DETAILED SOLUTIONS

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ESE 2025 : Prelims Exam
CLASSROOM TEST SERIES

CIVIL ENGINEERING

Test 6

Section A : Design of Steel Structure + Surveying and Geology

Section B : Solid Mechanics - 1

Section C : Geo-Technical & Foundation Engineering-2 + Environmental Engineering-2

1.	(a)	16.	(b)	31.	(c)	46.	(d)	61.	(d)
2.	(d)	17.	(c)	32.	(c)	47.	(c)	62.	(c)
3.	(c)	18.	(b)	33.	(c)	48.	(d)	63.	(c)
4.	(d)	19.	(a)	34.	(d)	49.	(c)	64.	(c)
5.	(b)	20.	(b)	35.	(d)	50.	(c)	65.	(a)
6.	(b)	21.	(c)	36.	(b)	51.	(d)	66.	(d)
7.	(c)	22.	(c)	37.	(a)	52.	(a)	67.	(a)
8.	(b)	23.	(a)	38.	(b)	53.	(a)	68.	(d)
9.	(b)	24.	(b)	39.	(b)	54.	(d)	69.	(b)
10.	(d)	25.	(c)	40.	(c)	55.	(d)	70.	(a)
11.	(d)	26.	(b)	41.	(b)	56.	(c)	71.	(a)
12.	(b)	27.	(c)	42.	(c)	57.	(c)	72.	(c)
13.	(d)	28.	(d)	43.	(c)	58.	(*)	73.	(b)
14.	(c)	29.	(b)	44.	(d)	59.	(a)	74.	(c)
15.	(b)	30.	(b)	45.	(b)	60.	(c)	75.	(a)

***Q.11 :** *Answer has been Updated.*

***Q.58 :** *Marks will be awarded to all. [None of the options are correct.]*

DETAILED EXPLANATIONS

Section A : Design of Steel Structure + Surveying and Geology

1. (a)

The primary structural advantage of using steel as a structural material is its small weight-to-strength ratio, also known as the high strength to weight ratio.

This means that steel is exceptionally strong relative to its weight, making it ideal for constructing large, durable and light weight structures such as bridges and industrial building.

Speed of erection: While steel structures can be erected quickly due to prefabrication, this is a construction advantage.

Speed of dismantling: This is a practical benefit for certain project but not a structural advantage.

Scrap Value: Steel has a high scrap value, but this is an economic advantage not a structural advantage.

2. (d)

As per IS : 875-2015 (Part-3), the design wind velocity at any height for the structure is given by

$$V_z = V_b \cdot k_1 k_2 k_3 k_4$$

where, V_b = Basic maximum wind speed (it obtained from wind map of the country)

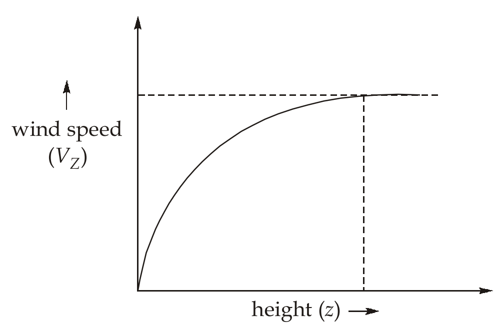
k_1 = Probability factor or risk coefficient

k_2 = Terrain, height and structure size factor

k_3 = Topography factor of the area

k_4 = Factor for cyclonic region

Note: V_z (wind speed) upto a 10 m height from the mean ground level is considered constant.



3. (c)

Shape factor: It is the ratio of plastic moment capacity to yield moment capacity of the section.

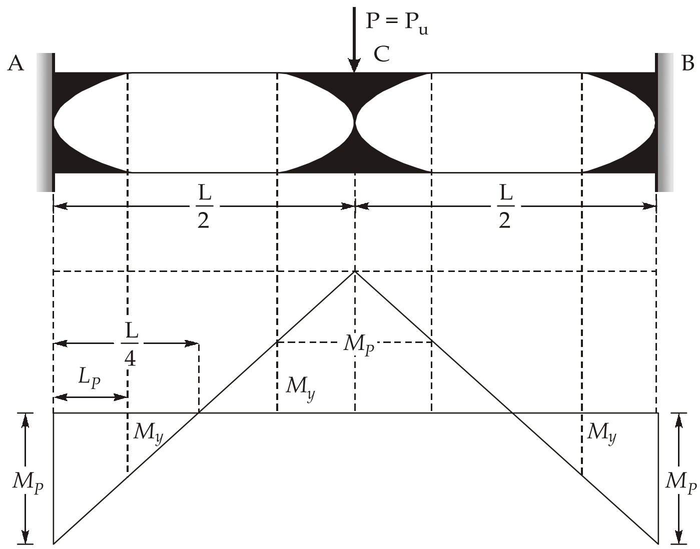
$$S = \frac{M_P}{M_y} = \frac{f_y Z_p}{f_y Z_e} = \frac{Z_P}{Z_e}$$

where, Z_p = Plastic section modulus

Z_e = Elastic section modulus

Shape factor gives an idea of the margin provided by the reserve of strength.

4. (d)



BMD at the time of collapse ($P = P_u$)

Let plastic hinge length at fixed end at the time of collapse is 'L_P'.
From the collapse BMD.

$$\frac{M_P}{\left(\frac{L}{4}\right)} = \frac{M_y}{\left(\frac{L}{4} - L_P\right)}$$

$$\Rightarrow \quad \frac{M_p}{M_y} = \frac{L/4}{\left(\frac{L}{4} - L_P\right)}$$

$$\Rightarrow \quad \frac{2}{3} = \frac{(L/4 - L_P)}{L/4}$$

$$\Rightarrow \quad L_P = \frac{L}{12}$$

$\therefore$ Plastic hinge length at fixed end at the time of collapse is $(L/12)$.

