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Uttar Pradesh
Public Service Commission

Combined State Engineering Services Examination
Assistant Engineer

Civil Engineering

Strength of Materials

Well Illustrated **Theory** *with*
Solved Examples and **Practice Questions**

MADE EASY
Publications

Strength of Materials

Contents

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Properties of Metals, Simple Stress-Strain and Elastic Constants

1.1 Introduction

Strength of material is a branch of applied mechanics that deals with the behaviour of solid bodies subjected to various types of loading and internal forces developed due to these loading. The objective of our analysis is to determine the stresses, strains and deflections produced by the loads in different structures and loading conditions.

1.2 Normal Stress

- It is the internal resistance offered by the body against external loading or deformation which is force per unit area.
- Stress induced in the material depends upon the nature of force, point of application and cross-section area of material. Stress can be tensile or compressive in nature depending on the nature of load.

$$\sigma = \frac{P}{A} \text{ N/mm}^2 \text{ or MPa}$$

- Sign convention: Tensile stress = +ve; Compressive stresses = –ve
- Stresses are induced only when motion of bar is restricted either by some force or reaction induced. If a body or bar is free to move or free expansions allowed then no stresses will be induced.

NOTE: Pressure has same unit but pressure is different physical quantity than stress. Pressure is external normal force distributed over surface.

On the basis of cross-sectional area considered during calculation of stresses, direct stresses can be of following two types:

1. Engineering stress or nominal stress
2. True stress or Actual stress

- **Engineering stress (Nominal stress)**

  Mathematically, $\sigma = \dfrac{P}{A_0}$ where, A_0 = original cross-sectional area of specimen taken

- **True stress (Actual stress)**

  Mathematically, $\sigma = \dfrac{P}{A_a}$ where, A_a = Actual cross-sectional area of specimen at any

                    time of loading i.e. changed area of cross-section due to loading

  $$A_a = A_0 \pm \Delta A \quad \text{'+' for Compression, '–' for Tension}$$

Remember

- In tension, true or actual stress is always greater than engineering or nominal stress.
- In compression, true or actual stress is always less than engineering or nominal stress.

1.3   Strain

Strain is a measure of deformation representing the displacement between particles in the body relative to a reference length.

Mathematically strain can be calculated as

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

Unit: Strain is dimensionless quantity. It is always expressed in the form of number. If the member is in tension, the strain is called a tensile strain. If the member is in compression, the strain is called a compressive strain.

On the basis of length of member used in calculation of strain, strain can be of following two types:

1. Engineering or nominal strain
2. True or Actual strain

Engineering or Nominal Strain

Engineering or nominal strain is strain calculated, when length of member is taken as original length

$$\in_0 = \frac{\Delta l}{l_0} \qquad l_0 = \text{original length of member}$$

True or Actual Strain

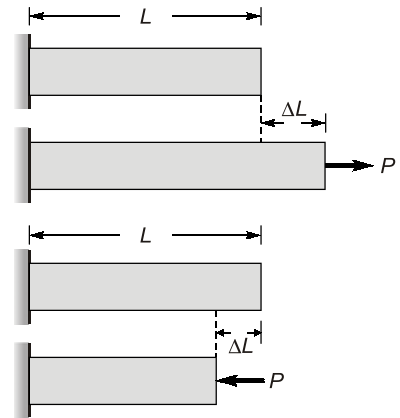True or actual strain is strain calculated, when length of member is taken as actual length of member at loading

$$\in_a = \frac{\Delta l}{l_a} \qquad l_a = \text{Actual length of member}$$

$$l_a = l_0 \pm \Delta l$$

Sign convention:

- Tensile strains are positive where as compressive strains are negative.

1.4   Stress-Strain Curve

1. **Elastic Behavior:** Elastic behavior of the material occurs when the strains in the specimen are within the Ist region shown in Fig. Here the curve is actually a *straight line* throughout most of this region, so that the stress is *proportional* to the strain. The material in this region is said to be *linear elastic*. The upper stress limit to this linear relationship is called the **proportional limit**, σ_{pl}. If the stress slightly exceeds the proportional limit, the curve tends to bend and flatten out as shown. This continues until the stress reaches the **elastic limit**.

    Upon reaching this point, if the load is removed the specimen will still return back to its original shape. Normally for steel, however, the elastic limit is seldom determined, since it is very close to the proportional limit and therefore rather difficult to detect.

2. **Yielding:** A slight increase in stress above the elastic limit will result in a breakdown of the material and cause it to *deform permanently*. This behavior is called **yielding**, and it is indicated by the

rectangular IInd region of the curve. The stress that causes yielding is called the **yield stress** or **yield point**, σ_y and the deformation that occurs is called **plastic deformation**. Although not shown in Fig. for low carbon steels or those that are hot rolled, the yield point is often distinguished by two values. The **upper yield point** occurs first, followed by a sudden decrease in load-carrying capacity to a **lower yield point**. Notice that once the yield point is reached, then as shown in Fig. the specimen will continue to elongate (strain) *without any increase in load*. When the material is in this state, it is often referred to as being **perfectly plastic**.

