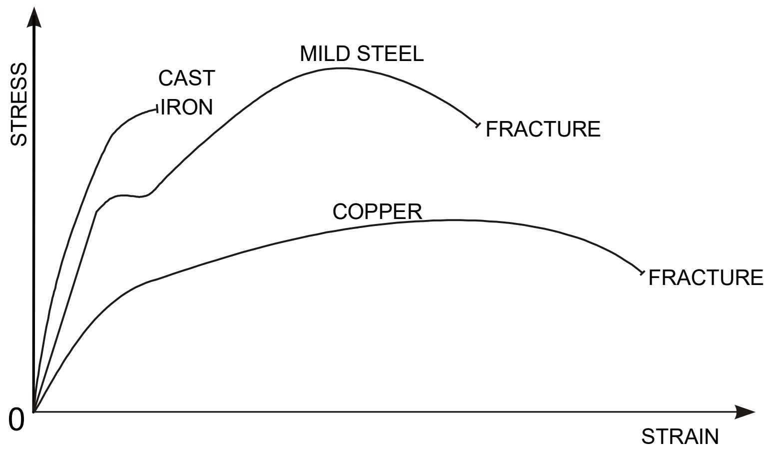
Higher Engineering Science

Properties of Materials
& Factor of Safety



Name: ______________________

Teacher: ____________________

Class: ______________________

Mrs Gault

Learning Intentions

- Understanding the different properties of materials
    - ❑Brittleness
    - ❑Elasticity
    - ❑Ductility
    - ❑Plasticity
    - ❑Strength
    - ❑Malleability
- Understanding Young’s modulus of elasticity
- Learning about Factor of Safety and the impact it has on structures
- Understanding Stress/Strain (load/extension) graphs
- Knowing about elastic strain energy Es = 1/2Fx

Success Criteria

- I can describe the different properties of materials.
- I can complete Young’s modulus calculations.
- I can Complete factor of safety calculations and describe the effect on a structure.
- I can use, annotate and describe what is happening in stress/strain or Load/extension graphs.
- I can remember the formula and complete elastic strain energy calculations.

In this unit we will build on the skills learned in National 5 Engineering Science.

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.

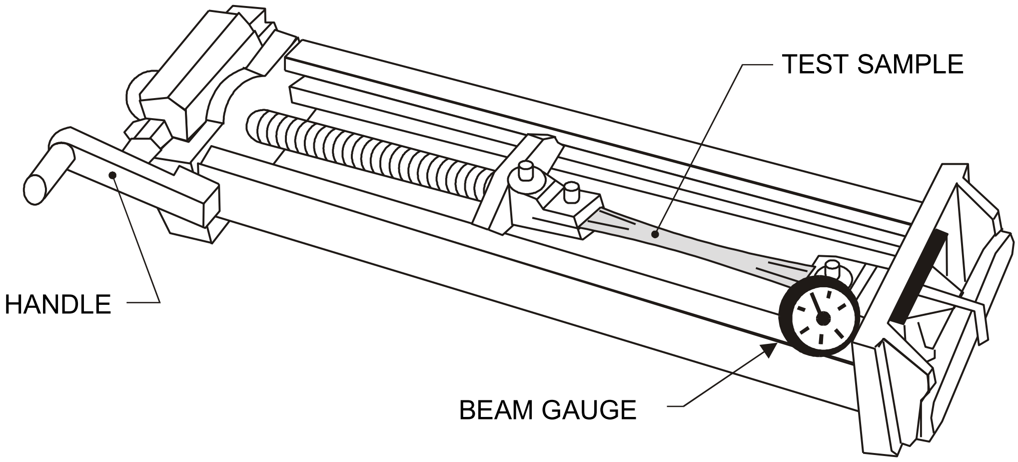
MATERIALS TESTING

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.

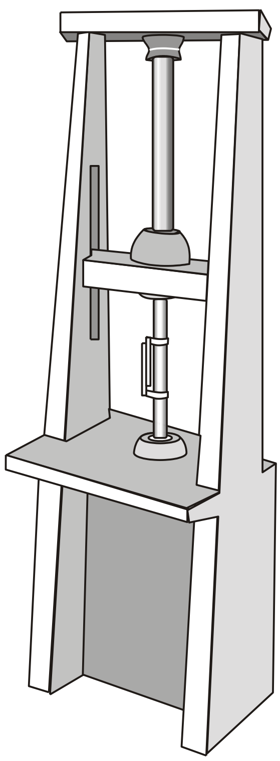
Results from tensile tests allow us to determine the following properties:

