance.

Example 2



SM H O.1fig20

$$\Sigma M = 0$$

$$CWM = ACWM$$

$$(F \times 4) = (6 \times 2)$$

$$4F = 12$$

$$F = \frac{12}{4}$$

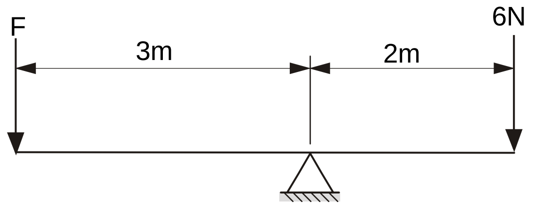
$$F = 3N$$

Assignments: Moments

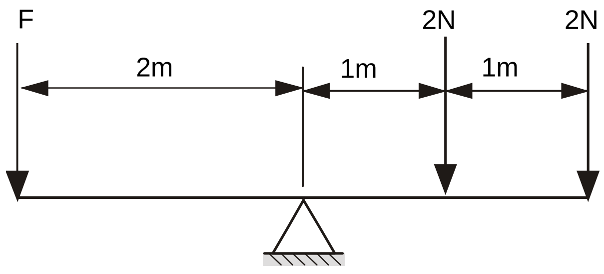
The beams shown below are in equilibrium. Find the unknown quantity for each arrangement.

Question 1

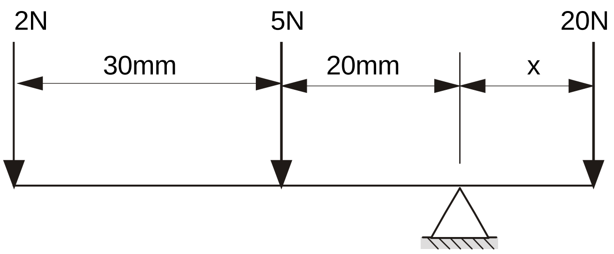
a)



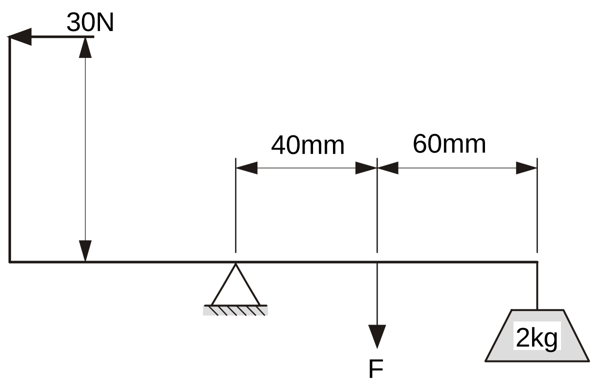
b)



c)



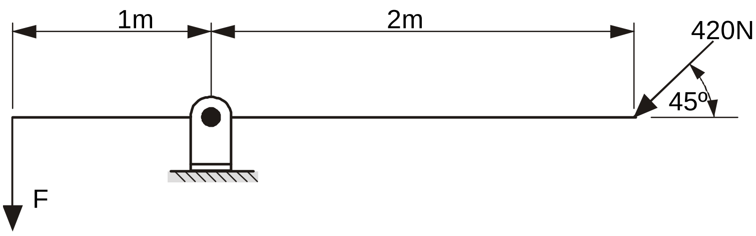
d)



The following beams, in equilibrium, have inclined forces. Find the unknown quantity.

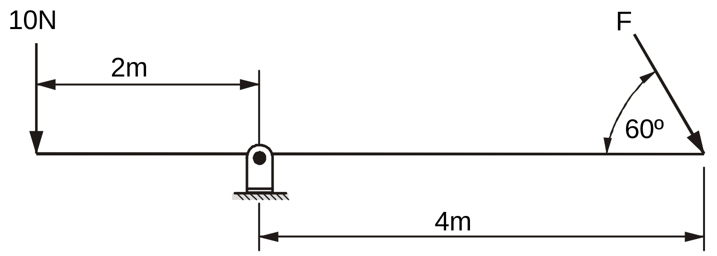
Question 2

a)



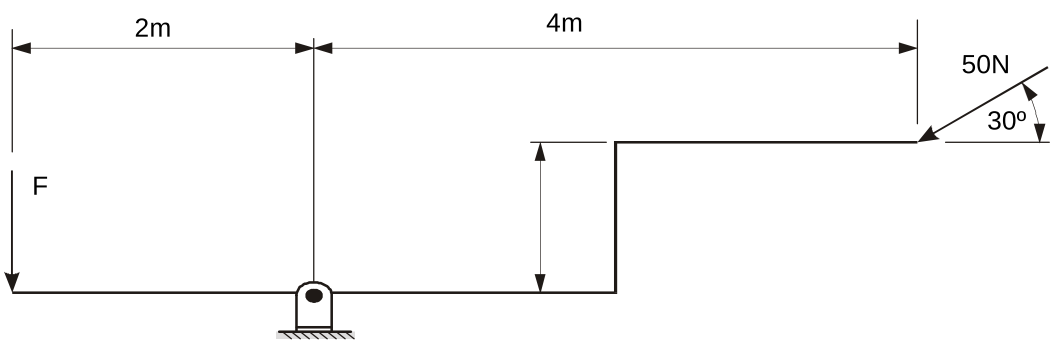
SM H O.1fig25

b)



SM H O.1fig26

c)



SM H O.1fig27

BEAM REACTIONS

We are now going to study beams with external forces acting on them. We shall resolve forces into their components and use moments to find the support reactions.

Definitions of some of the terms you have met already:

RESULTANT	The resultant is that single force that replaces a system of forces and produces the same effect as the system it replaces.
EQUILIBRIUM	Equilibrium is the word used to mean balanced forces. A body several forces acting on it which all balance each other is to be in a state of equilibrium. A body in equilibrium can be at rest or traveling with uniform motion in a straight line.

Conditions of Equilibrium

In the force system in this section you shall apply the three condition of equilibrium that you have used before. To solve the force systems the conditions of equilibrium are applied in a certain order, the correct order is shown below.

1. The sum of all the moments equals zero.

$$\Sigma M_o = 0$$

2. The sum of the forces in the y direction equals zero.

$$\Sigma F_y = 0$$

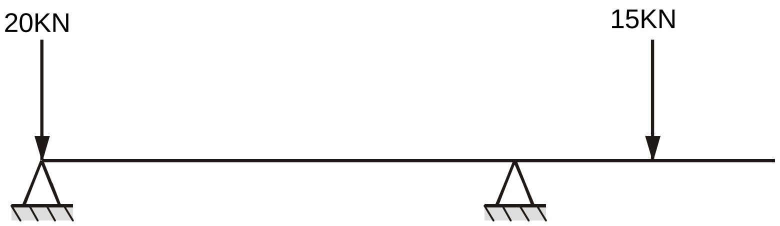
3. The sum of the forces in the x direction equals zero.

$$\Sigma F_x = 0$$

Beam Reactions

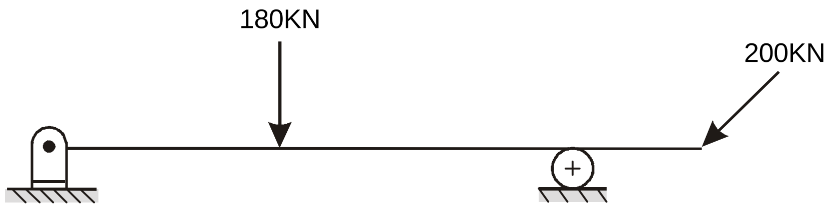
A beam is usually supported at two points. There are two main ways of supporting a beam -

1. Simple supports (knife edge)



SM H O.1fig28

2. Hinge and roller



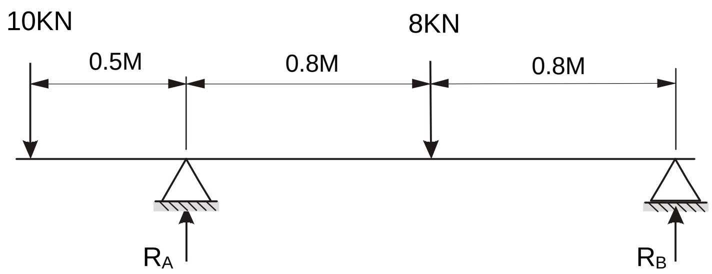
SM H O.1fig29

Worked Examples

1. SIMPLE SUPPORTS

Simple supports are used when there is no sideways tendency to move the beam.

Consider this loaded beam, "simply" supported.



SM H O.1fig30

1. The forces at the supports called reactions, always act vertically.

2. The beam is in equilibrium; therefore the conditions of equilibrium apply.

The value of Reactions $\mathbf{R_A}$ and $\mathbf{R_B}$ are found as follows.

Take moments about R_A

$$\Sigma M_{RA} = 0$$
$$CWM = ACWM$$
$$(8 \times 0.8) = (R_B \times 1.6) + (10 \times 0.5)$$
$$6.4 = 1.6R_B + 5$$
$$1.6R_B = 6.4 - 5$$
$$R_B = \frac{1.4}{1.6}$$

$$R_B = 0.88KN$$

There are two methods available to find R_A

1. Take moments again, this time about R_B, or
2. Equate the vertical forces (since the beam is in equilibrium)

Equating vertical forces

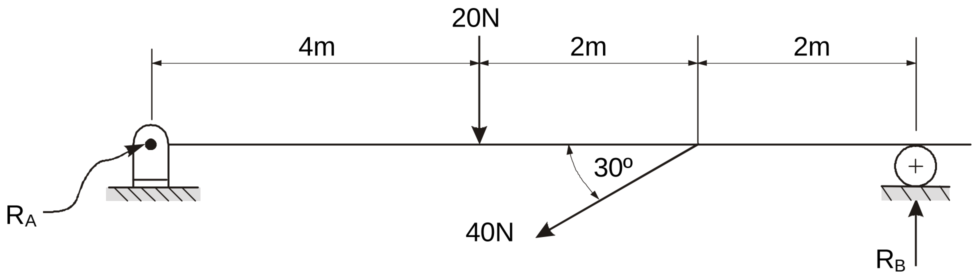
$$\Sigma F_V = 0$$
$$R_A + R_B = 10 + 8$$
$$R_A = 18 - R_B$$

$$R_A = 18 - 0.88$$

$$R_A = 17.12KN$$

2. HINGE AND ROLLER SUPPORTS

Hinge and roller supports are used when there is a possibility that the beam may move sideways.



SM H O.1fig31

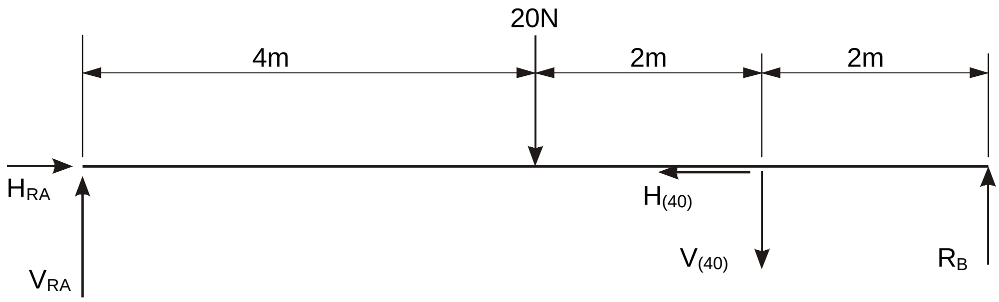
Note: The reaction at a roller support is always at right angles to the surface. The direction of $\mathbf{R_A}$ is assumed. If any of the components work out as negative values then the direction will be opposite the assumed direction.

The reaction at the hinge support can be any direction.
(Find the two components of the hinge reaction, then the resultantant)

There are three unknown quantities above: -

1. The magnitude of Reaction $\mathbf{R_B}$.
2. The magnitude of Reaction $\mathbf{R_A}$.
3. The direction of Reaction $\mathbf{R_A}$.

