IAS & IFS

(Objective & Conventional)
Previous Solved Questions

Strength of Materials

Previous 35 Years Solved Questions of
Civil & Mechanical Engineering

Useful for ESE, CSE, State Engg. Services, PSUs
and Other Competitive Examinations

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IAS & IFS (Objective & Conventional) Previous Solved Questions : Strength of Materials

First Edition: 2015
Reprint : 2017
Second Edition (Revised) : 2018

Reprint : 2022

Preface

I am thankful to **Mr. B. Singh, CMD of MADE EASY Group**, who is ever ready to help the Student Community by providing them newest type of books, as in the present book with typical/ thought provoking/mind racking questions asked in IFS and IAS. Prelims and Mains of UPSC, for the last 35 years for both Civil and Mechanical Engineering, in the subject of Strength of Materials. For the solution of each question a student must be equipped with strong concepts in the subject, and the students are the beneficiaries of the latest and comprehensive knowledge of the subject of the qualified and dedicated faculty of MADE EASY.

In the present form, the book has been thoroughly revised and enlarged including the question of IAS and IFS.

Further improvements in the text of the book will be made after getting the feedback from the students.

Any error in printing or calculations pointed out by the reader will be acknowledged with thanks by the author.

Dr. U.C. Jindal

Author

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IAS & IFS (Objective & Conventional) Previous Solved Questions

Strength of Materials

01 Chapter
Simple Stresses in Uniform and Compound Bars

Q.1.1 A steel rod of length 300 mm and diameter 30 mm is subjected to a pull P, and the temperature rise is 100°C. If the total extension of the rod is 0.40 mm, calculate the magnitude of P. Take α for steel = 12×10^{-6}/°C and $E = 0.215 \times 10^6$ N/mm^2.

[CSE-Mains, 2011, CE : 12 Marks]

Solution:

$$P = \text{Pull in N}$$

$$A = \text{Area of cross-section} = \frac{\pi}{4} \times 30^2 = 706.86 \text{ mm}^2$$

Extension due to pull, (assuming pull axial)

$$\delta l_1 = \frac{P}{AE} \times L = \frac{P \times 300}{706.86 \times 0.215 \times 10^6} = 1.974 \times 10^{-6} P \text{ mm}$$

δl_2 extension due to temperature change

$$= \alpha L \Delta T$$

$$= 12 \times 10^{-6} \times 300 \times 100 = 0.36$$

$$0.36 + 1.974 \times 10^{-6} P = 0.4 \quad \text{total extension}$$

$$1.974 \times 10^{-6} P = 0.04$$

$$P = \frac{0.04 \times 10^6}{1.974} = 20263 \text{ N} = 20.263 \text{ kN}$$

Q.1.2 A metallic bar 250 mm × 100 mm × 50 mm is loaded as shown in the figure 1.1. Work out the change in volume. What should be the change that should be made in the 4 MN load in order that there should be no change in the volume of the bar.

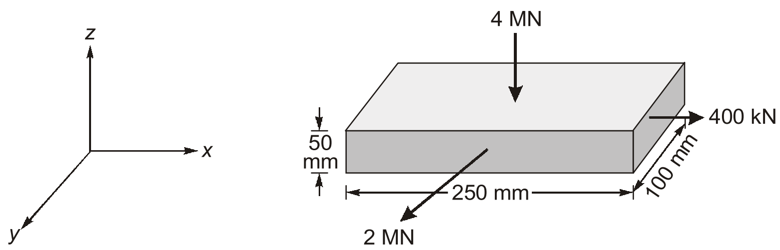


Fig. 1.1

Assume $E = 2 \times 10^5$ N/mm^2, Poisson's ratio = 0.25.

[IFS 2011, CE : 15 Marks]

Solution:

Stresses
$$\sigma_x = +\frac{400{,}000}{5000} = +80 \text{ MPa}$$
$$\sigma_y = +\frac{2\times10^6}{50\times250} = +160 \text{ MPa}$$
$$\sigma_z = -\frac{4\times10^6}{250\times100} = -160 \text{ MPa}$$

Volumetric strain,
$$\varepsilon_v = \frac{\sigma_x+\sigma_y+\sigma_z}{E} - 2\nu\left(\frac{\sigma_x+\sigma_y+\sigma_z}{E}\right)$$
$$= \frac{80}{E} - 2\times0.25\times\frac{80}{E} = \frac{40}{E}$$
$$\text{Volume} = 250\times100\times50 \text{ mm}^3$$
$$\delta V = \text{change in volume} = \varepsilon_v\times V = \frac{40}{E}\times250\times100\times50$$
$$= \frac{50\times10^6}{E} = \frac{50\times10^6}{2\times10^5} = 250 \text{ mm}^3$$

(b) For
$$\varepsilon_v = 0$$
$$\sigma_x+\sigma_y+\sigma_z-2\nu(\sigma_x+\sigma_y+\sigma_z) = 0$$
$$(\sigma_x+\sigma_y)(1-2\nu) = 2\nu(\sigma_z)-\sigma_z$$
$$(80+160)(1-2\nu) = (2\nu-1)\sigma_z$$
$$240\times0.5 = (2\nu-1) = -0.5\,\sigma_z$$
$$120 = -\sigma_z\times0.5$$
$$\sigma_z = -240 \text{ MPa}$$

where in load,
$$P_y' = 240\times250\times100 = 6 \text{ MN}$$

4 MN load should be increased to 6 MN load in same direction

So that σ_z becomes -240 N/mm^2.

Q.1.3 A crane chain having an area 7.25 cm^2 carries a load of 15 kN. It is being lowered at a uniform speed of 50 m/minute, the chain gets jammed suddenly, at that time the length of chain unwound is 12 m. Estimate the stress induced in the chain due to sudden stoppage. Neglect weight of the chain. Assume $E = 2.1\times10^5$ N/mm^2.