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

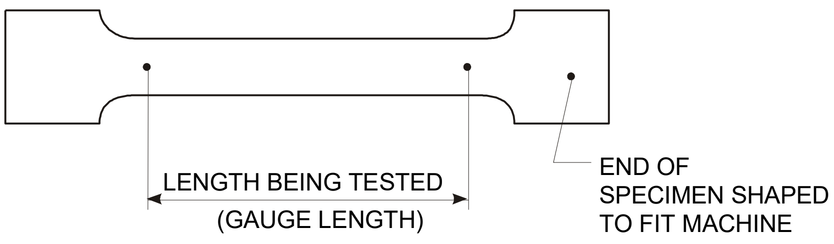
A tensometer or tensile testing machine is designed to apply a controlled tensile force to a sample of the material. A tensometer that might be found in schools is shown below.



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.

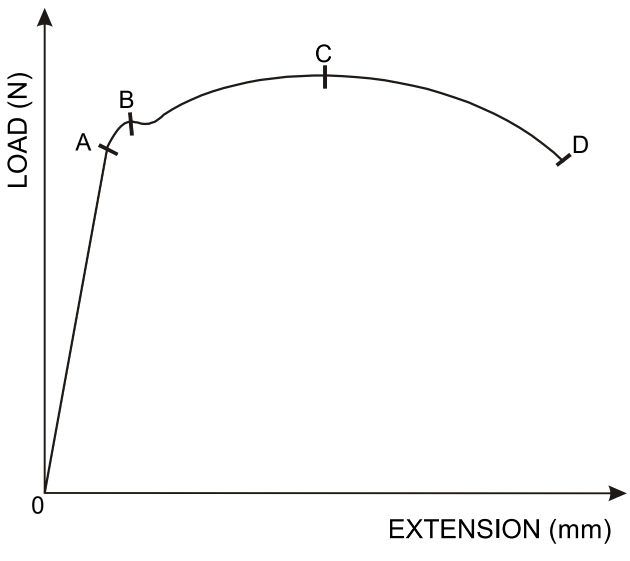


In order for tests to be carried out on a consistent basis, the shape of the specimen to be tested must conform to British Standards. The test sample is prepared to have a thin central section of uniform cross-section. A typical test specimen is shown below.



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.



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

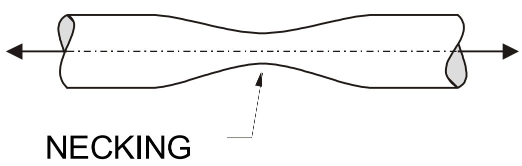
Between points 0 and ‘A’ the material behaves elastically and this part of the graph is known as the elastic region. This means that the material stretches under the load but returns to its original length when the load is removed. In fact, the force and extension produced are proportional and this part 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.

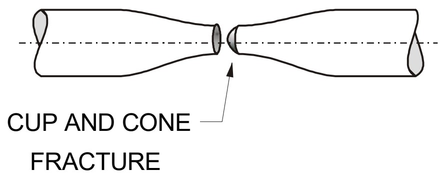
‘B’ is called the yield point and a permanent change in length results even when the load is removed. Loading beyond this point results in rapidly increasing extension.
Between points ‘B’ and ‘D’ the material behaves in a plastic or ductile manner.

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’.



‘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.

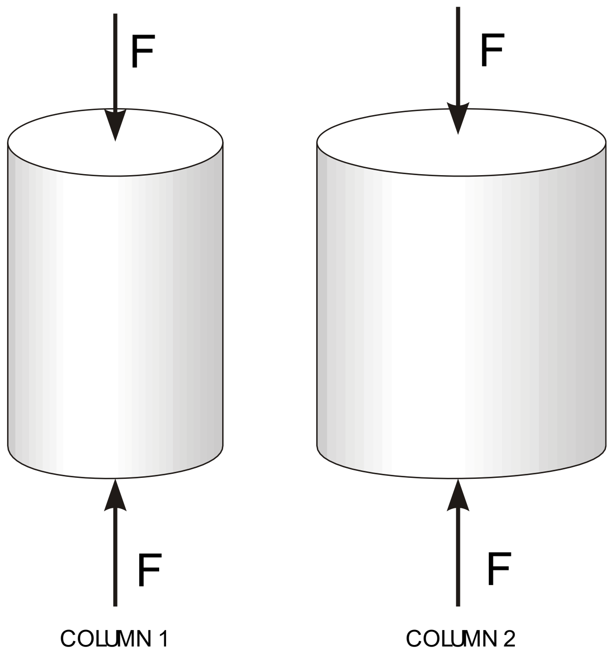


STRESS STRAIN GRAPHS

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.



