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Director's Message

B. Singh (Ex. IES)

Engineering is one of the most chosen graduating field. Taking engineering is usually a matter of interest but this eventually develops into "purpose of being an engineer" when you choose engineering services as a career option.

Train goes in tunnel we don't panic but sit still and trust the engineer, even we don't doubt on signalling system, we don't think twice crossing over a bridge reducing our travel time; every engineer has a purpose in his department which when coupled with his unique talent provides service to mankind.

I believe *"the educator must realize in the potential power of his pupil and he must employ all his art, in seeking to bring his pupil to experience this power".* To support dreams of every engineer and to make efficient use of capabilities of aspirant, MADE EASY team has put sincere efforts in compiling all the previous years' ESE-Pre questions with accurate and detailed explanation. The objective of this book is to facilitate every aspirant in ESE preparation and so, questions are segregated chapterwise and topicwise to enable the student to do topicwise preparation and strengthen the concept as and when they are read.

I would like to acknowledge efforts of entire MADE EASY team who worked hard to solve previous years' papers with accuracy and I hope this book will stand up to the expectations of aspirants and my desire to serve student fraternity by providing best study material and quality guidance will get accomplished.

B. Singh (Ex. IES)
CMD, MADE EASY Group

Volume-II

MECHANICAL ENGINEERING

Objective Solved Questions

of UPSC Engineering Services Examination

Contents

UNIT

I

Strength of Materials and Engineering Mechanics

Syllabus

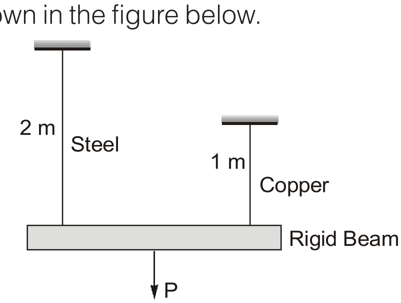
Analysis of System of Forces, Friction, Centroid and Centre of Gravity, Dynamics; Stresses and Strains-Compound Stresses and Strains, Bending Moment and Shear Force Diagrams, Theory of Bending Stresses-Slope and deflection-Torsion, Thin and thick Cylinders, Spheres.

Contents

1 Stress and Strain

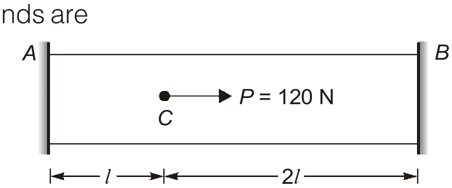
1.1 The state of plane stress in a plate of 100 mm thickness is given as
σ_{xx} = 100 N/mm^2, σ_{yy} = 200 N/mm^2
Young's modulus = 300 N/mm^2
Poisson's ratio = 0.3
The stress developed in the direction of thickness is
(a) zero (b) 90 N/mm^2
(c) 100 N/mm^2 (d) 200 N/mm^2
[ESE : 2000]

1.2 A rigid beam of negligible weight is supported in a horizontal position by two rods of steel and copper, 2 m and 1 m long having values of cross-sectional area 1 cm^2 and 2 cm^2 and E of 200 GPa an 100 GPa respectively. A load P is applied as shown in the figure below.



If the rigid beam is to remain horizontal then
(a) the forces on both sides should be equal
(b) the force on copper rod should be twice the force on steel
(c) the force on the steel rod should be twice the force on copper
(d) the force P must be applied at the centre of the beam [ESE : 2002]

1.3 A straight bar is fixed at edges A and B. Its elastic modulus is E and cross-section is A. There is a load P = 120 N acting at C. The reactions at the ends are



(a) 60 N at A, 60 N at B
(b) 30 N at A, 90 N at B
(c) 40 N at A, 80 N at B
(d) 80 N at A, 40 N at B [ESE : 2002]

1.4 A bar of length L tapers uniformly from diameter 1.1D at one end of 0.9D at the other end. The elongation due to axial pull is computed using mean diameter D. What is the approximate error in computed elongation?
(a) 10% (b) 5%
(c) 1% (d) 0.5% [ESE : 2004]

1.5 A solid uniform metal bar of diameter D and length L is hanging vertically from its upper end. The elongation of the bar due to self weight is
(a) Proportional to L and inversely proportional to D^2
(b) Proportional to L^2 and inversely proportional to D^2
(c) Proportional to L but independent of D
(d) Proportional to L^2 but independent of D
[ESE : 2005]

1.6 In a tensile test, near the elastic limit zone
(a) tensile stress increases at a faster rate
(b) tensile stress decreases at a faster rate
(c) tensile stress increases in linear proportion to the stress
(d) tensile stress decreases in linear proportion to the stress
[ESE : 2006]

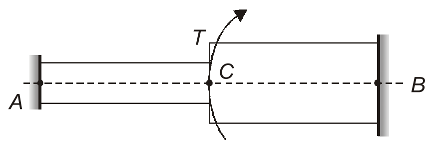
1.7 Two tapering bars of the same material are subjected to a tensile load P. The lengths of both the bars are the same. The larger diameter of each of the bars is D. The diameter of the bar A at its smaller end is D/2 and that of the bar B is D/3. What is the ratio of elongation of the bar A to that of the bar B?
(a) 3 : 2 (b) 2 : 3
(c) 4 : 9 (d) 1 : 3 [ESE : 2006]

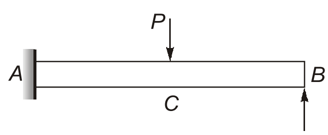
1.8 Which one of the following expresses the total elongation of a bar of length L with a constant cross-section of A and modulus of elasticity E hanging vertically and subject to its own weight W?

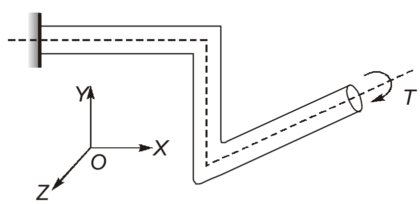
(a) $\frac{WL}{AE}$ (b) $\frac{WL}{2AE}$

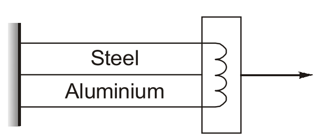
(c) $\frac{2WL}{AE}$ (d) $\frac{WL}{4AE}$ [ESE : 2007]

1.9 Which one of the following is not a statically indeterminate structure?

(a)


(b)


(c)


(d)


[ESE : 2010]

Directions: The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

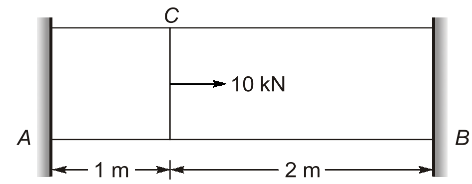
Codes:

(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

1.10 **Assertion (A):** A plane state of stress always results in a plane state of strain.
Reason (R): A uni-axial state of stress results in a three-dimensional state of strain. [ESE : 2010]