Redraw as a free-body diagram showing vertical and horizontal components of the forces.



SM H O.1fig32

The vertical and horizontal components of the 40N force are found first $\mathbf{V_{(40)}}$ and $\mathbf{H_{(40)}}$ -

$V_{40} = \sin 30^0 \times 40$ $\qquad$ $H_{40} = \cos 30^0 \times 40$

$V_{40} = 20N$ $\qquad$ $H_{40} = 34.64N$

To find $\mathbf{R_B}$ -take moments about $\mathbf{V_{RA}}$, this eliminates one of the unknown vertical forces.

$$\Sigma M_A = 0$$
$$CWM = ACWM$$
$$(20\times 4) + (20\times 6) = (R_B \times 8)$$
$$8R_B = 200$$
$$R_B = \frac{200}{8}$$
$$R_B = 25N$$

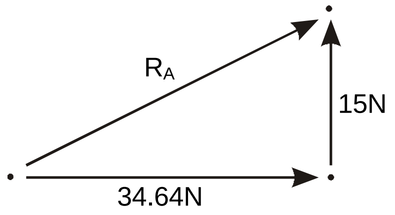
Vertical forces

$$\Sigma F_Y = 0$$
$$V_{RA} + R_B = 20 + 20$$
$$V_{RA} = 40 - R_B$$
$$V_{RA} = 40 - 25$$
$$V_{RA} = 15N$$

Horizontal forces

$$\Sigma Fx = 0$$
$$H_{RA} - 34.64 = 0$$
$$H_{RA} = 34.64N$$

Use V_{RA} and H_{RA} to find R_A

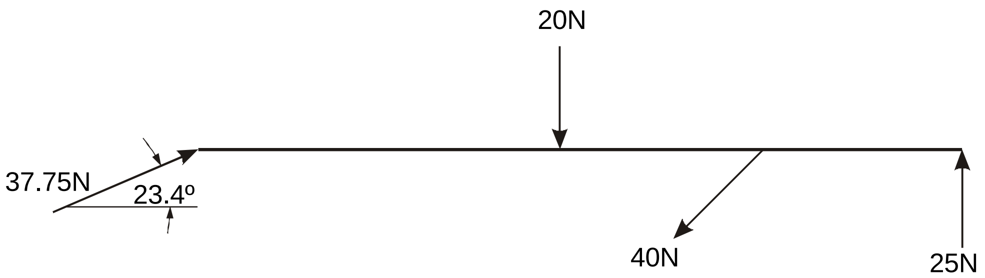


SM H O.1fig33

$$\begin{aligned} R_A &= \sqrt{15^2 + 34.64^2} \\ &= \sqrt{225 + 1199.93} \\ &= 37.75N \end{aligned}$$

Find direction of R_A

$$\begin{aligned} \tan a &= \frac{VR_A}{HR_A} \\ &= \frac{15}{34.64} \\ &= 23.4^\circ \end{aligned}$$

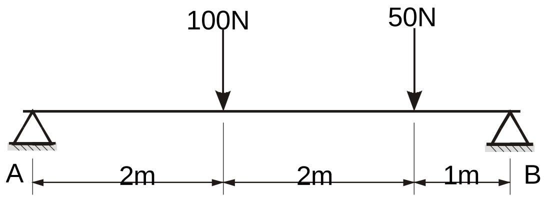


SM H O.1fig34

Assignments: Beam Reaction

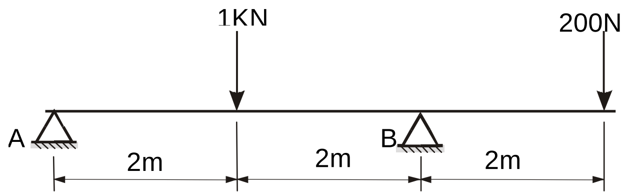
1) Find the reactions at supports A and B for each of the loaded beams shown below.

a)



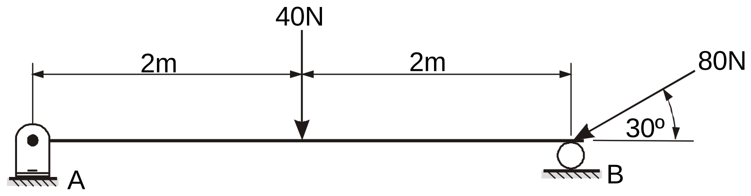
SM H O.1fig37

b)



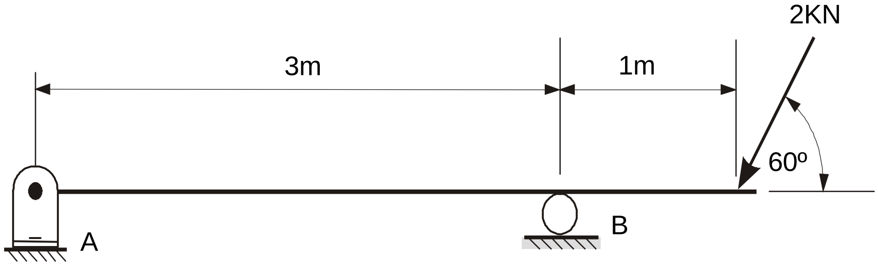
SM H O.1fig38

c)



SM H O.1fig39

d)

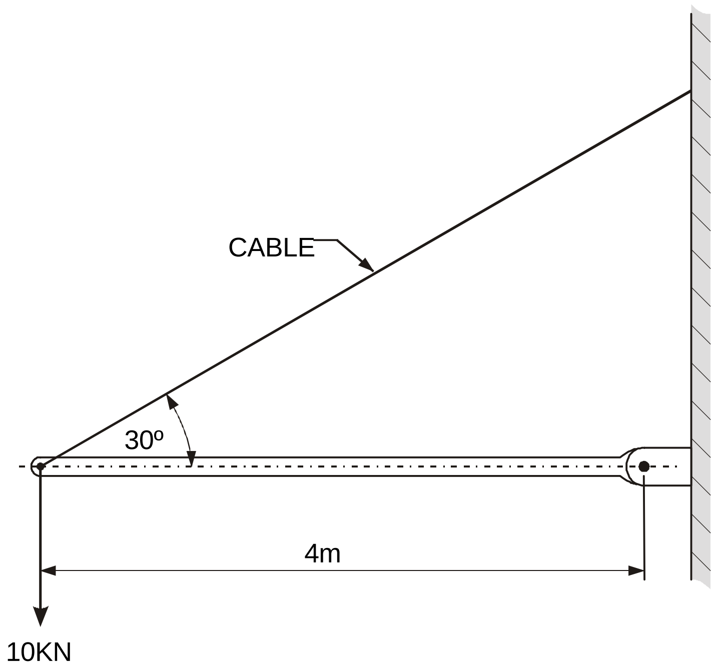


SM H O.1fig40

Task - Beam Reaction (continued)

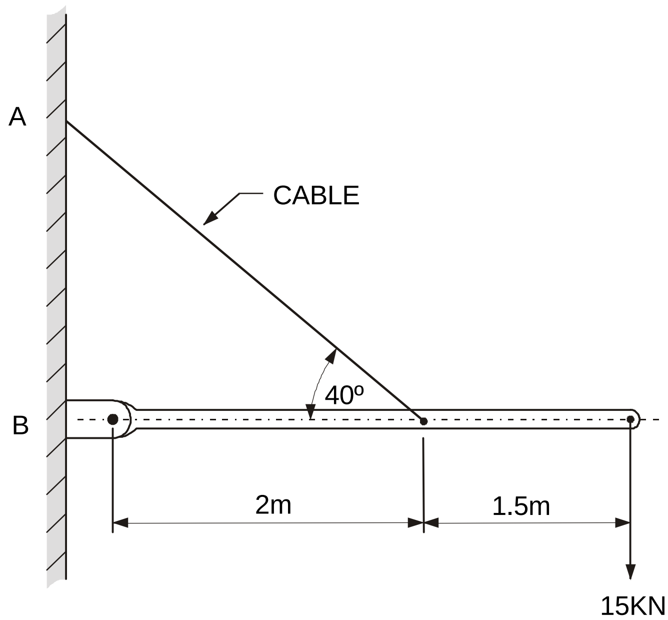
2) Find the reactions at supports A and B for each of the loaded beams shown below.

a)



SM H O.1fig41

b)



SM H O.1fig42

TECHNOLOGICAL STUDIES

HIGHER

STRUCTURES AND MATERIALS

SECTION 2

OUTCOME 2

OUTCOME 2

Apply the conditions of static equilibrium in solving problems on simple structural systems.

It is recommended that the learning outcomes for the Structures and Materials unit are presented to the students in the sequence they are listed in the arrangements document.

When the students have completed this unit they should be able to

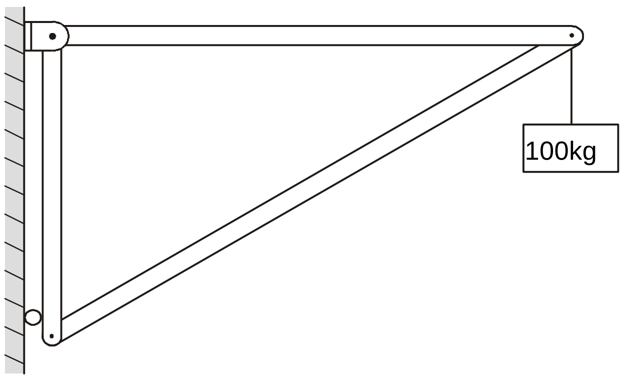
- Recognise how ties and struts behave in a frame structure.
- Understand that a node in a frame structure is in equilibrium.
- Apply the conditions of static equilibrium at a frame structures node.
- Use the nodal analysis method to determine the loads in members.
- Be able to determine the support reactions for a frame structure.

For this learning outcome unit it is assumed that students have completed the work for Structures and Materials learning outcome 1.

There are no separate homework sheets in this learning outcome unit. It is envisaged that tasks could be started in class and finished at home. This will probably be necessary due to the number of tasks to be done in the time available.

FRAMED STRUCTURES

A frame structure is an assembly of members and joints (usually called Nodes) which is designed to support a load. Examples of frame structures include roof trusses, bridges, pylon towers etc.



SM H O.2 fig 1

The members in this framed structure can be as ties or struts, depending on the type of force they support.

STRUTS AND TIES

When solving problems in frame structures you will be required to determine the Magnitude and Nature of the forces in the members of the frame. That is, determine, in addition to the size of the force in the member, whether the member is a Strut or a Tie.

Strut

Members that are in compression, due to external forces trying to compress them, are known as Struts.

Tie

Members that are in tension, due to external forces trying to pull them apart, are known as Ties.

NODAL ANALYSIS

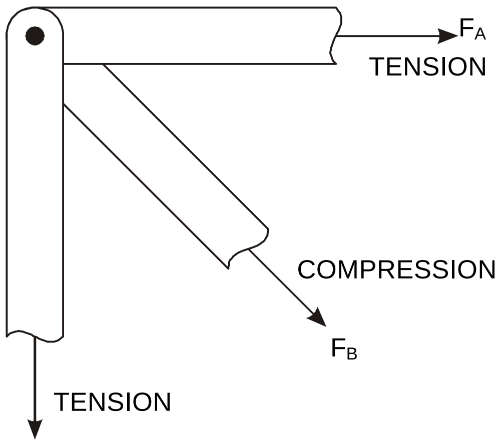
There are several methods of solving frame structure problems. The method we shall use is called Nodal Analysis.

Any joint where members meet is known as a node.

This method relies on the fact that if structures are in equilibrium then each node will be in equilibrium. The sum of the forces acting on any the node will zero.

Nodes

The members are either in compression (strut) or tension (tie). They can be represented at the node as shown below -



SM H O.2 fig 4

$\mathbf{F_B}$ is under compression and pushes into the node, $\mathbf{F_A}$ is under tension and pulls away from the node.

