DETAILED SOLUTIONS

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ESE 2023 : Prelims Exam
CLASSROOM TEST SERIES

CIVIL ENGINEERING

Test 4

Section A : Solid Mechanics [All Topics]
Section B : Environmental Engineering-I [Part Syllabus]
Section C : Geo-technical & Foundation Engineering-I [Part Syllabus]

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

Note:
(i) Q.9, Q.56 (Marks to all)
(ii) Revised answer key Q.28, Q.29

DETAILED EXPLANATIONS

1. (d)

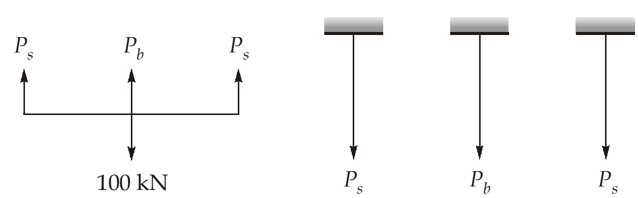
- In a tensile test on a mild steel specimen, as stress goes beyond the yield point, number of dislocations in the material increases. These new dislocations pile up at the grain boundaries and create a dislocation forest.
- This dislocation forest opposes the further movement of dislocation within the grain. The stress by which the dislocation forest opposes the movement of dislocation is called back stress, i.e., this back stress is now opposing the movement of dislocations occurring under tension.
- Now, when we unload the material and load in opposite direction (compression), the back stress will now support the movement of dislocation and hence yield point in compression will appear prematurely. This phenomenon is called **Baushinger effect**.
- Due to this phenomenon, when a mild steel specimen is subjected to tensile test cycle, elastic limit in tension is raised and elastic limit in compression is lowered. So, statement (1) is correct.
- Presence of microscopic cracks in brittle materials tend to weaken the materials in tension. Hence linear elastic range in compression is larger as compared to that in tension. So, statement (2) is correct.
- The characteristic of a material by which it undergoes inelastic strains beyond the strain at the elastic limit is known as plasticity. So, statement (3) is incorrect.

2. (a)

Here, stress is developed in the rods due to the load as well as temperature rise.

Let us assume tension in both steel and brass rods.

FBD:



Due to loading:

$$2P_s + P_b = 100$$

$$\Rightarrow \quad 2(\sigma_s A_s) + \sigma_b A_b = 100 \times 10^3$$

$$\Rightarrow \quad 2(\sigma_s \times 500) + \sigma_b \times 500 = 100 \times 10^3$$

$$\Rightarrow \quad 2\sigma_s + \sigma_b = 200 \quad \text{...(i)}$$

Due to temperature rise (assuming tension in both rods):

$$\Delta_s = \Delta_b$$

$$\Rightarrow \quad (l\alpha\Delta T)_s + \frac{\sigma_s l_s}{E_s} = (l\alpha\Delta T)_b + \frac{\sigma_b l_b}{E_b}$$

Since, $l_s = l_b$,

$$\therefore \quad 12\times10^{-6}\times50 + \frac{\sigma_s}{200\times10^3} = 18\times10^{-6}\times50 + \frac{\sigma_b}{100\times10^3}$$

$$\Rightarrow \quad \sigma_s - 2\sigma_b = 60 \quad \text{...(ii)}$$

Solving (i) and (ii)

$$\sigma_s = +92 \text{ MPa}, \quad \sigma_b = +16 \text{MPa}$$

+ve sign indicates that our assumption is correct and both the rods are in tension.

3. (c)

As we rotate the nut, nut moves inwards and applies compressive force on brass tube. Brass tube tries to resist this compression by applying force on the nut in opposite direction. Since the nut is moving on the steel bolt, this force on nut is transferred to steel bolt. So steel bolt will be in tension.

