Sunday, April 11, 2021

Young's Modulus

Deformation of solid & Elasticity of materials – Module 2

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Materials : *Young's Modulus*

Learning Objectives

1. To understand the keywords associated with the deformation of different types of solids

2. To be able to calculate stress, strain and hence Young's modulus

3. To be able to describe and compare stress-strain graphs

Materials : *Definitions 1*

Elasticity: The ability of a solid to <u>regain</u> its shape & size after it has been deformed or distorted.

Tensile : Deformation due to stretching.

Compressive Deformation: deformation due to compression.

Ductile: The ability to be drawn into a long thin wire. (Copper is a good example)

Brittle: Material breaks easily. Cannot be permanently stretched.

Malleable: Can be bent or beaten into various shapes (e.g. thin sheets) without fracturing or break.

Materials : *Tensile Stress*

Tensile Stress

This is the force per unit area of cross section when a material is stretched

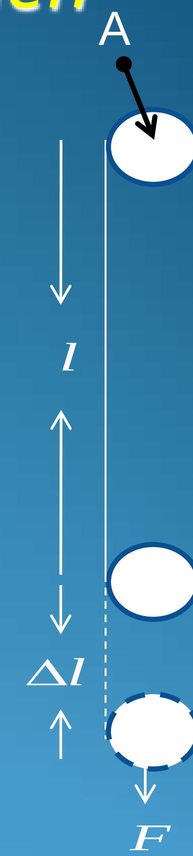
For a wire of length L and cross sectional area A

Tensile Stress = Tension / Area

$\sigma = F/A$

Units : Derived N/m^2, named Pascals (Pa)

Area is often for a wire with a circular cross section. So πr^2, but $\frac{1}{4}\pi d^2$ is more convenient since we measure diameter with a micrometer rather than radius



Materials : *Tensile Strain*

Tensile Strain

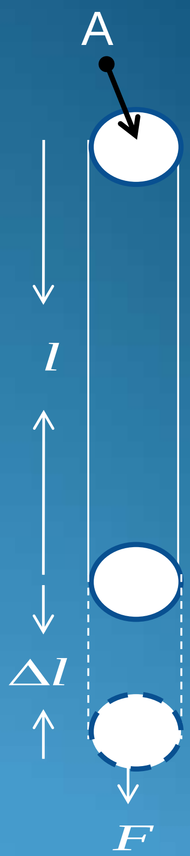
This is the ratio of change in length (ΔL) to original length (L)

For a wire of length L

Tensile Strain = Extension / Original Length

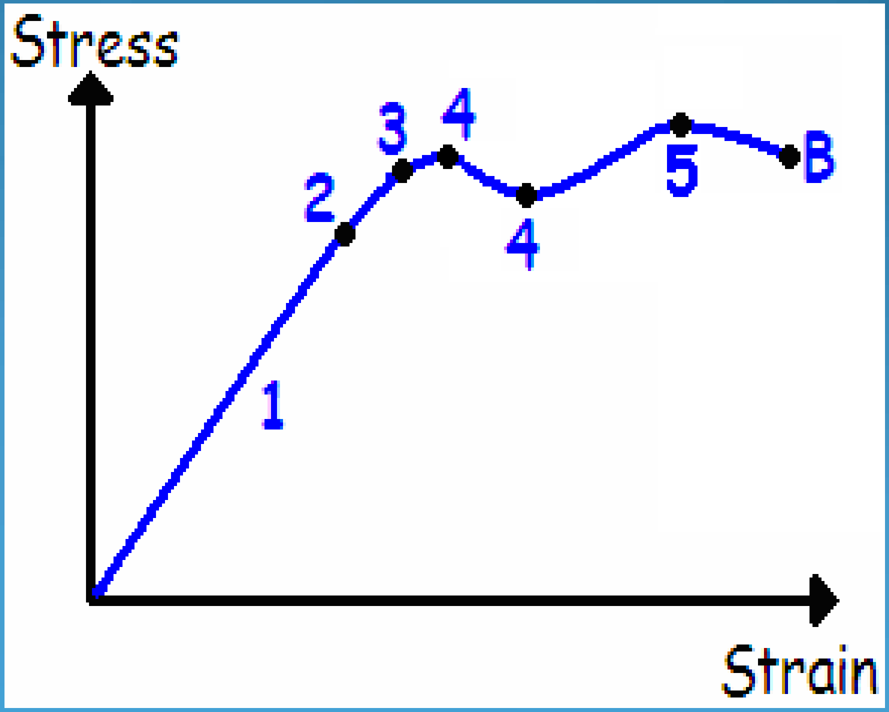
$\varepsilon = \Delta L / L$

Units : None! It is a ratio (units cancel out)