Conditions of Static Equilibrium

SUM OF THE MOMENTS = 0	$\Sigma M_o = 0$
SUM OF THE VERTICAL FORCES = 0	$\Sigma F_V = 0$
SUM OF THE HORIZONTAL FORCES = 0	$\Sigma F_H = 0$

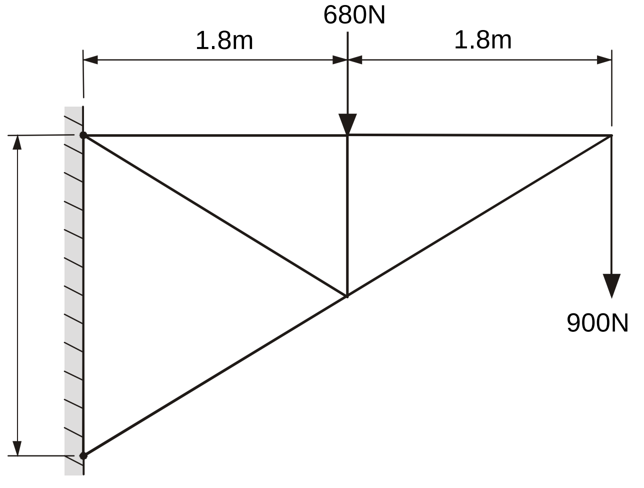
When solving frame structures some analysis of the structure is required to determine the best starting point and which of the conditions of static equilibrium to apply first.

Solving Simple Frame Structures

To help solve frame structure problems there are some simple rules to follow depending on the type of structure.

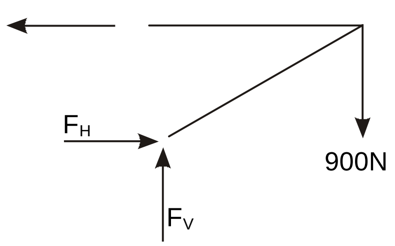
Cantilevered frame structures

For this frame structure it is not necessary to use moments to help find the forces in the members. .
The node with the 900N load acting has only one unknown vertical component.



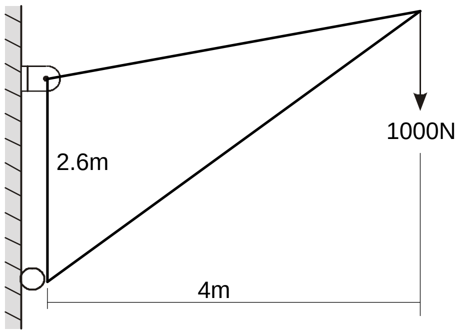
As all vertical forces acting on the node must equal zero then $\mathbf{F_V}$ must equal 900N.

By using trigonometry it is now possible to find the other forces acting on this node.

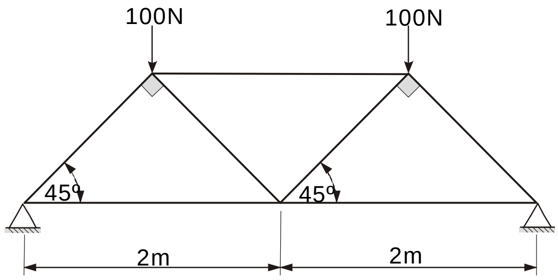


In this example all nodes have more than one unknown force or component of a force.

To solve this frame structure take moments about the top support to find the reaction force at the roller support.



Truss frame structures

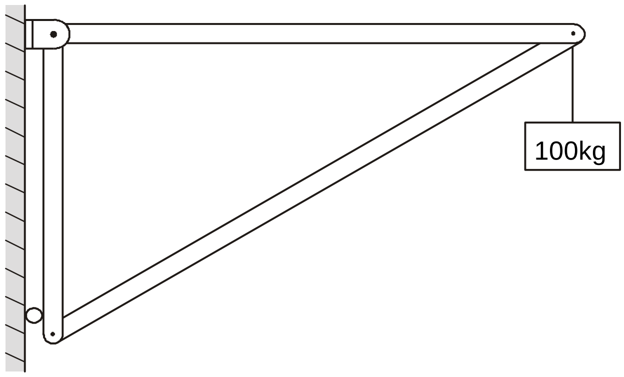


Treat structure like this as a beam and use moments to find reactions. Until the reaction forces are found all nodes have more than one unknown force or component.

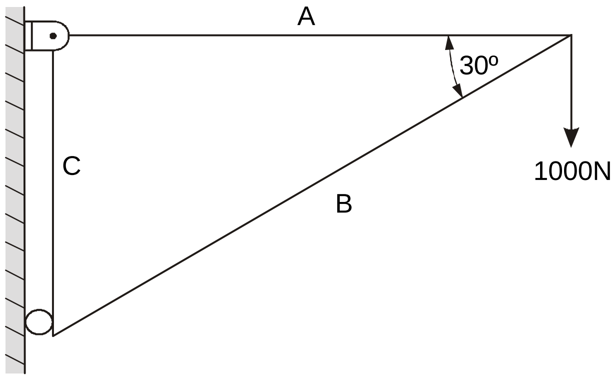
Then start analysis at $\mathbf{R_1}$ or $\mathbf{R_2}$, which will now have only one unknown component.

Worked Example

For the crane shown below we shall find the forces in the members and the reaction forces at the wall.



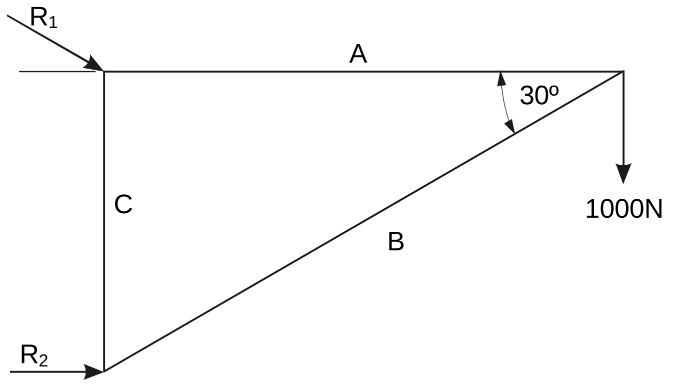
Draw a free body diagram of the frame structure.



The framework is supported at two points. The hinge support at the top is being pulled away from the wall. $\mathbf{R_1}$ will act against this pull and keep the hinge attached to the wall. The roller support is being pushed into the wall. $\mathbf{R_2}$ will act against this force and in the opposite direction as shown below.

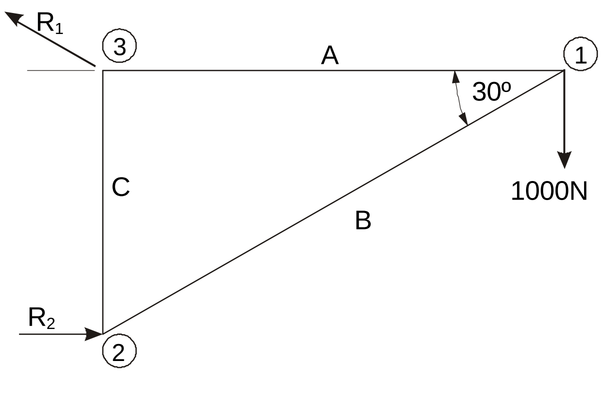
As member **B** is acting on a roller then $\mathbf{R_2}$ will be at 90° to member **C**

As $\mathbf{R_1}$ is acting at a hinge support there will be a vertical and horizontal component. At this stage guess the direction of $\mathbf{R_1}$.



If a wrong assumption about the member being in tension or compression or the direction of a force is made then a negative value will be produced from the calculation. If this is the case the direction of the force is simply reversed

To find the forces in the members and the reactions at the supports, study each of the structure nodes separately.

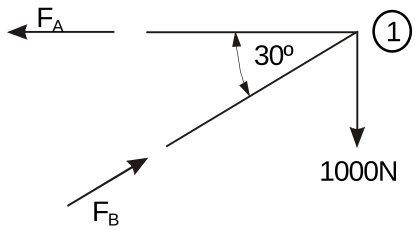


Each node is in equilibrium so we can use the conditions of equilibrium.

SUM OF THE VERTICAL FORCES = 0	$\Sigma F_V = 0$
SUM OF THE HORIZONTAL FORCES = 0	$\Sigma F_H = 0$
SUM OF THE MOMENTS = 0	$\Sigma M_o = 0$

In this sort of problem where the structure is cantilevered out from the wall, it is normally solvable without considering the moments. Start by finding a node that has only one unknown vertical or horizontal component.

Node 1
The forces acting on node 1 are shown below.

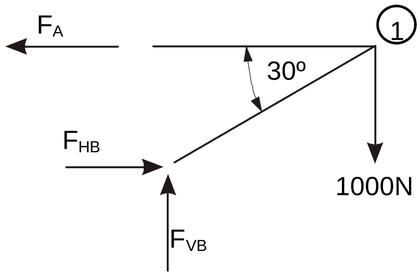


Note - an assumption has been made about the direction of $\mathbf{F_A}$ and $\mathbf{F_B}$.

$\mathbf{F_A}$ is assumed to be in tension and acting away from the node 1.

$\mathbf{F_B}$ is assumed to be in compression and acting in towards the node 1.

Split $\mathbf{F_B}$ into its horizontal ($\mathbf{F_{HB}}$) and vertical ($\mathbf{F_{VB}}$) components.

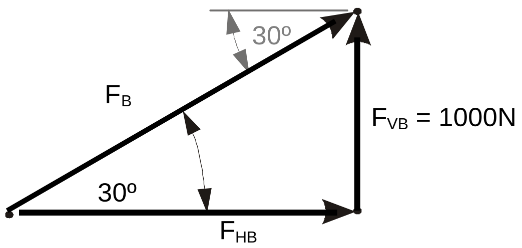


Apply a condition of static equilibrium -

$$\Sigma F_V = 0$$

As the sum of Vertical forces is equal to zero then the vertical component of $\mathbf{F_B}$ ($\mathbf{F_{VB}}$) is 1000N acting up.

From this we can find $\mathbf{F_B}$ - we can redraw $\mathbf{F_B}$ and the two components $\mathbf{F_{HB}}$ and $\mathbf{F_{VB}}$ to form a triangle as shown below.



$$u \sin g - \sin q = \frac{opp}{hyp}$$

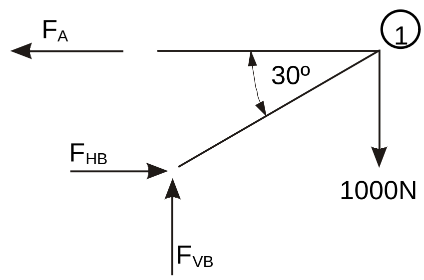
$$\sin 30° = \frac{F_{VB}}{F_B}$$

$$F_B = \frac{F_{VB}}{Sin 30°}$$

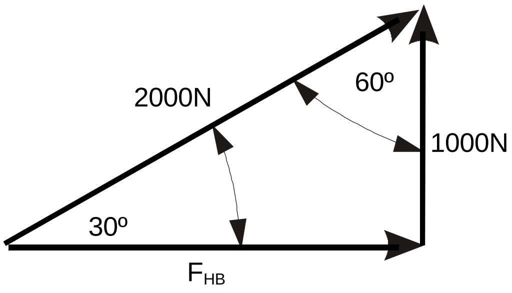
$$= \frac{1000}{0.5}$$

$$= 2000N$$

The force in member **A** ($\mathbf{F_A}$) will equal and opposite to $\mathbf{F_{HB}}$.



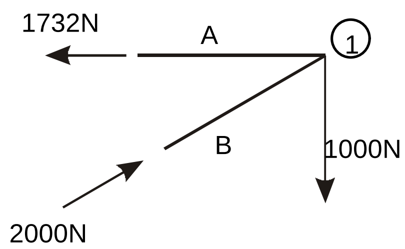
Find $\mathbf{F_{HB}}$ -



$$\cos 30° = \frac{F_{HB}}{F_B}$$
$$F_{HB} = \cos 30° \times F_B$$
$$= 0.87 \times 2000$$
$$= 1732N$$

From above $\mathbf{F_A}$ = 1732N

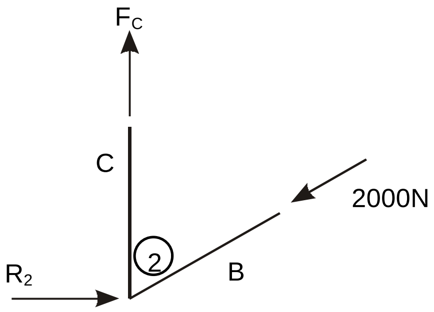
This diagram shows all the forces acting at node 1.