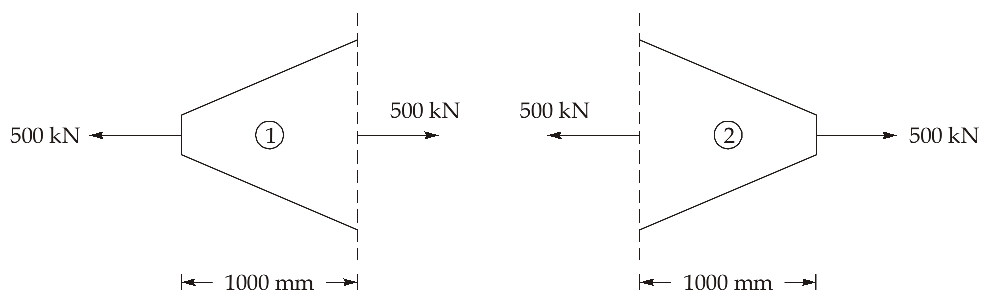
4. (c)

As per IS 210 : 2009 [Grey Iron casting specifications]

Annexure C: Typical properties of Gray Cast Iron, minimum modulus of elasticity in tension and compression (FG 150) is 100 GPa and it goes upto 145 GPA for FG 400.

- Modulus of elasticity of aluminium is one-third of that of the steel.

5. (a)

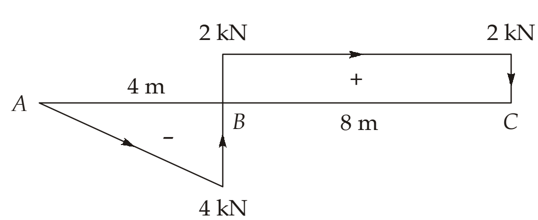


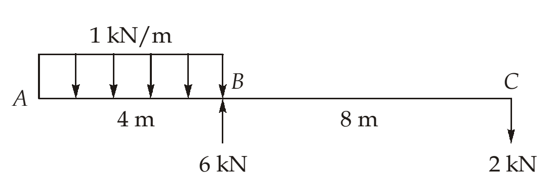
$$\text{Total elongation} = 2\times\left[\frac{PL}{(B_1-B_2)tE}\ln\left(\frac{B_1}{B_2}\right)\right]$$

$$= 2\times\left[\frac{500\times10^3\times1000}{(100-50)\times50\times200\times10^3}\ln\left(\frac{100}{50}\right)\right]$$

$$= 1.386 \text{ mm} \simeq 1.4 \text{ mm}$$

6. (c)





Loading diagram

From the loading diagram,

$$\Sigma M_c = 6 \times 8 - 4 \times 1 \times (8 + 2)$$
$$= 48 - 40$$
$$= 8 \text{ kN-m } (\Sigma M_c \neq 0)$$

∴ There is an concentrated moment of 8 kN-m on the beam which the shear force diagram could not sense. Due to this concentrated moment there would be a jump in the bending moment diagram. If there is a shear release just to the right of B, shear force would be zero there. From the given shear force diagram, shear force to the right of B is 2 kN. Hence there is no shear release in the beam.

7. (d)

Elongation due to self weight (Δ) = (Elongation of bar (1) due to its self weight) + (Elongation of bar (2) due to its self weight) + (Elongation bar (1) due to weight of bar (2))

$$\Rightarrow \quad \Delta = \frac{\gamma L^2}{2E} + \frac{\gamma L^2}{2E} + \frac{W_2 L}{A_1 E} \qquad \left(\because W_2 = \gamma(A_2 L) \text{ and } \frac{A_1}{A_2} = 4\right)$$

$$\Rightarrow \quad \Delta = \frac{\gamma L^2}{2E} + \frac{\gamma L^2}{2E} + \frac{\gamma L^2}{4E} = \frac{5\gamma L^2}{4E}$$

8. (d)

$$\text{Radius of the Mohr's circle } (r) = \tau_{max} = \sqrt{\left(\frac{p - p'}{2}\right)^2 + q^2}$$