[IFS 2012, CE : 10 Marks]

Solution:

$$W = 15 \text{ kN} = 15000 \text{ N} \quad (\because \text{self weight of chain negligible})$$
$$A,\ \text{chain area of cross-section} = 725 \text{ mm}^2$$

Length,
$$L = 12000 \text{ mm}$$
$$\text{Volume of chain} = 12000\times725 = 87\times10^5 \text{ mm}^3$$
$$\text{Say, stress developed} = \sigma_i,\ \text{instantaneous in N/mm}^2$$

Speed,
$$V = \frac{50}{60} = 0.833 \text{ m/s}$$

$$\text{Kinetic energy absorbed by chain} = \frac{mV^2}{2} = \frac{15000}{9.81}\times\frac{0.833^2}{2} = 530.5 \text{ Nm} = 530500 \text{ Nmm}$$

Change in length, $\delta L = \dfrac{\sigma_i}{E} \times l = \dfrac{\sigma_i \times 12000}{E}$

Change in potential energy $= W\delta l$

$$= \frac{15000 \times \sigma_i \times 12000}{2.1 \times 10^5} \text{ Nmm } = 857.143\, \sigma_i \text{ Nmm}$$

Total strain energy absorbed by chain $= 530500 + 857.143\, \sigma_i = \dfrac{\sigma_i^2}{2E}$ volume

$$530500 + 857.14\, \sigma_i = \frac{\sigma_i^2}{2 \times 2.1 \times 10^5} \times 87 \times 10^5 = 20.7143\, \sigma_i^2$$

or $\sigma_i^2 - 41.38\sigma_i - 25610.3 = 0$

$$\sigma_i = \frac{41.38 + \sqrt{41.38^2 + 4 \times 25610.3}}{2}$$

$$= \frac{41.38 + \sqrt{1712.30 + 102441.2}}{2}$$

$$= \frac{41.38 + 322.728}{2}$$

$$= 182.054 \text{ N/mm}^2$$

Q.1.4 Prove that Poisson's ratio cannot be greater than 0.5.

[CSE-Mains, 1988, ME : 15 Marks]

Solution:

Figure shows a sphere under uniform hydrostatic pressure p.

If E = Young's modulus and ν is Poisson's ratio, ν, then

Volumetric strain, $\varepsilon_v = \dfrac{3p}{E}(1 - 2\nu) = 0$

or ν, Poisson's ratio $= 0.5$

If ν is greater than 0.5, then in place of decrease in volume there will be increase in volume, which is not possible.

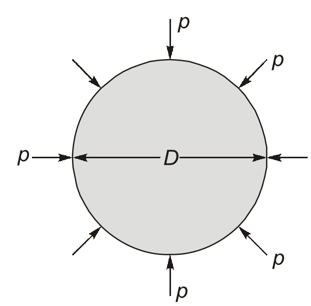


Fig. 1.2

Q.1.5 A 1000 mm long bar is subjected to an axial pull P which induces a maximum stress of 1500 kg/cm^2. The area of cross-section of the bar is 2 cm^2 over a length of 950 mm and for the central 50 mm length, the sectional area is equal to 1 cm^2.

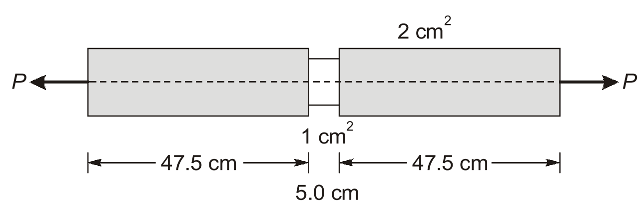


Fig. 1.3

Assuming that E for bar material is 20×10^5 kgf/cm^2, calculate strain energy stored in bar

[CSE-Mains, 1990, ME : 20 Marks]

Solution:

Maximum stress will occur in central portion of area 1 cm^2,

$$= 1500 \text{ kgf/cm}^2$$

$$\text{Stress in other portion} = \frac{1500 \times 1}{2} = 750 \text{ kgf/cm}^2$$

$$U\text{, strain energy} = \frac{1500^2}{2E} \times 5 \times 1 + \frac{750^2}{2E} \times 47.5 \times 2$$

$$= \frac{5625 \times 10^3}{E} + \frac{26718.75 \times 10^3}{E}$$

$$= \frac{32343750}{E} = \frac{32343750}{20 \times 10^5}$$

$$= 16.17 \text{ kgf-cm (Strain energy stored)}$$

Q.1.6 A steel rod of square cross-section is loaded as shown in the figure 1.4.

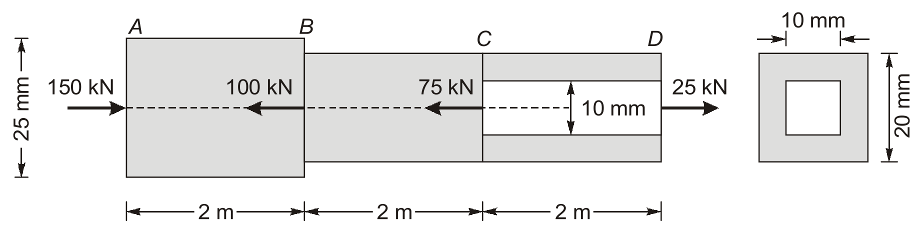


Fig. 1.4

Find the section which is subjected to maximum stress, its magnitude and nature. What will be the change in its length? Take E = 200 GPa.

Solution:

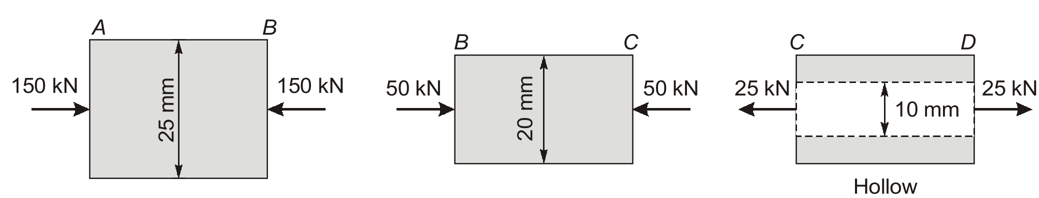


Fig.1.5

Considering compressive stress as (–ve) and vice-versa

$$\sigma_{AB} = -\frac{150{,}000}{625} = -240 \text{ MPa (square section)}$$

$$\sigma_{BC} = -\frac{50{,}000}{400} = -125 \text{ MPa}$$

$$\sigma_{CD} = +\frac{25000}{400-100} = +83.33 \text{ MPa}$$

$$\sigma_{max} = -240 \text{ MPa} \quad \text{(in portion } AB\text{)}$$

$$\text{Change in length} = -\frac{240}{200{,}000} \times 2000 - \frac{125 \times 2000}{200{,}000} + \frac{83.33 \times 2000}{200{,}000}$$