Worked Example (continued)

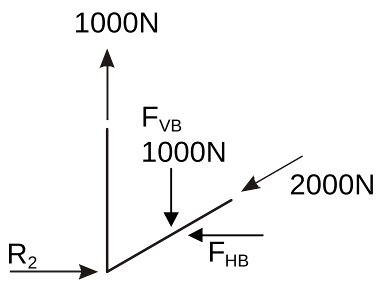
Node 2

There are three forces acting at node 2.



During analysis of node 1, $\mathbf{F_B}$ was found to be 2000N and was not negative so the assumed direction towards the node (compression) was correct.

In node 1, $\mathbf{F_B}$ is shown to be acting as a compressive force towards the node with a magnitude of 2000N.



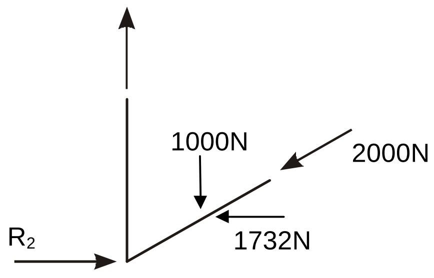
$\mathbf{F_C}$ will be equal and opposite to the Vertical component of $\mathbf{F_B}$ ($\mathbf{F_{VB}}$).

From analysis of node 1 $\mathbf{F_{VB}}$ was equal to 1000 N therefore -

$$\mathbf{F_C} = 1000 \text{ N}$$

As **R_2** is a roller support the reaction will be at 90° to the surface.

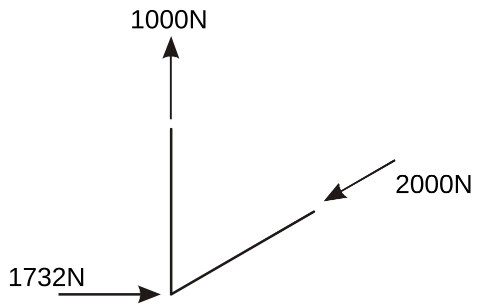
R_2 will be equal to the Horizontal component of **F_B**.



From above **H_B** was equal to 1732 N therefore -

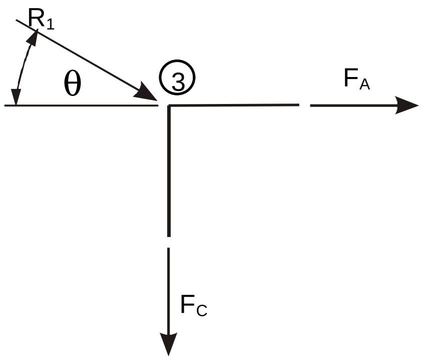
$$\mathbf{R_2} = 1732\text{N}$$

The forces acting at node 2 are shown below.



Node 3

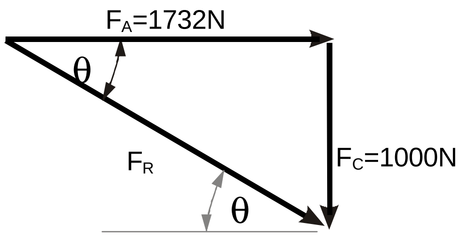
Node 3 has three forces acting on it.



$\mathbf{R_1}$ will be equal and opposite to the resultant of $\mathbf{F_A}$ and $\mathbf{F_C}$.

From analysis of node 1 $\mathbf{F_A}$ was found to be 1732N.
From analysis of node 2 $\mathbf{F_C}$ was found to be 1000N

Find resultant of $\mathbf{F_A}$ & $\mathbf{F_C}$ - $\mathbf{F_R}$

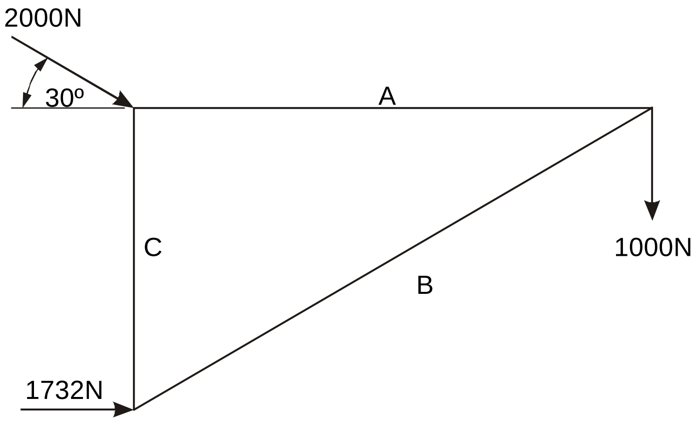


$$\begin{aligned} F_R &= \sqrt{F_A{}^2 + F_C{}^2} \\ &= \sqrt{1732^2 + 1000^2} \\ &= 2000N \end{aligned}$$

Find angle of resultant (**θ**) -

$$\begin{aligned} \tan q &= \frac{F_C}{F_A} \\ &= \frac{1000}{1732} \\ &= 0.58 \\ q &= 30^{o} \end{aligned}$$

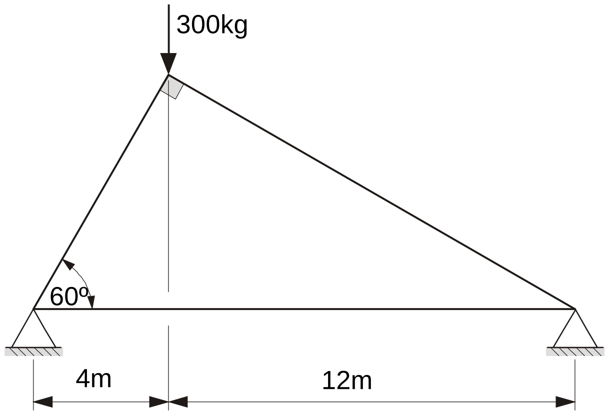
The task was to find the forces in the members and the reactions forces at the supports. The results can be shown as below -



MEMBER	FORCE	TYPE OF FORCE
A	1732N	TENSION
B	2000N	COMPRESSION
C	1000N	TENSION

Assignment 1

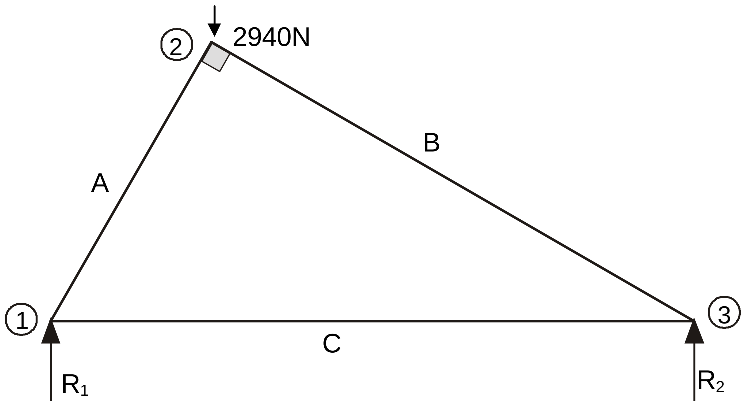
Find the reactions R_1 and R_2 and the forces for the members in the frame structure shown below.



The free body diagram with the nodes and members labeled is given below.

In this type of problem where the structure is acting as a beam, find R1 and R_2 using moments.

Take moments about R_1 -



$$\Sigma M_{R1} = 0$$

$$(2940 \times 4) + (-R_2 \times 16) = 0$$

$$R_2 \times 16 = 11760$$

$$R_2 = \frac{11760}{16}$$

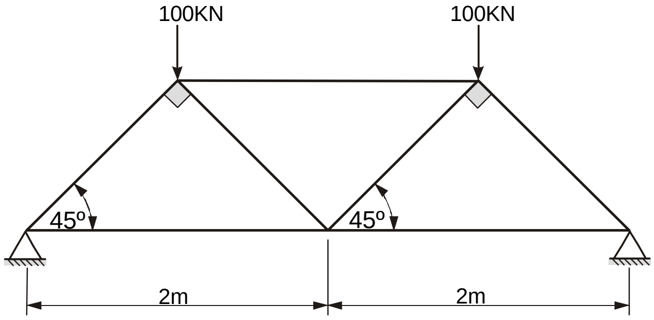
$$R_2 = 735N$$

Now complete this task and find R_1 and the forces in A, B and C.

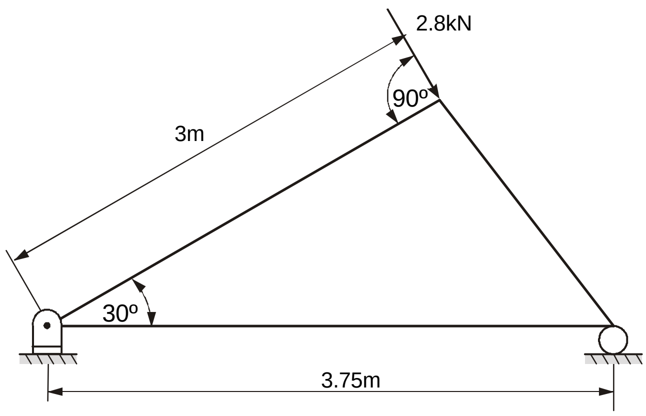
Assignment 2

Find the reactions, the magnitude and nature of the forces in the members of the frame structures shown below.

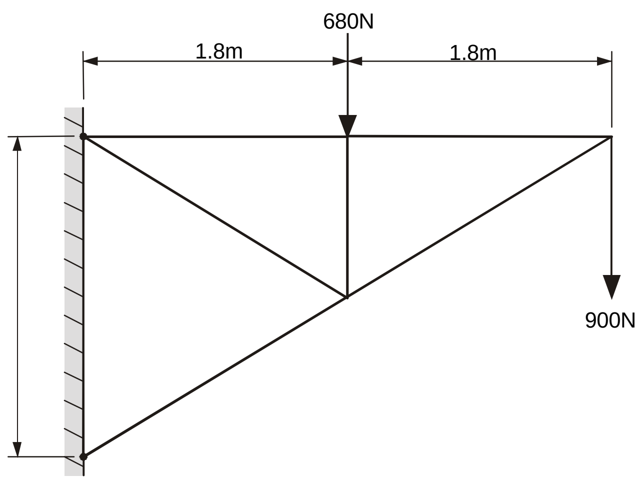
1)



2)

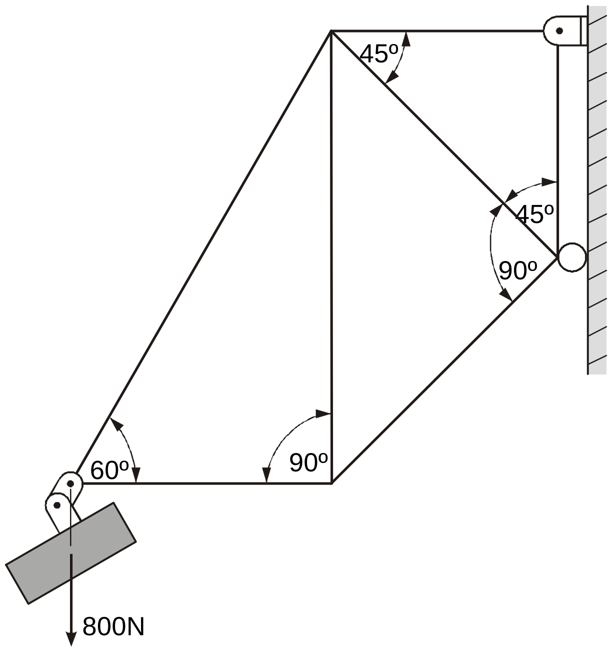


3)



Assignment 3

Calculate reactions and find the magnitude and nature of forces in the members in the lighting gantry structure shown below.