1.11 **Assertion (A):** A state of plane strain always results in plane stress conditions.
Reason (R): A thin sheet of metal stretched in its own plane results in plane strain conditions. [ESE : 2010]

1.12 A prismatic bar, as shown in figure is supported between rigid supports. The support reactions will be



(a) $R_A = \frac{10}{3}$ kN and $R_B = \frac{20}{3}$ kN

(b) $R_A = \frac{20}{3}$ kN and $R_B = \frac{10}{3}$ kN

(c) $R_A = 10$ kN and $R_B = 10$ kN

(d) $R_A = 5$ kN and $R_B = 5$ kN [ESE : 2011]

1.13 A rod of length l tapers uniformly from a diameter D at one end to a diameter d at the other. The Young's modulus of the material is E. The extension caused by an axial load P is

(a) $\frac{4Pl}{\pi(D^2 - d^2)E}$ (b) $\frac{4Pl}{\pi(D^2 + d^2)E}$

(c) $\frac{4Pl}{\pi DdE}$ (d) $\frac{2Pl}{\pi DdE}$ [ESE : 2012]

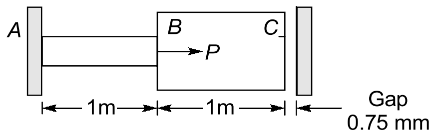
1.14 Consider the following statements :
1. State of plane stress occurs at the surface
2. State of plane strain occurs at the surface
3. State of plane stress occurs in the interior part of the plate
4. State of plane strain occurs in the interior part of the plate

Which of these statements are correct?

(a) 1 and 3 (b) 2 and 4
(c) 1 and 4 (d) 2 and 3

[ESE : 2013]

1.15 In the arrangement as shown in the figure, the stepped steel bar ABC is loaded by a load P. The material has Young's modulus E = 200 GPa and the two portions AB and BC have area of cross section 1 cm^2 and 2 cm^2 respectively. The magnitude of load P required to fill up the gap of 0.75 mm is

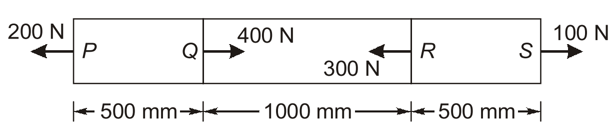


(a) 10 kN (b) 15 kN
(c) 20 kN (d) 25 kN **[ESE : 2013]**

1.16 A copper rod of 2 cm diameter is completely encased in a steel tube of inner diameter 2 cm and outer diameter 4 cm. Under an axial load, the stress in the steel tube is 100 N/mm^2.
If $E_s = 2\,E_c$, then the stress in the copper rod is
(a) 50 N/mm^2 (b) 33.33 N/mm^2
(c) 100 N/mm^2 (d) 300 N/mm^2
[ESE : 2015]

1.17 **Assertion (A):** Tensile strength of CI is much higher than that of MS.
Reason (R): Percentage of carbon in CI is more than 1.5.
(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true **[ESE : 2015]**

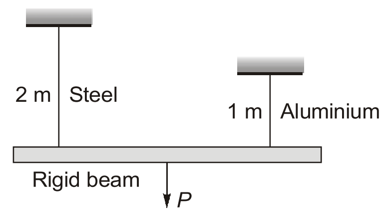
1.18 A steel rod of cross-sectional area 10 mm^2 is subjected to loads at points *P*, *Q*, *R* and *S* as shown in the figure below :



If E_{steel} = 200 GPa, the total change in length of the rod due to loading is
(a) – 5 μm (b) – 10 μm
(c) – 20 μm (d) – 25 μm
[ESE : 2016]

1.19 Two steel rods of identical length and material properties are subjected to equal axial loads. The first rod is solid with diameter *d* and the second is a hollow one with external diameter *D* and internal diameter 50% of *D*. If the two rods experience equal extensions, the ratio of $\frac{d}{D}$ is
(a) $\frac{3}{4}$ (b) $\frac{\sqrt{3}}{2}$
(c) $\frac{1}{2}$ (d) $\frac{1}{4}$ **[ESE : 2016]**

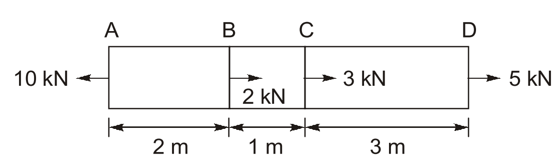
1.20 A rigid beam of negligible weight, is supported in a horizontal position by two rods of steel and aluminium, 2 m and 1 m long, having values of cross-sectional areas 100 mm^2 and 200 mm^2, and Young's modulus of 200 GPa and 100 GPa, respectively. A load *P* is applied as shown in the figure below:



If the rigid beam is to remain horizontal, then
(a) the force *P* must be applied at the centre of the beam
(b) the force on the steel rod should be twice the force on the aluminium rod
(c) the force on the aluminium rod should be twice the force on the steel-rod
(d) the forces on both the rods should be equal
[ESE : 2018]

1.21 The resilience of steel can be found by integrating stress-strain curve up to the
(a) ultimate fracture point
(b) upper yield point
(c) lower yield point
(d) elastic point **[ESE : 2018]**

1.22 The loads acting on a 3 mm diameter bar at different points are as shown in the figure:



If *E* = 205 GPa, the total elongation of the bar will be nearly
(a) 29.7 mm (b) 25.6 mm
(c) 21.5 mm (d) 17.4 mm
[ESE : 2019]

1.23 In a propeller shaft, sometimes apart from bending and twisting, end thrust will also develop stresses which would be
(a) tensile in nature and uniform over the cross-section
(b) compressive in nature and uniform over the cross-section
(c) tensile in nature and non-uniform over the cross-section
(d) compressive in nature and non-uniform over the cross-section [ESE : 2019]

1.24 A copper piece originally 305 mm long is pulled in tension with a stress of 276 MPa. If the deformation is entirely elastic and the modulus of elasticity is 110 GPa, the resultant elongation will be nearly
(a) 0.43 mm (b) 0.54 mm
(c) 0.65 mm (d) 0.77 mm
[ESE : 2019]

1.25 A 1.25 cm diameter steel bar is subjected to a load of 2500 kg. The stress induced in the bar will be
(a) 200 MPa (b) 210 MPa
(c) 220 MPa (d) 230 MPa
[ESE : 2020]

1.26 A 13 mm diameter tensile specimen has 50 mm gauge length. If the load corresponding to the 0.2% offset is 6800 kg, the yield stress will be nearly
(a) 31 kg/mm^2 (b) 43 kg/mm^2
(c) 51 kg/mm^2 (d) 63 kg/mm^2
[ESE : 2020]

1.27 The linear relationship between stress and strain for a bar in simple tension or compression is expressed with standard notations by the equation
(a) $\sigma = E\varepsilon$ (b) $\sigma = E\nu$
(c) $\sigma = G\nu$ (d) $\sigma = G\varepsilon$ [ESE : 2020]