$$= -2.4 - 1.25 + 0.833 = -2.817 \text{ mm (contraction)}$$

Q.1.7 A rigid bar *AD* is pinned at *A* and attached to the bars *BC* and *ED* as shown in figure 1.6. The entire system is initially stress free and weight of all bars are negligible. The temperature of the bar *BC* is lowered by 25°C and that of bar *ED* is raised by 25°C. Neglecting any possibility of lateral buckling, find the normal stress in bars *BC* and *ED*.
For *BC*, of brass, E = 90 GPa, $\alpha = 20 \times 10^{-6}$/°C
For *ED*, of steel, E = 200 GPa and $\alpha = 12 \times 10^{-6}$/°C
Cross-sectional area of *BC* is 500 mm^2 and that of *ED* is 250 mm^2.

[IFS 2011, CE : 10 Marks]

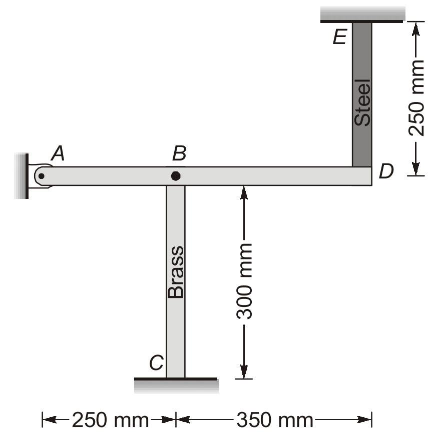


Fig. 1.6

Solution:

Free expansion in steel bar (if there were no resultant)

$$\delta l_S = 250 \times 12 \times 10^{-6} \times 25 = 0.075 \text{ mm}$$

Free contraction in brass bar, $\delta l_B = 300 \times 20 \times 10^{-6} \times 25 = 0.15$ mm

If brass bar is free to move down, then end D would move by

$$0.15 \times \frac{600}{250} = 0.36 \text{ mm}$$

($\because$ *ABD* is rigid, vertical deflection in *ABD* will be linearly proportional to distance from *A*)

But free expansion in steel bar is only 0.075 mm.

Therefore steel bar will be pulled down and brass bar will be pulled up, or stretched to prevent, free contraction

Say

$$\sigma_S = \text{Stress in steel bar}$$
$$\sigma_B = \text{Stress in brass bar}$$
$$P_S = \text{Force in steel bar} = \sigma_S \times 250 \text{ N}$$
$$P_B = \text{Force in brass bar} = \sigma_B \times 500 \text{ N}$$

Taking moments about B

$$600 \times P_S = 250 P_B$$
$$600 \times \sigma_S \times 250 = 250 \times 500 \times \sigma_B$$
$$150000\sigma_S = 125000\sigma_B$$
$$\sigma_S = 0.833\sigma_B$$

or

$$\sigma_B = 1.2\sigma_S \quad \ldots(i)$$

Brass bar

$$\text{Final contraction} = 0.15 - \frac{\sigma_B}{E_B} \times 300 = \delta l_B'$$

Steel bar

$$\text{Final extension} = 0.075 + \frac{\sigma_S}{E_S} \times 250 = \delta l_S'$$

But

$$\delta l_S' = \frac{600}{250} \times \delta l_B' = 2.4\ \delta l_B'$$

Putting the value

$$0.075 + \frac{\sigma_S}{E_S} \times 250 = 2.4\left[0.15 - \frac{\sigma_B}{E_B} \times 300\right]$$

$$0.075 + \frac{\sigma_S}{200{,}000} \times 250 = 0.36 - \frac{1.2\sigma_S}{90{,}000} \times 720$$

$$\sigma_S \times 1.25 \times 10^{-3} + \sigma_S \times 9.6 \times 10^{-3} = 0.285$$
$$\sigma_S[10.85] = 285$$
$$\sigma_S = 26.26 \text{ N/mm}^2 \text{ (tensile)}$$
$$\sigma_B = 31.52 \text{ N/mm}^2 \text{ (tensile)}$$

Checking

$$\text{Steel bar, total extension} = 0.075 + 0.032825 = 0.107825 = \delta l_S'$$
$$\text{Brass bar, final contraction} = 0.15 - \frac{31.52}{90{,}000} \times 300 = 0.15 - 0.105066$$
$$\delta l_B' = 0.04493$$
$$\delta l_B' \times 2.4 = 0.10784 \simeq \delta l_S'$$

Q.1.8 A plate is riveted to a channel section in a structure as shown in figure 1.7. An eccentric load of 12.5 kN acts as shown on the plate. Determine the rivet diameter so that the maximum shear stress in any rivet is not to exceed 40 MPa. Diameter of the rivet should be chosen from preferred series diameter (in mm)
r = 141.4 mm, r^2 = 20000 mm^2
12, 14, 16, 18, 20, 22, 24, 27, 30, 33, 36, 39, 42, 48 rivet diameter
[CSE-Mains, 2009, ME : 40 Marks]

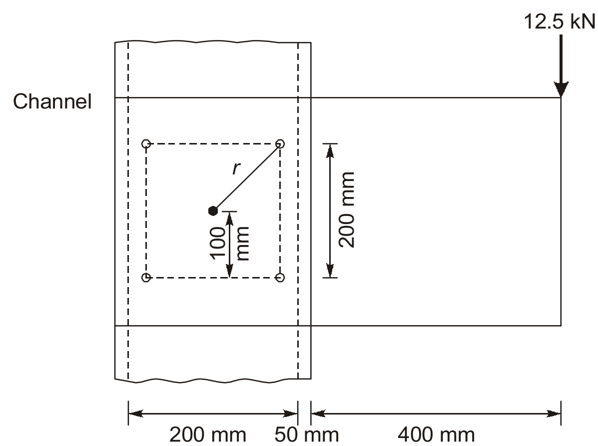


Fig. 1.7

Solution:

$$\text{Number of rivets} = 5$$
$$\text{Load} = 12.5 \text{ kN}$$
$$\text{Direct shear load on each rivet} = \frac{12.5}{5} = 2.5 \text{ kN}$$