TECHNOLOGICAL STUDIES

HIGHER

STRUCTURES AND MATERIALS

SECTION 3

OUTCOME 3

OUTCOME 3

Use and interpret data from a tensile test in studying properties of materials.

It is recommended that the learning outcomes for the Structures and Materials unit are presented to the students in the sequence they are listed in the arrangements document.

When the students have completed this unit they should be able to

- Plot a load extension graph from given test data
- Identify important points on the graph
- Describe the effect of increased loading on a test piece
- Calculate Young’s Modulus, stress and strain
- Describe the properties of a material from test data

For this learning outcome unit it is assumed that students have completed the work for Structures and Materials learning outcome 1.

There are no separate homework sheets in this learning outcome unit. It is envisaged that tasks could be started in class and finished at home. This will probably be necessary due to the number of tasks to be done in the time available.

PROPERTIES OF MATERIALS

It is not only the shape of a structure that will influence its overall performance but also the material that each member in the structure is made from. If any one member was to fail within the structure itself, it would create a domino effect on the other members and ultimately the structure would collapse.

In order to select a material for a particular purpose the structural engineer must consider a range of materials, all with different properties. He/she will choose the material that is best suited to the job in hand.

The most common properties to be considered include:

1. **STRENGTH -** the ability of a material to resist force. All materials have some degree of strength - the greater the force the material can resist, the stronger the material. Some materials can be strong in tension but weak in compression, for example mild steel. The converse can also be true, as is the case with concrete, which is strong in compression but weak in tension. Hence, the reason that concrete is often reinforced with mild steel.

2. **ELASTICITY** - the ability of a material to return to its original shape or length once an applied load or force has been removed. A material such as rubber is described as elastic because it can be stretched but when it is released it will return to its original condition.

3. **PLASTICITY** - the ability of a material to change its shape or length under a load and stay deformed even when the load is removed.

4. **DUCTILITY** - the ability of a material to be stretched without fracturing and be formed into shapes such as very thin sheets or very thin wire. Copper, for example, is very ductile and behaves in a plastic manner when stretched.

5. **BRITTLENESS** - the property of being easily cracked, snapped or broken. It is the opposite of ductility and therefore the material has little plasticity and will fail under loading without stretching or changing shape. Cast iron and glass are obvious examples of materials that are brittle.

6. **MALLEABILITY -** the ability of a material to be shaped, worked or formed without fracturing. It is closely related to the property of plasticity.

7. **TOUGHNESS -** the ability to absorb a sudden sharp load without causing permanent deformation or failure. Tough materials require high elasticity.

8. **HARDNESS -** the ability to resist erosion or surface wear. Hard materials are used in situations where two surfaces are moving across or over each other.

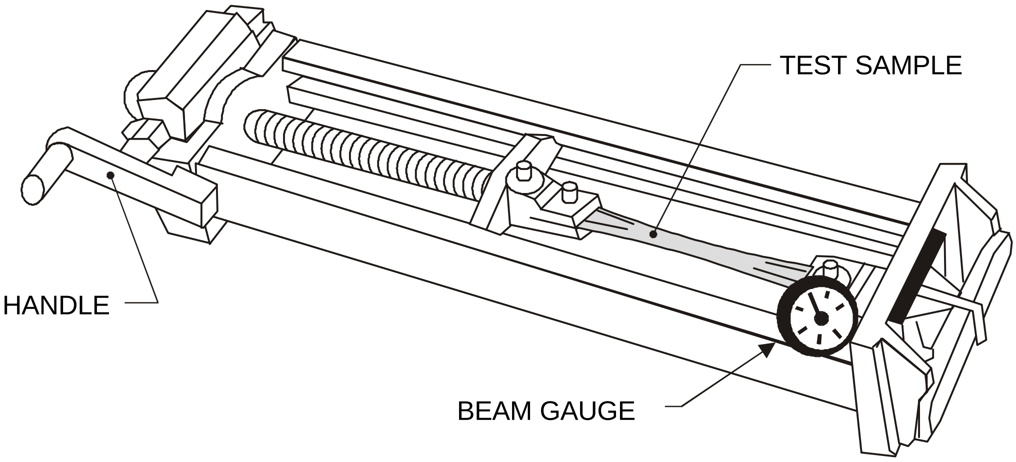
MATERIALS TESTING

In order to discover the various properties of a material we must carry out material tests. There are many different types of tests available but the most common is the tensile test. As the name suggests the material is subjected to a tensile force or in other words, the material is stretched or pulled apart.

Results from tensile tests allow us to determine the following properties:

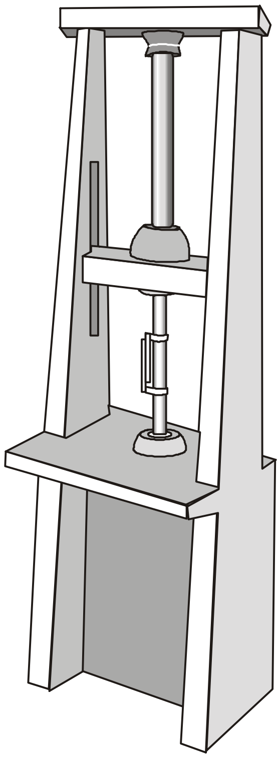
1. The elasticity of a material
2. The plasticity or ductility of the material
3. The ultimate tensile strength of the material.

A tensometer or tensile testing machine is designed to apply a controlled tensile force to a sample of the material. A tensometer that might be found in schools is shown below.



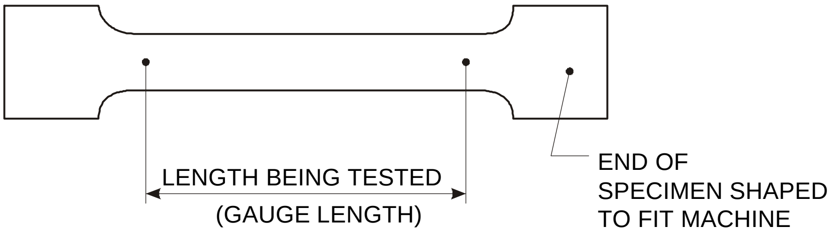
SM.H.O3.fig1

More sophisticated tensometers are available and are commonly used in industry. The main advantage of these machines is that they are able to plot a graph of how the material behaves during the test. A Hounsfield tensometer is shown below.



SM.H.O3.fig2

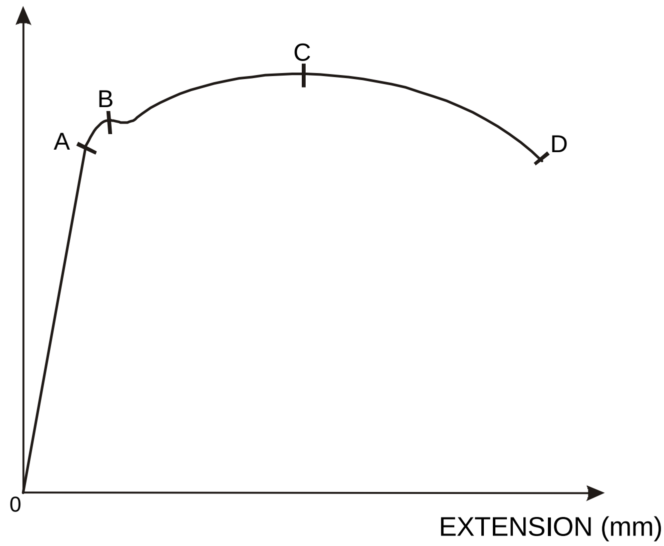
In order for tests to be carried out on a consistent basis, the shape of the specimen to be tested must conform to British Standards. The test sample is prepared to have a thin central section of uniform cross-section. A typical test specimen is shown below.



SM.H.O3.fig.3

The principle of tensile testing is very simple. As the force is applied to the specimen, the material begins to stretch or extend. The tensometer applies the force at a constant rate and readings of force and extension are noted until the specimen finally breaks. These readings can be plotted on a graph to show the overall performance of the material.

The results of a typical tensile test for a sample of mild steel are shown.



SM.H.O3.fig4

The shape of the graph is very important and helps us predict how the material will behave or react under different loading conditions.

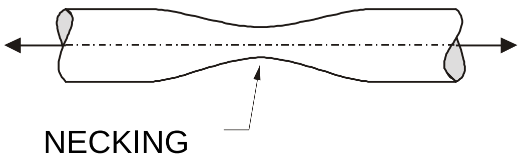
Between points 0 and ‘A’ the material behaves elastically and this part of the graph is known as the elastic region. This means that the material stretches under the load but returns to its original length when the load is removed. In fact, the force and extension produced are proportional and this part of the graph will be a straight line. This relationship is known as Hooke’s Law and is very important to structural engineers.

‘A’ is called the Limit of Elasticity and any loading beyond this point results in plastic deformation of the sample.

‘B’ is called the yield point and a permanent change in length results even when the load is removed. Loading beyond this point results in rapidly increasing extension.
Between points ‘B’ and ‘D’ the material behaves in a plastic or ductile manner.

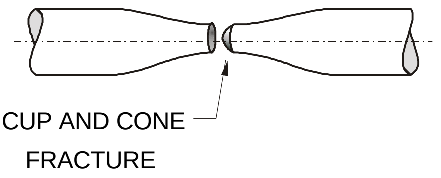
At point ‘C’ the maximum or ultimate tensile force that the material can withstand is reached.

Between ‘C’ and ‘D’ the cross-sectional area of the sample reduces or ‘necks’.



SM.H.O3.fig5

‘Necking’ reduces the cross-sectional area of the specimen, which in turn reduces the strength of the sample. The sample eventually breaks or fractures at point ‘D’. The shape of a typical fractured specimen is shown below.



SM.H.O3.fig6

Assignments: Tensile Testing

You intend to carry out a tensile test on a piece of soft copper to establish some of its physical properties and characteristics.

a) Explain, briefly, how you would carry out such a test and what equipment would be required to do this.
b) Sketch a typical specimen test piece that would be used in such a test. Indicate clearly two important physical readings that would have to be taken at the beginning of the test.
c) State one property that may be established from the results of the test.

2.
a) Sketch a typical load extension graph for a mild steel specimen that has undergone a tensile test to destruction. On the graph, indicate the following points:

Yield point
Elastic region
Plastic region
Breaking point
Maximum load

b) State three properties that can be compared between two specimens of identical shape and size, one made from mild steel and the other from annealed copper, if they are both tested to destruction using tensile tests.

3.
a) Explain the difference between plastic deformation and elastic deformation with respect to engineering materials.

b) Give an example of two pieces of modern engineering design: one designed to display elastic deformation; the other to display plastic deformation.

4. A tensile test on an unknown material produced the following results.

Force kN	4.45	8.9	17.8	26.7	35.6	44.5	53.4	62.3
Extension mm	0	1.2	2.3	4.5	4.6	5.7	7.7	11

Plot a graph of the load against the extension.

A mild steel specimen 25 mm in diameter and 250 mm long was subjected to a gradually increasing tensile load until finally the specimen snapped. The following results were obtained.

Force kN	20	40	60	80	100	120
Extension mm	0.048	0.097	0.142	0.196	0.241	0.287
Force kN	140	160	170	180	190	
Extension mm	0.343	0.39	0.42	0.46	0.52	

a) Plot a graph of load against extension.

b) On the graph indicate three important points.

The results from a tensile test to destruction are shown below.

Force kN	50	100	150	200	250	260	270
Extension mm	0.0007	0.0014	0.0022	0.0029	0.0036	0.004	0.005
Force kN	280	290	300	290	280	270	260
Extension mm	0.0066	0.0094	0.02	0.0238	0.0256	0.028	0.03

a) Plot a graph of load against extension.

b) On the graph indicate three important points.

c) With reference to the graph, describe the effect of gradually increased tensile load on the specimen.