5. (b)

S.No.	Shape (cross-section)	Shape factor
1.	H-section (wide flange weak axis) or Rectangular section	1.5
2.	Square section (diagonal Parallel to Horizontal axis)	2
3.	Circular section	$\frac{16}{3\pi} = 1.7$
4.	I-section (wide flange strong axis)	1.14
5.	Triangular section (base parallel to horizontal axis)	2.34

6. **(b)**

7. **(c)**

Refer IS : 800 : 2007 Table-2 (Limiting width to thickness ratio)

8. **(b)**

As per IS 800 : 2007

CL 7.6.4 : Lacing bars, whether in double or single systems, shall be inclined at an angle not less than 40° and not more than 70° to the axis of the built-up member.

- ***Cl* 7.6.3**: Thickness of flat lacing shall not be less than (1/40) of its effective length for single lacings and (1/60) of the effective length for double lacings.

$$t_{min} \not< \begin{cases} \dfrac{l}{40} \text{ for single lacing} \\ \dfrac{l}{60} \text{ for double lacing} \end{cases}$$

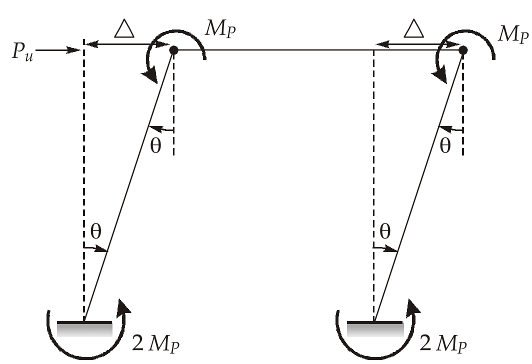
- **CL 7.6.6.1**: Lacing should be designed for transverse shear force in columns due to bending, lateral loading or accidental eccentricity. Transverse shear force is taken as 2.5% of column load.
- **CL 7.6.1.5**: The effective slenderness ratio of laced columns shall be taken as 5% more than the actual maximum slenderness ratio, in order to account for shear deformation effects.

$$\lambda_{\text{Laced column}} = 1.05\, \lambda_{\text{Actual}}$$

9. **(b)**

Number of independent mechanisms

$$n = N - r = 4 - 3 = 1 \text{ (Sway mechanism)}$$



$\Delta = \theta l$

$$\text{External work done} = \text{Internal work done}$$

$$\Rightarrow \quad P_u \times l \times \theta = 2M_P \times \theta + M_P\theta + M_P\theta + 2\, M_P\theta$$

$$\Rightarrow \quad P_u \times l = 6M_P$$

$$\Rightarrow \quad P_u = \frac{6M_P}{l}$$

10. (d)

For single-V groove weld:

In this case incomplete penetration is there and hence throat thickness

$$t_e = \frac{5}{8} t_{min} = \frac{5}{8} \times 12 = 7.5\,\text{mm}$$

where, t_{min} = thickness of thinner plate

Effective length of weld l_{eff} = 140 mm

$$\text{Strength of weld } P_1 = \left(\frac{f_y}{\gamma_{mw}}\right) t_e l_{eff}$$

$$\Rightarrow \quad P_1 = \frac{250}{1.5} \times 7.5 \times 140\,\text{N} = 175\,\text{kN}$$

For double-V groove weld:

In this case complete penetration takes place and hence throat thickness

$$t_e = t_{min} = 12\,\text{mm}$$

$$\text{Strength of weld } P_2 = \left(\frac{f_y}{\gamma_{mw}}\right) \times t_e \times l_{eff} = \frac{250}{1.5} \times 12 \times 140\,\text{N} = 280\,\text{kN}$$

$$\therefore \quad P_2 - P_1 = 280 - 175 = 105\,\text{kN}$$

11. (d)

IS : 875 (Part II) specify the following live loads to be assumed in the analysis of an industrial building.

Roof slope	Access	Live load
$\leq 10°$	Provided	1.5 kN/m^2 of plain Area
	Not provided	0.75 kN/m^2 of plain Area
$> 10°$		For roof membrane sheets or Purless 0.75 kN/m^2 less 0.02 kN/m^2 for every degree increase in slope over 10° $\nless$ 0.4 kN/m^2.

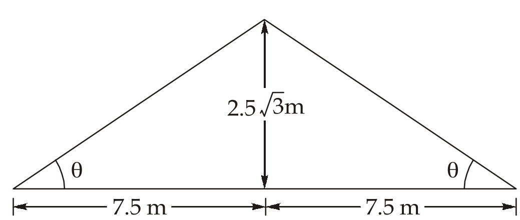
Given:

Span = 15 m

Pitch = $2.5\sqrt{3}$ m

Spacing = 3 m c/c

$$\tan\theta = \frac{2.5\sqrt{3}}{7.5} = \frac{\sqrt{3}}{3} = \frac{1}{\sqrt{3}}$$



$$\therefore \quad \theta = 30° > 10°$$

$\therefore$ Live load on roof truss $= 0.75 - 0.02\,(30° - 10°)$

$= 0.35\,kN/m^2 \ngtr 0.4\,kN/m^2$

12. (b)

Equivalent stress $f_e = \sqrt{3f_s^2 + f_b^2} \le \frac{f_u}{\sqrt{3}\gamma_{mw}}$

13. (d)

$$P_{max} = \min.\begin{cases}\text{(i) Grosss strength of plate}\\ \text{(ii) Strength of weld}\end{cases}$$

(i) Gross strength of plate $= f_{\text{Permissible plate}} \times A_g$

$= 160 \times 80 \times 8 \text{ N} = 102.4 \text{ kN}$

(ii) Strength of weld $= f_{\text{Per weld}} \times (0.7S \times l_w)$

$= 110 \times (0.7 \times 6 \times 2 \times 140) \text{ N} = 129.36 \text{ kN}$

$\therefore \quad P_{max} = 102.4 \text{ kN}$

14. (c)