If $\quad A$ = Area of rivet

$$\tau_d = \frac{2500}{A} \text{ N/mm}^2$$
$$\text{Torsional shear stress, } \tau_S \propto r$$
$$\text{Torsional shear force} = krA$$
$$4\,kA\,(r^2) = \text{P.e.} = 12500 \times (100 + 50 + 400)$$
$$4\text{ kA }(20000) = 12500 \times 550 \text{ Nmm}$$
$$kA = \frac{12500 \times 550}{80000} = 85.9375$$
$$k = \frac{85.9375}{A}$$

Torsional shear stress

$$\tau_s\text{, in outer rivets} = kr = \frac{85.9375 \times 141.4}{A} = \frac{12151.5625}{A}$$
$$\tau_d = \frac{2500}{A}$$
$$\tau_r = \sqrt{(\tau_S \times \sin 45° + \tau_d)^2 + (\tau_S \times \cos 45°)^2}$$

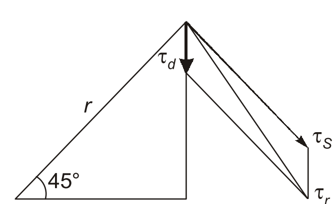


Fig. 1.8

$$= \sqrt{\left(\frac{12151.5625}{A}\times 0.707+\frac{2500}{A}\right)^2+\left(\frac{12151.5625}{A}\times 0.707\right)^2}$$

$$= \sqrt{\left(\frac{11091.15}{A}\right)^2+\left(\frac{8591.15}{A}\right)^2}$$

$$= \frac{1000}{A}\sqrt{123.01+73.80} = \frac{1000\times 14.03}{A}$$

$$\frac{14030}{A} = 40 \text{ MPa (permissible shear stress)}$$

$$A = 350.073 \text{ mm}^2 = \frac{\pi}{4}d^2$$

$$d = 21.11 \text{ mm}$$

Rivet diameter from preferred series = 22 mm.

Q.1.9 A compound tube is made by shrinking a thin steel tube on a thin brass tube. The areas of cross-section of these tubes are A_s and A_b, while the Young's moduli are E_s and E_b respectively. Show that for any tensile load, the extension of the compound tube is equal to that of a single tube of same length and total cross-section area, but having a Young's modulus of $\dfrac{E_sA_s + E_bA_b}{A_s + A_b}$.

[CSE-Mains, 2005, ME : 20 Marks]

Solution:

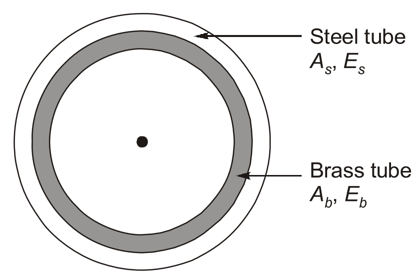


Fig.1.9

Say
$$P = \text{axial load}$$
$$= \sigma_s A_s + \sigma_b A_b$$

But
$$\delta l_s = \delta l_b$$
$$\frac{\sigma_s}{E_s} l = \frac{\sigma_b}{E_s}\times L$$
$$\frac{\sigma_s}{\sigma_b} = \frac{E_s}{E_b}$$
$$P = \sigma_b \times \frac{E_s}{E_b}\times A_s \times \sigma_b \times A_b = \sigma_b\left[\frac{E_s}{E_b}A_s + A_b\right]$$
$$P = \sigma_b\left[\frac{E_sA_s + A_bE_b}{E_b}\right] = \frac{\sigma_b}{E_b}[E_sA_s + A_bE_b] \quad \text{...(i)}$$
$$\delta l_b = \delta l_s$$
$$\delta l_b = \frac{\sigma_b}{E_b}\times l$$
$$\frac{\delta l_b}{l} = \frac{\sigma_b}{E_b}$$

Strain,
$$\varepsilon_b = \frac{P}{E_sA_s + E_bA_b} \quad \text{(From eq. (i)}$$

(For single bar having modulus of elasticity E)

$$\varepsilon = \frac{P}{(A_s + A_b)}\times\frac{1}{E}$$

or
$$\frac{P}{E_sA_s + E_bA_b} = \frac{P}{E(A_s + A_b)}$$

or
$$E = \frac{E_sA_s + E_bA_b}{A_s + A_b}, \text{ for a single bar}$$

Q.1.10 A copper tube 22 mm internal diameter, 30 mm outer diameter and 150 mm long is compressed by a nut tightening over a steel bolt, 20 mm diameter and 1 mm pitch. (i) If the nut is tightened by a quarter of a turn beyond the just touching position, determine the stress in the bolt. (ii) what would be the final stress in the bolt if the temperature of the assembly is to increase by 10°C. Assume $E_s = 2 \times 10^6$ kg/cm^2, $E_{cu} = 6 \times 10^5$ kg/cm^2, $\alpha_s = 12 \times 10^{-6}$/°C, $\alpha_{cu} = 18 \times 10^{-6}$/°C.

[CSE-Mains, 1999, ME : 30 Marks]

Solution:

$$A_s \text{ area of cross-section of bolt} = \frac{\pi}{4} \times 20^2 = 100\pi \text{ mm}^2$$

A_{cu}, area of cross-section of copper tube

$$= \frac{\pi}{4}\left(30^2 - 22^2\right) = 104\pi$$

(i) For equilibrium, compressive force in tube = Tensile force in bolt

$$\sigma_{cu} \times A_{cu} = \sigma_s \times A_s$$
$$\sigma_{cu} \times 104\pi = \sigma_s \times 100\pi$$
$$\sigma_s = 1.04\, \sigma_{cu} \quad \text{...(i)}$$