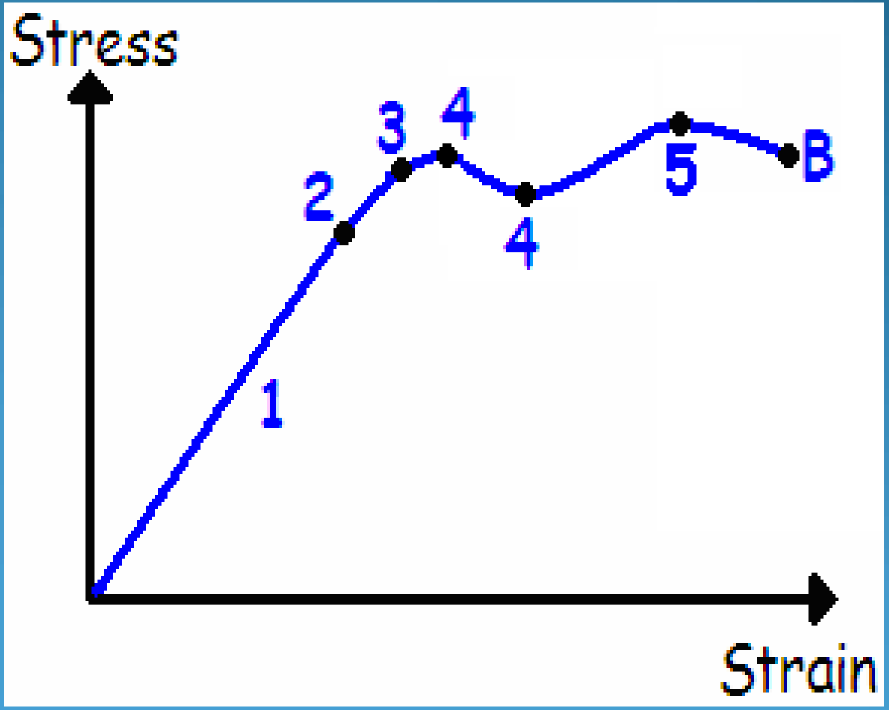
Materials : *Stress – Strain Curves 1*

Graphs of Stress against Strain are useful. They provide a method of comparing materials of different thicknesses and original lengths



Materials : *Stress – Strain Curves 2*

1. Linear region where Hooke's law is obeyed
2. The limit of proportionality
3. Elastic Limit – point where the material stops returning to its original length
4. Yield point(s) where the material 'necks'
5. Ultimate Tensile Stress (U.T.S.)
6. B. breaking point



Materials : *Definitions*

Definitions

Elastic Limit: The maximum amount a material can be stretched by a force and still return to its original shape and size. The material has no permanent change in shape or size

Yield Point: Beyond the elastic limit, a point is reached at which there is a noticeably larger permanent change in length. This results in plastic behaviour

Ultimate Tensile Strength: The maximum stress that can be applied without breaking

Materials : *Definitions cont'd*

Plasticity: A plastic material does not return to its original size and shape when the force is removed. There is a permanent stretching and change of shape

So plasticity is the tendency of an object or a sample of material to retain any change in shape or size when any deforming forces are removed from it.

Elastic deformation $\Rightarrow$ a body initially deformed by an applied force returns to its original shape/size when (deforming) force is removed.