3. **Strain Hardening:** When yielding has ended, an increase in load can be supported by the specimen, resulting in a curve that rises continuously but becomes flatter until it reaches a maximum stress referred to as the **ultimate stress**, σ_u. The rise in the curve in this manner is called **strain hardening**, and it is identified in Fig. as the IIIrd region.

4. **Necking:** Up to the ultimate stress, as the specimen elongates, its cross-sectional area will decrease. This decrease is fairly uniform over the specimen's entire gauge length; however, just after, at the ultimate stress, the cross-sectional area will begin to decrease in a localized region of the specimen. As a result, a constriction or "neck" tends to form in this region as the specimen elongates further as shown in, Fig. (a). This region of the curve due to necking is indicated as IVth region in Fig. Here the stress–strain diagram tends to curve downward until the specimen breaks at the **fracture stress**, σ_f as shown in Fig. (b).
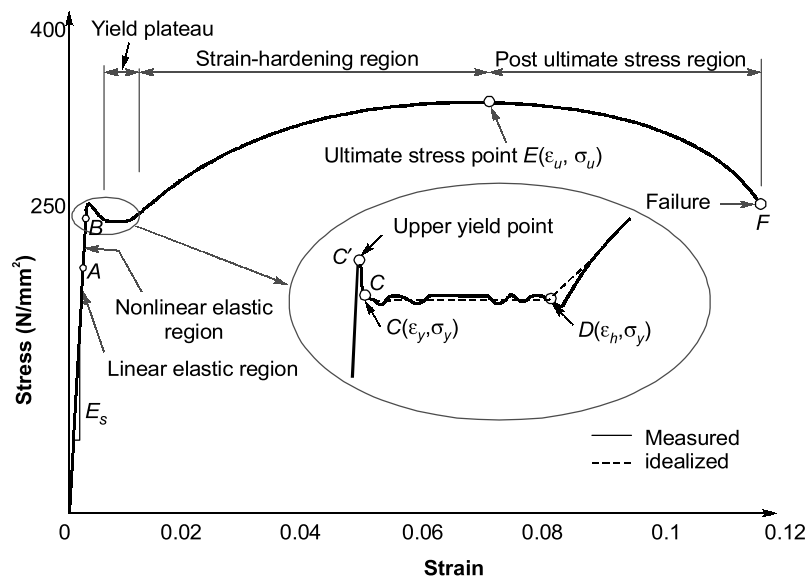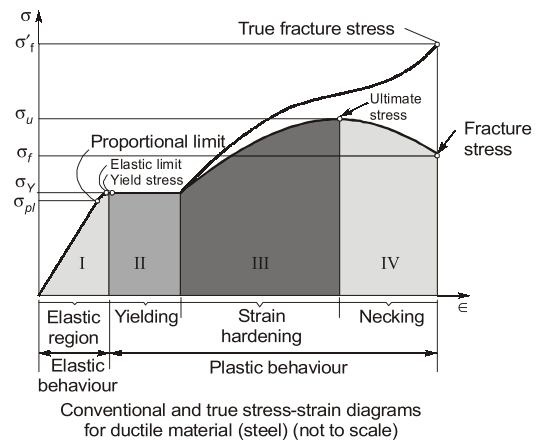

(a) Necking
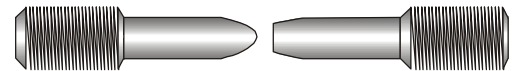
(b) Failure of a ductile material (formation of a cup-cone shape at the fracture location)

Fig.

True Stress–Strain Diagram: Instead of always using the original cross-sectional area and specimen length to calculate the (engineering) stress and strain, we could have used the actual cross-sectional area and specimen length at the instant the load is measured. The values of stress and strain found from these measurements are called true stress and true strain, and a plot of their values is called the **true stress–strain diagram**. Note that the conventional and true $\sigma-\in$ diagrams are practically coincident when the strain is small.

The differences between the diagrams begin to appear in the strain-hardening range, where the magnitude of strain becomes more significant. In particular, there is a large divergence within the necking region. Here it can be seen from the conventional σ–$\in$ diagram that the specimen actually supports a *decreasing load*, since A_0 is constant when calculating engineering stress, $\sigma = P/A_0$. However, from the true σ–$\in$ diagram, the actual area A within the necking region is always decreasing until fracture, σ'_f and so the material actually sustains *increasing stress*, since $\sigma = P/A$.

Conventional and true stress-strain diagrams for ductile material (steel) (not to scale)

DO YOU KNOW?

Strain that occurs before the yield point is called elastic strain and that which occurs after yield point with no increase in stress is called plastic strain. For mild steel, plastic strain is 10 to 15 times of elastic strain.

- Ideal curve for tension is shown in the figure. However, actual behaviour is different and indicates apparently reduced yield stress in compression for mild steel. The divergence between tension and compression results is explained by Bauchinger and is called **Bauchinger effect**.