Due to tightening of nut as bolt

$$\text{Pitch} = 1 \text{ mm}$$
$$0.25 \text{ mm} = \frac{1}{4}\text{mm} = \text{Extension of bolt} + \text{Contraction in tube}$$
$$0.25 \text{ mm} = \frac{\sigma_s}{E_s} \times 150 + \frac{\sigma_{cu}}{E_{cu}} \times 150$$
$$\frac{0.25}{150} = \frac{\sigma_s}{E_s} + \frac{\sigma_{cu}}{E_{cu}} = \frac{1.04\sigma_{cu}}{2 \times 10^4} + \frac{\sigma_{cu}}{6 \times 10^3}, \text{(here } \sigma_s \text{ and } \sigma_{cu} \text{ are in kg/mm}^2\text{)}$$
$$\frac{0.25 \times 10^3}{150} = \frac{1.04\sigma_{cu}}{20} + \frac{\sigma_{cu}}{6}$$
$$1.6667 = 0.052\, \sigma_{cu} + 0.1666\, \sigma_{cu} = 0.21866\, \sigma_{cu}$$
$$\sigma_{cu} = -7.622 \text{ kg/mm}^2 \text{ (comp.)}$$
$$\sigma_s = +7.927 \text{ kg/mm}^2 \text{ (tensile)}$$

or
$$\sigma_{cu} = -762.2 \text{ kg/cm}^2 \text{ (comp.)}$$
$$\sigma_s = +792.7 \text{ kg/cm}^2 \text{ (comp.)}$$

(ii) Increase in temperature

$$\alpha_{cu} > \alpha_s$$
$$\Delta T = 10°\text{C}$$

Compressive stress will be developed in copper tube due to temperature rate and tensile stress will be developed in stress bolt

$$\text{Strain in copper tube} = \text{Strain in steel bolt}$$

Hence,
$$\alpha_{cu}\Delta T - \frac{\sigma_{cuT}}{E} = \alpha_s\Delta T - \frac{\sigma_{sT}}{E}$$

or $$\frac{\sigma_{cuT}}{E_{cu}} + \frac{\sigma_{sT}}{E_s} = (\alpha_{cu} - \alpha_s)\,\Delta T$$

$$\frac{\sigma_{cuT}}{2\times 10^6} + \frac{\sigma_{sT}}{6\times 10^5} = (18-12)\times 10^{-6}\times 10$$ (here σ_{sT} and σ_{cuT} are in kg/cm^2)

$$\frac{\sigma_{cuT}}{20} + \frac{\sigma_{sT}}{6} = 6\times 10^{-6}\times 10^5\times 10 = 6$$

But $$\sigma_{cuT}\times 104\pi = \sigma_{sT}\times 100\pi$$

$$\sigma_{sT} = 1.04\,\sigma_{cuT}$$

$$\frac{\sigma_{cuT}}{20} + \frac{1.04\sigma_{cuT}}{6} = 6$$

$$\sigma_{cuT}[0.05 + 0.1733] = 6$$

$$\sigma_{cuT} = -26.866 \text{ kg/cm}^2 \text{ (comp.)}$$

$$\sigma_{sT} = +27.94 \text{ kg/cm}^2 \text{ (tensile)}$$

Final stress in steel bolt $$\sigma_{sT} = 792.7 + 27.94 = 820.64 \text{ kg/cm}^2 \text{ (tensile)}$$

Q.1.11 Three steel bars A, B and C having the same axial rigidity EA support a rigid beam ABC in figure. Determine the distance 'a' between bars A and B in order that the rigid beam will remain horizontal when a load 'F' is applied at its mid point. The value of length is given within the parenthesis.

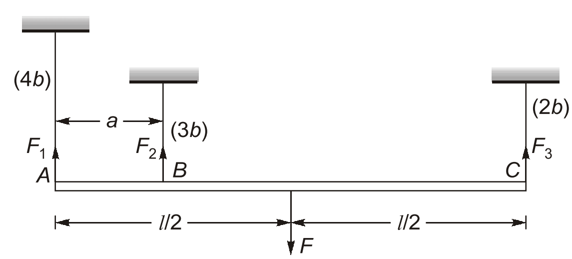


Fig.1.10

[IFS 2015, CE : 8 Marks]

Solution:

Rigid bar is to remain horizontal, extension in three bars will be the same. Say forces in 3 bars are F_1, F_2, F_3 respectively, so

$$\frac{F_1\times 4b}{AE} = \frac{F_2\times 3b}{AE} = \frac{F_3\times 2b}{AE} \quad \text{...(i)}$$

or $$F_2 = \frac{y}{3}F_1 \quad \text{...(ii)}$$

$$F_3 = 2F_1 \quad \text{...(iii)}$$

Taking moment about A

$$F_2\times a = \frac{Fl}{2} \quad \text{...(iv)}$$

Taking moment about C

$$F_1\times l + F_2(l - a) = \frac{Fl}{2} \quad \text{...(v)}$$

or $$F_2 a + F_3 l = F_1 k + F_2(l - a)$$

or $$F_3 l = F_1 l + F_2(l - 2a) \quad \text{...(vi)}$$

Putting the values of F_2 and F_3 in terms of F_1

$$2F_1l = F_1 \times l + \frac{4}{3}F_1(l - 2a)$$

or

$$2l = l + \frac{4}{3}l - \frac{8a}{3}$$

$$-\frac{l}{3} = -\frac{8a}{3}$$

$$a = \frac{l}{8}$$

Q.1.12 A member *ABCD* is subjected to concentrated loads as shown. Calculate

(i) the force P necessary for equilibrium and

(ii) total elongation of the bar.