Materials : *Definitions cont'd*

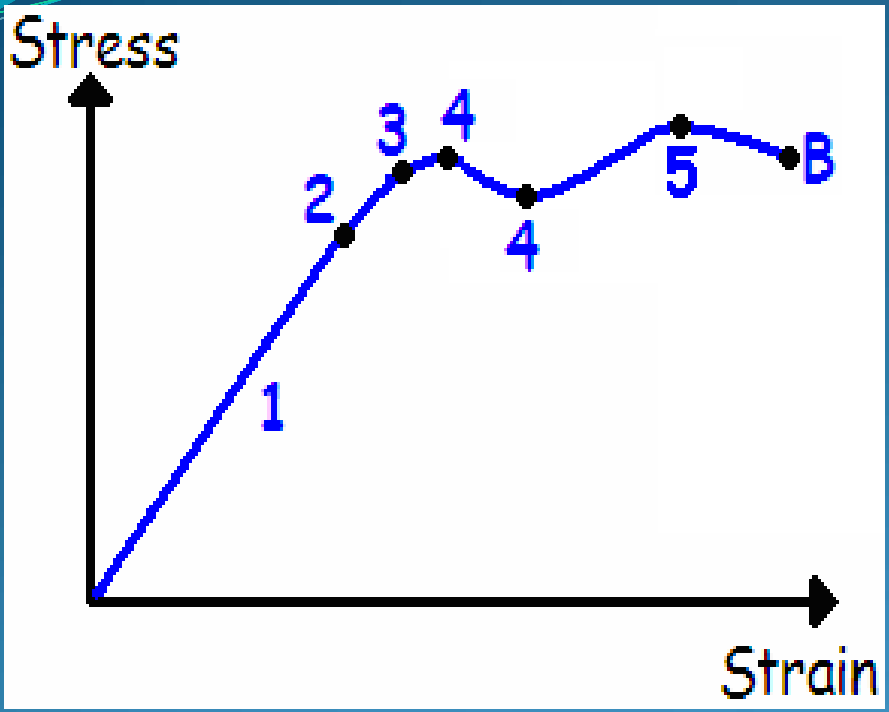
Stiffness: A measure of how difficult it is to change the size or shape of a material.

- Thick steel wire is stiffer than thin steel wire of the same length.

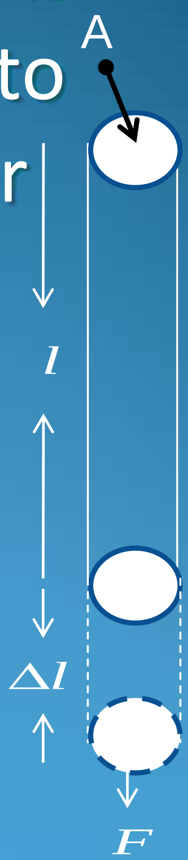
- Short steel wire is stiffer than longer steel wire of the same diameter.

- Steel is stiffer than copper of the same diameter and length, because copper extends more per unit force

Materials : *Young's Modulus*



To describe elastic properties of linear objects like wires, a convenient parameter is the ratio of the stress to the strain, a parameter called the "Young's modulus"



Young's Modulus = Tensile Stress / Tensile Strain

Expands to $E = \sigma/\varepsilon = F/A \div \Delta L/L$

Units simply come from the tensile stress N/m^2 or Pa

Materials : *Young's Modulus*

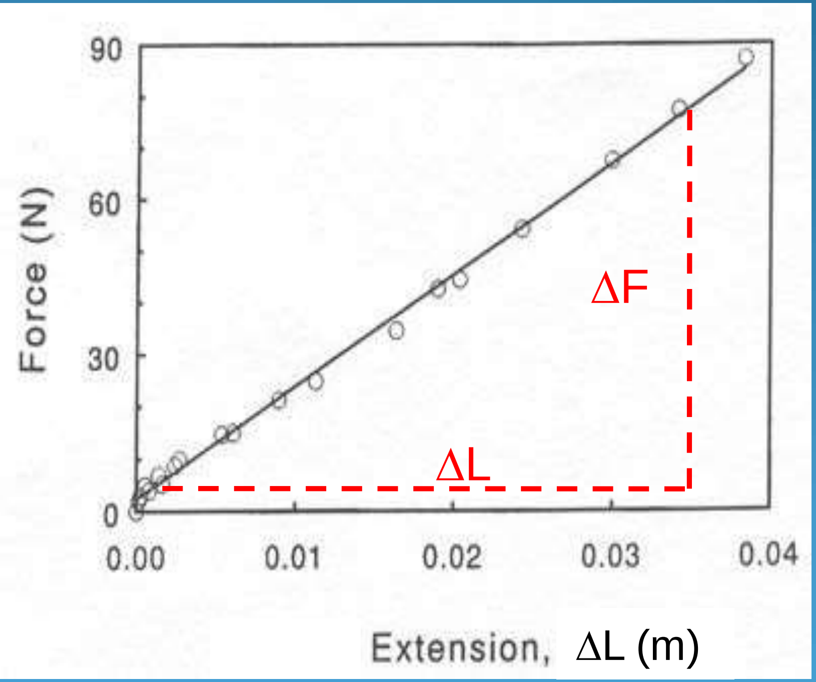
$E = F/A \div \Delta L/L$ Can be rearranged as