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

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

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

where Force is measured in Newtons (N) and Area is the cross-sectional area measured in mm2. Stress therefore is measured in Nmm-² 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.

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

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

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

$$\sigma = 1.25 \text{ Nmm}^{-2}$$

Stress in the bar = 1.25 Nmm^{-2}

A column of section 0.25 m^2 is required to act as a roof support. The maximum allowable working stress in the column is 50 Nmm^{-2}. Calculate the maximum compressive load acting on the column.

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

$$Force = Stress \times Area$$

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

$$Force = 12.5MN$$

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 Nmm^{-2}. Calculate the minimum diameter of wire required to support the load.

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

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

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

$$Area = 40mm^2$$

$$Area = \frac{\pi d^2}{4}$$

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

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

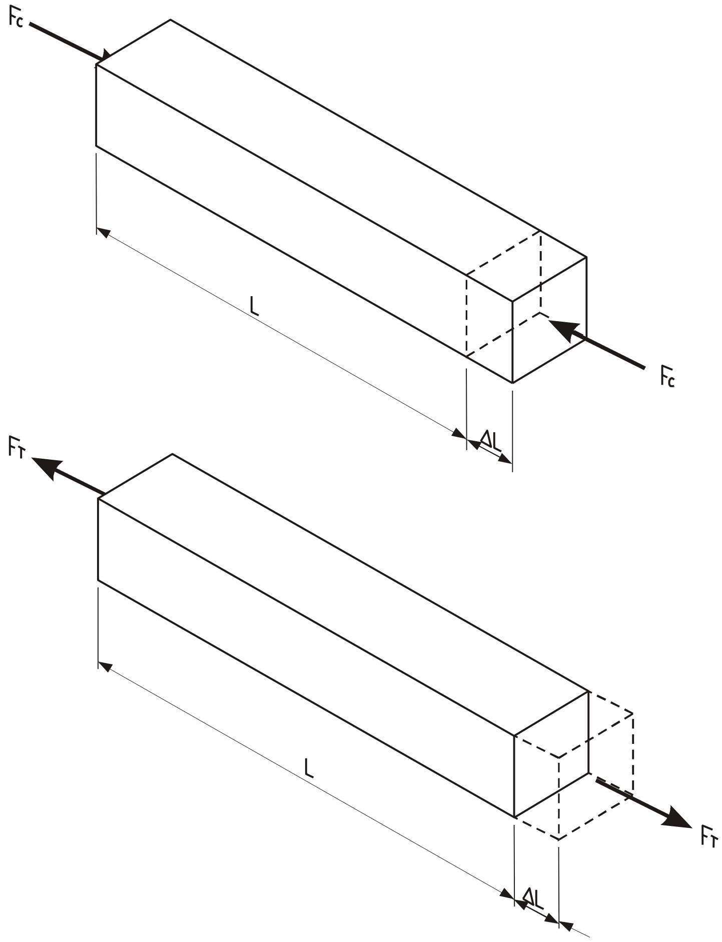
$$d = 7.14mm$$

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.



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

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

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

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.

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

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

$$\varepsilon = 0.0005$$

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.

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

$$\Delta L = \varepsilon \times L$$

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

$$\Delta L = 1.5 mm$$

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 mm^2 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 Nmm^{-2}.

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?

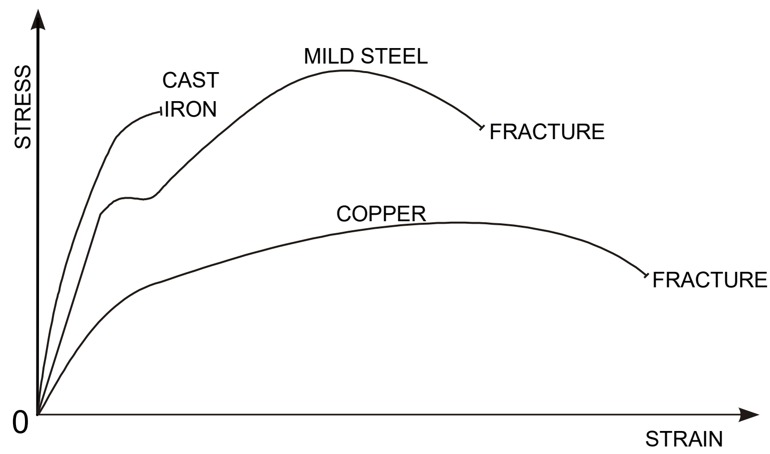
8. A piece of wire 6 m long and diameter of 0.75 mm stretched 24 mm under a force of 120 N. Calculate stress and strain.