Example - 1.1   A rod of dimension 20 mm × 20 mm is carrying an axial tensile load of 10 kN. The tensile stress developed is

(a) 0.025 MPa   (b) 0.25 MPa
(c) 25 MPa   (d) 250 MPa

Solution: (c)

$$\text{Induced stress, } \sigma = \frac{P}{A} = \frac{10 \times 1000}{20 \times 20} = 25 \text{ MPa}$$
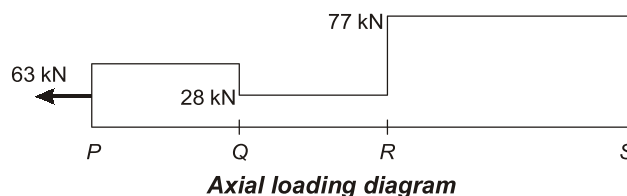
Example - 1.2   A cross-section bar of area 700 mm^2 is subjected to an axial load as shown in the figure below, what is the value of stress (MPa) in the section QR?

(a) 30   (b) 40
(c) 50   (d) 60

Solution: (b)

Axial loading diagram

load in *QR* section, $P_{QR} = +28$ kN

Induced stress, $\sigma_{QR} = \dfrac{PQR}{AQR} = \dfrac{28 \times 10^3}{700} - 40\,\text{MPa}$

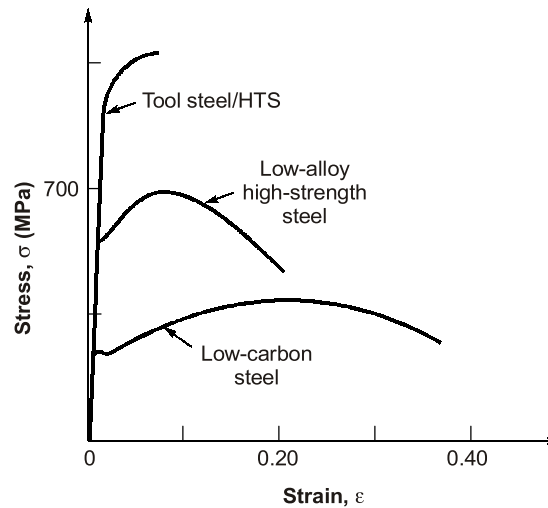### 1.4.1 Stress Strain Curve for Other Grades of Steel in Tension

Fig. *(a) Tensile stress-strain diagram for different grades of steel*

Remember

- All the grade of steel have same Young's modulus of elasticity.
- Among all grades high tension steel (HTS) is more brittle and mild steel is more ductile.
- High tension steel has higher ultimate strength than other grade of steel.

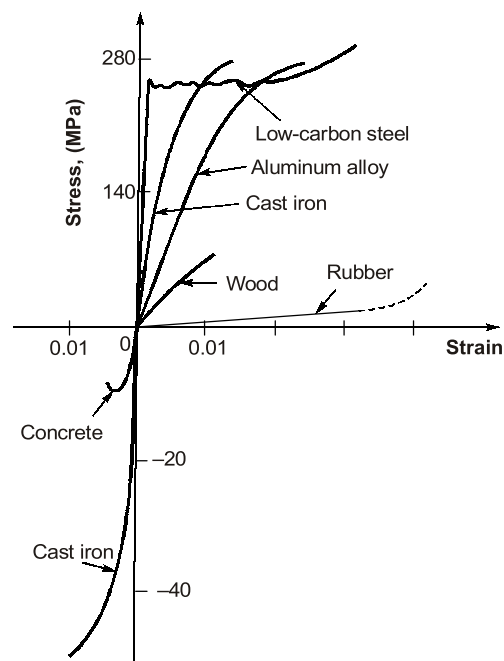### 1.4.2 Stress Strain Curve for Various Materials

Fig. *(b) Stress-strain diagram for different material*

1.5   Properties of Metals

1.5.1   Ductility

- Ductility is the property by which material can be stretched.
- Large deformations are thus possible in ductile materials before the absolute failure or rupture takes place.
- Some of the examples are mild steel, aluminium, copper, manganese, lead, nickel, brass, bronze, monal metal etc.

Example - 1.3   The percentage reduction in area in case of cast iron when it is subjected to tensile test is of the order of

(a) 0%   (b) 10%

(c) 20%   (d) 25%

Solution: (a)

The % reduction in area in case of cast iron when it is subjected to tensile test is of the order of 0%, because cast iron being brittle material does not undergo elongation.

1.5.2   Brittleness

- Brittleness is the lack of ductility i.e. material cannot be stretched.
- In brittle materials, failure takes place with a relatively smaller deformation. This property is undesirable.
- For brittle materials fracture point and ultimate points are same, and after proportional limit very small strain is seen. Some of the examples are cast iron, concrete and glass.

> **NOTE**
>
> - To distinguish between these two types of materials, materials with strain less than 5% at fracture point are regarded as brittle and those having strains greater than 5% at fracture point are called ductile (this value for mild steel at fracture is about 25%).

1.5.3   Malleability

- It is the property by which a material can be uniformly extended in a direction without rupture.
- A malleable material possess a high degree of plasticity. This property is of great use in operations like forging, hot rolling, drop (stamping) etc.