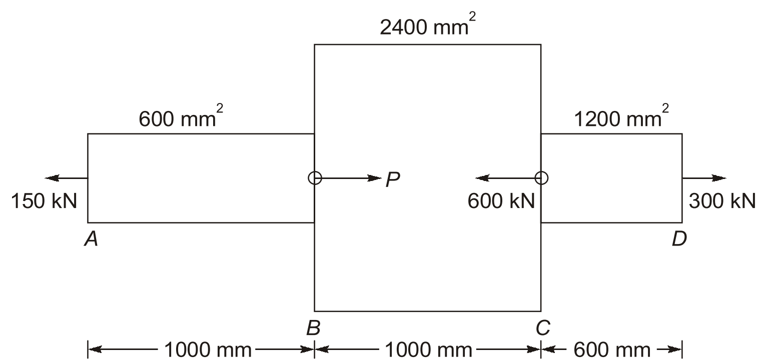


Fig.1.11

The value of Young's modulus of Elasticity is given as 2×10^5 N/mm^2

[IFS 2015, CE : 8 Marks]

Solution:

For equilibrium

$$150 + 600 = P + 300$$

$$P = 450 \text{ kN}$$

Portion *AB* Tensile force = 150 kN

Portion *BC*, Compressive force = 450 – 150 = 300 kN

Portion CD, Tensile force = 300 kN

Total elongation in bar

$$= \frac{150 \times 1000 \times 1000}{600 \times 2 \times 10^5} - \frac{300 \times 1000 \times 1000}{2400 \times 2 \times 10^5} + \frac{300 \times 1000 \times 600}{1200 \times 2 \times 10^5}$$

$$= 1.25 - 0.625 + 0.75 = 1.375 \text{ mm}$$

Q.1.13 A circular steel rod tapers uniformly from 40 mm diameter to 150 mm diameter in a length of 400 mm. How much the bar will elongate under an axial pull of 40 kN? Take E = 200 GPa.

[IFS 2015, ME : 8 Marks]

Solution:

Extension in tapered bar, $$\delta l = \frac{4PL}{\pi EDd}$$

where, P, axial pull = 40000 N

$$L\text{, length} = 400 \text{ mm}$$
$$E\text{, Young's modulus} = 200000 \text{ N/mm}^2$$
$$D\text{, Diameter at bigger end} = 150 \text{ mm}$$
$$d\text{, diameter of smaller end} = 40 \text{ mm}$$
$$\delta l = \frac{4 \times 40000 \times 400}{\pi \times 200000 \times 150 \times 40} = 0.017 \text{ mm}$$

Q.1.14 A tensile test specimen having a diameter of 12.7 mm was loaded to a load of 76 kN and its diameter was measured as 12 mm. Compare true stress and strain with engineering stress and strain.

[IFS 2015, ME : 10 Marks]

Solution:

Initial diameter, $d = 12.7$ mm

Final diameter, $d' = 12$ mm

Initial area, $A = \frac{\pi}{4} \times 12.7^2 = 126.677 \text{ mm}^2$

Final area, $A' = \frac{\pi}{4} \times 12^2 = 113.097 \text{ mm}^2$

Load, $N = 76 \text{ kN} = 76000 \text{ N}$

(i) Engineering stress, $\sigma = \frac{76000}{126.677} = 600 \text{ N/mm}^2$

True stress, $\sigma_t = \frac{76000}{113.097} = 671.99 \text{ N/mm}^2$

(ii) $AL = A'L'$, taking equal volume, no volume change in plastic stage

$$126.677\,L = 113.097\,L'$$

or final length, $L' = 1.120\,L$

$$\delta L = 0.120\,L$$

$$\in\text{, engineering strain} = \frac{\delta L}{L} = 0.120 = 12\%$$

True strain, $\in_t = \frac{\delta L}{L'} = \frac{0.120L}{1.120L} = 0.107 = 10.7\%$

Q.1.15 A circular punch 20 mm in diameter is used to punch, hole through a steel plate, 10 mm thick. If the force necessary to drive the punch is 250 kN, determine the maximum shearing stress developed in the plate.

[CES-Mains, ME: 10 Marks]

Solution:

Punching force, $P = 250$ kN

Punch diameter, $d = 20$ mm

Plate thickness, $t = 10$ mm

Maximum shearing stress, $= \tau_s$

$$\pi d t \tau_s = 250000$$

$$\tau_s = \frac{250000}{\pi \times 20 \times 10} = 397.9 \text{ N/mm}^2$$

Q.1.16 An aluminium square bar having the cross-section 50 mm × 50 mm and length 3 metres is fixed between two rigid supports as shown in the figure. Two loads, 15 kN and 30 kN are applied concentrically to the rod through collars as shown. Determine the stress developed at the right end of the bar. Young's modulus of aluminium is 70×10^9 N/m^2.

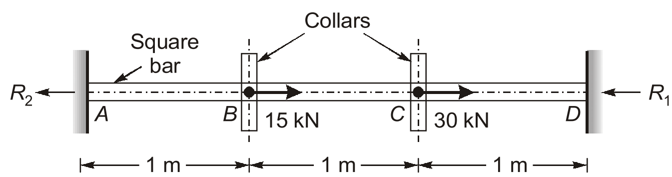


Fig.1.12

[IFS 2016, CE : 10 Marks]

Solution:

Say radius at *D* and *A* are R_1 and R_2 respectively

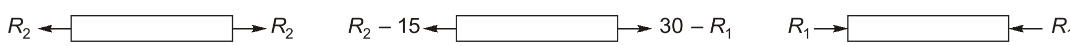


Fig.1.13

Forces on *AB*, *BC* and *CD* are as shown.

A and *D* are fixed.

$$\frac{R_2}{E} \times \frac{1}{A} + \frac{(R_2 - 15)1}{AE} - \frac{R_1}{AE} \times 1 = 0$$

$$2R_2 - 15 - R_1 = 0$$

$$2R_2 - R_1 = 15$$

$$R_2 + R_1 = 465$$

$$3R_2 = 60$$

$$R_2 = 20 \text{ kN}$$

$$R_1 = 25 \text{ kN}$$

Area, $A = 2500 \text{ mm}^2$

$$\sigma_{CD} = \frac{25}{2500} \times 1000 = -10 \text{ N/mm}^2 \text{ (Compressive)}$$

Q.1.17 Figure shows a circular copper rod carrying tensile load of 200 kN. Determine displacement of point B of copper rod.