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.



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

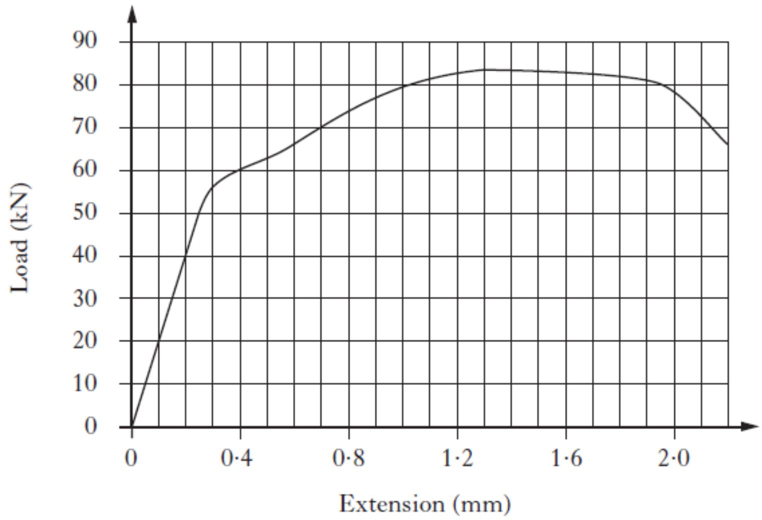
The yield strain is the maximum percentage plastic extension produced in a material before it fails under loading. A ductile material such as copper needs to be formed and shaped into items such as pipes. For this to be effective, the material requires a high value of yield strain.

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.

Questions

1. Below is the load-extension graph produced during a tensile test performed on an alloy-steel specimen.



The test specimen was 120mm long with a rectangular cross-section of 26mm x 6mm.

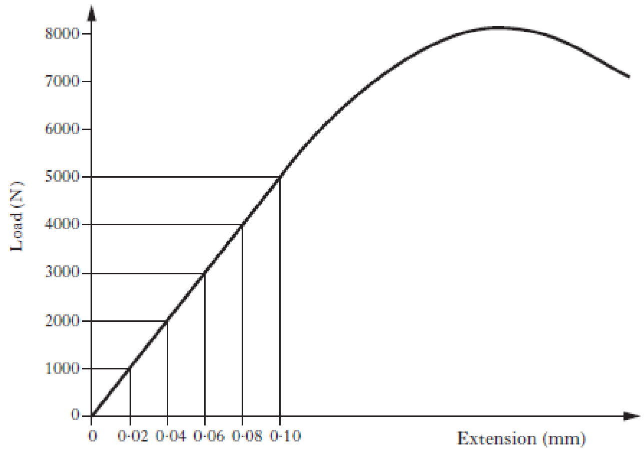
a) Calculate Young's Modulus for this material.

b) Describe the effect on the specimen of applying and then removing the following loads:

   i) 50kN

   ii) 80kN

2. A load-extension graph for a standard test specimen is shown below. The specimen is 200mm long and 11.3mm in diameter.



a) Calculate Young's Modulus for the test specimen.

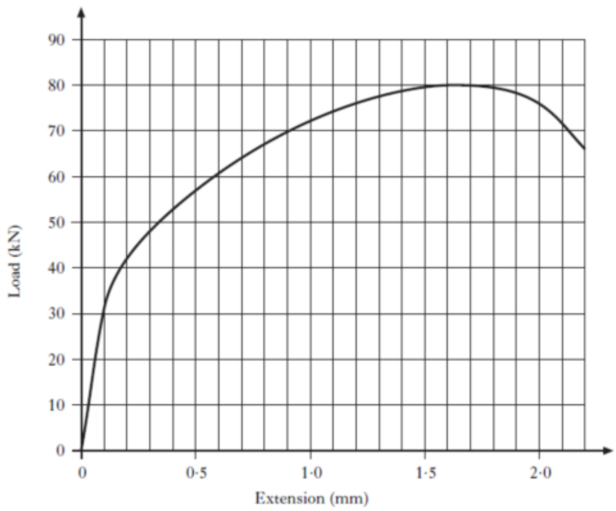
b) State the name of the material from which the test specimen is made.

c) Sketch the above graph, and on it show the yield point, the ultimate load, the plastic range and the elastic range.