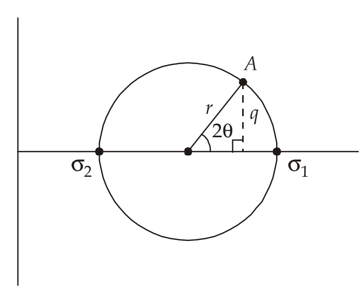
$$\Rightarrow \quad r = \frac{1}{2}\sqrt{(p - p')^2 + 4q^2}$$

Given that one of the planes is at an angle θ with the major principal plane. Angle on Mohr's circle would be 2θ.

$$\sin 2\theta = \frac{q}{r}$$

$$\Rightarrow \quad \sin 2\theta = \frac{q}{\frac{1}{2}\sqrt{(p - p')^2 + 4q^2}}$$

$$\Rightarrow \quad \sin 2\theta = \frac{2q}{\sqrt{(p - p')^2 + 4q^2}}$$



9. (*)

$$\sigma_1 = \frac{16}{\pi d^3}\left[M + \sqrt{M^2 + T^2}\right]$$

$$= \frac{16}{\pi d^3}\left[kT + \sqrt{k^2T^2 + T^2}\right] = \frac{16}{\pi d^3} \times T\left[k + \sqrt{1 + k^2}\right]$$

Now,

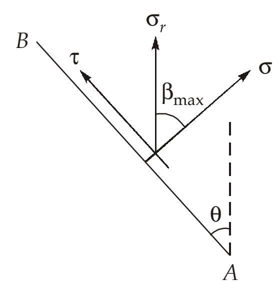
$$\tau_{max} = \frac{16}{\pi d^3}\sqrt{M^2 + T^2} = \frac{16}{\pi d^3}\sqrt{k^2T^2 + T^2}$$

$$\Rightarrow \qquad \tau_{max} = \frac{16T}{\pi d^3}\sqrt{1+k^2}$$

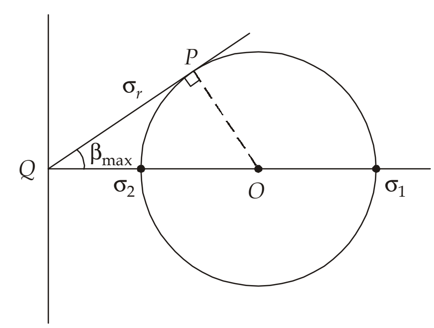
$$\therefore \qquad \frac{\sigma_1}{\tau_{max}} = \frac{k+\sqrt{1+k^2}}{\sqrt{1+k^2}}$$

10. (b)

Given, $\sigma_1 = 150\text{ N/mm}^2, \quad \sigma_2 = 50\text{ N/mm}^2$



Here, β_{max} is the angle made by the resultant stress with the normal.



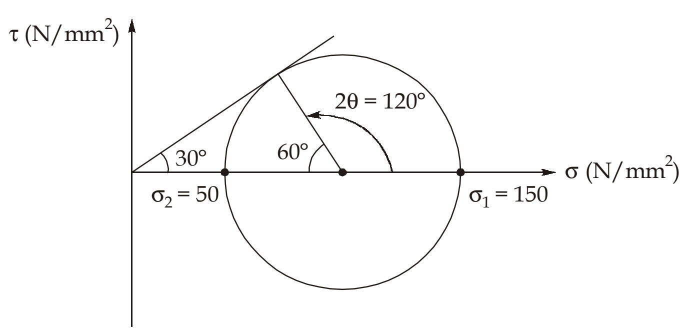
$$\sin(\beta_{max}) = \frac{OP}{OQ}$$

$$\Rightarrow \qquad \sin(\beta_{max}) = \frac{\frac{\sigma_1-\sigma_2}{2}}{\frac{\sigma_1+\sigma_2}{2}} = \frac{\sigma_1-\sigma_2}{\sigma_1+\sigma_2}$$

$$\beta_{max} = \sin^{-1}\left(\frac{\sigma_1-\sigma_2}{\sigma_1+\sigma_2}\right)$$

$$= \sin^{-1}\left(\frac{150-50}{150+50}\right) = \sin^{-1}\left(\frac{1}{2}\right) = 30°$$