$E = F/\Delta L \times L/A$ (invert the divisor $\div 2 \equiv \times \frac{1}{2}$)

Why is this helpful?

$F/\Delta L$ can be found Experimentally

Gradient of graph!



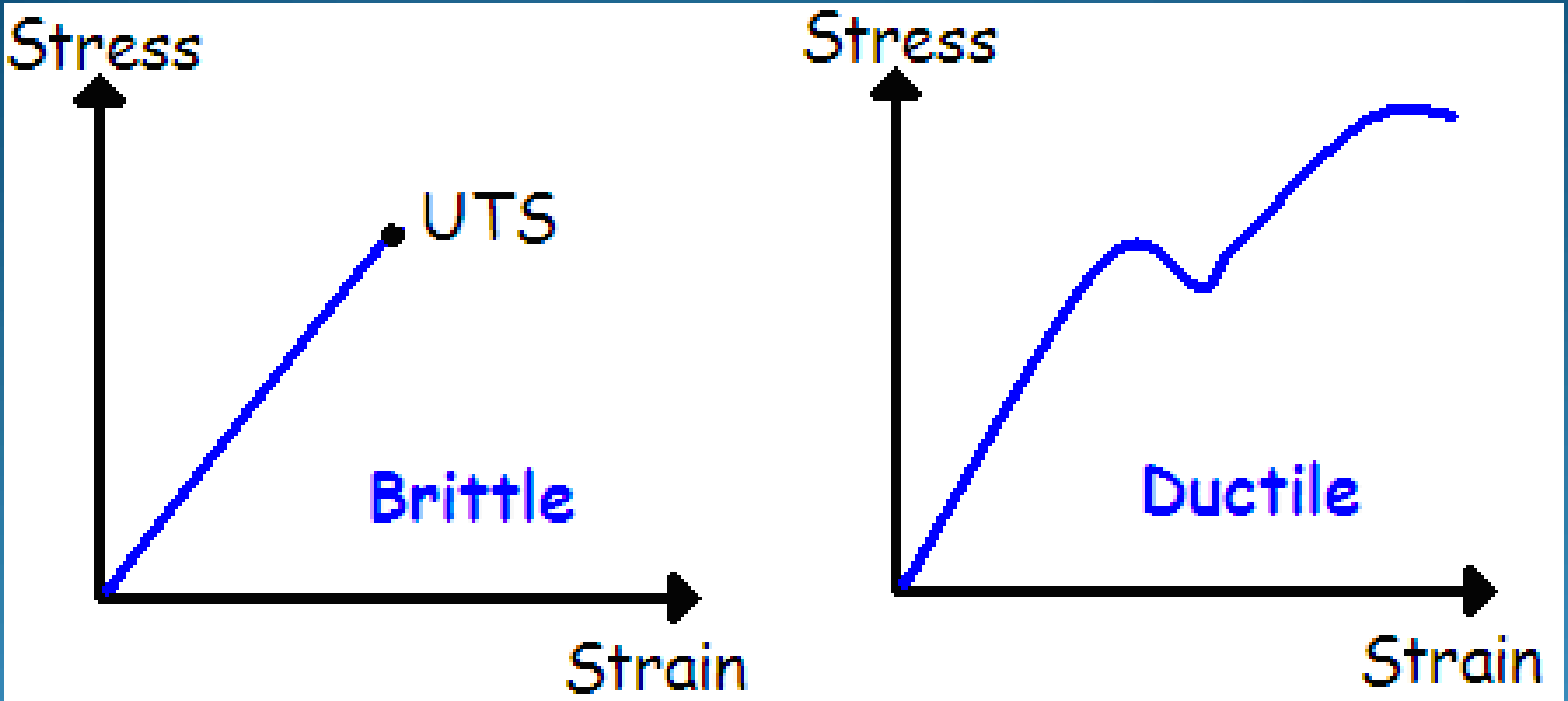
Materials : *Young's Modulus*

Definition

Young's modulus is defined as the ratio of the tensile stress applied to a material to the resulting tensile strain parallel to the tension when the material behaves elastically.

