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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

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UNIT

I

Strength of Materials and Engineering Mechanics

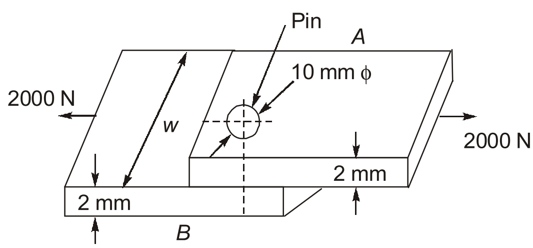
Syllabus

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

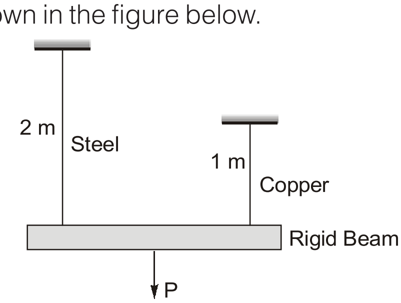
1.1 If permissible stress in plates of joint through a pin as shown in the figure is 200 MPa, then the width w will be



(a) 15 mm (b) 20 mm
(c) 18 mm (d) 25 mm [ESE : 1999]

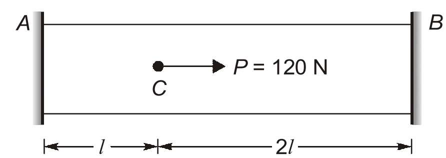
1.2 The state of plane stress in a plate of 100 mm thickness is given as
$\sigma_{xx} = 100$ N/mm^2, $\sigma_{yy} = 200$ N/mm^2
Young's modulus = 300 N/mm^2
Poisson's ratio = 0.3
The stress developed in the direction of thickness is
(a) zero (b) 90 N/mm^2
(c) 100 N/mm^2 (d) 200 N/mm^2
[ESE : 2000]

1.3 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]

1.4 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]

1.5 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]

1.6 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]

1.7 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]

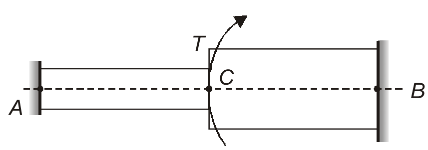
1.8 Two tapering bars of the same material are subjected to a tensile load *P*. The lengths of both the bars are the same. The larger diameter of each of the bars is *D*. The diameter of the bar *A* at its smaller end is *D*/2 and that of the bar *B* is *D*/3. What is the ratio of elongation of the bar *A* to that of the bar *B*?

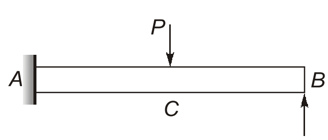
(a) 3 : 2 (b) 2 : 3
(c) 4 : 9 (d) 1 : 3 **[ESE : 2006]**

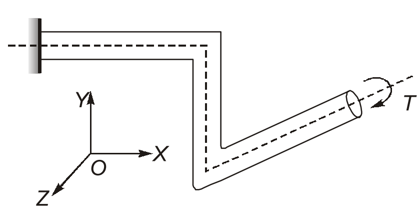
1.9 Which one of the following expresses the total elongation of a bar of length *L* with a constant cross-section of *A* and modulus of elasticity *E* hanging vertically and subject to its own weight *W*?

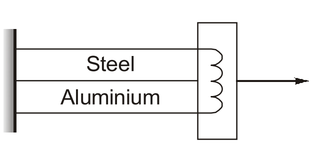
(a) $\frac{WL}{AE}$ (b) $\frac{WL}{2AE}$
(c) $\frac{2WL}{AE}$ (d) $\frac{WL}{4AE}$ **[ESE : 2007]**

1.10 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:

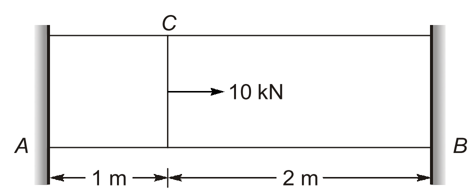
Codes:

(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

1.11 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]**

1.12 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]**

1.13 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]**

1.14 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]**

1.15 Consider the following statements :

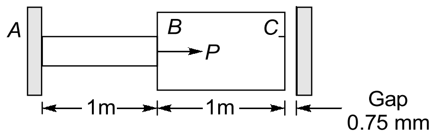
1. State of plane stress occurs at the surface
2. State of plane strain occurs at the surface
3. State of plane stress occurs in the interior part of the plate
4. State of plane strain occurs in the interior part of the plate

Which of these statements are correct?