1.28 The strain energy per unit volume required to cause the material to rupture is called
(a) modulus of toughness
(b) modulus of rigidity
(c) resilience
(d) proof resilience
[ESE : 2024]

1.29 Which one of the following is the ability of a material to regain its original shape on removal of the applied load?
(a) Proof resilience
(b) Resilience
(c) Modulus of resilience
(d) Gradual resilience [ESE : 2024]

■■■■

Answers Stress and Strain

1.1 (a)	1.2 (b)	1.3 (d)	1.4 (c)	1.5 (d)	1.6 (b)	1.7 (b)	1.8 (b)	1.9 (c)
1.10 (d)	1.11 (d)	1.12 (b)	1.13 (c)	1.14 (c)	1.15 (b)	1.16 (a)	1.17 (d)	1.18 (d)
1.19 (b)	1.20 (c)	1.21 (d)	1.22 (a)	1.23 (b)	1.24 (d)	1.25 (a)	1.26 (c)	1.27 (a)
1.28 (a)	1.29 (b)							

Explanations Stress and Strain

1.1 (a)

No stress will be developed in the direction of thickness i.e. $\sigma_{zz} = 0$.

1.2 (b)

For rigid beam is to remain horizontal

$$(\delta l)_{Cu} = (\delta l)_{St.}$$

$$\frac{F_{Cu} \times 1}{2 \times 100} = \frac{F_{St.} \times 2}{1 \times 200}$$

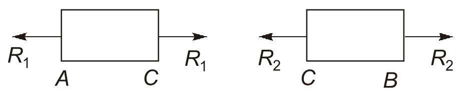
$$\boxed{F_{Cu} = 2F_{St.}}$$

1.3 (d)

$R_A = 120 \times (BC/AB) = 80$ N/mm^2

$R_B = 120 \times AC/AB = 40$ N/mm^2.

Free body diagrams,



$R_1 - R_2 = 120$ ...(i)

and $(\delta l)_1 + (\delta l)_2 = 0$

$$\frac{R_1 \times l}{A \times E} + \frac{R_2 \times 2l}{A \times E} = 0$$

$\therefore\ R_1 = -2R_2$ ...(ii)

From Equation (i) and (ii), we get

$R_2 = -40$ N

$R_2 = 40$ N (opposite direction to our assumption)

and $R_1 = 80$N

1.4 (c)

Equivalent diameter of the bar

$= \sqrt{1.1D \times 0.9\,D} = \sqrt{0.99}\ D$

$$\text{Elongation } (\Delta l_2) = \frac{4F}{E \times \pi \times 0.99\,D^2}$$

$$\text{Elongation due to mean diameter} = \frac{4F}{E \times \pi D^2}$$

$\therefore$ Percentage error,

$$= \frac{\dfrac{4F}{E\pi D^2}\left[\dfrac{1}{0.99} - 1\right]}{\dfrac{4F}{E\pi D^2 \times 0.99}} \times 100\% = \mathbf{1\%}$$

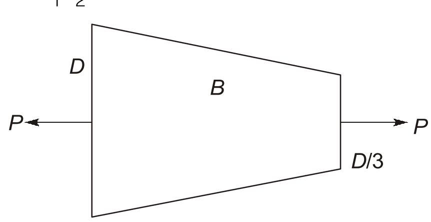
1.5 (d)

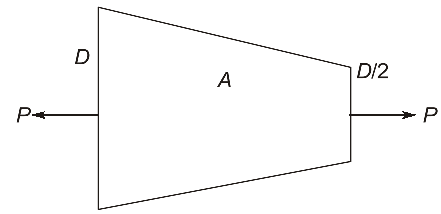
$$\text{Elongation due to self weight} = \frac{\gamma L^2}{2E}$$

1.7 (b)

$$\text{Elongation of taper bar} = \frac{4PL}{E\pi d_1 d_2}$$

$$\delta l \propto \frac{1}{d_1 d_2}$$

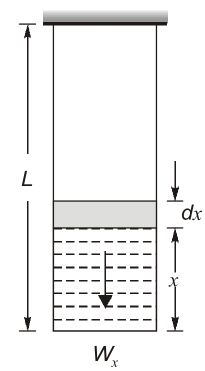




$$\frac{(\delta l)_A}{(\delta l)_B} = \frac{D \times \dfrac{D}{3}}{D \times \dfrac{D}{2}} = \frac{2}{3}$$

1.8 (b)

Deflection of elemental length 'dx'



$$d\Delta = \frac{W_x \cdot dx}{AE}$$

Total deflection

$$\Delta = \int_0^L \frac{W_x \cdot dx}{AE}$$

$$W_x = V_x \cdot \gamma = A \cdot x \cdot \gamma$$

where γ = Weight density of metal

$$\Delta = \int_0^L \frac{\gamma \cdot A \cdot x \cdot dx}{AE} = \frac{\gamma L^2}{2E} = \frac{W}{V} \times \frac{L^2}{2E}$$

$$\Delta = \frac{W}{A \times L} \times \frac{L^2}{2E} = \frac{WL}{2AE}$$

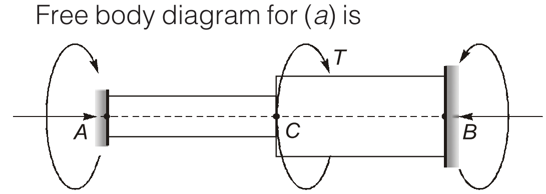
1.9 (c)

Degree of static indeterminacy of a plane structure

$(D_s) = R_e - 3$

where R_e is number of external reactions.

Free body diagram for (a) is



Degree of static indeterminacy for above figure is

In this case

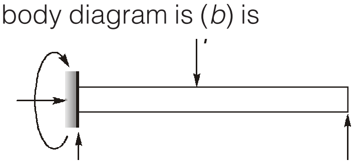
$R_e = 6$

hence $D_s = 6 - 3 = 3$

Since $D_s > 0$

it is statically inderminate structure.

Free body diagram is (b) is



Degree of static indeterminacy for above figure is

In this case

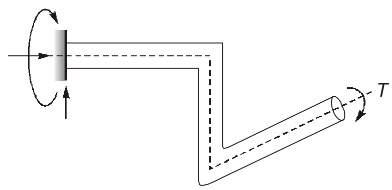
$R_e = 4$

hence $D_s = 4 - 3 = 1$

Since $D_s > 0$

it is statically indierminate structure.

Free body diagram is (*c*) is



Degree of static indeterminacy for above figure is

In this case $R_e = 3$

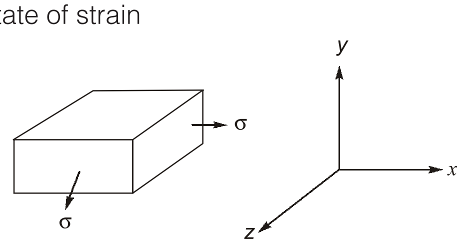
hence $D_s = 3 - 3 = 0$

Since $D_s = 0$

it is not statically inderminate structure.