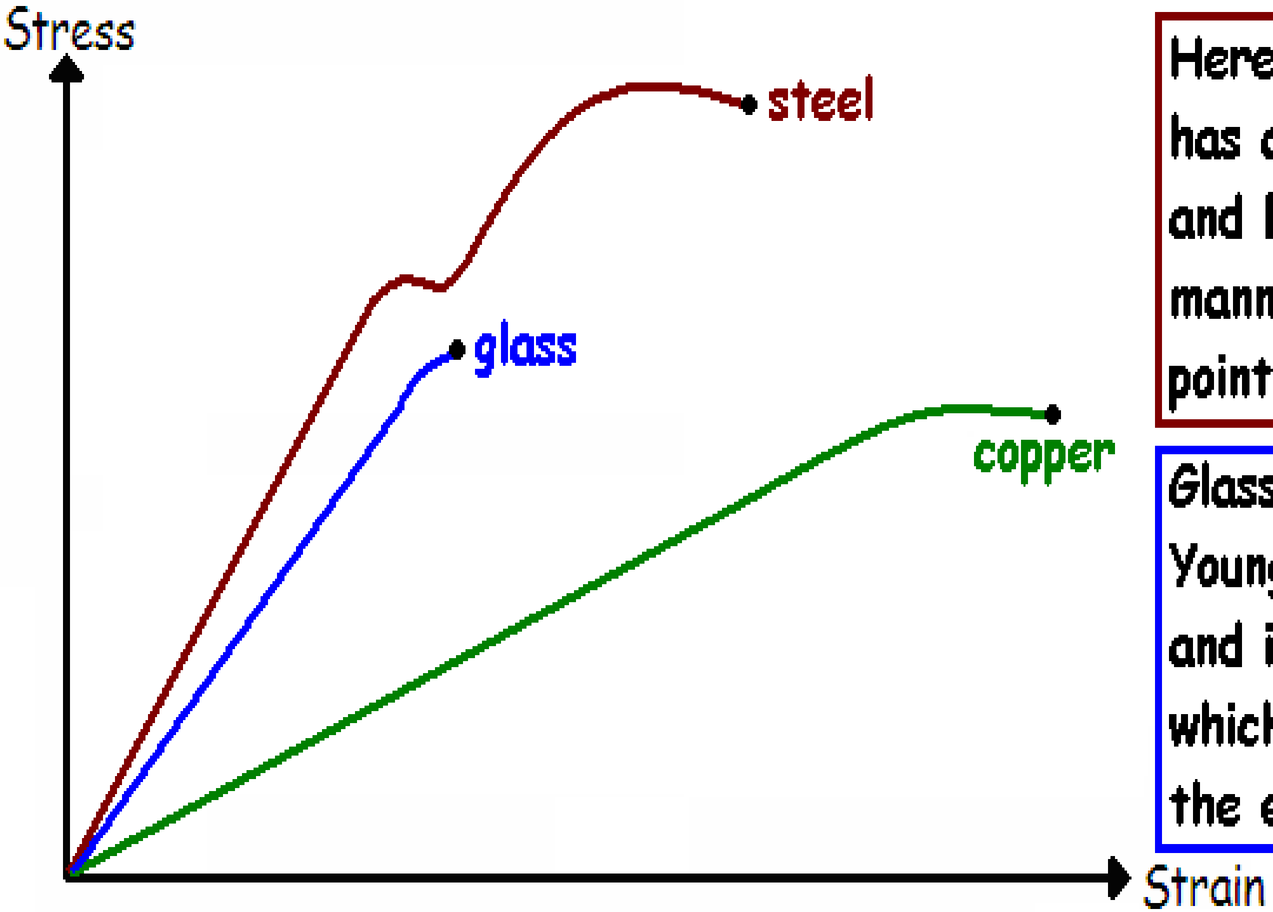
It is also known as modulus of elasticity