As per IS 800 : 2007 Clause 8.2.1.2

Design bending strength

$$M_d = \frac{\beta_b Z_P f_y}{\gamma_{mo}}$$

For semi-compact section, $\beta_b = \frac{Z_e}{Z_p}$

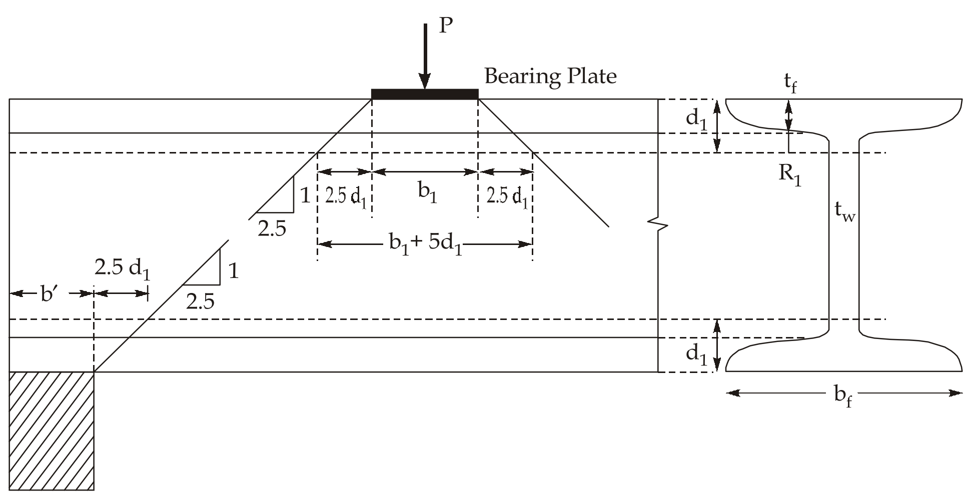
$$\therefore \quad M_d = \frac{Z_e}{Z_p} \times Z_p \times \frac{f_y}{\gamma_{mo}} = \frac{Z_e f_y}{\gamma_{mo}} = \frac{751.9 \times 10^3 \times 250}{1.1} \text{ N.mm}$$

$$\therefore \quad M_d = 170.89 \text{ kN-m} \simeq 170.9 \text{ kNm}$$

15. (b)

As per IS : 800 : 2007 Clause 8.7.1

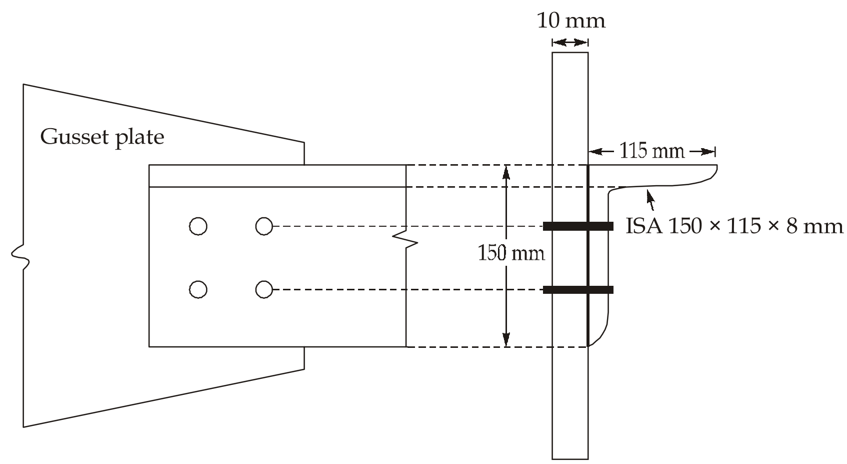
16. (b)



web crippling strength

$$F_w = \begin{cases} \dfrac{f_{yw}}{\gamma_{mo}} t_w (b_1 + 5d_1) \text{ at point load} \\ \dfrac{f_{yw}}{\gamma_{mo}} t_w (b' + 2.5d_1) \text{ at support} \end{cases}$$

17. (c)



Diameter of hole $d_o = 20 + 2 = 22$ mm

Area of connected leg, $A_c = \left(150 - 22 \times 2 - \dfrac{8}{2}\right) \times 8 = 816 \text{ mm}^2$

Area of outstanding leg, $A_o = \left(115 - \dfrac{8}{2}\right) \times 8 = 888 \text{ mm}^2$

18. (b)

The design compressive stress. f_{cd} of axially loaded compression members shall be calculated using the following equation.

$$f_{cd} = \chi\left(\frac{f_y}{\gamma_{mo}}\right)$$

where; χ = stress reduction factor

$$\chi = \frac{1}{\phi + (\phi^2 - \lambda^2)^{0.5}}$$

$$\phi = 0.5\,[1 + \alpha\,(\lambda - 0.2) + \lambda^2]$$

$$\lambda = \sqrt{\frac{f_y}{f_{cc}}} \quad \text{(non-dimensional effective slenderness ratio)}$$

$$f_{cc} = \frac{\pi^2 E}{(KL/r)^2} \quad \text{(Euler buckling stress)}$$

19. (a)

The sensitivity of a bubble tube primarily depends on the radius of curvature of its internal surface; a large radius of curvature results in a more sensitive bubble that will indicate a large change in level.

Other factors affecting sensitivity of bubble tube are:

- Diameter/Radius of curvature of internal surface : A larger diameter generally increases sensitivity.
- Length of the bubble: A longer bubble can enhance sensitivity.
- Liquid viscosity: Lower viscosity of the liquid inside the tube leads to greater sensitivity.
- Smoothness of the inner surface: A smoother inner surface improves sensitivity.
- Length of one division on the tube: Longer division indicates higher sensitivity.

20. (b)

Variation of magnetic declination:

1. **Secular variation**: Causes are not well understood.
2. **Annual variation**: It is caused because of the rotation of earth about Sun. It is found that the annual variation is about 1 to 2 min.
3. **Diurnal variation**: It is caused due to the following:
   - Geographical position of the place.
   - The time of the day (more in day)
   - Season of the year (more in summers)
   - The year of the cycle of secular variation.
4. **Irregular variation**: It is due to magnetic disturbances or storm.