Now by Mohr's circle,

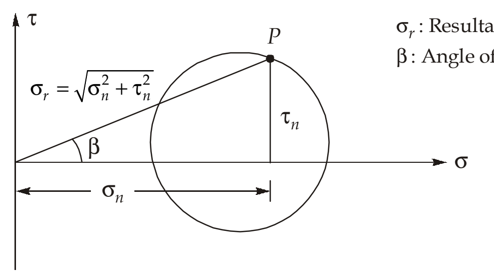


$$2\theta = 120°$$

$$\Rightarrow \qquad \theta = 60°$$

11. (d)

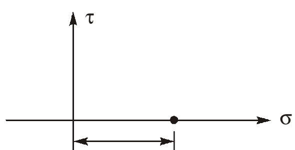
In general,



σ_r : Resultant stress on plane *P*

β : Angle of obliquity

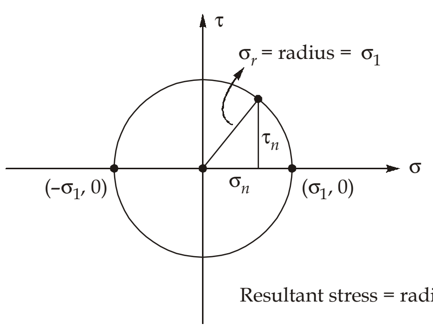
1.



$\sigma_r = \sigma_1$ on all planes, also angle of obliquity = 0

Major and minor principal stress = σ_1

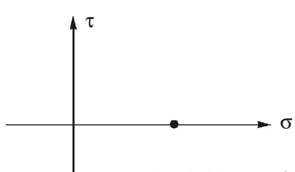
2.



Principal stress = $\sigma_1, -\sigma_1$

Resultant stress = radius = $\tau_{max} = \sigma_1$ = principal stress

3.



Angle of obliquity β = 0 Similar to 1

13. (c)

Maximum shear strain energy theory or distortion energy theory or Von-Mises's and Hencky's theory gives best results for ductile materials incase of pure shear.

14. (d)

Total strain energy per unit volume (U) = Volumetric strain energy per unit volume (U_v) + Shear strain energy per unit volume (U_s)

Total strain energy per unit volume (U) = $\frac{1}{2E}\left[\sigma_1^2+\sigma_2^2+\sigma_3^2-2\mu(\sigma_1\sigma_2+\sigma_2\sigma_3+\sigma_3\sigma_1)\right]$

Volumetric strain energy per unit volume (U_v) = $\frac{1}{2}\times\left(\frac{\sigma_1+\sigma_2+\sigma_3}{3}\right)\times\left(\frac{\sigma_1+\sigma_2+\sigma_3}{E}\right)(1-2\mu)$

$\left\{\text{i.e. } U_v=\frac{1}{2}\times \text{ Average stress}\times\text{Volumetric strain}\right\}$

∴ Shear strain energy per unit volume (U_s) = $U - U_v$

$$\Rightarrow \quad U_s = \frac{1}{12G}\left[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2\right]$$

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

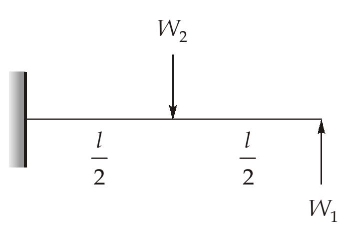
$$\Rightarrow \quad 200 = 2G(1+0.25)$$

$$\Rightarrow \quad G = \frac{200}{2\times 1.25} = 80 \text{ GPa}$$

$$\therefore \quad U_s = \frac{1}{12\times 80\times 10^3}\left[(50-40)^2+(40+30)^2+(-30-50)^2\right]$$

$$U_s = 0.011875 \text{ Nmm/mm}^3 \simeq 0.0119 \text{ Nmm/mm}^3$$

15. (b)