1.10 (d)

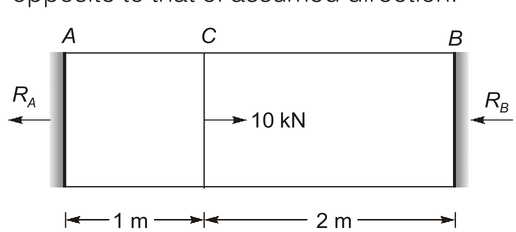
A plane state of stress does not result in a plane state of strain



$$\in_x = \frac{\sigma}{E},\ \in_y = -\frac{\mu\sigma}{E},\ \in_z = -\frac{\mu\sigma}{E}$$

1.12 (b)

Let us consider reaction R_A and R_B at point *A* and *B* in direction opposite to that of 10 kN. We are just assuming the direction. If value of reaction came out to be negative than just take the direction opposite to that of assumed direction.



By using equilibrium condition, we have

$$R_A + R_B = 10 \quad \text{...(i)}$$

By using deflection condition

$$\Delta_{AC} + \Delta_{CB} = 0$$

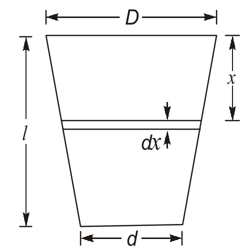
$$\frac{R_A \times 1}{AE} + \frac{(R_A - 10)\times 2}{AE} = 0$$

$$R_A \times 1 + 2R_A - 20 = 0$$

$$R_A = \frac{20}{3}\text{kN}$$

$$\therefore \quad R_B = \frac{10}{3}\text{kN}$$

1.13 (c)



Area of elementary ring $= \pi r^2 = \frac{\pi}{4}d_x^2$

$$d_x = ax + D$$

$$d = al + D$$

$$a = \frac{d - D}{l}$$

Elongation of element $= \left(\frac{\sigma}{E}\right)\times dx$

$$= \frac{P}{AE}dx = \frac{P}{E\frac{\pi}{4}d_x^2}dx$$

Total elongation $= \int_0^l \frac{4P}{\pi E}\frac{dx}{(ax+D)^2}$

$$= \frac{4P}{\pi E}\left[-\frac{1}{ax+D}\times\frac{1}{a}\right]_0^l$$

$$= \frac{4P}{\pi E}\left(-\frac{1}{a}\right)\left[\frac{1}{al+D} - \frac{1}{D}\right]$$

$$= \frac{4P}{\pi E}\left(-\frac{1}{a}\right)\left[\frac{1}{\frac{d-D}{l}l + D} - \frac{1}{D}\right]$$

$$= \frac{4P}{\pi E}\left(-\frac{1}{\frac{d-D}{l}}\right)\left(\frac{D-d}{dD}\right) = \frac{4Pl}{\pi dDE}$$

1.14 (c)

Plane stress condition for thin plates.

Plane strain condition for thick plates.

1.15 (b)

$$\Delta_{total} = \Delta_{AB} = 0.75 \text{ mm}$$

$$\therefore \quad \left(\frac{PL}{AE}\right)_{AB} = 0.75 \text{ mm}$$

(since $\Delta_{BC} = 0$)

where, $L_{AB} = 1000$ mm; $A_{AB} = 1 \text{ cm}^2 = 100 \text{ mm}^2$

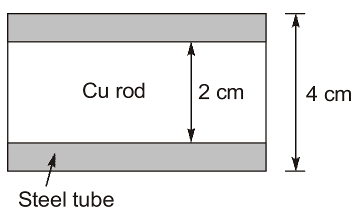
$E = 200 \times 10^3$ MPa

$$\frac{P \times 1000}{100 \times 200 \times 10^3} = 0.75 \text{ mm}$$

$$P = 15000 \text{ N}$$

$$P = 15 \text{ kN}$$

1.16 (a)



Given:

$$\sigma_s = 100 \text{ MPa}$$

$$E_s = 2E_C$$

$$\delta_s = \delta_c$$

$$\frac{P_s L_s}{A_s E_s} = \frac{P_c L_c}{A_c E_c}$$

$$\frac{\sigma_s}{E_s} = \frac{\sigma_c}{E_c} \qquad [\because L_s = L_c]$$

$$\sigma_c = \frac{\sigma_s}{E_s} \times E_c$$

$$\sigma_c = \frac{\sigma_s}{2}$$

$$\sigma_c = \frac{100}{2} = 50 \text{ MPa}$$

1.17 (d)

Since tensile strength of MS is much higher than cast iron, Statement I is wrong. Cast Iron is strong in compression.

Statement II is correct.

1.18 (d)

$$\Delta = \Delta_{PQ} + \Delta_{QR} + \Delta_{RS}$$

$$= \frac{F_{PQ} L_{PQ}}{AE} + \frac{F_{QR} L_{QR}}{AE} + \frac{F_{RS} L_{RS}}{AE}$$

$$= \frac{1}{AE}[(200 \times 0.5) + (-200 \times 1) + (100 \times 0.5)]$$

$$= \frac{100 - 200 + 50}{10 \times 10^{-6} \times 200 \times 10^9} = -25 \times 10^{-6} \text{ m}$$

$$= -25 \ \mu\text{m}$$

1.19 (b)

$$\Delta_s = \Delta_H$$

$$\frac{PL}{A_S . E} = \frac{PL}{A_H . E}$$

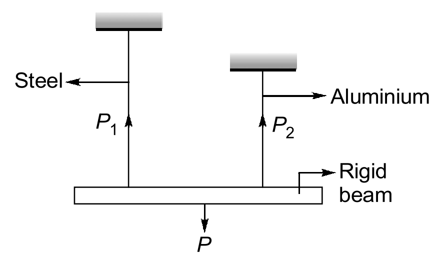
$$\therefore \quad A_S = A_H$$

$$d^2 = D^2 - \left(\frac{D}{2}\right)^2$$

$$d^2 = \frac{3D^2}{4}$$

$$\therefore \quad \frac{d}{D} = \frac{\sqrt{3}}{2}$$

1.20 (c)



If the rigid beam is to remain horizontal

$$(\delta_L)_1 = (\delta_L)_2$$

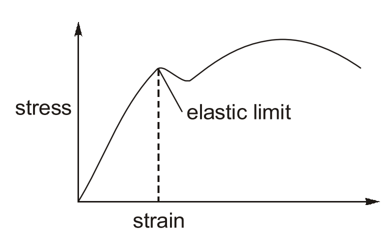
$$\frac{P_1 L_1}{A_1 E_1} = \frac{P_2 L_2}{A_2 E_2}$$

$$\frac{P_1 \times 2000}{100 \times 200 \times 10^3} = \frac{P_2 \times (1000)}{200 \times 100 \times 10^3}$$

$$P_2 = 2P_1 \text{ [i.e. } P_{Al} = 2P_{steel}]$$

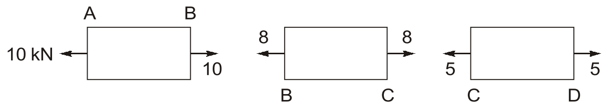
1.21 (d)

The resilience of steel can be found by integrating stress-strain curve upto elastic point.