Materials : *Stress – Strain Curves 3*



Comparing stress/strain graphs of brittle and ductile materials for example glass and copper

Materials : *Stress – Strain Curves 4*



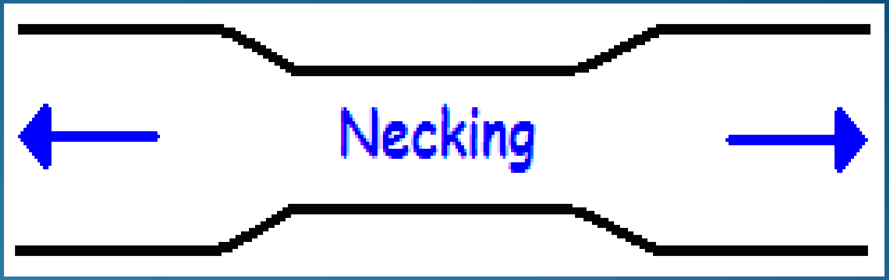
Here you can see that steel has a higher Young's Modulus and behaves in a ductile manner with a couple of yield points.

Glass has a slightly smaller Young's Modulus than steel and is a brittle material which breaks just after or at the elastic limit.

Copper has a relatively small Young's Modulus and shows some plastic deformation before it breaks. Copper has a large region where Hooke's Law is obeyed

Materials : Young's Modulus

Ductile materials have a very large plastic region. Just before it fails the material necks



Cross sectional area reduces, and as stress = F/A the neck sees an increase in tensile stress.

Brittle materials show little plastic deformation. Failure is sudden and 'catastrophic'. Better under compression

Applications of Young's modulus

1. Buildings/civil/mechanical engineering designs

– Reinforced concrete industry

- Guidelines include a substantial safety margin designed to assure the safety of all persons.

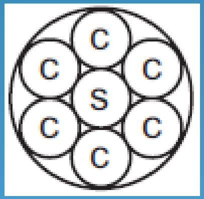
2. Medicine – bone (Orthopaedic)

3. Automobile/aeronautical engineering

Applications

An electric power cable in the National grid consists of six aluminium (or copper) wires c surrounding a steel core s.

The steel core provides reinforcement – mechanical strength.



Steel-reinforced cables

Applications

Steel-reinforced concrete

Applications

High rise buildings

Applications

Impeccable! Architectural masterpiece

Applications

Road network & bridges

Applications

Principal cause of building collapse – Bad design, faulty foundation, use of substandard materials and poor workmanship.

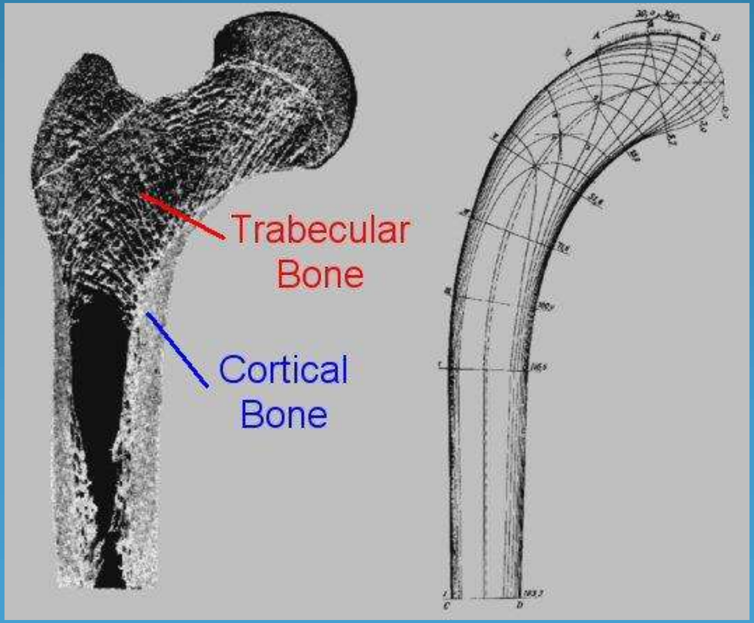
Hence need for regulation and supervision in building industry.