Two further specimens were tensile tested. The dominant mechanical property of specimen A was brittleness, and that of B was ductility.

d) Sketch, on the same axes, typical stress-strain graphs for specimen A and specimen B. Clearly label the axes and identify each graph.

3. A load-extension graph is shown below for a tensile test on a sample of a special type of steel.



a) State whether this material is brittle or ductile.

The test specimen was 50mm long with a cross-sectional area of $80mm^2$.

b) Calculate Young's Modulus for the material.

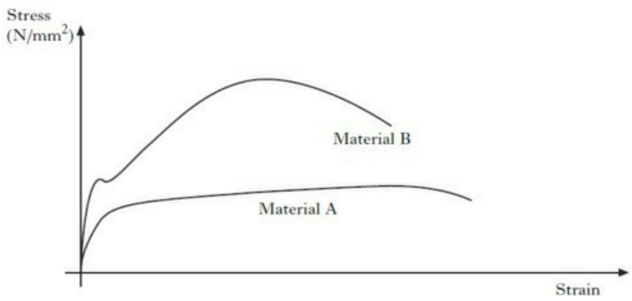
c) Calculate the ultimate tensile stress for the material.

A bar with a rectangular cross-section of 30mm x 10mm is manufactured from the material. The bar is to be loaded in tension with a Factor of Safety of 6.

d) i) Calculate the safe working stress for the bar.

ii) Calculate the safe working load for the bar.

4. The stress-strain graphs for two different materials are shown below.



a) From the information given, state one property of material A, giving a reason for your choice.

b) Describe the difference between elastic and plastic deformation.

Another material with a gauge length of 120mm and a cross-sectional area of $12mm^2$ was tested. It was found that at just below the yield point a force of 2.96kN caused an increase in length of 0.185mm.

c) i) Calculate the Modulus of Elasticity for this material.

ii) State the name of the material.

iii) State one reason why this material might be selected for a cable supporting an overhead lighting gantry.

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 Nmm^{-2}. If the working stress on a component is 50 Nmm^{-2}, calculate the factor of safety applied in the design of the component.

$$Factor of Safety = \frac{Ultimate Stress}{Safe Working Stress}$$

$$Factor of Safety = \frac{300}{50}$$

$$Factor of Safety = 6$$

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 E $kNmm^{-2}$	Yield stress σ_y Nmm^{-2}	Ultimate tensile stress Nmm^{-2}	Ultimate compressive stress Nmm^{-2}
Mild steel	196	220	430	430
Stainless steels	190–200	286–500	760–1280	460–540
Low-alloy steels	200–207	500–1980	680–2400	680–2400
Cast iron	120	–	120–160	600–900
Aluminium alloy	70	250	300	300
Titanium alloy	110	950	1000	1000
Nickel alloys	130–234	200–1600	400–2000	400–2000
Concrete	–	–	–	60
Concrete (steel reinforced)	45–50	–	–	100
Concrete (post stressed)	–	–	–	100
Plastic, ABS polycarbonate	2·6	55	60	85
Plastic, polypropylene	0·9	19–36	33–36	70
Wood, parallel to grain	9–16	–	55–100	6–16
Wood, perpendicular to grain	0·6–1·0	–	–	2–6

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.

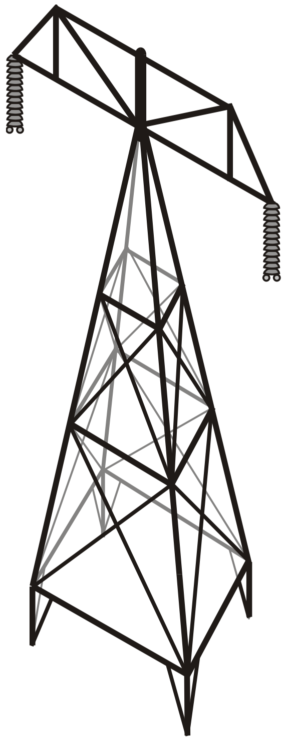
Ultimate Tensile Stress - the maximum value of stress the material can withstand before failing due to tension.