Resilience involves ability to absorb energy by a material upto elastic limit.

1.22 (a)



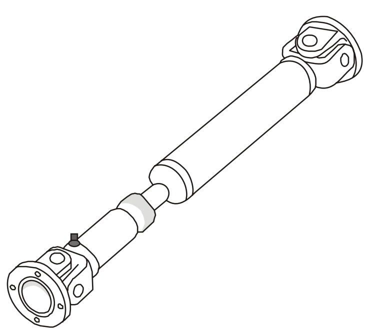
$$\Delta = \Delta_{AB} + \Delta_{BC} + \Delta_{CD}$$

$$= \frac{10\times10^3\times2000}{AE} + \frac{8\times10^3\times1000}{AE} + \frac{5\times10^3\times3000}{AE}$$

$$= \frac{43\times10^6}{AE} = \frac{43\times10^6}{\frac{\pi}{4}\times3^2\times205\times10^3}$$

$$= 29.68 \text{ mm}$$

1.23 (b)



Propeller shaft is under compression due to thrust in X-Y.

1.24 (d)

$$\delta L = \frac{PL}{AE} \text{ or } \frac{\sigma_a L}{E} = \frac{276\times305}{110\times10^3}$$

$$= 0.765 \text{ mm} \simeq 0.77 \text{ mm}$$

1.25 (a)

$$\text{Axial stress, } \sigma = \frac{P}{A} = \frac{2500\times9.81}{\frac{\pi}{4}(12.5)^2} = 200 \text{ MPa}$$

1.26 (c)

$$\text{Yield stress, } \sigma = \frac{\text{Load}}{\text{Artea}} = \frac{6800}{\frac{\pi}{4}\times(13)^2}$$

$$= 51.25 \text{ kg/mm}^2$$

■■■■

2 Stress-strain Relationship and Elastic Constants

2.1 The Poisson ratio of a material which has Young's modulus of 120 GPa and shear modulus of 50 GPa, is

(a) 0.1 (b) 0.2
(c) 0.3 (d) 0.4 **[ESE : 2001]**

2.2 For a given material, the modulus of rigidity is 100 GPa and Poisson's ratio is 0.25. The value of modulus of elasticity in GPa is

(a) 125 (b) 150
(c) 200 (d) 250 **[ESE : 2002]**

2.3 The modulus of elasticity for a material is 200 GN/m^2 and Poisson's ratio is 0.25.
What is the modulus of rigidity?

(a) 80 GN/m^2 (b) 125 GN/m^2
(c) 250 GN/m^2 (d) 320 GN/m^2
[ESE : 2004]

2.4 Which one of the following is correct in respect of Poisson's ratio (μ) limits for an isotropic elastic solid?

(a) $-\infty \le \mu \le \infty$ (b) $\frac{1}{4} \le \mu \le \frac{1}{3}$
(c) $-1 \le \mu \le \frac{1}{2}$ (d) $-\frac{1}{2} \le \mu \le \frac{1}{2}$
[ESE : 2004]

2.5 If *E*, *G* and *K* denote Young's modulus, modulus of rigidity and bulk modulus, respectively, for an elastic material, then which one of the following can be possible true for certain value of Poisson's ratio?

(a) $G = 2K$ (b) $G = E$
(c) $K = E$ (d) $G = K = E$
[ESE : 2005]

2.6 *E*, *G*, *K* and μ represent the elastic modulus, shear modulus, bulk modulus and Poisson's ratio respectively of a linearly elastic, isotropic and homogeneous material. To express the stress-strain relations completely for this material, at least

(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 **[ESE : 2006]**

2.7 If the ratio *G*/*E* (*G* = Rigidity modulus, *E* = Young's modulus of elasticity) is 0.4, then what is the value of the Poisson ratio?

(a) 0.20 (b) 0.25
(c) 0.30 (d) 0.33 **[ESE : 2007]**

2.8 What is the relationship between the linear elastic properties; Young's modulus (*E*), rigidity modulus (*G*) and bulk modulus (*K*)?

(a) $\frac{1}{E} = \frac{9}{K} + \frac{3}{G}$ (b) $\frac{3}{E} = \frac{9}{K} + \frac{1}{G}$
(c) $\frac{9}{E} = \frac{3}{K} + \frac{1}{G}$ (d) $\frac{9}{E} = \frac{1}{K} + \frac{3}{G}$
[ESE : 2008]

2.9 What is the relationship between elastic constants *E*, *G* and *K*?

(a) $E = \frac{KG}{9K+G}$ (b) $E = \frac{9KG}{K+G}$
(c) $E = \frac{9KG}{K+3G}$ (d) $E = \frac{9KG}{3K+G}$
[ESE : 2009]

2.10 A bar produces a lateral strain of magnitude -60×10^{-5}, when subjected to tensile stress of magnitude 300 MPa along the axial direction. What is the elastic modulus of the material, if the Poisson's ratio is 0.3?

(a) 100 GPa (b) 150 GPa
(c) 200 GPa (d) 400 GPa
[ESE : 2009]

2.11 If a piece of material neither expands nor contracts in volume when subjected to stress, then the Poisson's ratio must be

(a) Zero (b) 0.25
(c) 0.33 (d) 0.5 **[ESE : 2011]**

2.12 An elastic material of Young's modulus E and Poisson's ratio ν is subjected to a compressive stress of σ_1 in the longitudinal direction. Suitable lateral compressive stress σ_2 are also applied along the other two lateral directions to limit the net strain in each of the lateral directions to half of the magnitude that would be under σ_1 acting alone. The magnitude of σ_2 is

(a) $\frac{\nu}{2(1+\nu)}\sigma_1$ (b) $\frac{\nu}{2(1-\nu)}\sigma_1$

(c) $\frac{\nu}{(1+\nu)}\sigma_1$ (d) $\frac{\nu}{(1-\nu)}\sigma_1$

[ESE : 2012]

2.13 A copper rod 400 mm long is pulled in tension to a length of 401.2 mm by applying a tensile stress of 330 MPa. If the deformation is entirely elastic, the Young's modulus of copper is

(a) 110 GPa (b) 110 MPa

(c) 11 GPa (d) 11 MPa **[ESE : 2012]**

2.14 Consider the following statements :

Modulus of rigidity and bulk modulus of a material are found to be 60 GPa and 140 GPa respectively. Then

1. Elasticity modulus is nearly 200 GPa
2. Poisson's ratio is nearly 0.3
3. Elasticity modulus is nearly 158 GPa
4. Poisson's ratio is nearly 0.25

Which of these statements are correct?