The results of performing a tensile test on a specimen are shown below.

Force kN	Extension mm	Force kN	Extension mm
10	0.02	70	0.552
20	0.036	71	0.678
30	0.056	72	0.822
40	0.076	73	1.02
50	0.095	72	1.22
55	0.104	71	1.35
60	0.12	70	1.48
64	0.202	69	1.59
67	0.299	68	1.66
68	0.391	65	1.7

a) Plot a graph of load against extension.

b) With reference to the graph, describe the properties of the material tested.

Results from a tensile test to destruction are shown below.

Force kN	Extension mm	Force kN	Extension mm
16.5	0.04	81.3	0.3
25.5	0.062	81.2	0.3
33.2	0.0805	80	0.4
38.2	0.0927	80.8	0.5
44	0.107	82	0.75
55	0.134	75.5	20.8
77.7	0.188	72	2.38
80	0.24	67.6	2.75
80.7	0.25	61	3.17
81.5	0.252	54	3.5

a) Plot a graph of load against extension.

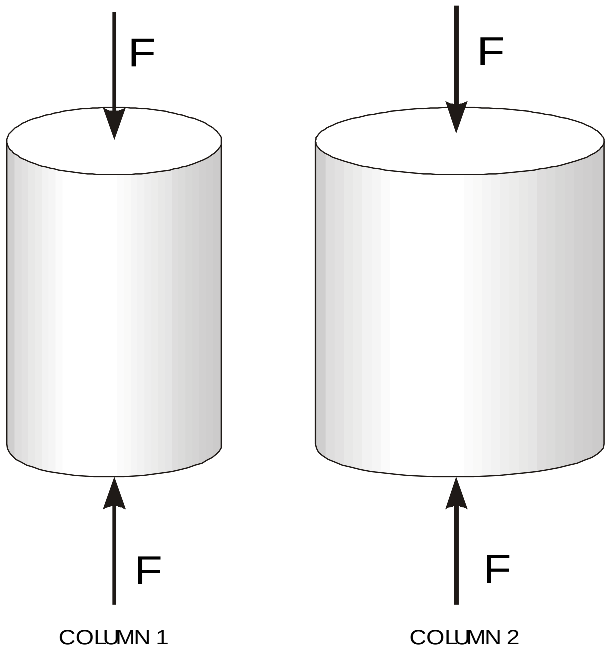
b) With reference to the graph, describe the properties of the material tested.

STRESS STRAIN GRAPHS

Far more useful to an engineer than a load extension graph is a stress strain graph. This in many ways resembles a load extension graph but the data in this form can be interpreted more easily in design situations. First let us examine what is meant by stress and strain.

Stress

When a direct force or load is applied to the member of a structure, the effect will depend on the cross-sectional area of the member. Lets look at column 1 and 2 below. Column 2 has a greater cross-sectional area than column 1. If we apply the same load to each column, then column 1 will be more effected by the force.



SM.H.O3.fig7

The effect that the force has on a structural member or element is called STRESS. This is calculated using the formula:

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

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

where Force is measured in Newtons (N) and Area is the cross-sectional area measured in mm2. Stress therefore is measured in N/mm2 and is denoted by the Greek letter sigma (σ).

Worked examples: Stress

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

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

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

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

$$s = 1.25 N/mm^2$$

Stress in the bar = 1.25 N/mm^2

A column of section 0.25 m2 is required to act as a roof support. The maximum allowable working stress in the column is 50 N/mm2. Calculate the maximum compressive load acting on the column.

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

$$Force = Stress \times Area$$

$$Force = 50 \times 0.25 \times 10^6$$

$$Force = 12.5 MN$$

Maximum compressive load acting on the column = 12.5 MN

The stress in a steel wire supporting a load of 8 kN should not exceed 200 N/mm2. Calculate the minimum diameter of wire required to support the load.

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

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

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

$$Area = 40mm^2$$

$$Area = \frac{pd^2}{4}$$

$$d = \sqrt{\frac{4A}{p}}$$

$$d = \sqrt{\frac{4 \times 40}{p}}$$

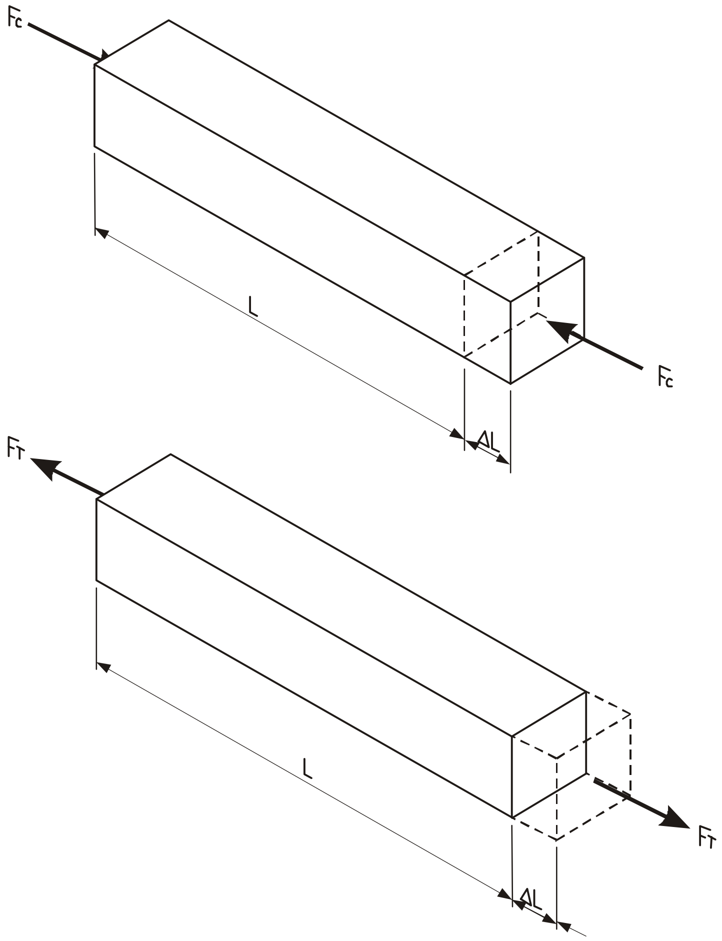
$$d = 7.14mm$$

Minimum diameter of wire required to support load = 7.14 mm

Strain

The result of applying a load or force to a structural member is a change in length. Every material changes shape to some extent when a force is applied to it. This is sometimes difficult to see in materials such concrete and 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.



SM.H.O3.fig8

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

$$Strain = \frac{Change\ in\ Length}{Original\ Length}$$

$$e = \frac{\Delta L}{L}$$

where length in both cases is measured in the same units (m or mm). As the units cancel each other out, strain is dimensionless. This means that there are no units of strain. Put simply, 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).

Worked examples: Strain

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

$$e = \frac{\Delta L}{L}$$

$$e = \frac{2.5}{5000}$$

$$e = 0.0005$$

Strain in the wire = 0.0005

2. The strain in a concrete column must not exceed 5 x 10-4. If the column is 3 m high, find the maximum reduction in length produced when the column is loaded.

$$e = \frac{\Delta L}{L}$$

$$\Delta L = e \times L$$

$$\Delta L = \left(5 \times 10^{-4}\right) \times 3000$$

$$\Delta L = 1.5 mm$$

Reduction in length of column = 1.5 mm

Assignments: Stress and Strain

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

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

3. What diameter of round steel bar is required to carry a tensile force of 10 kN if the stress is not to exceed 14.14 N/mm2.

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

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

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

7. During testing, a shaft was compressed by 0.06 mm. If the resulting strain was 0.00012, what was the original length of the shaft?

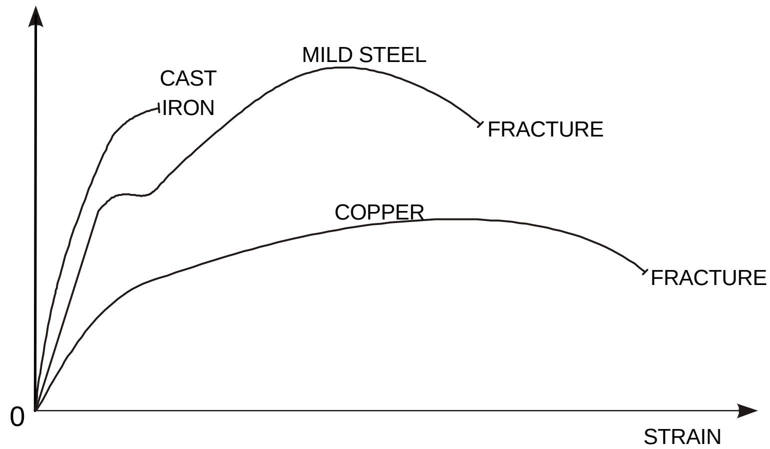
8. A piece of wire 6 m long and diameter of 0.75 mm stretched 24 mm under a force of 120 N. Calculate stress and strain.

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

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

Using Data from Stress Strain Graphs

As we have already learned, vital information can be obtained from tensile tests when the data is plotted in the form of a stress strain graph. The graph below represents the relationship between stress and strain for common materials.



SM.H.O3.fig9

The following points are important in relation to the graph.

1. Yield Stress

The yield stress is the maximum stress that can be applied to a structural member without causing a permanent change in length. The loading on any structural member should never produce a stress that is greater than the yield stress. That is, the material should remain elastic under loading.

2. Yield Strain

The yield strain is the maximum percentage plastic extension produced in a material before it fails under loading. A ductile material such as copper needs to be formed and shaped into items such as pipes. For this to be effective, the material requires a high value of yield strain.

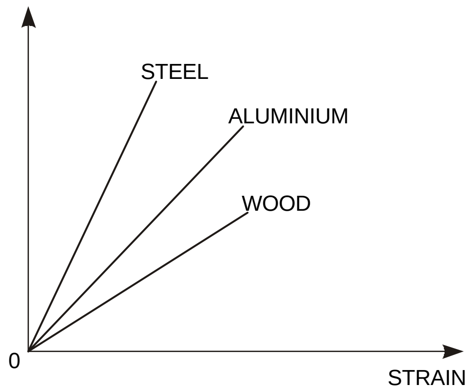
3. Ultimate Tensile Stress

The ultimate tensile stress (UTS) of a material is the maximum stress the material can withstand before it starts to fail. If a member in a structure is loaded beyond the UTS, the cross-section will reduce and the member will quickly fail.

YOUNG’S MODULUS

When a material is constantly loaded past its elastic limit, its performance becomes unpredictable. This could be disastrous, even fatal, if we consider the scale and type of structures we use every day. For this reason, structural engineers must ensure that projected stresses in structural members are held within the materials elastic limit.

When we test a range of common material we find that they all behave in an elastic manner up to a certain level of loading, even very brittle materials.



SM.H.O3.fig10

We also find that within the elastic limit, the graphs are a straight line therefore conforming to Hooke’s Law. This means that stress is proportional to strain. We use the principle of Hooke’s Law to find a value called young’s Modulus. Young’s Modulus is sometimes called the Modulus of elasticity and is calculated using the formula:

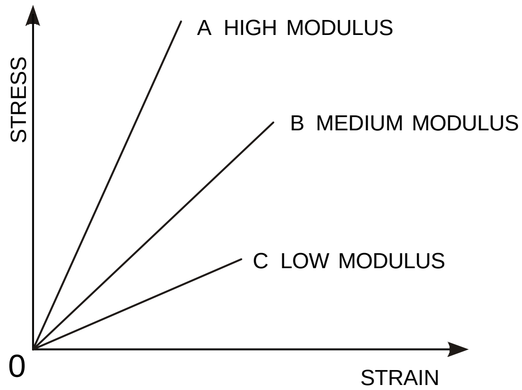
$$\mathrm{E} = \frac{Stress}{Strain}$$

$$\mathrm{E} = \frac{s}{e}$$

and is measured in kN/mm2.