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

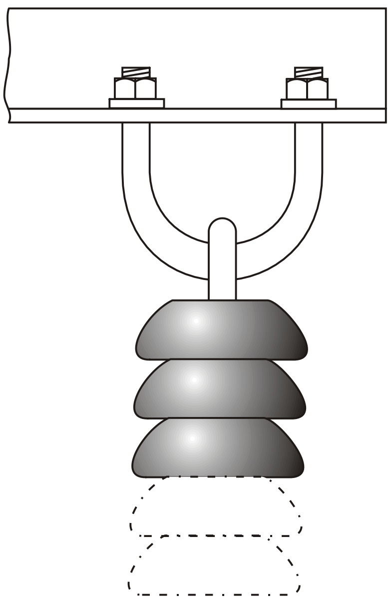
You will notice from the table that some materials perform quite differently in tension and compression, for example soft brass performs better in compression than tension. Other materials perform equally well under both types of loading, for example low-alloy steel and titanium alloys.

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 Nmm^{-2} and a value for Young's Modulus of 207 $kNmm^{-2}$. 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 Nmm^{-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 Nmm^{-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?

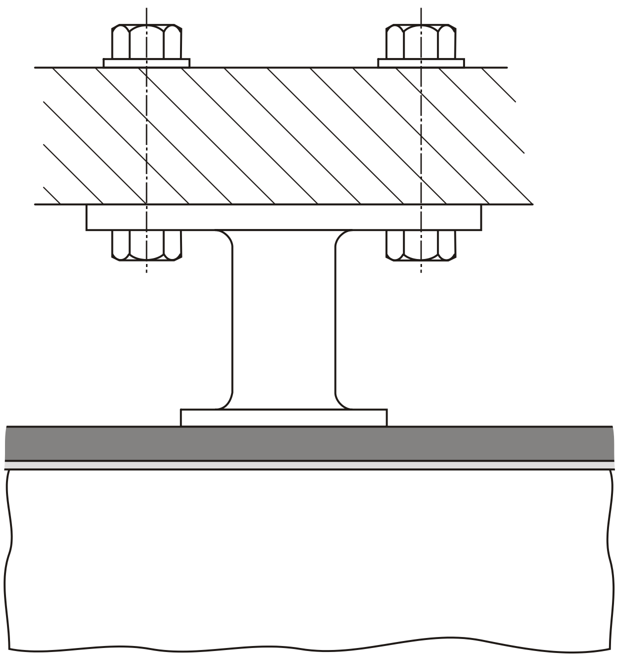
14. A lifting jack has a maximum lift of 300 mm and the diameter of the ram is 75 mm. Find the maximum force the jack may exert if the ram has to have a factor of safety of 7 and the ultimate tensile stress of the metal is 483 Nmm^{-2}. Find the change in length of the ram if the modulus of elasticity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

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 Nmm^{-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.

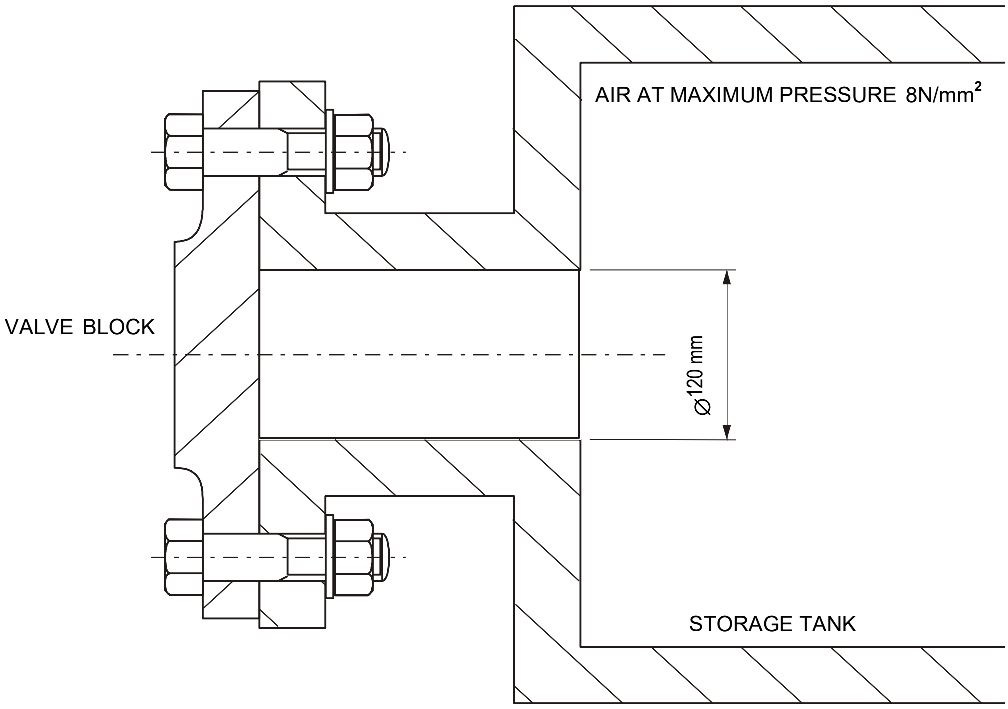
16. A display screen in a lecture theatre is held in place by a bracket fixed to the roof by two mild steel bolts as shown in figure 3. The bolts are initially tightened so that the tensile stress in them is 7 Nmm^{-2} before any load is Applied.