21. (c)

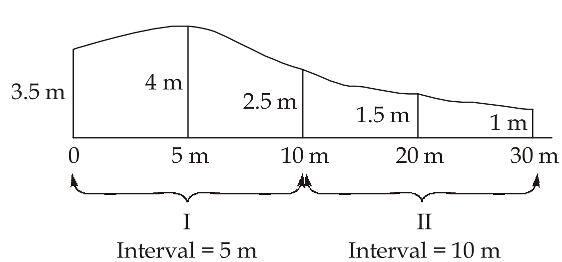
By proportionate method.

$$\text{Correction to 1}^{\text{st}}\text{ bearing} = \frac{\theta}{n} = \frac{4^\circ}{8} = 0.5^\circ$$

$$\text{Correction to 4}^{\text{th}}\text{ bearing} = 4\left(\frac{\theta}{n}\right) = 2^\circ$$

$$\text{Correction to last bearing} = 8\left(\frac{\theta}{8}\right) = 4^\circ$$

22. (c)



$$\text{Area} = A_{\text{Portion-I}} + A_{\text{Portion-II}}$$

$$= \frac{5}{3}[(3.5+2.5)+4(4)] + \frac{10}{3}[(2.5+1)+4(1.5)]$$

$$= 36.67 + 31.67 = 68.34 \text{ m}^2 \simeq 68 \text{ m}^2$$

23. (a)

For topographical maps, a general rule is

$$\text{Contour interval} = \frac{25}{\text{Number of cm per km}} \text{(meter)}$$

Given: $\text{Scale} = 1 : 20{,}000$

$\Rightarrow$ $20{,}000 \text{ m} = 1 \text{ m} = 100 \text{ cm}$

$\Rightarrow$ $1000 \text{ m} = 1 \text{ km} = \frac{100 \times 1000}{20{,}000} = 5 \text{ cm}$

$\therefore$ $\text{Contour interval} = \frac{25}{5} = 5 \text{ m}$

24. (b)

Total number of divisions through which the bubble has moved

$$n = \frac{(20-10)+(20-10)}{2} = 10$$

Change in staff reading, $S = 1.68 - 1.602 = 0.078 \text{ m}$

$\therefore$ $\frac{S}{D} = \frac{nl}{R}$

$\Rightarrow$ $R = \frac{nlD}{S} = \frac{10 \times 2 \times 10^{-3} \times 100}{0.078} \text{ m} = 25.64 \text{ m} \simeq 25.6 \text{ m}$

25. (c)

Difference in RL, $\Delta H = \frac{(2.125-1.624)+(1.326-0.825)}{2}$

$\Rightarrow$ $\Delta H = 0.501 \text{ m}$

$\therefore$ $\Delta H = +\text{ve}$ So, station P lies above station Q.

$\therefore$ $RL_P - RL_Q = \Delta H$

$\Rightarrow$ $100 \text{ m} - RL_Q = 0.501 \text{ m}$

$\Rightarrow$ $RL_Q = 99.499 \text{ m}$

26. (b)

Sum of latitudes

$$\Sigma L = \Sigma\text{Northing} - \Sigma\text{Southing}$$
$$= (101 + 419) - (437 + 83) = 0$$

Sum of departures

$$\Sigma D = \Sigma\text{Easting} - \Sigma\text{Westing}$$
$$= (199.25 + 299.75) - (300.5 + 200.5) = -2 \text{ m}$$

Magnitude of closing error

$$e = \sqrt{0^2 + (-2)^2} = 2 \text{ m}$$

Direction of closing error $\theta = \tan^{-1}\left(\frac{\Sigma D}{\Sigma L}\right) = \tan^{-1}\left(\frac{-2}{0}\right) = 270°$

27. (c)

- Hypometric leveling is a surveying technique that determines the height of a location by measuring the temperature at which water boils
- Hypometric leveling uses the relationship between atmospheric pressure and the boiling point of water.

28. (d)

Given : Declination $\delta = 70°05' \text{ N}$

Latitude $\theta = 48°10' \text{ N}$

$\delta > \theta$

$\therefore$ Zenith distance at lower culmination

$$= 180° - (\theta + \delta)$$

$$= 180° - (70°05' + 48°10') = 61°45'$$

29. (b)

$$\text{Correction for slope} = \frac{h^2}{2L} = \frac{(1.2)^2}{2 \times 30} = 0.024 \text{ m (always subtractive)}$$

$$\therefore \quad \text{Horizontal distance} = 30 - 0.024 = 29.976 \text{ m}$$

30. (b)

$$\text{Area of square field} = (\text{Side})^2$$

$$\frac{d(\text{Area})}{d(\text{Side})} = 2 \times \text{Side}$$

$$\Rightarrow \quad d(\text{Area}) = 2 \times \text{Side} \times d(\text{Side})$$

$$= 2 \times 200 \times 0.05 = 20 \text{ m}^2$$

31. (c)

$$\text{Weight of } (A - B) = \frac{1}{\frac{1}{2} + \frac{1}{3}} = \frac{6}{5}$$

$$\text{Weight of } \left(\frac{A - B}{5}\right) = \frac{\text{weight of } (A - B)}{\frac{1}{5^2}} = \frac{6 \times 5^2}{5} = 30$$

$$\text{Weight of } \left[5.5 + \frac{(A - B)}{5}\right] = \text{Weight of } \left(\frac{A - B}{5}\right) = 30$$

32. (c)

True bearing of the line $= 5°15' + 1°$

$\Rightarrow$ T.B. $= 6°15'$

Present declination $= 8°30'$ (West)

$\therefore$ True bearing $=$ Magnetic bearing $- (8°30')$

$\Rightarrow$ Magnetic bearing $= 6°15' + 8°30' = 14°45'$

33. (c)

34. (d)

$$K = 100 \text{ and } C = 0.5 \text{ m}$$

$$K = \frac{f}{i} \quad (\text{where, } \; f = 25 \text{ cm})$$

$$\Rightarrow \quad i = \frac{f}{k} = \frac{25}{100} \text{ cm} = 0.25 \text{ cm} = 2.5 \text{ mm}$$

$$C = f + d$$

$$\Rightarrow \quad d = C - f$$

$$= 0.5 - 0.25$$

$$= 0.25 \text{ m} = 25 \text{ cm}$$

35. (d)

- Plane table surveying not suitable when accuracy is required.
- This method is suitable in magnetic areas, where a compass survey will not be reliable.
- Many features can be accurately represented as the surveyor has the objects or features in view while plotting.
- It is very suitable for preparing small scale maps.