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

[ESE : 2013]

1.16 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

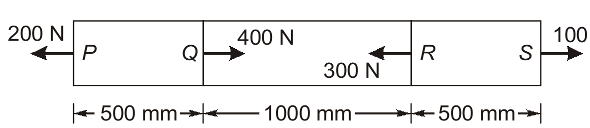


(a) 10 kN (b) 15 kN
(c) 20 kN (d) 25 kN **[ESE : 2013]**

1.17 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]

1.18 **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]**

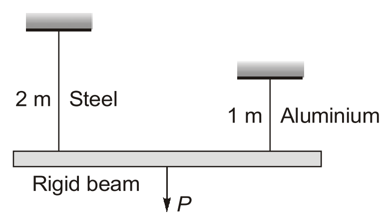
1.19 A steel rod of cross-sectional area 10 mm^2 is subjected to loads at points *P*, *Q*, *R* and *S* as shown in the figure below :



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]

1.20 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]**

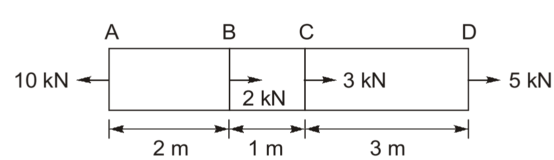
1.21 A rigid beam of negligible weight, is supported in a horizontal position by two rods of steel and aluminium, 2 m and 1 m long, having values of cross-sectional areas 100 mm^2 and 200 mm^2, and Young's modulus of 200 GPa and 100 GPa, respectively. A load *P* is applied as shown in the figure below:



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]

1.22 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]**

1.23 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]

1.24 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]

1.25 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]

1.26 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]

1.27 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]

1.28 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]

■■■■

Answers Stress and Strain

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

Explanations Stress and Strain

1.1 (a)

$$A \times \sigma = F$$

$(W - 10) \times 2 \times 200 = 2000$

$\therefore \quad W - 10 = 5$

$\therefore \quad W = \mathbf{15\ mm}$

1.2 (a)

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

1.3 (b)

For rigid beam is to remain horizontal

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

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

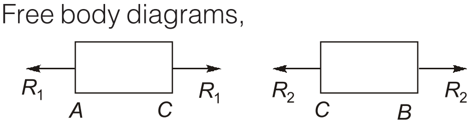
$$\boxed{F_{Cu} = 2F_{St.}}$$

1.4 (d)

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

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

Free body diagrams,



$$R_1 - R_2 = 120 \quad \text{...(i)}$$

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

1.5 (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,

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

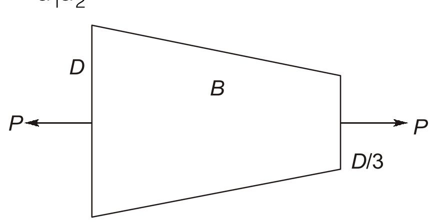
1.6 (d)

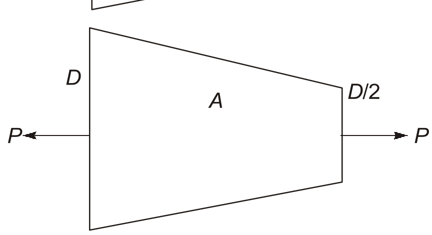
$$\text{Elongation due to self weight} = \frac{\gamma L^2}{2E}$$

1.8 (b)