    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.



17. Part of a pneumatic system is shown in figure 4. Compressed air is stored in the tank at a maximum pressure of 8 Nmm^{-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 Nmm^{-2} and the ultimate tensile stress for the bolts is 370 Nmm^{-2}. The factor of safety for the system is 5.



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.

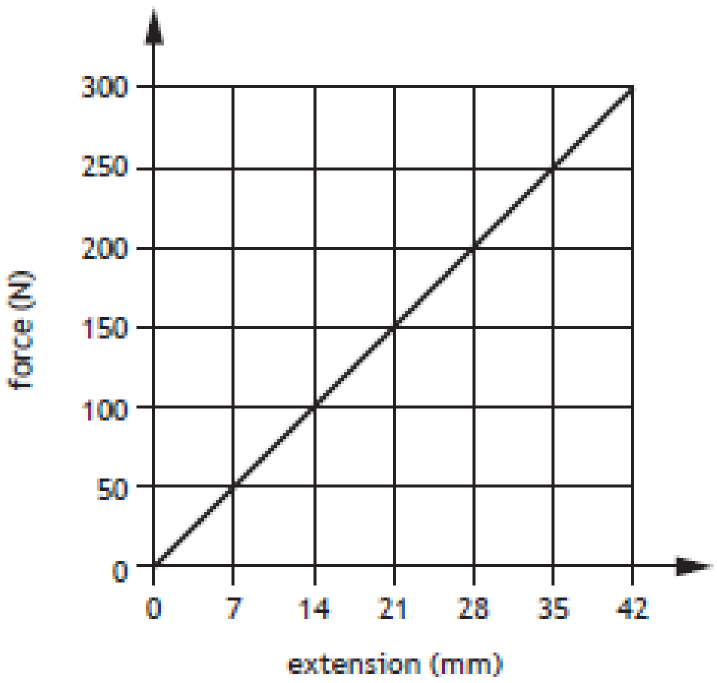
d) Calculate the load to be carried by each bolt.

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

2023 Past Paper

3. (continued)

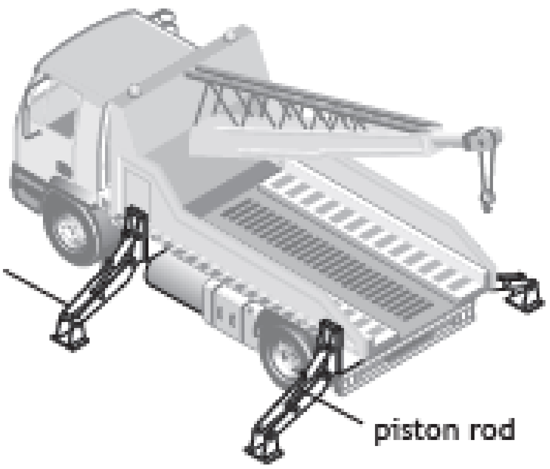
A force-extension graph for the rope is shown below.



(b) Calculate the strain energy in the rope when it experiences a tensile force of 150 N. **2**

11. A tow truck is designed to include additional structural and safety features.

The tow truck uses outriggers to ensure stability when heavier vehicles are lifted.



The piston in each outrigger produces a force of 49 kN. The piston rods are to be manufactured from mild steel with a factor of safety of 15. The piston rod has a circular cross section.

(a) (i) Calculate the required diameter of the piston rod. 4

11. (a) (continued)

Each piston rod is 320 mm long.

(ii) Calculate the change in length of a piston rod when it experiences a stress value of 86 $N\,mm^{-2}$. **3**

2022 Past Paper

1. A new material is being tested for use in the manufacture of ships.

The results of a tensile test on the material are shown in Figure 1.