(a) 1 and 3 (b) 2 and 4

(c) 1 and 4 (d) 2 and 3 **[ESE : 2013]**

2.15 A 16 mm diameter bar elongates by 0.04% under a tensile force of 16 kN. The average decrease in diameter is found to be 0.01%. Then :

1. E = 210 GPa and G = 77 GPA
2. E = 199 GPa and ν = 0.25
3. E = 199 GPa and ν = 0.30
4. E = 199 GPa and G = 80 GPa

Which of these values are correct?

(a) 3 and 4 (b) 2 and 4

(c) 1 and 3 (d) 1 and 4 **[ESE : 2013]**

2.16 The modulus of rigidity and the bulk modulus of a material are found as 70 GPa and 150 GPa respectively. Then

1. Elasticity modulus is 200 GPa
2. Poisson's ratio is 0.22
3. Elasticity modulus is 182 GPa
4. Poisson's ratio is 0.3

Which of the above statement are correct?

(a) 1 and 2 (b) 1 and 4

(c) 2 and 3 (d) 3 and 4 **[ESE : 2014]**

2.17 A tension member of square cross-section of side 10 mm and Young's modulus E is to be replaced by another member of square cross-section of same length but Young's modulus $E/2$. The side of the new square cross-section, required to maintain the same elongation under the same load, is nearly

(a) 14 mm (b) 17 mm

(c) 8 mm (d) 5 mm **[ESE : 2014]**

2.18 A rod of length l tapers uniformly from a diameter D at one end to a diameter $D/2$ at the other end and is subjected to an axial load P. A second rod of length l and of uniform diameter D is subjected to the same axial load P. Both the rods are of same material with Young's modulus of elasticity E. The ratio of extension of the first rod to that of the second rod is

(a) 4 (b) 3

(c) 2 (d) 1 **[ESE : 2014]**

2.19 For a material following Hooke's law, the values of elastic and shear moduli are 3×10^5 MPa and 1.2×10^5 MPa respectively. The value for bulk modulus is

(a) 1.5×10^5 MPa (b) 2×10^5 MPa

(c) 2.5×10^5 MPa (d) 3×10^5 MPa

[ESE : 2015]

2.20 An isotropic elastic material is characterized by

(a) two independent moduli of elasticity along two mutually perpendicular directions

(b) two independent moduli of elasticity along two mutually perpendicular directions and Poisson's ratio

(c) a modulus of elasticity, a modulus of rigidity and Poisson's ratio

(d) any two out of a modulus of elasticity, a modulus of rigidity and Poisson's ratio

[ESE : 2016]

2.21 Measured mechanical properties of material are same in a particular direction at each point. This property of the material is known as

(a) isotropy (b) homogeneity
(c) orthotropy (d) anisotropy

[ESE : 2016]

2.22 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 **[ESE : 2017]**

2.23 A bar produces a lateral strain of magnitude 60×10^{-5} m/m when subjected to a tensile stress of magnitude 300 MPa along the axial direction. What is the elastic modulus of the material if the Poisson's ratio is 0.3?

(a) 200 GPa (b) 150 GPa
(c) 125 GPa (d) 100 GPa

[ESE : 2017]

2.24 Which one of the following statements is correct?

(a) The strain produced per unit volume is called resilience.
(b) The maximum strain produced per unit volume is called proof resilience.
(c) The least strain energy stored in a unit volume is called proof resilience.
(d) The greatest strain energy stored in a unit volume of a material without permanent deformation is called proof resilience.

[ESE : 2017]

2.25 A 10 mm diameter bar of mild steel of elastic modulus 200×10^9 Pa is subjected to a tensile load of 50000 N, taking it just beyond its yield point. The elastic recovery of strain that would occur upon removal of tensile load will be

(a) 1.38×10^{-3} (b) 2.68×10^{-3}
(c) 3.18×10^{-3} (d) 4.62×10^{-3}

[ESE : 2017]

2.26 A rod of copper originally 305 mm long is pulled in tension with a stress of 276 MPa. If the modulus of elasticity is 110 GPa and the deformation is entirely elastic, the resultant elongation will be nearly

(a) 1.0 mm (b) 0.8 mm
(c) 0.6 mm (d) 0.4 mm

[ESE : 2020]

2.27 The maximum energy which can be stored in a body up to the elastic limit is called

(a) Proof resilience
(b) Modulus of resilience
(c) Impact toughness
(d) Endurance strength **[ESE : 2020]**

2.28 A rod of length 2 m and diameter 50 mm is elongated by 5 mm when an axial force of 400 kN is applied. The modulus of elasticity of the material of the rod will be nearly

(a) 66 GPa (b) 72 GPa
(c) 82 GPa (d) 96 GPa

[ESE : 2020]

2.29 Consider the following statements for stress and strain analysis:

1. The stress components on any inclined plane can easily be found with the help of a geometrical construction known as Mohr’s stress circle.
2. The ratio of longitudinal strain to lateral strain is known as Poisson’s ratio.
3. When a body is acted upon by three mutually perpendicular forces, there is change in the volume of the body which is referred to as dilation of the material.
4. The ratio of original volume to increase in volume is known as volumetric strain.

Which of the above statements are correct?

(a) 1 and 3 only (b) 2 and 4 only
(c) 3 and 4 only (d) 1, 2, 3 and 4

[ESE : 2021]

2.30 Consider the following statements related to stress and strain:

1. Shear stress is always tangential to the area over which it acts.
2. Shear stresses on the transverse pair of faces are known as complimentary shear stresses.
3. Shear strain is defined as the change in the right angle to the element measured in radians.

4. Modulus of rigidity is the ratio of shear strain to shear stress.

Which of the above statements are correct?
(a) 1, 3 and 4 only (b) 2 and 4 only
(c) 3 and 4 only (d) 1, 2 and 3 only
[ESE : 2021]

2.31 A material has modulus of rigidity equal to 0.4×10^5 N/mm^2 and bulk modulus equal to 0.75×10^5 N/mm^2. The Poisson's ratio is
(a) 0.2736 (b) 0.1927
(c) 0.3121 (d) 0.4376 [ESE : 2022]

2.32 **Statement (I):** When a material is subjected to a tensile strain, there is a simultaneous shortening of the cross-sectional dimensions perpendicular to the direction of the tensile strain.
Statement (II): The ratio of the shortening strain to the tensile strain is called Poisson's ratio.
(a) Both statement (I) and statement (II) are individually true statement (II) is the corect explanation of statement (I).
(b) Both statement (I) and statement (II) are individually true, but statement (II) is not the corect explanation of statement (I).
(c) Statement (I) is true, but Statement (II) is false.
(d) Statement (I) is false, but Statement (II) is true. [ESE : 2023]

2.33 Which one of the following is defined as the ratio of shearing stress to shearing strain within elastic limit?
(a) Shear modulus (b) Poisson's ratio
(c) Modulus of rigidity (d) Young's modulus
[ESE : 2023]