1.5.4   Toughness

- The property which enables material to absorb energy without fracture. This property is very desirable in case of cyclic loading or shock loading.
- The **modulus of toughness** is measured as area under entire stress-strain curve and it is the energy absorbed by material of the specimen per unit volume upto fracture point.

$$\text{Modulus of toughness} = \left[\frac{\sigma_y + \sigma_u}{2}\right] \in_f$$

Where, σ_y = Yield tensile strength; σ_u = Ultimate tensile strength; $\in_f$ = Strain at fracture point

- The modulus of toughness will depend upon ultimate tensile strength and strain at failure (fracture strain). Hence the material which is very ductile will exhibit a higher modulus of toughness as the case with mild steel.

- The **modulus of resilience** is the maximum elastic energy per unit volume that can be absorbed without attaining plastic stage.

$$\text{Modulus of resilience } (u) = \frac{\sigma_y^2}{2E}$$

- **The modulus of resilience** depends upon yield strength and hence a material with higher yield strength will have higher modulus of resilience.

NOTE: Higher toughness is a desirable property in materials used for gears, chains, crane hooks, freight car etc. Higher resilience is desirable in springs.

1.5.5 Hardness

- Hardness is defined as the resistance to indentation or scratching or surface abrasion.
- There are two methods of hardness measurement:
    1. Scratch hardness - commonly measured by Moh test.
    2. Indentation hardness (abrasion) measured by
        (a) Brinell hardness method   (b) Rockwell hardness
   (c) Vickers hardness   (d) Knoop hardness

NOTE: It should be noted that ductile materials are tough and brittle materials are hard.

1.5.6 Fatigue

- The behaviour of material under variable loading (dynamic loading) is referred to as **fatigue**.
- Factors affecting fatigue are:
    1. Loading conditions   2. Frequency of loading   3. Corrosion
    4. Temperature   5. Stress concentration

1.5.5 Creep

where, Δ_e = Elastic deflection = $\dfrac{PL}{AE}$

P = Static load

Δ_c = Deformation due to creep
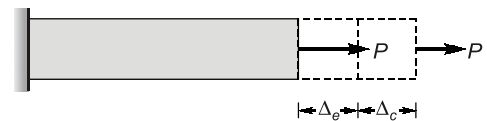
Creep is permanent deformation which is recorded with passage of time at constant loading. Total creep deformation continues to increase with time asymptotically.

Factors affecting creep are as follows:

1. Magnitude of load
2. Type of loading (static or dynamic)
3. Time or Age of loading
4. Temperature
    – At higher temperature, due to greater mobility of atoms most of the materials loose their strength and elastic constants also get reduced. Hence, greater deformation at elevated temperature results, even under constant loading. Therefore, creep is more pronounced at higher temperature, and thus it must be considered for design of engines and furnaces.
    – Temperature at which the creep becomes very appreciable is half of the melting point temperature on absolute scale and known as *homologous temperature*.

1.5.6 Stress Relaxation

If a wire of metal is stretched between two immovable supports, so that it has an initial tension σ_0. The stress in the wire gradually diminishes, eventually reaching a constant value. This process, which is manifestation of creep is called **stress relaxation**. (This is the reason why electric wires sag after long time).
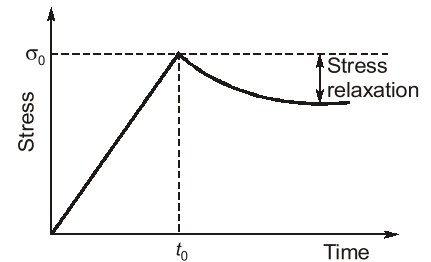
1.6 Hook's Law

- It states that within elastic limit, stress for most of the metals is proportional to strain upto proportion at limit.

$$\text{Stress} \propto \text{strain}$$
$$\sigma = E\in$$
$$\frac{\text{Stress}}{\text{Strain}} = \text{Constant} = E$$

Where, E = Young's modulus of elasticity

- Hook's law is valid upto limit of proportionality. However for mild steel proportional limit and elastic limit are almost equal. But for other metals and materials elastic limit may be higher than proportional limit. e.g. rubber.

- The slope of stress-strain curve is called modulus of elasticity (E). The **modulus of elasticity** (E) is the constant of proportionality which is defined as the intensity of stress that causes unit strain. Thus, modulus of elasticity (E) has the units same as units of stress.
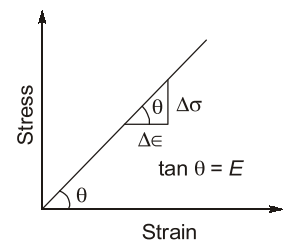
Assumptions in Hooke's Law:

1. Material is homogeneous (properties are equal at all points).
2. Material is isotropic (properties are equal in all direction).
3. Material is elastic.

> **NOTE**
>
> 1. If elastic properties are different in three mutually perpendicular direction then material is called **Orthotropic material**, e.g. plywood.
> 2. If properties are different in all direction then material is called Non-isotropic or Anisotropic material, e.g., Crystal.