For any material, which obeys Hooke’s Law, the slope of the straight line within the elastic limit can be used to determine young’s Modulus. Although any value of stress and strain can be taken from within this region, it is customary for values to be taken from the graph at 50% of yield stress.

Modulus of elasticity determines the stiffness of a material. The higher the modulus, the greater the stiffness. Stiffness is a measure of a materials resistance to buckling under compressive loading. If a structural member starts to buckle it will bend and eventually collapse.



SM.H.O.3.fig11

Worked example: Young’s Modulus

An aluminium tie rod is 1.5 m long and has a square cross-section of 20 mm x 20 mm.

A tensile load of 5.6 kN is applied and produces a change in length of the rod of 0.3 mm.

Calculate young’s Modulus for the rod.

$$Young's Modulus = \frac{Stress}{Strain}$$

a) Calculate the stress in the rod.

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

$$s = \frac{5600}{40 \times 40}$$

$$s = 14 N/mm^2$$

b) Calculate the strain in the rod.

$$e = \frac{\Delta L}{L}$$

$$e = \frac{0.3}{1500}$$

$$e = 0.2 \times 10^{-3}$$

c) Calculate Young's Modulus

$$E = \frac{s}{e}$$

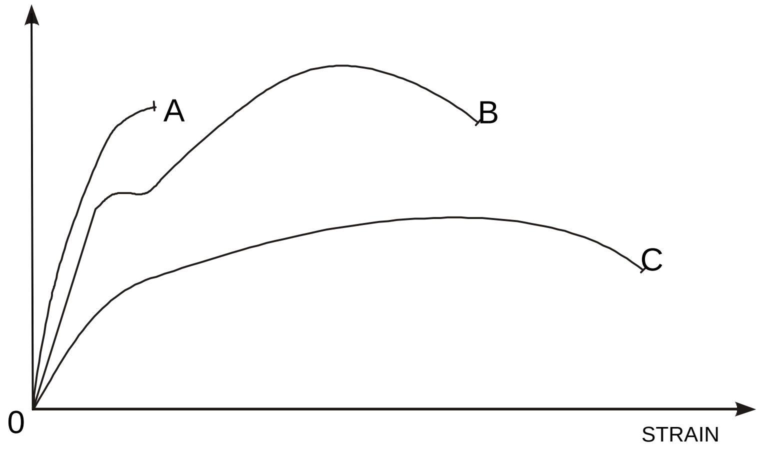
$$E = \frac{14}{0.2 \times 10^{-3}}$$

$$E = 70kN / mm^2$$

Young's Modulus = 70kN/mm^2

Assignments: Young's Modulus

1. Figure SM.H.O3.fig12 shows a stress strain graph for three metals A, B and C.



SM.H.O3.fig12

a) Which metal is the most ductile?
b) Which metal can withstand the greatest load?
c) Which metal is the most elastic?
d) Which metal has the lowest modulus of elasticity?
e) Which metal is the stiffest?
f) Which metal is the most brittle?

2. The following data was the result of a tensile test to destruction. On a common axis, plot each stress/strain graph and then compare the results in terms of their Ultimate Tensile Stress, Ductility and young's Modulus.

Specimen A		**Specimen B**	
Stress(N/mm^2)	Strain (x 10-3)	Stress(N/mm^2)	Strain (x 10-3)
100	2.85	100	4.75
200	5.71	200	9.4
300	8.57	300	14.11
350 (yield point)	10	425 (yield point)	20
370 (UTS)	12.75	440 (UTS)	22.5

3. A column 6 m high is compressed 1.5 mm when a load is applied. The column has a cross-sectional area of 7500 mm^2. Find the magnitude of the load if young's Modulus for the material has a value of 200 kN/mm^2.

4. A force of 1.5 kN is applied to the free end of a vertical wire 6 m long. The extension produced as a result was 12 mm. If young's Modulus for the material is 196 kN/mm^2, what is the diameter of the wire?

5. A test on a duralumin test piece 150 mm^2 in cross-sectional area and 50 mm long showed that it followed Hooke's Law up to a load of 38 kN with an extension of 0.16 mm for that load.

Calculate the stress at this load and the value for Young's Modulus for duralumin. Use your results to find the load that can be carried by a duralumin tension member 425 mm^2 in cross-sectional area and 325 mm long if the maximum permissible extension is 7.5 mm.

6. A bar of steel 500 mm long has a cross-sectional area of 500 mm^2 and is subjected to a direct pull of 20 kN. Determine the stress in the bar and the extension produced if Young's Modulus is 200 kN/mm^2.

7. A round brass rod in tension carries a load of 40 kN. Determine its diameter if the stress is not to exceed 40 N/mm^2. What will be the extension of the rod if the length is 2 m, and the modulus of elasticity for brass is 100 kN/mm^2?

8. A metal bar of length 250 mm and cross-sectional area 150 mm^2 is gradually loaded in tension up to the elastic limit. From the load-extension graph it is found that a load of 25 kN produces an extension of 0.2 mm. Find Young's Modulus of the material.

9. If a specification for steel in a structure limits the working stress for the material to 150 N/mm^2. Calculate a suitable diameter of a tie-rod if it requires to withstand a pull of 170 kN. Find the extension in the rod if the original length is 3 m and young's Modulus is 200 kN/mm^2.

10. A polypropylene rope is used to tie a small boat to a pier. The boat exerts a force of 750 N on the rope, which has free length of 6 m. If the rope should not stretch more than 30 mm, calculate the required diameter of rope.

TECHNOLOGICAL STUDIES

HIGHER

STRUCTURES AND MATERIALS

SECTION 4

OUTCOME 4

OUTCOME 4

Produce a specification for a structural component.

It is recommended that the learning outcomes for the Structures and Materials unit are presented to the students in the sequence they are listed in the arrangements document.

When the students have completed this unit they should be able to:

- Use tabulated and graphical data to select materials
- Calculate factor of safety
- Consider the effect of the environment on structures.

Before you start this unit you should have an understanding of:

- Stress
- Strain
- Young's Modulus
- Properties of materials.

For this learning outcome unit it is assumed that students have completed the work for Structures and Materials learning outcome 1.

There are no separate homework sheets in this learning outcome unit. It is envisaged that tasks could be started in class and finished at home. This will probably be necessary due to the number of tasks to be done in the time available.

FACTOR OF SAFETY

Most structures are extremely safe and well designed but due to unforeseen circumstances some structures fail or collapse. A structural engineer can never be absolutely certain that he/she has accounted for every possible type of load that will affect the structure. When a structure has failed, an investigation normally takes place to discover the reason for failure. The most common reasons include:

Overloading

This is when the load on the structure exceeds the value that was used during the design process. This type of failure may be due to the structure being used inappropriately, e.g. a man riding a child's bike, or because the circumstances have changed since the original design. This may be the case in bridges that were designed many years ago, where original calculations accounted mainly for cars passing over the bridge. Nowadays, we are only too aware of the increasing traffic on the road especially heavy goods vehicles. This leads to traffic jams where the traffic comes to a standstill. This may overload the structure beyond its design limit.

The most dangerous cause for a sudden change in loading on a structure is probably the weather. This is because of its unpredictable nature. No one can predict with any certainty what the weather will be like tomorrow, next week or next year. Freak weather conditions like hurricanes produce an additional force on a structure over and above what may have been calculated for a normal windy day.

Material/Joint Failure

The material within the structure may fail if it is not of consistent quality or because it has deteriorated due to the working environment of the structure. We could never guarantee the performance of natural materials such as wood as they all contain natural defects such as knots, shakes etc. Some materials are susceptible to particular conditions, for example wood swells up as it absorbs moisture, mild steel rusts due to oxygen and water.

The joints used within the structure may fail because they are inappropriate and cannot support the load, or if they have been poorly made. This is particularly relevant with techniques such as welding. The welds on large structures are usually x-rayed in order to detect any defects.

Fatigue

It is difficult to predict exactly when a structure will fail. Repeated loading and unloading of a structure will wear down the material's resistance to breaking and eventually it will fail. This may even be the case if the load remains within the maximum used in the original design calculations. The principle of fatigue can be demonstrated by bending a paper clip backwards and forwards. The paper clip will not snap the first time, or probably the second. After that we are unsure just when the paper clip will fail. Each time we bend it we are not applying any greater a force but eventually the paper clip snaps.

Applying a Factor of Safety

Depending on the performance criteria which a structure must meet; a factor of safety will be applied to the design. Factors of safety vary from one structure to another, depending on the consequences of failure. The factor of safety applied to a nuclear power station is much higher than that for a conventional power station because the implications of structural failure are far more serious. The factors of safety applied to any design is decided through the experience and knowledge of the designer in charge, as well as close examination of the structure itself and the job it is expected to do. The higher the value for factor of safety, the more cautious the engineer is about the design.

The actual load which the structure or component is designed to carry is only one factor in a complicated process. The designer must remember certain other things such as that very high quality materials are expensive; very accurate dimensions are difficult to achieve during manufacture; quality of bolts, rivets or welds may vary; there may be very high stresses during the construction process; and so on. The following points affect the decision on the factor of safety:

1. The value of the maximum load and accuracy of calculations.

2. The type of load on the structure.

3. The reliability/quality of the material.

4. The effect of corrosion or wear on the dimensions of the structure.

5. Errors during manufacture or construction.

6. The consequences of failure.

To help with this process, the designer might ask himself/herself the following questions:

1. What is likely to be the cause of structural failure? Have I considered every possibility even the obvious causes such as the material, shape of the structure, joining techniques?

2. What are the implications if the structure fails? What damage will be caused and what effect will this have on human life and existence?

3. What are the operating conditions of the structure like? Is this a harsh working environment in terms of weather or chemicals that may corrode the materials within the structure?

4. What external factors or conditions might affect the structure? What is the structure built upon? Is there likely to be any ‘freak’, one-off incidents such as a sudden impact?

5. Are there likely to be changes to any of these conditions within the working life of the structure?

It is easy to think that we can improve the performance of a structure by increasing the size or thickness of members within the structure, even increasing the number of structural members. In doing so however, it is possible to make the structure weaker and more susceptible to failure. As you make these changes, the structure becomes heavier and loading increases under its own weight. You may be solving one problem but creating another.

Calculating Factor of Safety

We can apply a factor of safety to a structure in one of two ways. The first is in terms of the loading the structure can withstand and the second is in terms of the stress within the structure.

$$FactorofSafety = \frac{UltimateLoad}{SafeWorkingLoad}$$

$$FactorofSafety = \frac{UltimateStress}{SafeWorkingStress}$$

If a structure is designed to support a load of say 10 kN and a factor of safety of 2 is applied to the design, then in fact the structure should be able to support 20 kN. In industrial settings such as factories, lifting devices are marked to show how much the weight can be lifted safely. This is known as the safe working load (SWL).

The loading on any structural member should never produce a stress that is greater than the yield stress of the material that the member is made from. In fact, the working stress to which a structural member will be subjected is generally well below the material's yield stress, therefore operating well within the elastic region. This ensures that if any sudden unexpectedly high loading is applied, the stress in the structural element will not exceed the yield stress preventing permanent deformation in the element. A factor of safety (FOS) of 2 means that the design is stressed to half the value at the yield point.

Worked example: Factor of Safety

The maximum ultimate tensile stress for aluminium is 300 N/mm^2. If the working stress on a component is 50 N/mm^2, calculate the factor of safety applied in the design of the component.

$$FactorofSafety = \frac{UltimateStress}{SafeWorkingStress}$$

$$FactorofSafety = \frac{300}{50}$$

$$FactorofSafety = 6$$

ACCESSING TABULATED DATA

Most commonly used materials have been tested exhaustively and the test data is available in British Standards publications. In the course of your work in Technological Studies you will be required to use extracts from these publications in the same way an engineer might.

The table below is a copy of information provided within the SQA data booklet for use in exams.