Safety in building industry involves multifaceted approach:

- **Good Design & Approval**
- **Implementation,**
- **Supervision of Project execution for compliance with design**

Class discussion

Application of Young's Modulus in orthopaedic research revealed that bone mechanical properties are highly variable according to species, age, anatomical site, liquid content, etc.



Orthopaedic research

Applications

- The Human heart is elastic.
- Watch the pumping of the heart – contraction of the ventricles (Cardiac_cycle video).

Applications

In manufature of:

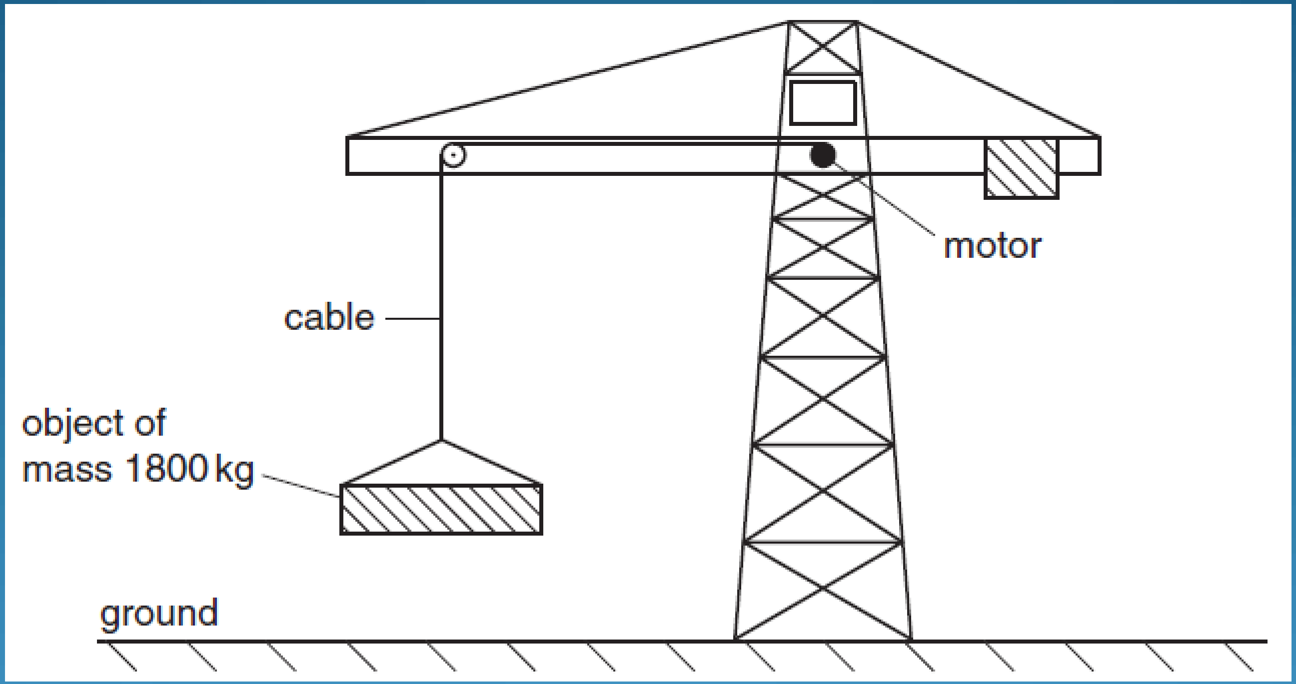
1. Armoured vehicles equipped with a protective metal covering against bullets, missiles, weapons.

2. Tractors, caterpillar, earth-moving equipment such as bulldozer or mechanical digger.

Applications

Tension in the steel cable used in crane for lifting loads from the ground at construction sites etc. The crane moves heavy objects through the use of a motor, which winds cable around a winch, and a system of pulleys.

Applications



- Suspended speaker in churches etc.
- Ropes used in tug of war, tug boat, towing vehicles
- Lifting NEPA/PHCN poles to be erected from trucks.
- Camera are mounted on cranes for video recording.