1.7 Proof Stress

- When a material such as **aluminium** does not have an obvious yield point and yet undergoes large strains after the proportional limit is exceeded, an arbitrary yield stress may be determined by the **offset method**.

- A line parallel to initial linear part is drawn, which is offset by some standard amount of strain such as 0.2%. The intersection of the offset point (B) defines the yield stress or offset yield stress, which is slightly above the proportional limit and is called **proof stress**.
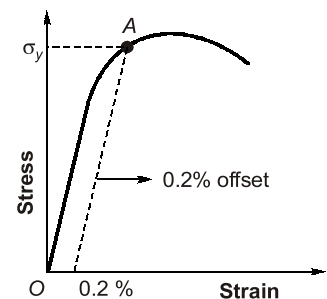
Example - 1.10 The strain energy per unit volume of a round bar under uni-axial tension with axial stress σ and modulus of elasticity E is

(a) $\dfrac{\sigma^2}{E}$

(b) $\dfrac{\sigma^2}{2E}$

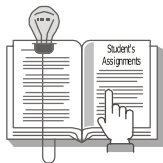(c) $\dfrac{\sigma^2}{3E}$

(d) $\dfrac{\sigma^2}{4E}$

Solution: (b)

$$\text{Strain energy/volume} = \frac{1}{2}\times\sigma\times E = \frac{1}{2}\times\sigma\times\frac{\sigma}{E} = \frac{\sigma^2}{2E}$$

Example - 1.11 Total area under the stress-strain curve of a mild steel specimen tested up to failure under tension is a measure of its

(a) Breaking strength
(b) Toughness
(c) Hardness
(d) Stiffness

Solution: (b)

Student's Assignment

Q.1 The ratio of Young's modulus to modulus of rigidity for a material having Poisson's ratio 0.2 is

(a) $\dfrac{12}{5}$

(b) $\dfrac{5}{12}$

(c) $\dfrac{5}{14}$

(d) $\dfrac{14}{5}$

Q.2 A straight wire 15 m long is subjected to tensile stress of 2000 kgf/cm². Elastic modulus is 1.5×10^6 kgf/cm². Coefficient of linear expansion for the material is 16.66×10^{-6}/°F. The temperature change (in °F) to produce the same elongation as due to the 2000 kgf/cm² tensile stress in the material is:

(a) 40
(b) 80
(c) 120
(d) 160

Q.3 Two similar round bars A and B are each 30 cm long as shown in the given figure. The ratio of strain energies stored by the bars A and B, $\dfrac{U_B}{U_A}$ is

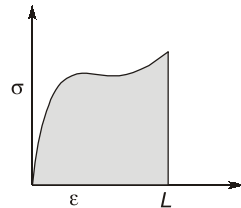(Assume both bars to be axially loaded equally)
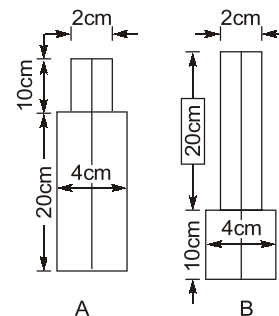
(a) 3/2
(b) 1.0
(c) 5/8
(d) 2/3

Q.4 Match **List-I** with **List-II** and select the correct answer using the codes given below the lists:
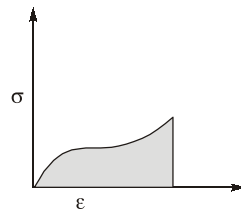
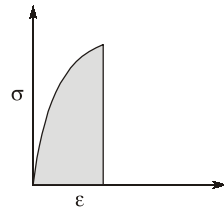| List-I	List-II

1. Soft & Weak   **A.**

2. Hard brittle   **B.**

3. Hard strong   **C.**

4. Soft tough   **D.**
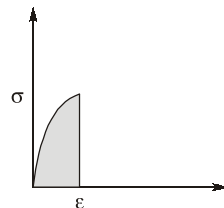
5. Hard tough   **E.**
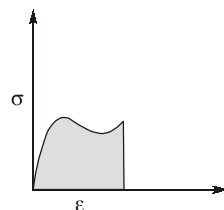
Codes:

	1	2	3	4	5
(a)	E	D	C	B	A
(b)	A	B	C	D	E
(c)	E	C	B	D	A
(d)	A	D	C	B	E

Q.5 A gradually applied load W is suspended by wire ropes AB and CD as shown in the figure. The wires AB and CD, made of the same material and of the same cross-section are connected to a rigid block from which the load W is suspended in such a way that both the ropes stretch by the same amount. If the stress in AB and CD are p_1 and p_2 respectively, then the ratio $\dfrac{p_1}{p_2}$ will be
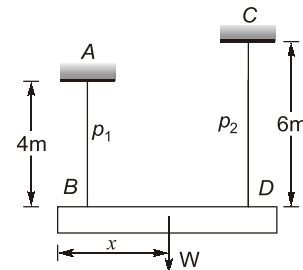
(a) 3/2   (b) 2/3

(c) 9/4   (d) 4/9

Q.6 ABC is a rigid bar. It is hinged at A and suspended at B and C by two wires, BD and CE made of copper and steel respectively, as shown in the given figure. The bar carries a load of 10 kN at F, midway between B and C.