36. (b)

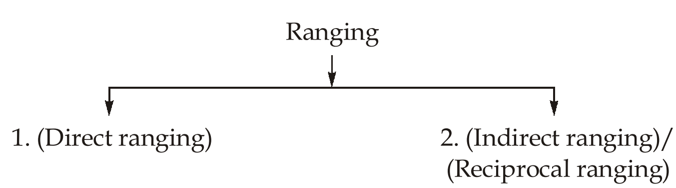
Web buckling is due to thin section of the web.

Web crippling is due to large stresses generated due to stress concentration at the junction of web and flange.

37. (a)

The possibility of block shear failure increases with the use of high bearing strength material and high strength bolts which results in fewer bolts and smaller connection length.

38. (b)



Indirect ranging is followed when both the ends of the survey line are not intervisible either due to high intervening ground or due to long distance between them.

Section B : Solid Mechanics - 1

39. **(b)**

The fundamental mechanical properties of a material are those that affect its strength, shape and how it reacts to stress and strain.

These properties are important for choosing material in many industries.

Example: Strength, hardness, elasticity, stiffness, creep, plasticity, ductility etc.

Density is a physical property of a material and not a fundamental mechanical property.

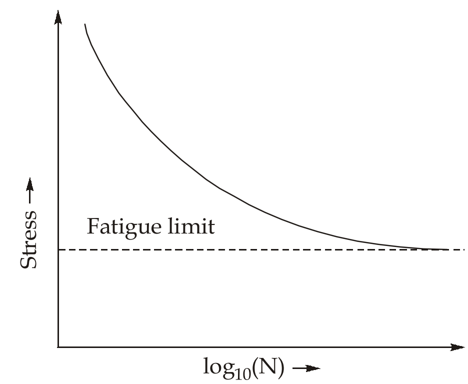
40. **(c)**

Endurance limit : It is the value of stress below which structural steel will not produce fatigue failure. It can be defined as the half of the ultimate stress.

Hence, $$\text{Endurance limit} = \frac{f_u}{2} = \frac{1}{2}\times 450 = 225 \text{ MPa}$$

Note:

- Endurance limit (also called fatigue limit) is the stress level, below which fatigue failure does not occur.
- This limit exists only for some ferrous and titanium alloys for which the *S-N* curve becomes horizontal at higher '*N*' value.

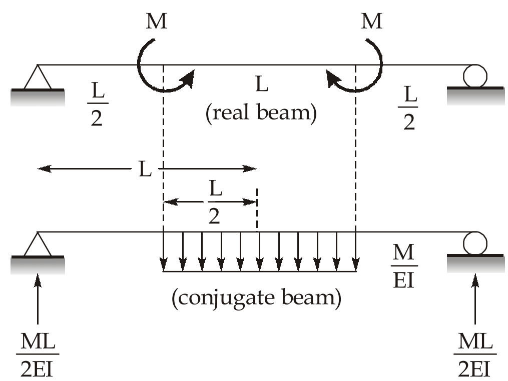


41. **(b)**

The intensity of perpendicular component of applied force per unit area of the section is called as pressure and intensity of internal resistance per unit area of the section is called as unit stress.

- Poisson's ratio $\mu = \left|\frac{\text{Lateral strain}}{\text{Longitudinal strain}}\right|$
- Lateral strain = – μ × longitudinal strain
- For rubber, Poisson's ratio is in the range of 0.45 to 0.50.

42. (c)



Maximum deflection will occur at Mid-span of beam.

$$\Delta_{max} = BM \text{ at Mid-span of conjugate beam.}$$

$$= \frac{ML}{2EI} \times L - \left(\frac{M}{EI} \times \frac{L}{2}\right) \times \frac{L}{4} = \frac{ML^2}{2EI}\left(1 - \frac{1}{4}\right) = \frac{3ML^2}{8EI}$$

43. (c)

$$\mu = \frac{\frac{\delta d}{d}}{\frac{\delta l}{l}}$$

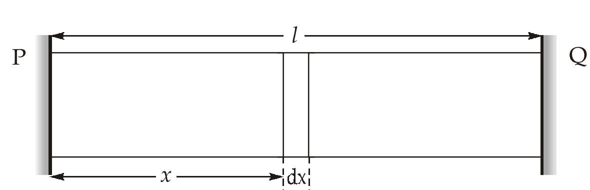
$$\Rightarrow \quad \mu = \frac{\frac{\delta d}{d}}{\frac{P}{AE}}$$

$$\Rightarrow \quad \mu = \frac{(\delta d)(AE)}{Pd}$$

$$\Rightarrow \quad P = \frac{0.0095 \times 1500 \times 200 \times 10^3}{0.3 \times 90 \times 10^3} \text{ kN}$$

$$\Rightarrow \quad P = 105.56 \text{ kN} \simeq 105 \text{ kN}$$

44. (d)



Consider an element at a distance 'x' from 'P'