Copper rod, area of cross-section = 5000 mm^2

Area of cross-section of iron rods = 5000 mm^2

Length of copper rod = 3 m

Length of iron rod = 1 m

E_{iron} = 210 GPa

E_{copper} = 120 Gpa

[CES-Mains, CE: 2016, 10 Marks]

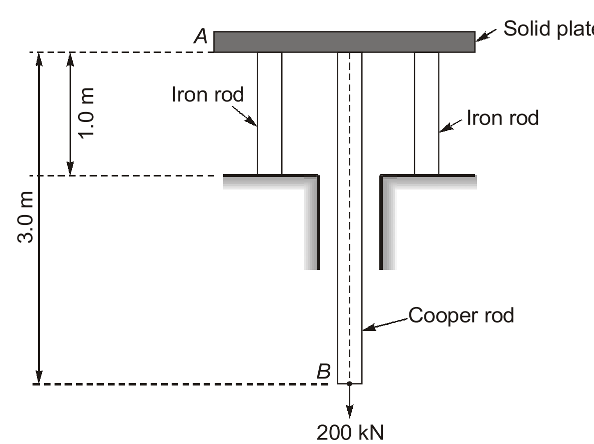


Fig. 1.14

Solution:

Compressive load on each steel bar = 100 kN

δl_s = Contraction in steel bar

$$= \frac{100 \times 100}{5000} \times \frac{1000}{210000} = 0.095 \text{ mm}$$

Tensile load on copper bar = 200 kN

Extension in copper rod, $\delta l_{Cu} = \frac{200 \times 1000 \times 3000}{5000 \times 120000} = 1.0$ mm

Downward movement of point B = 1.095 mm = $\delta l_s + \delta l_{Cu}$

Q.1.18 A rod of 1 m length is kept at a temperature of 30°C. Find the expansion of the rod when the temperature is raised to 80°C. If this expansion is prevented, find the stress induced in the material of the rod. Take E = 100 GPa and α = 0.000012/°C.

[IFS 2017, ME : 8 Marks]

Solution:

Length of the road, L = 1 m

Initial temperature, T_1 = 30°C

Find temperature, T_2 = 80°C

Increase in temperature, ΔT = 80 – 30 = 50°

Coefficient of the rural expansion, $\alpha = 12 \times 10^{-6}$/°C

Expansion in length, $\delta L = \alpha . \Delta T . L$

$= 12 \times 10^{-6} \times 50 \times 1$

$= 600 \times 10^{-6}$ m = 0.6 mm

Expansion prevented

Strain bar, $\varepsilon = \frac{\delta L}{L} = \frac{600 \times 10^{-6}}{1} = 6 \times 10^{-6}$

Young's modulus, E = 100 GPa = 100 × 1000 N/mm^2

Stress induced in material, $\sigma = \varepsilon . E$

$= 60 \times 10^{-6} \times 10^5$

$= 6$ N/mm^2 (Compressive)

Objective Questions

Q.1 In a semi-infinite plate shown in the figure **1.15.** The theoretical stress concentration factor k_t, for an elliptical hole of major axis 2a and minor axis 2b is given by

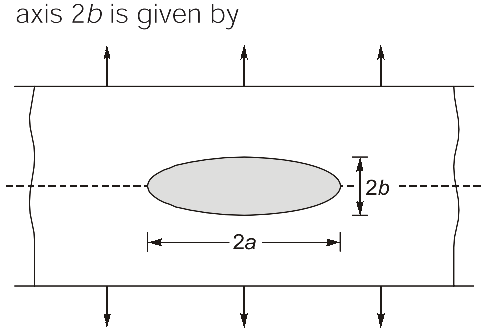


Fig. 1.15

(a) $k_t = \frac{a}{b}$ (b) $k_t = 1 + \frac{a}{b}$

(c) $k_t = \frac{2b}{a}$ (d) $k_t = 1 + \frac{2a}{b}$

[CSE-Prelims, ME : 1998]

Q.2 In a simple tensile test, Hooke's law is valid upto the

(a) elastic limit

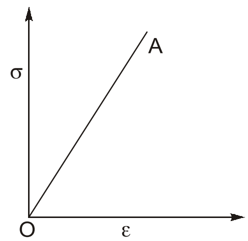
(b) limit of proportionality

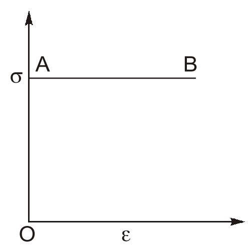
(c) ultimate stress

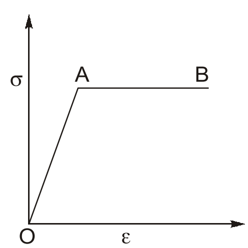
(d) breaking point

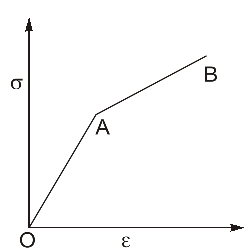
[CSE-Prelims, ME: 1998]

Q.3 The stress strain curve for an ideal strain hardening material will be as in

(a)


(b)


(c)


(d)


[CSE-Prelims, ME : 1998]

Q.4 The percentage elongation of a material as obtained from static tension test, depends on
(a) diameter of the test specimen
(b) gauge length of the specimen
(c) nature of end grips of the testing machine
(d) geometry of the test specimen

[CSE-Prelims, ME : 1998]

Q.5 A horizontal force of 200 N is applied at '*A*' to lift the load *W* at *C*, as shown in **figure 1.16.** Value of weight *W* is

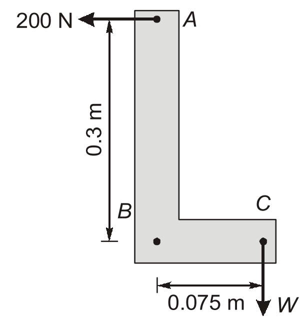


Fig. 1.16

(a) 200 N (b) 400 N
(c) 600 N (d) 800 N

[CSE-Prelims, ME : 1998]

Q.6 Which one of the following pairs is not correctly matched?
If E = Young's modulus
α = coefficient of linear expansion
T = Temperature rise
A = Area of cross-section
L = Original length
(a) Temperature strain with permitted expansion

$$\delta \text{ is } \left(\frac{\alpha TL - \delta}{L}\right)$$

(b) Temperature stress — αTE
(c) Temperature thrust — αTEA
(d) Temperature stress with permitted expansion δ — $E(\alpha TL - \delta)$

Q.7 Which one of the following pairs is not correctly matched?
(a) Uniformly distributed stress: Force passes through centroid of the cross-section
(b) Elastic deformation : work done by external forces during elastic deformation is fully dissipated as heat
(c) Potential energy of strain : Body is in a state of elastic deformation
(d) Hooke's law : Relation between stress and strain

[CSE-Prelims, ME : 1999]

Q.8 Match the **List-I** (material properties) with **List-II** (technical definition represents) and select the correct answer.