2.34 The extension of a bar uniformly tapering from a diameter of (d + a) to (d – a) in a length L is calculated by treating it as a bar of uniform cross-section of average diameter d. What is the percentage error?
(a) $25\frac{a^2}{d^2}$ (b) $50\frac{a^2}{d^2}$
(c) $75\frac{a^2}{d^2}$ (d) $100\frac{a^2}{d^2}$ [ESE : 2023]

2.35 A Surveyor's steel tape 30 m long has a cross-section of 15 mm × 0.75 mm. With this, line AB is measured as 150 m. If the force applied during measurement is 120 N more than the force applied at the time of calibration, what is the elongation? (Take modulus of elasticity for steel as 200 kN/mm^2).
(a) 4.400 mm (b) 3.375 mm
(c) 2.125 mm (d) 1.600 mm
[ESE : 2023]

2.36 Consider the following statements regarding principle of superposition:
1. The principle of superposition states that if a body is acted upon by a number of loads on various segments of the body, then the net effect on the body is the sum of the effects caused by each of the loads acting independently on the respective segment of the body.
2. The superposition principle applies to all parameters like stress, strain and deflection.
3. The superposition principle is applicable to materials with non-linear stress-strain characteristic, which do not follow Hooke's law.

Which of the above statements are correct?
(a) 1 and 2 only (b) 1 and 3 only
(c) 2 and 3 only (d) 1, 2 and 3
[ESE : 2024]

2.37 Rails are laid such that they have no stress at 24 °C. What is the stress in the rails at 80 °C, when there is no allowance for expansion? (Assume coefficient of linear expansion = 11×10^{-6} °C^{-1} and Young's modulus of rails metal = 205 GPa)
(a) 126.28 MPa (b) 251.84 MPa
(c) 296.72 MPa (d) 325.35 MPa
[ESE : 2024]

■■■■

Answers Stress-strain Relationship and Elastic Constants

2.1 (b)	2.2 (d)	2.3 (a)	2.4 (b)	2.5 (c)	2.6 (c)	2.7 (b)	2.8 (d)	2.9 (d)
2.10 (b)	2.11 (d)	2.12 (b)	2.13 (a)	2.14 (d)	2.15 (b)	2.16 (d)	2.17 (a)	2.18 (c)
2.19 (b)	2.20 (d)	2.21 (b)	2.22 (b)	2.23 (b)	2.24 (d)	2.25 (c)	2.26 (b)	2.27 (a)
2.28 (c)	2.29 (a)	2.30 (d)	2.31 (a)	2.32 (b)	2.33 (a,c)	2.34 (d)	2.35 (d)	2.36 (a)
2.37 (a)								

Explanations Stress-strain Relationship and Elastic Constants

2.1 (b)

$$E = 2G(1+\mu)$$

$$\Rightarrow \quad 120 = 2\times 50(1+\mu)$$

$$\therefore \quad \mu = \mathbf{0.2}$$

2.2 (d)

$E = 2G(1+\mu)$

$= 2\times 100\times 1.25 =$ **250 GPa**

2.3 (a)

$$E = 2G(1+\mu)$$

$$\therefore \quad G = \frac{200}{2\times 1.25} = 80 \text{ GN/m}^2$$

2.4 (b)

For isotropic material, Poisson ratio, μ = 1/4. However, more recent calculations based upon a model of atomic structure give μ = 1/3. Both of these values are close to actual measured values, which are in the range of 0.25 to 0.35 for many metals and other material. Material with an extremely low value of Poisson's ratio include cork, for which μ is practically zero, and concrete, for which μ is about 0.1 to 0.2. A theoretical upper limit for Poisson's ratio is 0.5. Rubber comes close to this limiting value.

2.5 (c)

The Poisson ratio lies between 0.25 to 0.35. Hence $E = K$ for μ = 0.33

2.6 (c)

$E = 2G(1+\mu)$ ...(i)

$E = 3K(1-2\mu)$ ...(ii)

Here four unknown quantity and only two equation. Hence any two of the four must be known for complete stress relationship.

2.7 (b)

We know that, $E = 2G(1+\mu)$

$$\frac{G}{E} = \frac{1}{2(1+\mu)} = 0.4$$

$$\therefore \quad 1+\mu = 1.25$$

$$\therefore \quad \mu = \mathbf{0.25}$$

2.8 (d)

$E = 2G(1+\mu)$ ... (i)

$E = 3K(1-2\mu)$ ... (ii)

Solving Eq. (i) and (ii)

$$\Rightarrow \quad \frac{E}{2G} - 1 = \frac{1}{2} - \frac{E}{6K}$$

$$\Rightarrow \quad E\left(\frac{1}{2G} + \frac{1}{6K}\right) = \frac{3}{2}$$

$$\Rightarrow \quad E\left(\frac{3K+G}{6KG}\right) = \frac{3}{2}$$

$$\Rightarrow \quad \frac{9}{E} = \frac{3K+G}{KG}$$

$$\therefore \quad \frac{9}{E} = \frac{3}{G} + \frac{1}{K}$$

2.9 (d)

$E = 2G(1+\mu)$ ...(i)

$E = 3K(1-2\mu)$ ...(ii)

Solving Eq. (i) and (ii)

$$\frac{E}{2G} - 1 = \left(1 - \frac{E}{3K}\right)\frac{1}{2}$$

$$\Rightarrow \quad \frac{E}{2G} - 1 = \frac{1}{2} - \frac{E}{6K} \Rightarrow E\left(\frac{1}{2G} + \frac{1}{6K}\right) = \frac{3}{2}$$

$$\Rightarrow \quad E\left(\frac{3K+G}{6KG}\right) = \frac{3}{2}$$

$$\Rightarrow \qquad E = \frac{9KG}{3K+G}$$

2.10 (b)

$$\frac{-\mu\sigma}{E} = \text{Lateral strain}$$

$$\Rightarrow \quad \frac{-0.3\times300\times10^6}{E} = -60\times10^{-5}$$

$$\Rightarrow \quad E = \frac{0.3\times300\times10^6}{60\times10^{-5}}$$

$$= 150\times10^9 \text{ Pa}$$

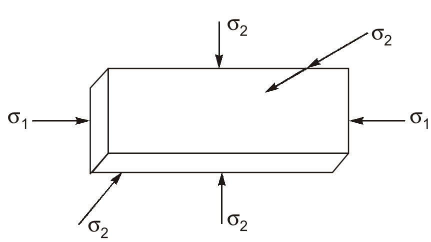
$$= \mathbf{150\ GPa}$$

2.11 (d)

Poisson's Ratio is ratio of lateral strain to the longitudinal strain. It is denoted by μ. When volume change on loading is zero, value of μ is 0.5.

$$\in_v = \frac{(1-2\mu)}{E}(\sigma_x+\sigma_y+\sigma_z)$$

2.12 (b)