Given that

A_c = 4cm^2, A_s = 2cm^2, E_c = 1 × 10^5 N/mm^2,

E_s = 2 × 10^5 N/mm^2

Subscript c and s stands for copper and steel. If the extensions in the steel and copper wires are Δ_s and Δ_c respectively, the ratio $\dfrac{\Delta_s}{\Delta_c}$ would be
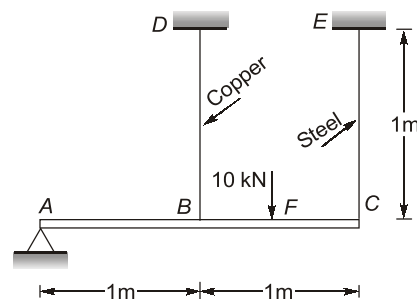
(a) 1/4   (b) 4

(c) 2   (d) 1/2

Q.7 A bar of elastic material is subjected to a direct compressive stress σ_1 in the longitudinal direction. Suitable lateral compressive stress σ_2 is applied along each of the other two lateral directions to limit the net strain in each of the lateral directions to half the magnitude of what it could be under σ_1 acting alone. If μ is the Poisson's ratio of the material, then the magnitude of σ_2 is

(a) $\dfrac{2(1-\mu)}{\mu}\sigma_1$ (b) $\dfrac{1}{2}\dfrac{(1-\mu)}{\mu}\sigma_1$

(c) $\dfrac{1}{2}\dfrac{\mu}{(1-\mu)}\sigma_1$ (d) $\dfrac{1}{2}\dfrac{\mu}{(1-\mu^2)}\sigma_1$

Q.8 What is the reason of low toughness of grey cast iron?
(a) Strain rate   (b) Notch effect
(c) Grain size effect   (d) Crystal structure

Q.9 Which one of the following favours brittle fracture in a ductile material?
(a) Elevated temperature
(b) Slow rate of straining
(c) Presence of notch
(d) Circular cross-section

Q.10 The modulus of rigidity of an elastic material is found to be 38.5% of the value of its Young's modulus. The Poisson's ratio μ of the material is nearly
(a) 0.28   (b) 0.30
(c) 0.33   (d) 0.35

Q.11 The capacity of a material to absorb energy when deformed elastically and then to have this energy recovered upon unloading is called
(a) Endurance   (b) Resilience
(c) Toughness   (d) Ductility

Q.12 A steel rod of cross-section area 10 mm^2 is subjected to loads at points P, Q, R and S as shown in the figure below:
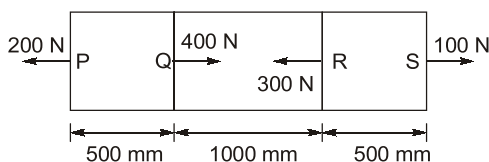
If E_{steel} = 200 GPa, the total change in length of the rod due to loading is

(a) $-5\,\mu m$ (b) $-10\,\mu m$
(c) $-20\,\mu m$ (d) $-25\,\mu m$

Q.13 A rod of variable cross-section (are as A_1 & A_2) fixed at one end is subjected to an axial force P as shown in figure. If the allowable normal stress in tension is 100 MPa then the maximum allowable load P (neglecting stress concentration).
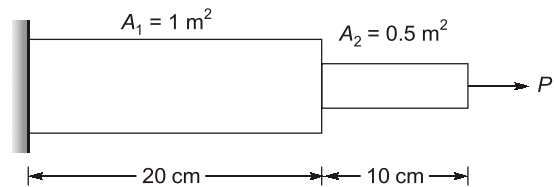
(a) 100 MN   (b) 200 MN
(c) 50 MN   (d) 50 KN

Q.14 The linear relation between the stress and strain of a material is valid until
(a) fracture stress
(b) elastic limit
(c) ultimate stress
(d) proportional limit

Q.15 A steel rod of length 300 mm is held between two fixed supports so that the rod cannot elongate or contract in the axial direction. If the temperature of the rod is raised by 20°C, the axial stress induced in the rod due to this rise in temperature is (for steel E = 200 GPa, α = 11.5 × 10^{-6}/°C).
(a) 46 MPa tension
(b) 46 MPa compression
(c) 23 MPa tension
(d) 23 MPa compression
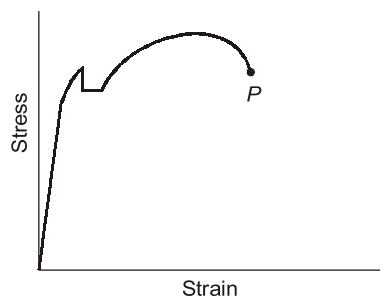
Q.16 If a material expands freely due to heating what type of stress will develop?
(a) thermal stress   (b) tensile stress
(c) no stress   (d) bending

Q.17 If Poisson's ratio for a material is 0.5, then the elastic modulus for the material is
(a) 3 times its shear modulus
(b) 4 times its shear modulus
(c) Equal to its shear modulus
(d) Indeterminate