List-I

A. Hardness

B. Toughness

C. Malleability

D. Ductility

List-II

1. Percentage elongation
2. Resistance to indentation
3. Ability to absorb energy during plastic deformation
4. Ability to be rolled into plates

Codes:

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

[CSE-Prelims, ME : 1999]

Q.9 A measure of Rockwell hardness is

(a) depth of penetration of indentor

(b) surface area of indentation

(c) projected area of indentation

(d) height of rebound

[CSE-Prelims, ME : 1999]

Q.10 If a block of material of length 25 cm, breadth 10 cm and height 5 cm undergoes volumetric strain of $\frac{1}{5000}$, then change in volume will be

(a) 0.50 cm^3 (b) 0.25 cm^3

(c) 0.20 cm^3 (d) 0.75 cm^3

[CSE-Prelims, ME : 2000]

Q.11 For an isotropic homogeneous and linearly elastic material, which obeys Hooke's law, The number of independent elastic constants are

(a) 1 (b) 2

(c) 3 (d) 6

Q.12 Assuming E = 180 GPa and G = 100 GPa for a material a strain tensor is

$$\begin{pmatrix} 0.002 & 0.004 & 0.006 \\ 0.004 & 0.003 & 0 \\ 0.006 & 0 & 0 \end{pmatrix}$$

Shear stress τ_{xy} is

(a) 400 MPa (b) 500 MPa

(c) 800 MPa (d) 1000 MPa

[CSE-Prelims, ME : 2001]

Q.13 With the increase of percentage of carbon in steel, which one of the following properties does increase

(a) modulus of elasticity

(b) ductility

(c) toughness

(d) hardness

[CSE-Prelims, ME : 2001]

Q.14 Match **List-I** (material) and **List-II** (Stress-strain curve) and select the correct answers.

List-I

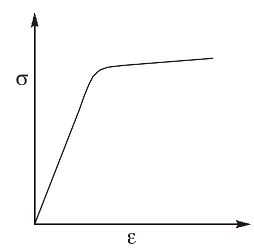
A. Mild steel

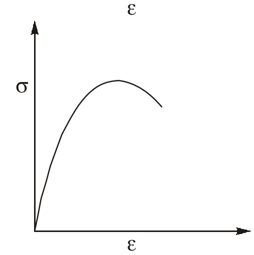
B. Pure copper

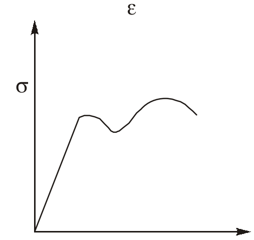
C. Cast iron

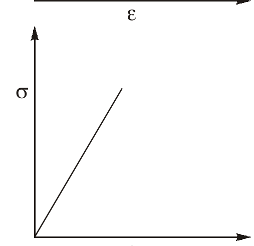
D. Aluminium

List-II

1.


2.


3.


4.


Answers

1. (d)	2. (b)	3. (d)	4. (b)	5. (d)
6. (d)	7. (b)	8. (c)	9. (a)	10. (b)
11. (b)	12. (c)	13. (d)	14. (b)	15. (a)
16. (c)	17. (c)	18. (c)	19. (a)	20. (d)
21. (a)	22. (d)	23. (d)	24. (b)	25. (c)
26. (c)	27. (d)	28. (a)	29. (d)	30. (c)
31. (d)	32. (d)	33. (c)	34. (c)	35. (b)
36. (d)	37. (c)	38. (b)	39. (b)	40. (d)
41. (a)	42. (a)	43. (b)	44. (c)	45. (d)
46. (d)	47. (a)	48. (a)	49. (a)	50. (b)
51. (b)	52. (b)	53. (a)		

Explanations

1. (d)

$$k_t = 1 + \frac{2a}{b}$$

$2a$ is major axis perpendicular to axis of loading. Stress concentration factor (k_t) is a dimensionless factor which is used to quantify how concentrated the stress is in a material. It is defined as the ratio of the highest stress in the element to the reference stress.

$$k_t = \frac{\sigma_{max}}{\sigma_{ref}}$$

Reference stress is the stress in the part within an element under the same loading conditions without having holes, acts, shoulders or narrow passes.

2. (b)

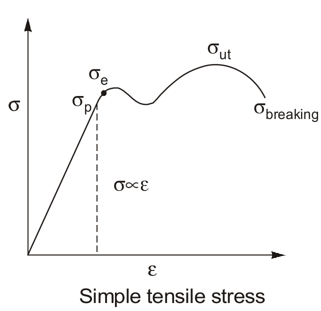


Fig. 1.24

Hooke's law valid only upto σ_p, limit of proportionality.

3. (d)

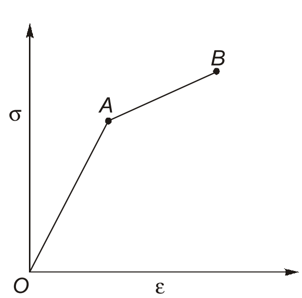


Fig. 1.25

OA = elastic

AB = strain hardening portion

4. (b)

$$\% \text{ elongation} = \frac{\delta L}{\text{gauge length}} = \frac{\text{change in length}}{\text{gauge length}}$$

5. (d)

$$200 \times 0.3 = 0.075\, W$$

$$W = 800 \text{ N} \qquad \text{(moment about } B\text{)}$$

6. (d)

is not correctly matched.

Temperature stress with permitted explain is not $E(\alpha TL - \delta)$.

7. (b)

Elastic deformation work done by external forces during elastic deformation is not dissipated fully as heat.

8. (c)

A. Hardness	2. Resistance to inductation
B. Toughness	3. Ability to absorb energy during plastic
C. Malleability	4. Ability to be rolled into plates
D. Ductility	1. Percentage of elongation

9. (a)

A measure of Rockwell hardness is a depth of penetration of indentor.

10. (b)

$$\delta V = \frac{25 \times 10 \times 5}{5000} = 0.25 \text{ cm}^3$$

11. (b)

E and μ are two independent elastic constants.