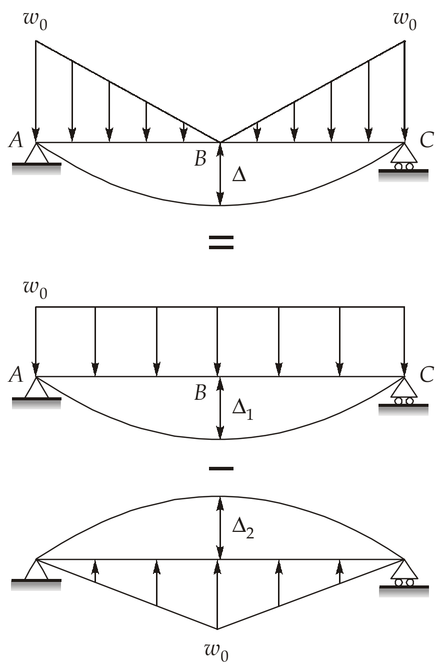
$$\text{Deflection at free end} = \frac{W_1 l^3}{3EI}-\left[\frac{W_2\left(\frac{l}{2}\right)^2}{6EI}\left(3(l)-\frac{l}{2}\right)\right]$$

$$= \frac{W_1 l^3}{3EI}-\frac{W_2 l^2}{24EI}\left(\frac{5l}{2}\right)$$

$$= \frac{W_1 l^3}{3EI}-\frac{5W_2 l^3}{48EI}$$

$$= \frac{l^3}{6EI}\left[2W_1-\frac{5}{8}W_2\right]$$

16. (c)

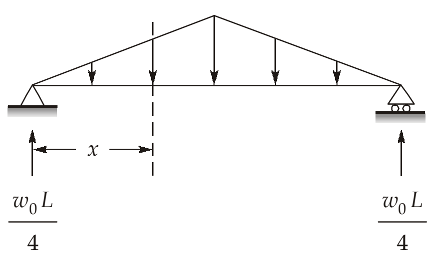


By principle of superposition,

$$\Delta = \Delta_1 - \Delta_2$$

$$\Delta_1 = \frac{5w_0 L^4}{384EI}$$

For Δ_2 :



$\left(x \text{ varies from 0 to } \frac{L}{2}\right)$

$$EI\frac{d^2y}{dx^2} = \frac{w_0 L}{4}x - \frac{1}{2} \times x \times \frac{2w_0 x}{x} \times \frac{x}{3} = \frac{w_0 L}{4}x - \frac{w_0 x^3}{3L}$$

$$EI\frac{dy}{dx} = \frac{w_0 L}{8}x^2 - \frac{w_0 x^4}{12L} + C_1$$

$$EI\, y = \frac{w_0 L}{x_1}x^3 - \frac{w_0 x^5}{60L} + C_1 x + C_2$$

Due to symmetry maximum deflection occurs at centre and slope is zero.

∴ At, $x = \frac{L}{2}, \quad \frac{dy}{dx} = 0$

$$\Rightarrow \qquad 0 = \frac{w_0 L^3}{32} - \frac{w_0 L^3}{192} + C_1$$

$$C_1 = \frac{w_0 L^3}{192} - \frac{w_0 L^3}{32} = -\frac{5w_0 L^3}{192}$$

$$\therefore \qquad EI\, y = \frac{50L}{x_1} x^3 - \frac{w_0 x^5}{60L} - \frac{5w_0 L^3}{192} x + C_2$$

At, $x = 0, \quad y = 0$

$$\Rightarrow \qquad 0 = C_2$$

$$\therefore \qquad EI\, y = \frac{w_0 L}{x_1} x^3 - \frac{w_0 x^5}{60L} - \frac{5w_0 L^3}{192} x$$