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

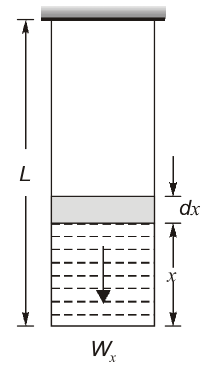
$$\delta l \propto \frac{1}{d_1 d_2}$$





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

1.9 (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

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

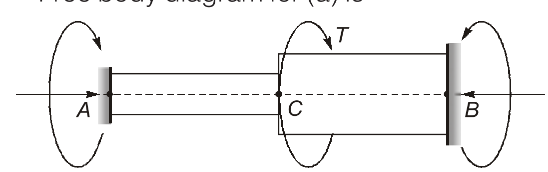
$$\Delta = \frac{W}{A \times L} \times \frac{L^2}{2E} = \frac{WL}{2AE}$$

1.10 (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

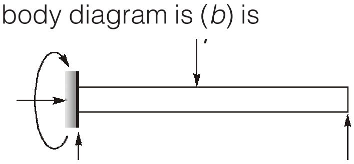
$R_e = 6$

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

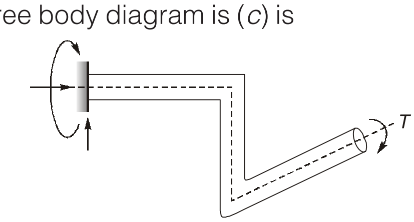
$R_e = 4$

hence $D_s = 4 - 3 = 1$

Since $D_s > 0$

it is statically inderminate structure.

Free body diagram is (c) is



Degree of static indeterminacy for above figure is

In this case $R_e = 3$

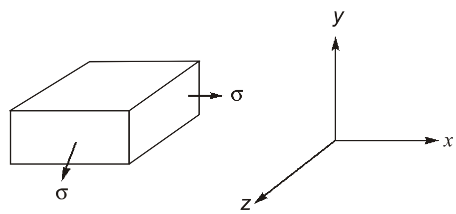
hence $D_s = 3 - 3 = 0$

Since $D_s = 0$

it is not statically inderminate structure.

1.11 (d)

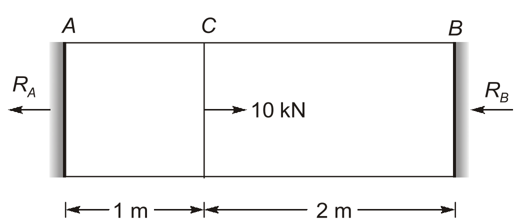
A plane state of stress does not result in a plane state of strain



$$\epsilon_x = \frac{\sigma}{E},\ \epsilon_y = -\frac{\mu\sigma}{E},\ \epsilon_z = -\frac{\mu\sigma}{E}$$

1.13 (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

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

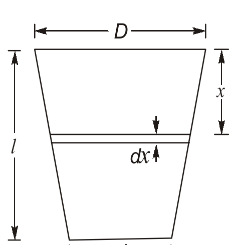
$$\frac{R_A \times 1}{AE} + \frac{(R_A - 10) \times 2}{AE} = 0$$

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

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

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

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

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

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

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

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

1.15 (c)

Plane stress condition for thin plates.

Plane strain condition for thick plates.

1.16 (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; $A_{AB} = 1\ \text{cm}^2 = 100\ \text{mm}^2$

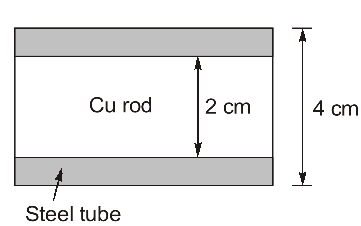
$E = 200 \times 10^3$ MPa

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

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

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

1.17 (a)



Given:

$$\sigma_s = 100 \text{ MPa}$$
$$E_s = 2E_C$$
$$\delta_s = \delta_c$$
$$\frac{P_sL_s}{A_sE_s} = \frac{P_cL_c}{A_cE_c}$$
$$\frac{\sigma_s}{E_s} = \frac{\sigma_c}{E_c} \qquad [\because L_s = L_c]$$
$$\sigma_c = \frac{\sigma_s}{E_s}\times E_c$$
$$\sigma_c = \frac{\sigma_s}{2}$$
$$\sigma_c = \frac{100}{2} = 50 \text{ MPa}$$

1.18 (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.