The range of 0 to A is shown magnified in Figure 2.

Figure 1

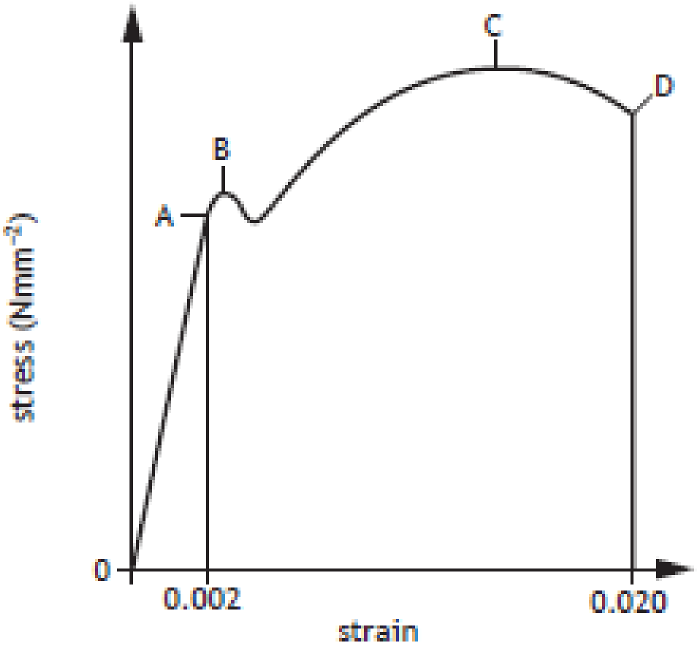
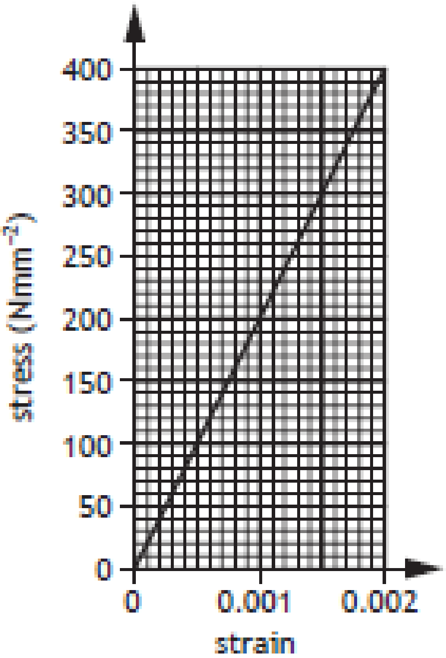


Figure 2



1. (continued)

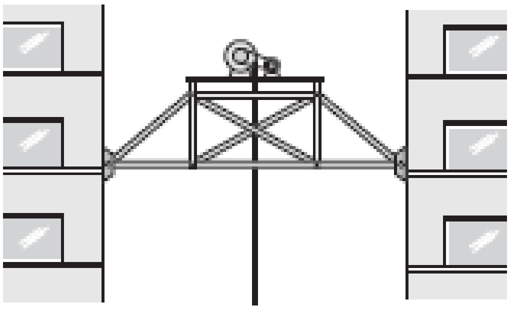
(a) (i) State the name of the range 0 to A. **1**

(ii) State the name of the range A to D. **1**

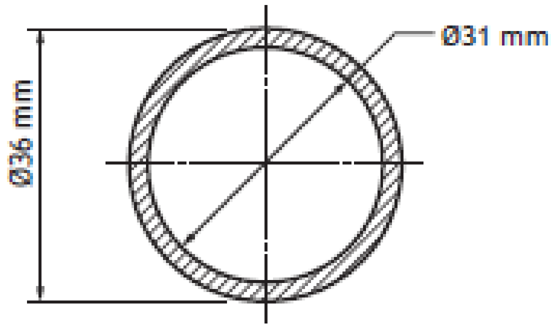
(b) (i) Calculate, using the information from **Figure 2**, Young's Modulus for this material. **1**

(ii) State the property identified by point C on **Figure 1**. **1**

11. During a construction project in a city centre location, a lifting platform is installed between two high rise buildings.



One of the members in the structure has a cross-section as shown below, with an internal diameter of 31 mm, and an external diameter of 36 mm.



This mild steel member has a strain of 4.6×10^{-5} when subjected to a load.

(a) Calculate the load carried by this member. **4**