Material	Young's Modulus kN/mm^2	Yield Stress N/mm^2	Ultimate Tensile Stress N/mm^2	Ultimate Compressive Stress N/mm^2
Mild Steel	196	220	430	430
Stainless Steel	190-200	286-500	760-1280	460-540
Low-alloy steel	200-207	500-1980	680-2400	680-2400
Cast iron	120	-	120-160	600-900
Aluminium alloy	70	250	300	300
Soft Brass	100	50	80	280
Cast Bronze	120	150	300	-
Titanium alloy	110	950	1000	1000
Nickel alloys	130-234	200-1600	400-2000	400-2000
Concrete (steel reinforced)	45-50	-	-	100

For each material listed in the table, data is given on:

Young’s Modulus - the elasticity or stiffness of a material.

Yield Stress - the value of stress which, if exceeded, will result in the material changing length permanently.

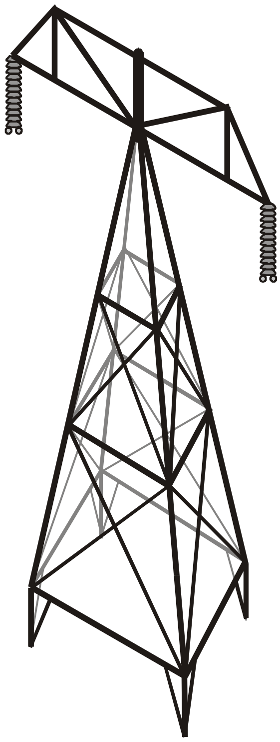
Ultimate Tensile Stress - the maximum value of stress the material can withstand before failing due to tension.

Ultimate Compressive Stress - the maximum value of stress the material can withstand before failing due to compression.

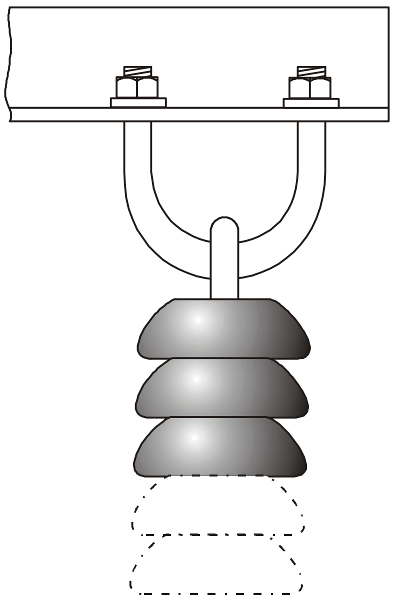
You will notice from the table that some materials perform quite differently in tension and compression, for example soft brass performs better in compression than tension. Other materials perform equally well under both types of loading, for example low-alloy steel and titanium alloys.

Assignments: Tabulated Data

1. Figure 1 shows a general view of an electricity pylon. The cross-arm supports conductor wires by means of an insulator suspended from its end. The insulator is fixed to the pylon by means of a low-alloy U-bolt shown in figure 2. Explain why a high factor of safety is required for this particular application. Suggest ways in which the structure might fail.



SM H O.4 fig1



SM H O.4 fig2

2. A lighting gantry in a theatre is suspended from the ceiling by wire ropes. The gantry hangs above the audience and is designed to hold 10 lights. A factor of safety of 10 is applied to the design. Explain the reasons why the engineer has used such a high factor.

3. In an Art Gallery, a sphere weighing 10 kN is to be suspended from the ceiling by a stainless steel bar 20 mm in diameter and 3 m long.

Select a value for Young's Modulus for Stainless Steel and hence calculate the extension of the bar when loaded. State any assumptions made.

If a factor of safety of 5 was applied to the design, discuss the effect of this on the dimensions of the bar. (Use the Data Booklet.)

4. A soft brass bar, which is used in a structure, is 120 mm long. It is subjected to a tensile load that elongates its original length by 0.03 mm.
   Determine the factor of safety employed in the design of this bar. (Use the Data Booklet.)

5. A steel overhead wire 25 mm in diameter has an ultimate tensile stress of 1250 N/mm^2 and a value for Young's Modulus of 207 kN/mm^2. If the factor of safety is 5, calculate the allowable pull on the wire and find the corresponding change in length on a 36 m span.

6. The maximum load in a tensile test on a mild steel specimen is 76 kN. If the test piece is 15 mm in diameter, calculate the ultimate tensile stress. What is the working stress and greatest allowable load on a bar 30 mm in diameter made from the same material? Use a factor of safety of 3.

7. A tensile test on a specimen of an unknown material provided the following data:

Cross-sectional area = 120 mm^2
Gauge (original) length = 75 mm
Load (within elastic limit) = 30 kN
Extension of gauge length = 0.17 mm

a) Determine Young's Modulus of the material.

b) By referring to the Data Booklet, suggest which material was being tested.

c) Calculate the factor of safety for this material for the conditions described by the data given above.

8. A stainless steel tie-bar in a structure is to be designed to carry a load of 450 kN, with a factor of safety of 4.

   a) Explain why this material is suitable for a use as a tie but not a strut.

   b) Calculate the diameter of the bar.

   c) Calculate the amount the tie-bar will stretch if its original length is 3.5 m.

9. A mild steel bar 25 mm in diameter and 0.5 m long is held in tension as it supports a sign above a shop. Find the safe load that can be supported by the bar if a factor of safety of 8 is applied to the design. Find the extension in the bar under this load.

Describe ways in which the bar might fail given these conditions.

10. A trapeze wire is made from a material for which the ultimate tensile stress is 1000 N/mm^2 and the yield stress is 950 N/mm^2. The wire has a working load of 3 kN.

    a) Calculate the factor of safety to keep the stress just within the elastic limit for the material.

    b) Calculate the diameter of the wire for this factor of safety.

    c) Calculate the diameter of the wire for a factor of safety of 3.

    d) Which factor of safety would you apply to this design? Explain your answer.

11. Winches are used on aircraft carriers to haul helicopters across the landing deck. The winch cables are made from mild steel and are fixed to the helicopter landing gear. The tension in the cables is 20 kN and a factor of safety of 8 is applied to the design. Calculate the diameter of the cable.

12. A single mild steel cable supports a lift. The safe working load of the lift is 30 kN and a factor of safety of 12 is applied to the cabling. If the length of the cable is 100 m and the allowable extension is 50 mm, calculate the required diameter of the cable. Explain why such a high factor of safety has been applied in this design. Suggest one way to improve the design of this system.

13. If the ultimate tensile stress of a steel wire is 750 N/mm^2, what load could safely be carried by the wire of diameter 2.5 mm? Use a factor of safety of 5.

If the wire is 6 m long and the extension is 4.8 mm, what is the value of Young’s Modulus?

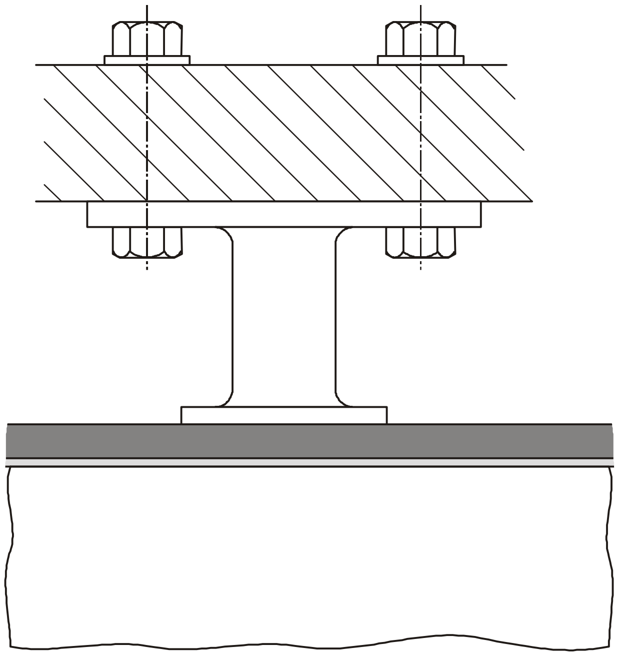
14. A lifting jack has a maximum lift of 300 mm and the diameter of the ram is 75 mm. Find the maximum force the jack may exert if the ram has to have a factor of safety of 7 and the ultimate tensile stress of the metal is 483 N/mm^2. Find the change in length of the ram if the modulus of elasticity of the material is 201 kN/mm^2.

15. A tension member in a roof truss is subjected to a pull of 117 kN. The material has an ultimate tensile stress of 465 N/mm^2. When a factor of safety of 5 is used, find the diameter of the member. If the member is 3 m long and stretches 1.35 mm under loading, calculate the modulus of elasticity.

16. A display screen in a lecture theatre is held in place by a bracket fixed to the roof by two mild steel bolts as shown in figure 3. The bolts are initially tightened so that the tensile stress in them is 7 N/mm^2 before any load is applied.

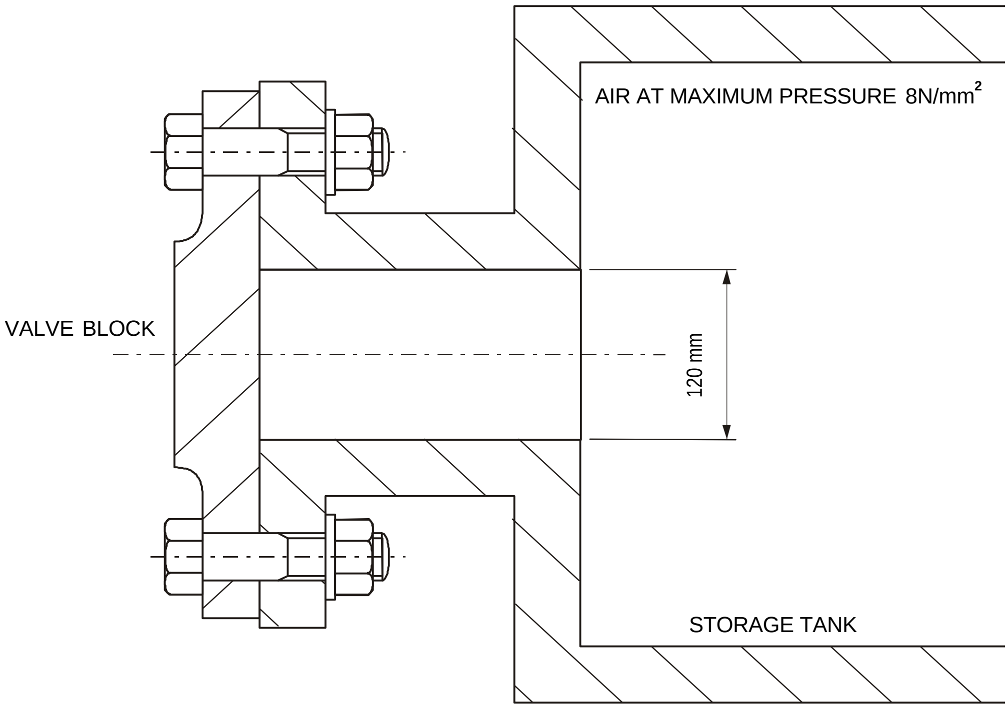
The weight of the screen is 3 kN and the bolts carry an equal share of this load. The bolts are designed with a factor of safety of 9.

Determine the diameter of the bolts needed for this application.



SM H O.4 fig3

17. Part of a pneumatic system is shown in figure 4. Compressed air is stored in the tank at a maximum pressure of 8 N/mm^2 and the 120 mm diameter outlet is sealed by means of a valve block which is held in place using 15 mm (M15) diameter bolts as shown. The normal stress set up in each bolt due to tightening is 6 N/mm^2 and the ultimate tensile stress for the bolts is 370 N/mm^2. The factor of safety for the system is 5.



SM H O.4 fig4

a) Calculate the force on the value block using the formula, Force = Pressure x Area.

b) Calculate the safe working stress that can be carried by the bolts.

c) Calculate the stress in each bolt due to loading.

d) Calculate the load to be carried by each bolt.

e) Determine how many bolts are required to attach the valve block to the storage tank.