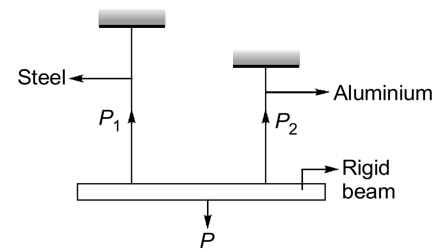
1.19 (d)

$$\Delta = \Delta_{PQ} + \Delta_{QR} + \Delta_{RS}$$
$$= \frac{F_{PQ}L_{PQ}}{AE} + \frac{F_{QR}L_{QR}}{AE} + \frac{F_{RS}L_{RS}}{AE}$$
$$= \frac{1}{AE}[(200\times 0.5) + (-200\times 1) + (100\times 0.5)]$$
$$= \frac{100 - 200 + 50}{10\times 10^{-6}\times 200\times 10^{9}} = -25\times 10^{-6} \text{ m}$$
$$= \mathbf{-25\ \mu m}$$

1.20 (b)

$$\Delta_s = \Delta_H$$
$$\frac{PL}{A_S.E} = \frac{PL}{A_H.E}$$
$$\therefore \quad A_S = A_H$$
$$d^2 = D^2 - \left(\frac{D}{2}\right)^2$$
$$d^2 = \frac{3D^2}{4}$$
$$\therefore \quad \frac{d}{D} = \frac{\sqrt{3}}{2}$$

1.21 (c)

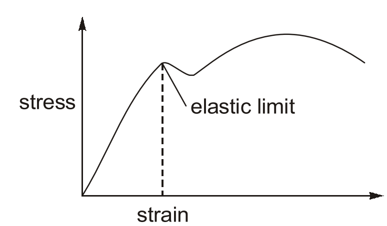


If the rigid beam is to remain horizontal

$$(\delta_L)_1 = (\delta_L)_2$$
$$\frac{P_1L_1}{A_1E_1} = \frac{P_2L_2}{A_2E_2}$$
$$\frac{P_1\times 2000}{100\times 200\times 10^3} = \frac{P_2\times(1000)}{200\times 100\times 10^3}$$
$$P_2 = 2P_1 \text{ [i.e. } P_{Al} = 2P_{steel}]$$

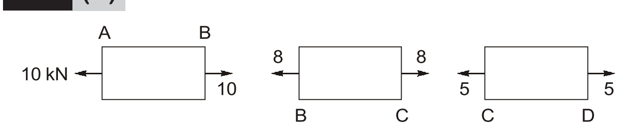
1.22 (d)

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



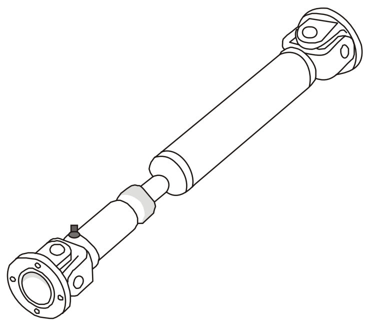
Resilience involves ability to absorb energy by a material upto elastic limit.

1.23 (a)



$$\Delta = \Delta_{AB} + \Delta_{BC} + \Delta_{CD}$$
$$= \frac{10\times 10^3\times 2000}{AE} + \frac{8\times 10^3\times 1000}{AE} + \frac{5\times 10^3\times 3000}{AE}$$
$$= \frac{43\times 10^6}{AE} = \frac{43\times 10^6}{\frac{\pi}{4}\times 3^2\times 205\times 10^3}$$
$$= 29.68 \text{ mm}$$

1.24 (b)



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

1.25 (d)

$$\delta L = \frac{PL}{AE} \text{ or } \frac{\sigma_a L}{E} = \frac{276\times 305}{110\times 10^3}$$
$$= 0.765 \text{ mm} \simeq 0.77 \text{ mm}$$

1.26 (a)

$$\text{Axial stress, } \sigma = \frac{P}{A} = \frac{2500\times 9.81}{\frac{\pi}{4}(12.5)^2} = 200 \text{ MPa}$$

1.27 (c)

$$\text{Yield stress, } \sigma = \frac{\text{Load}}{\text{Artea}} = \frac{6800}{\frac{\pi}{4}\times(13)^2}$$
$$= 51.25 \text{ kg/mm}^2$$

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