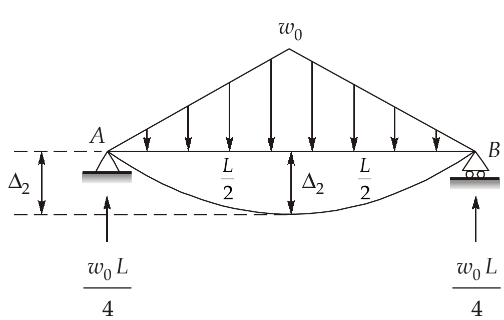
At, $x = \frac{L}{2}, \quad y = y_{max}$

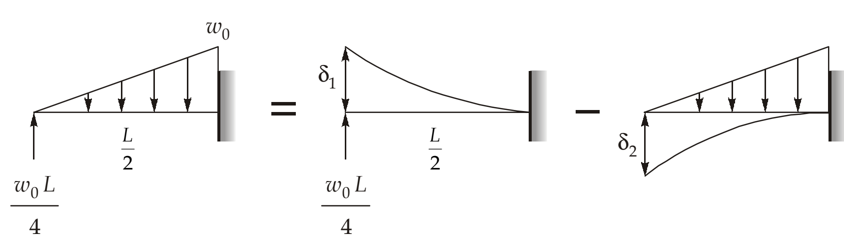
$$\Delta_2 = y_{max} = \frac{1}{EI}\left[\frac{w_0 L^4}{192} - \frac{w_0 L^4}{1920} - \frac{5w_0 L^4}{384}\right]$$

$$\Delta_2 = y_{max} = -\frac{w_0 L^4}{120EI} (\downarrow) \qquad \left\{\begin{array}{l}\text{But loading is upward} \\ \therefore \quad \Delta_2 = \dfrac{w_0 L^4}{120EI} (\uparrow)\end{array}\right\}$$

$$\Delta = \Delta_1 - \Delta_2 = \frac{5w_0 L^4}{384EI} - \frac{w_0 L^4}{120EI} = \frac{3w_0 L^4}{640EI}$$

Alternate solution:





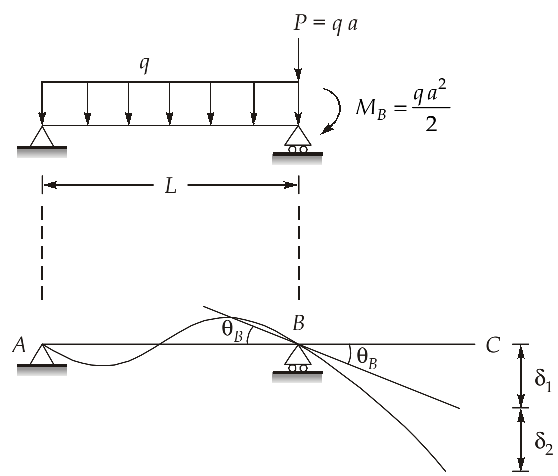
$$\Delta_2 = \delta_1 - \delta_2$$

$$\Delta_2 = \frac{\left(\frac{w_0 L}{4}\right)\left(\frac{L}{2}\right)^3}{3EI} - \frac{w_0 \left(\frac{L}{2}\right)^3}{30EI}$$

$$\Delta_2 = \frac{w_0 L^4}{120EI}$$

$$\Delta = \frac{5w_0 L^4}{384EI} - \frac{w_0 L^4}{120EI} = \frac{3w_0 L^4}{640EI}$$

17. (c)



$$\theta_B = -\frac{qL^3}{24EI} + \frac{M_B L}{3EI} = -\frac{qL^3}{24EI} + \frac{qa^2L}{6EI}$$

$$\delta_1 = \theta_B \times a = -\frac{qL^3}{24EI}a + \frac{qa^3L}{6EI}$$

$$\delta_2 = \frac{qa^4}{8EI}$$

$\therefore$

$$\delta_c = \delta_1 + \delta_2 = -\frac{qL^3}{24EI}a + \frac{qa^3L}{6EI} + \frac{qa^4}{8EI}$$

$$= \frac{qa}{24EI}\left[-L^3 + 4a^2L + 3a^3\right]$$

$$= \frac{qa}{24EI}\left[L(4a^2 - L^2) + 3a^3\right]$$

18. (b)

If several choices are available, select the lightest beam that will provide the required section modulus.