Applications

- Para troopers in military drills

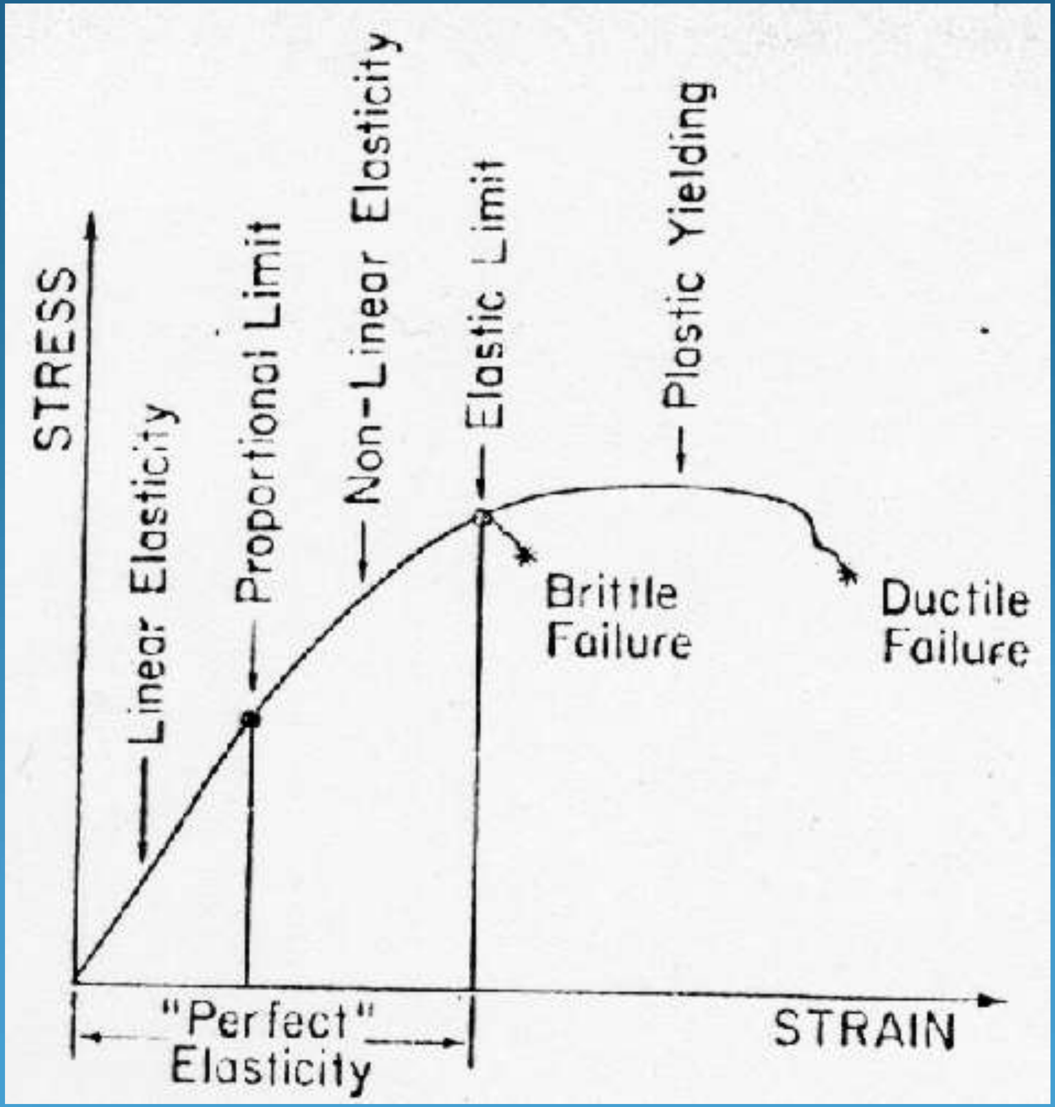
Applications

- Velocity of sound in solid is given by

$$V = \sqrt{\frac{E}{\rho}},$$

- where E = Young's modulus and ρ is the density. e.g. for iron v is approx. 5,000 m/s.

Stress-strain behaviour of materials



CLASS EXPERIMENT TO DETERMINE YOUNG MODULUS OF THE MATERIAL OF A WIRE (COPPER)

Credits

Dr Poulton and Mr Moore
Ranelagh A level Physics Wikispace