Q.18 The number of independent elastic constraints required to express the stress-strain relationship for a linearly elastic isotropic material is
(a) One   (b) Two
(c) Three   (d) Four

Q.19 What is the strain energy stored in a body of volume V with stress σ due to gradually applied load?
(a) $\dfrac{\sigma E}{V}$ (b) $\dfrac{\sigma E^2}{V}$
(c) $\dfrac{\sigma V^2}{E}$ (d) $\dfrac{\sigma^2 V}{2E}$

Q.20 The slope of the stress-strain curve in the elastic deformation region is known by:
(a) Elastic modulus   (b) Plastic modulus
(c) Poisson's ratio   (d) None of the these

Q.21 Elastic limit is the point
(a) up to which stress is proportional to strain
(b) At which elongation takes place without application of additional load
(c) Up to which if the load is removed, original volume and shapes are regained
(d) None of the these   **[UPPSC]**

Q.22 Where is the necking region?
(a) The area between lower yield point and upper yield point.
(b) The area between the plastic limit and elastic limit.
(c) The area between the ultimate point and initial point.
(d) The area between the ultimate point and rupture.

Q.23 The law which states that within elastic limits strain produced is proportional to the stress producing it is known as _____
(a) Bernoulli's law   (b) Hooke's law
(c) Stress law   (d) Poisson's law

Q.24 What is the factor of safety?
(a) The ratio of stress to strain
(b) The ratio of permissible stress to the ultimate stress
(c) The ratio of ultimate stress to the permissible stress
(d) The ratio of longitudinal strain to stress
                                    [UPPSC]

Q.25 The materials which have the same elastic properties in all directions are called _____
(a) Isotropic   (b) Brittle
(c) Homogeneous   (d) Hard   **[UPPSC]**

Q.26 As the elastic limit reaches, tensile strain _____.
(a) Increases more rapidly
(b) Decreases more rapidly
(c) Increases in proportion to the stress
(d) Decreases in proportion to the stress

Q.27 Find the strain of a brass rod of length 250 mm which is subjected to a tensile load of 50 kN when the extension of rod is equal to 0.6 mm?
(a) 0.024   (b) 0.0012
(c) 0.0046   (d) 0.0014

Q.28 A tensile test was conducted on a steel bar. The gauge length of the bar was 10 m and the extension was 2mm. What will be the percentage elongation?
(a) 0.002   (b) 0.02
(c) 0.2   (d) 2

Q.29 Structural members subjected to a long time sustained loads deform progressively with time especially at elevated temperatures. What is such a phenomenon called?
(a) Fatigue   (b) Creep
(c) Creep relaxation (d) Fracture   **[UPPSC]**

Q.30 What is the point P shown in the stress-strain curve?

(a) Lower yield point
(b) Elastic limit
(c) Proportionality limit
(d) Breaking point/fracture point

Q.31 If the material has different elastic properties in perpendicular directions, it is called
(a) Elastic   (b) Isotropic
(c) Orthotropic   (d) Plastic

Q.32 Which one of the following pairs is NOT correctly matched?
(a) Visco-elastic – small plastic zone
(b) Orthotropic material – different properties in three perpendicular directions
(c) Strain hardening material – stiffening effect felt at some stage
(d) Isotropic material – same physical property in all directions at a point

Q.33 The effect of a force on a body depends on its:
(a) direction
(b) magnitude
(c) position
(d) all of these

Q.34 A solid metal bat of uniform diameter D and length L is hung vertically from a ceiling. If the density of the material of the bar is γ and the modulus of elasticity is E, then the total elongation of the bar due to its own weight will be _____.
(a) $\gamma L/2E$
(b) $\gamma L^2/2E$
(c) $\gamma E/2L$
(d) $\gamma E/2L^2$

Q.35 A bar of diameter 30 mm is subjected to a tensile load such that the measured extension on a gauge length of 200 mm is 0.09 mm and the change in diameter is 0.0045 mm. What will the Poissons ratio?
(a) 1/3
(b) 1/4
(c) 1/5
(d) 1/6

Q.36 An experiment was done and it was found that the bulk modulus of a material is equal to its shear modulus. Then what will be its Poissons ratio?
(a) 0.125
(b) 0.150
(c) 0.200
(d) 0.375

Q.37 What will be the approximate value of shear modulus of a material if the modulus of elasticity is 200 GN/m^2 and its Poissons ratio is 0.30?
(a) 76.9 GN/m^2
(b) 80 GN/m^2
(c) 93.3 GN/m^2
(d) 103.9 GN/m^2

Q.38 What is the bulk modulus of elasticity?
(a) The ratio of shear stress to shear strain
(b) The ratio of direct stress to direct strain
(c) The ratio of volumetric stress to volumetric strain
(d) The ratio of direct stress to volumetric strain

Q.39 E, G, K and μ elastic modulus, shear modulus, bulk modulus and Poisson's ratio respectively. To express the stress strain relations completely for this material
(a) E, G and μ must be known
(b) E, K and μ must be known
(c) Any two of the four must be known
(d) All the four must be known