Elongation of length dx due to change in temperature is given as

$$dL = \alpha \, dx \, T_x$$

$$\Rightarrow \quad dL = T\left(\frac{x}{l}\right)^4 \alpha \cdot dx$$

Total elongation of bar

$$\Delta L = \int_0^l T\left(\frac{x}{l}\right)^4 \alpha dx = \frac{l\alpha T}{5}$$

$$\text{Strain } (\in) = \frac{\Delta L}{l} = \frac{\alpha T}{5}$$

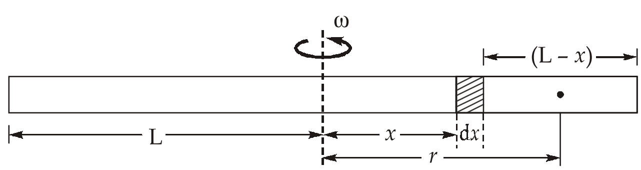
$$\text{Stress } (\sigma) = \in E = \frac{E\alpha T}{5}$$

Note:

If $T_x = T\left(\frac{x}{l}\right)^n$, then the thermal stress is given by

$$\sigma_{\text{thermal}} = \frac{E\alpha T}{(n+1)}$$

45. (b)



Force on elemental strip.

$$F_x = mrw^2$$

where, m = mass of $(L - x)$ length of bar

$$\Rightarrow \quad m = \frac{\gamma}{g} A(L-x)$$

$$r = x + \frac{(L-x)}{2} = \frac{L+x}{2}$$

$$\therefore \quad F_x = \frac{\gamma}{g} A(L-x) \times \left(\frac{L+x}{2}\right)\omega^2 = \frac{\gamma A\omega^2}{2g}\left(L^2 - x^2\right)$$

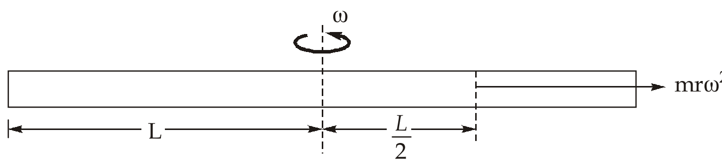
Stress on elemental strip

$$\sigma_x = \frac{F_x}{A} = \frac{\gamma\omega^2}{2g}\left(L^2 - x^2\right)$$

For maximum stress $\dfrac{d\sigma_x}{dx} = 0 \quad \Rightarrow \quad x = 0$

$$\therefore \quad \sigma_{\max} = \frac{\gamma\omega^2 L^2}{2g}$$

Alternate Solution



Maximum stress develope at mid point

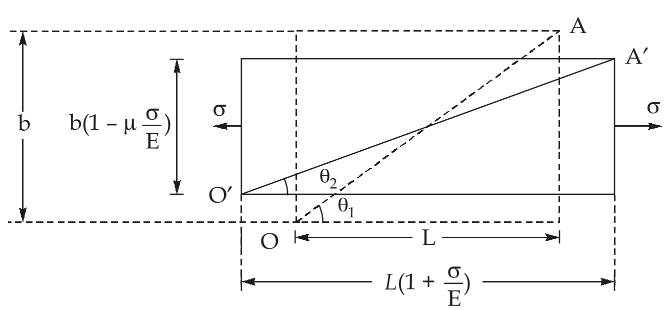
$$\sigma_{max} = \frac{\text{Force}}{A} = \frac{mr\omega^2}{A}$$

$$\Rightarrow \qquad \sigma_{max} = \frac{\frac{\gamma}{g} \times LA\left(\frac{L}{2}\right)\omega^2}{A} = \frac{\gamma L^2 \omega^2}{2g}$$

46. (d)

Slope of line OA line before loading $(m_1) = \frac{b}{L}$

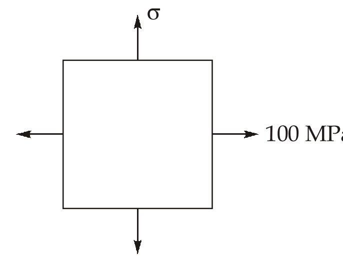
Slope of line OA after loading $(m_2) = \frac{b_f}{L_f} = \frac{b\left(1-\mu\frac{\sigma}{E}\right)}{L\left(1+\frac{\sigma}{E}\right)}$



$$\therefore \quad \text{Change in slope} \qquad \Delta m = m_1 - m_2 = \frac{b}{L} - \frac{b}{L}\frac{\left(1-\mu\frac{\sigma}{E}\right)}{\left(1+\frac{\sigma}{E}\right)}$$

$$\Rightarrow \qquad \Delta m = \frac{(1+\mu)\frac{\sigma}{E}}{\left(1+\frac{\sigma}{E}\right)}\left(\frac{b}{L}\right)$$

47. (c)



Given, $\in_x = 3\in_y$

$$\Rightarrow \quad \frac{\sigma_x}{E} - \mu\left(\frac{\sigma_y}{E}\right) = 3\left[\frac{\sigma_y}{E} - \mu\left(\frac{\sigma_x}{E}\right)\right]$$

$$\Rightarrow \quad \frac{100}{E} - 0.25 \times \frac{\sigma}{E} = \frac{3\sigma}{E} - 3 \times 0.25 \times \frac{100}{E}$$

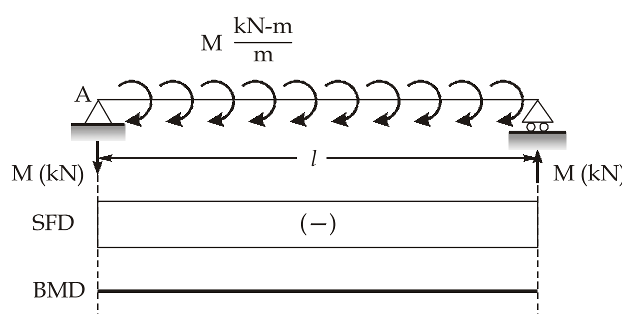
$$\Rightarrow \quad 3.25\,\sigma = 100 + 75$$

$$\Rightarrow \quad \sigma = 53.846 \text{ MPa} \simeq 53.85 \text{ MPa}$$

48. (d)

- A couple produces a sudden change in the bending moment and equation can not be integrated across such a discontinuity.
- The rate of bending moment changes at the point of application of concentrated load.
- $\frac{dM}{dx} = V$; This equation is not valid for uniformly distributed moment.