Strain in lateral direction

$$\in_1 = \frac{\sigma_2}{E} - \nu\left[\frac{\sigma_1}{E}+\frac{\sigma_2}{E}\right]$$

Strain when σ_1 acting alone

$$\in_2 = -\nu\frac{\sigma_1}{E}$$

Given, $\quad \in_1 = \dfrac{\in_2}{2}$

$$\frac{\sigma_2}{E} - \nu\left[\frac{\sigma_1}{E}+\frac{\sigma_2}{E}\right] = -\frac{\nu\sigma_1}{2E}$$

$$2\frac{\sigma_2}{E} - 2\nu\frac{\sigma_1}{E} - 2\nu\frac{\sigma_2}{E} = -\frac{\nu\sigma_1}{E}$$

$$\frac{\sigma_2}{E}[2-2\nu] = \frac{\sigma_1}{E}[-\nu+2\nu]$$

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

2.13 (a)

$$E = \frac{\sigma}{\in} = \frac{330\times10^6}{1.2/400}$$

$$= 110\times10^9 \text{ Pa} = \mathbf{110\ GPa}$$

2.14 (d)

$G = 60$ GPa; $K = 140$ GPa,

$$E = 2G(1+\nu) = 3K(1-2\nu)$$

$$\therefore \quad 2G(1+\nu) = 3K(1-2\nu)$$

$$\Rightarrow \quad 2\times60(1+\nu) = 420(1-2\nu)$$

$$\Rightarrow \quad 120+120\nu = 420-840\nu$$

$$\text{or} \quad (120+840)\nu = 300$$

$$\therefore \quad \nu = \frac{300}{960} = 0.3125$$

$$E = 2\times60(1+0.3125)$$

$$= \mathbf{157.5\ GPa}$$

2.15 (b)

Poisson's ratio,

$$\mu = -\frac{\text{lateral strain}}{\text{longitudinal strain}}$$

$$= \frac{-(-0.01)}{0.04} = 0.25$$

$$E = \frac{P}{A\in} = \frac{16\times10^3}{\frac{\pi}{4}\times16^2\times0.04\times10^{-2}\times10^{-6}}$$

$$= 198.943\times10^9 = 198.943 \text{ GPa}$$

$$E = 2G(1+\mu)$$

$$G = \frac{198.943}{2\times1.25} = 79.577 \text{ GPa}$$

2.16 (d)

$G = 70$ GPa; $K = 150$ GPa

$$E = 2G(1+\nu) = 3K(1-2\nu)$$

$$\frac{3K}{2G} = \frac{(1+\nu)}{(1-2\nu)}$$

$$\text{or,} \quad \frac{3\times150}{2\times70} = \frac{1+\nu}{1-2\nu}$$

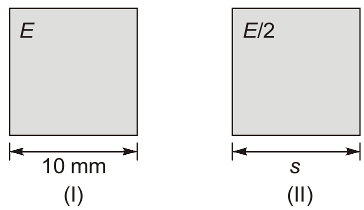
$$\Rightarrow 450-900\nu = 140+140\nu$$

$$\text{or,} \quad \nu = \frac{450-140}{900+140} = 0.298 \text{ or } 0.3$$

$$E = 2G(1+\nu) = 2\times70(1+0.3)$$

$$= \mathbf{182\ GPa}$$

2.17 (a)



$$\delta_I = \delta_{II}$$

or, $\left(\frac{PL}{AE}\right)_I = \left(\frac{PL}{AE}\right)_{II}$

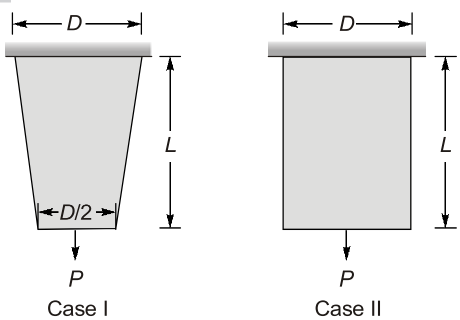
or, $A_I E_I = A_{II} E_{II}$

or, $A_{II} = \frac{E_I}{E_{II}} . A_I = 2 \times 10 \times 10 = 200 \text{ mm}^2$

$s^2 = 200 \text{ mm}^2$

$\Rightarrow$ $s =$ **14.14 mm**

2.18 (c)



$$\delta_1 = \frac{4PL}{\left(\pi D \times \frac{D}{2}\right)E} = \frac{8PL}{(\pi D^2)E}$$

$$\delta_2 = \frac{PL}{AE} = \frac{4PL}{(\pi D^2)E}$$

$$\frac{\delta_1}{\delta_2} = \frac{8}{4} = \mathbf{2}$$

2.19 (b)

$E = 3 \times 10^5$ MPa; $G = 1.2 \times 10^5$ MPa; $K = ?$

$$E = \frac{9KG}{3K+G} = \frac{1}{\frac{1}{3G}+\frac{1}{9K}}$$

$$\frac{1}{3G}+\frac{1}{9K} = \frac{1}{E};$$

$$\frac{1}{9K} = \frac{1}{E}-\frac{1}{3G} = \frac{1}{3\times10^5}-\frac{1}{3\times1.2\times10^5}$$

$$\frac{1}{9K} = \frac{1}{18\times10^5}$$

$K =$ **2 × 10⁵ MPa**

2.20 (d)

Isotropic material is characterized by two independent elastic constant.

2.22 (b)

$G = 0.385\ E$

now $E = 2G(1 + \mu)$

$\therefore$ $\frac{E}{2G} = 1 + \mu$

$\therefore$ $\mu = \frac{E}{2G} - 1 = 0.298$

2.23 (b)

$$\mu = -\frac{\text{lateral strain}}{\text{longitudinal strain}}$$

$\therefore$ Longitudinal strain,

$\in = 200 \times 10^{-5}$

now $\sigma = 300$ MPa

$\therefore$ Elastic modulus,

$$E = \frac{\sigma}{\in} = 150 \text{ GPa}$$

2.24 (d)

Maximum strain energy per unit/volume upto elastic limit is called as modulus of resilence.

2.25 (c)

Since the load is just beyond the elastic limit therefore total strain can be recovered.

$$\therefore \quad \in = \frac{\sigma}{E} = \frac{50000}{\frac{\pi}{4}(0.01)^2 \times 200 \times 10^9}$$

$= \mathbf{3.18 \times 10^{-3}}$

2.26 (b)

Elongation, $\Delta = \frac{PL}{AE} = \frac{\sigma L}{E} = \frac{276\times305}{110\times10^3}$

$= 0.765 \text{ mm} \simeq 0.8 \text{ mm}$

2.27 (a)

The maximum energy which can be stored in a body upto elastic limit, is called proof resilience.

2.28 (c)

Given, $L = 2$ m, $\Delta = 0.005$ m,
$p = 400 \times 103$ N, $d = 0.05$ m