Q.40 The ability of a material to undergo plastic deformation without rupture, when a compressive force is applied, is known as _____.
(a) Ductility
(b) Formability
(c) Brittleness
(d) Malleability **[UPPSC]**

Q.41 With an increase in temperature, malleability of material _____.
(a) Increases
(b) Decreases
(c) Remains constant
(d) Independent of temperature

Q.42 Stress-strain analysis is done to know which of the following properties of materials?
(a) Physical properties
(b) Optical properties
(c) Mechanical properties
(d) Magnetic properties

Q.43 The failure criterion for ductile materials is based on
(a) yield strength
(b) ultimate strength
(c) shear strength
(d) limit of proportionality

■■■■

ANSWER KEY		STUDENT'S ASSIGNMENT		
1. (a)	**2.** (b)	**3.** (a)	**4.** (a)	**5.** (a)
6. (c)	**7.** (c)	**8.** (b)	**9.** (c)	**10.** (b)
11. (b)	**12.** (d)	**13.** (c)	**14.** (d)	**15.** (b)
16. (c)	**17.** (a)	**18.** (b)	**19.** (d)	**20.** (a)
21. (c)	**22.** (d)	**23.** (b)	**24.** (c)	**25.** (a)
26. (a)	**27.** (a)	**28.** (b)	**29.** (b)	**30.** (d)
31. (c)	**32.** (a)	**33.** (d)	**34.** (b)	**35.** (a)
36. (a)	**37.** (a)	**38.** (d)	**39.** (c)	**40.** (d)
41. (a)	**42.** (c)	**43.** (a)		

HINTS & SOLUTIONS / STUDENT'S ASSIGNMENT

Strong/weak can be measured by ultimate tensile strength or peak of stress-strain curve. Based on these concepts the answer can be easily found.

1. (d)

$$G = \frac{E}{2(1+\mu)} \quad \Rightarrow \quad \frac{E}{G} = 2(1+\mu)$$

$$\frac{E}{G} = 2 \times 1.2 = 2.4 = \frac{12}{5}$$

2. (b)

$$\Delta L = \frac{\sigma L}{E} = L\alpha\Delta T$$

$$\therefore \quad \Delta T = \frac{\sigma}{E\alpha} = \frac{2000}{1.5 \times 10^6 \times 16.66 \times 10^{-6}}$$

$$= 80.03° \, F$$

3. (a)

$$U = \frac{P^2 L}{2AE} \text{ For axially loaded bar.}$$

$$U_A = \frac{P^2 L_1}{2A_1 E} + \frac{P^2 L_2}{2A_2 E}$$

$$= \frac{P^2}{2E}\left[\frac{10}{2^2} + \frac{20}{4^2}\right]$$

$$U_B = \frac{P^2 L_1}{2AE} + \frac{P^2 L_2}{2A_2 E}$$

$$= \frac{P^2}{2E}\left[\frac{20}{2^2} + \frac{10}{4^2}\right]$$

$$\frac{U_B}{U_A} = \frac{\left[\dfrac{20}{2^2} + \dfrac{10}{4^2}\right]}{\left[\dfrac{10}{2^2} + \dfrac{20}{4^2}\right]}$$

$$= \left(\frac{4 \times 20 + 10}{4 \times 10 + 20}\right)$$

$$= \frac{90}{60} = 1.5 = \frac{3}{2}$$

4. (a)

1-E, 2-D, 3-C, 4-B, 5-A

Toughness is measured by area under stress-strain curve. Brittleness is measured by strain at failure. Higher the yield point, the metal will be harder.

5. (a)

$$\Delta = \frac{p_1 l_1}{EA} = \frac{p_2 l_2}{EA}$$

$$\Rightarrow \quad \frac{p_1}{p_2} = \frac{l_2}{l_1} = \frac{6}{4} = \frac{3}{2}$$

6. (c)

The bar will remain straight with some inclination θ. Therefore from geometry.

$$\therefore \quad \frac{\Delta_c}{1} = \frac{\Delta_s}{2}$$

$$\frac{\Delta_s}{\Delta_c} = 2$$

7. (c)

Net strain in lateral direction

$$\epsilon_2 = \frac{1}{E}\left[-\sigma_2 + \mu(\sigma_1 + \sigma_2)\right]$$

Since all the stresses are compressive.
When σ_1 alone is acting compressive

$$\epsilon_2' = +\frac{\mu\sigma_1}{E}$$

Given, $\quad \epsilon_2 = \frac{\epsilon_2'}{2}$

$$-\sigma_2 + \mu(\sigma_1 + \sigma_2) = +\frac{\mu\sigma_1}{2}$$

$$2\sigma_2(1-\mu) = \mu\sigma_1$$

$$\sigma_2 = \frac{\mu}{2(1-\mu)}\sigma_1$$

8. (b)

Grey cast iron has very poor toughness. Its major reason is notch like an effect of graphite flakes. These flakes increase stress concentration in it lowering toughness.

9. (c)

Due to presence of notch in the specimen or workpiece. Ductile material fails as brittle fracture.