Example:



Slope of *BMD* ≠ Magnitude of *SF* at that point at any point

$\therefore$ $\frac{dM}{dx} = V$ not valid for uniformly distributed moment.

- Shear force does not change at the point of application of a couple.

49. (c)

Maximum bending moment $M = \frac{wl^2}{8} = \frac{4 \times 4^2}{8} = 8$ kNm

Bending stress in transformed section at the junction of wood and steel

$$\sigma_s = \frac{M.y}{I_{xx}} = \frac{8 \times 10^3 \times 0.8}{16 \times 10^{-6}} = 400 \times 10^6 \text{ N/m}^2 = 400 \text{ MPa}$$

$\therefore$ Stress in wood at junction of wood and steel is,

$$\sigma_{wood} = \sigma_{steel} \times \frac{E_{wood}}{E_{steel}} = 400 \times \frac{1}{20} = 20 \text{ MPa}$$

50. (c)

$$AB = \text{diameter of circle}$$

Radius of circle $OA = OB = \frac{AB}{2} = \frac{1}{2}\sqrt{(4+6)^2 + (5+5)^2}$

$$= \frac{1}{2}\sqrt{200} = 5\sqrt{2} \text{ MPa}$$

Principal stresses

$$\sigma_1 = 5\sqrt{2} - 1 = 6.07 \text{ MPa (Minor principal stress)}$$

$$\sigma_2 = -5\sqrt{2} - 1 = -8.07 \text{ MPa (Major principal stress)}$$

Sum of principal strains

$$\in_1 + \in_2 = \left(\frac{\sigma_1}{E} - \mu\frac{\sigma_2}{E}\right) + \left(\frac{\sigma_2}{E} - \mu\frac{\sigma_1}{E}\right)$$

$$= \left(\frac{\sigma_1 + \sigma_2}{E}\right) - \frac{\mu}{E}(\sigma_1 + \sigma_2) \qquad (\sigma_1 + \sigma_2 = -2 \text{ MPa})$$

$$= \left(\frac{\sigma_1 + \sigma_2}{E}\right)(1 - \mu) = \frac{-2}{2 \times 10^5}(1 - 0.3)$$

$$= -0.7 \times 10^{-5}$$

$$\in_1 + \in_2 = -7 \times 10^{-6}$$

51. (d)

- Point of contraflexure is the point where bending moment changes sign. At point of contraflexure bending moment is zero.
- Location of point of contraflexure and point of inflection is always the same.

52. (a)

- Castigliano's first theorem is applicable to only for elastic behavior case whereas method of virtual work applies to the inelastic behaviour cases.
- Castigeliano's theorem is applicable to structure that has constant temperature, unyielding support and linear elastic material response.

53. (a)

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54. (d)

Stability number

$$S_n = \frac{C}{\gamma H (FOS)}$$

$\Rightarrow$ $$FOS = \frac{25}{20 \times 10 \times 0.05} = 2.5$$

Critical height of the slope $H_C = (FOS) \cdot H$

$$= 2.5 \times 10 = 25 \text{ m}$$

55. (d)

56. (c)

As per IS 1892 : 1979 Appendix A:

- Standard Penetration test is preferred for non-cohesive soils without boulders.
- Static cone penetrometer test is preferred for cohesive soils.
- Dynamic cone penetrometer test is preferred for cohesive soils.

57. (c)

$$q = \text{Intensity of contact pressure} = \frac{600}{2\times 3} = 100\ kN/m^2$$

$$B = \text{Least lateral dimension of footing} = 2\text{ m}$$

$$\mu = 0.25$$

$$E_s = 20000\text{ kN/m}^2$$

$$I_f = 1.05$$

Immediate elastic settlement of the footing.

$$S_i = \frac{qI_fB(1-\mu^2)}{E_s} = \frac{100\times 1.05\times 2(1-0.25^2)}{20000}\text{ m} = 9.84\text{ mm}$$

58. (*)

Given $N_0 = 25, \quad \bar{\sigma}_0 = 105$ kPa

Overburden pressure correction,

$$N_1 = N_0\left(\frac{350}{\bar{\sigma}_0 + 70}\right) = 25\left(\frac{350}{105+70}\right)$$

$$N_1 = 50 > 15$$

Water table correction,

$$N_2 = 15 + \frac{(N_1 - 15)}{2} = 15 + \frac{(50-15)}{2} = 32.5$$

$\Rightarrow$ $N_2 \simeq 32$

59. (a)

60. (c)

$$Q_u = CN_C A_b + \alpha \bar{c} A_s$$

where $N_C = 9$

Safe load $$Q_{safe} = \frac{Q_u}{FOS} = \frac{CN_cA_b + \alpha\bar{c}A_s}{FOS}$$

$$= \frac{35\times 9\times \frac{\pi}{4}(0.3)^2 + 0.6\times 35\times(\pi\times 0.3\times 12)}{3.14} = 82.73\text{ kN}$$

$$\simeq 82.7\text{ kN}$$

61. (d)

Given: $n = 16, d = 0.40 \text{ m}, L = 10 \text{ m}$

Width of group $(B) = 3s + d = 3 \times 1.2 + 0.4 = 4 \text{ m}$

For the group
$$Q_{group} = C \times \text{perimeter} \times \text{length}$$
$$= 50 \times 4 \times 4 \times 10 = 8000 \text{ kN}$$

For the piles acting individually
$$Q_{pile} = n \,.\, Q_{up} = n \times \{\alpha\, C\, (\pi d L)\}$$
$$= 16 \times 0.8 \times 50 \times 3.14 \times 0.4 \times 10$$
$$= 8038.4 \text{ kN}$$

Load carrying capacity of pile group.
$$Q_{ug} = \min \{8000 \text{ kN}, 8038.4 \text{ kN}\}$$
$$Q_{ug} = 8000 \text{ kN}$$

62. (c)

- Capillary action generally increases the bearing capacity of soil by creating a tension between soil particles due to the upward pull of water molecules.
- The water in the soil pores experience a negative pore water pressure, which increases the effective stress
- Since bearing capacity of soil depends on effective stress so bearing capacity increases.

63. (c)

By Skempton's analysis.
$$q_{nu} = CN_C$$
$$C = \frac{UCS}{2} = \frac{108}{2} = 54 \text{ kN/m}^2$$
$$N_C = 5\left(1 + \frac{0.2D_f}{B}\right) \qquad \text{(for strip footing)}$$

Now;
$$q_{safe} = \frac{P_{safe}}{B} = \frac{q_{nu}}{FOS}$$
$$\Rightarrow \quad \frac{90}{B} = \frac{54N_C}{3} = 18 \times 5\left(1 + \frac{0.2 \times 1}{B}\right)$$
$$\Rightarrow \quad \frac{1}{B} = 1 + \frac{1}{5B}$$
$$\therefore \quad B = 0.8 \text{ m}$$

64. (c)

For sand deposit,
$$\frac{S_f}{S_P} = \left[\frac{B_f\left(B_P + 0.3\right)}{B_P\left(B_f + 0.3\right)}\right]^2$$

$$\frac{S_f}{10\text{ mm}} = \left[\frac{1.5(0.3+0.3)}{0.3(1.5+0.3)}\right]^2 = \left(\frac{1.5\times0.6}{0.3\times1.8}\right)^2$$

$$\Rightarrow \quad S_f = 27.78\text{ mm}$$

65. (a)

Given

Average sewage flow = 80×10^6 lt/day

Average 5 days BOD = 300 mg/lt

$$\text{Population equivalent} = \frac{BOD\text{ (5 days) of sewage}}{BOD\text{ (5 days of domestic sewage per person per day)}}$$

$$= \frac{80\times10^6\times300}{60\times10^3} = 4\text{ lakh}$$

66. (d)

Sludge age/Solids retention time

$$\theta_C = \frac{VX}{Q_w X_u}$$

Now,

$$\text{Volume } V = 30000\frac{\text{m}^3}{\text{day}}\times 6\text{ hr} \times \frac{1\text{ day}}{24\text{ hr}} = 7500\text{ m}^3$$

$$\theta_c = \frac{7500\times10^3\times2400}{3000\times10^6}\text{day} = 6\text{ days}$$

67. (a)

To minimize marine pollution:

- Sewage should be discharged only in deep lake areas to avoid the hypolimnion zone.
- The outfall sewer should be placed on a firm rock foundation.

68. (d)

Types of water body	K_R (20°C) per day
• Small Pond	0.05 – 0.10
• Large Lakes	0.10 – 0.15
• Large stream of low velocity	0.15 – 0.20
• Large stream of Normal velocity	0.20 – 0.30
• Swift streams	0.30 – 0.50
• Rapids and water falls	> 0.5

69. (b)

Eckenfelder developed an equation to measure the performance of trickling filter based on the rate of waste removal.

$$Y_t = Y_0 e^{-\frac{KD}{Q_o^n}}$$

where,
Y_0 = BOD_5 of the influent entering into the filter (mg/lt)
Y_t = BOD_5 of the effluent getting out of the filter (mg/lt)
K = Rate constant (per day)
D = Depth of filter (m)
Q_o = Hydraulic loading rate (m^3/day-m^3)

$$\text{BOD removal efficiency } (\eta) = \frac{(Y_0 - Y_t)}{Y_0} \times 100$$

From Eckenfelder equation, as depth (D) of filter increases, Y_t decreases.
If 'Y_t' decreases then efficiency increases.

70. (a)

$$V_2 = V_1\left(\frac{100 - P_1}{100 - P_2}\right)$$

$$\Rightarrow \quad V_2 = 90 \times \frac{(100-95)}{(100-85)} = 30 \text{ m}^3/\text{day}$$

71. (a)

$$NH_3 + 2O_2 \xrightarrow{\text{Micro-organism}} NO_3^- + H^+ + H_2O \quad (\text{Molecular mass of } NH_3 \text{ is 17 g/mol})$$

$$\text{Moles of } NH_3 = \frac{40 \text{ mg/lt}}{17 \text{ g/mol}} = 2.35 \times 10^{-3} \text{ mol/lt}$$

According to the stoichiometry, 1 mole of NH_3 requires 2 moles of O_2

∴ Moles of O_2 = 2.35×10^{-3} mol/lt × 2 = 4.7×10^{-3} mol/lt

∴ Mass of O_2 required per liter = $4.7 \times 10^{-3} \times 32$ gm/lt
= 150.4 mg/lt

72. (c)

- Ultimate BOD represents the total amount of oxygen required by micro-organisms to completely decompose the biodegradable organic matter in waste water under aerobic conditions.
- It does not depend on temperature and it is a function of the organic matter content in the waste water

Note: Temperature affects the rate of BOD exertion, but not the ultimate BOD.

73. (b)

Stabilization ponds are not primarily designed for nitrogen removal. They are more effective for organic matter degradation and pathogen removal. Nitrogen removal in stabilization ponds is limited and is not considered as a major process.

74. **(c)**

Inner piles should be driven first because if pile driving mechanism starts from the periphery, it would be uneconomical to drive the inner piles into the highly compacted ground.

75. **(a)**

Blanket rising occurs due to high sludge age.

$$\text{Sludge age } '\theta_c' = \frac{VX\downarrow}{Q_w X_u} \text{ and } \frac{F}{M} = \frac{Q_o S_o}{VX\downarrow}$$

An increase in F/M ratio decreases 'θ_c' which prevents blanket rising.

■■■■