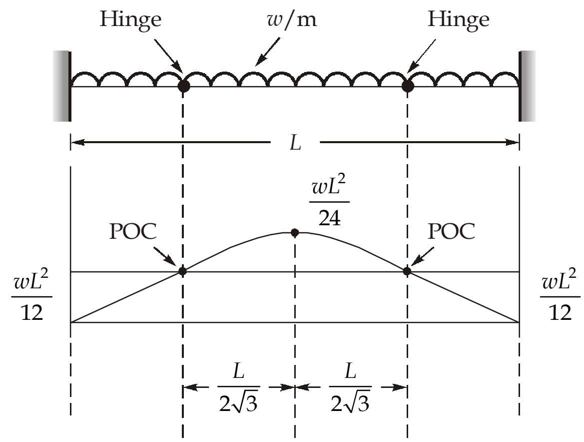
$$M_{max} = \frac{qL^2}{8} = \frac{4 \times (3)^2}{8} = 4.5 \text{ kN-m}$$

$$\text{Required section modulus } Z = \frac{M_{max}}{\sigma_{allow}} = \frac{4.5 \times 10^6}{12} = 0.375 \times 10^6 \text{ mm}^3$$

The lightest beam that supplies a section modulus of atleast 0.375×10^6 mm^3 about axis 1 – 1 is 75 mm × 200 mm beam.

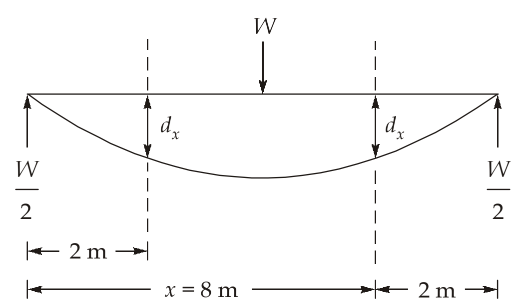
19. (a)

When hinges are introduced at the points of contra flexure of the fixed beam, the bending moment diagram and the elastic curve will be same as that of the fixed beam.
This type of construction is called double cantilever construction.



- Can also be verified by drawing free body diagram.

20. (d)



$\because \quad M = fz$

$\Rightarrow \quad f \times \frac{b d_x^2}{6} = \frac{W}{2} x$

$\Rightarrow \quad d_x = \sqrt{\frac{3W}{fb} x}$

$\therefore \quad d_x \propto \sqrt{x} \qquad \left(x < \frac{l}{2}\right)$

The section which is at 8 m from left support will be at 2 m from the right support and thus depth of beam at this section will also be 200 mm.

21. (c)

Moment shared by hatched area $(M) = \frac{\sigma_{max}}{y_{max}} \times I_A$

I_A = Moment of inertia of hatched area about N.A.

$= \frac{bh^3}{4}$

$$\therefore \quad M = \frac{\sigma_{max}}{y_{max}} \times I_A$$

$$\Rightarrow \quad M = \frac{10}{120} \times \frac{150 \times 120 \times 120 \times 120}{4} = 5400 \times 10^3 \text{ N-mm}$$

$$\Rightarrow \quad M = 5400 \text{ N-m}$$

22. (b)

$$\frac{(\sigma_{wood})_{max}}{15} = \frac{(\sigma_{wood})_{junction}}{12.5}$$

$$\Rightarrow \quad (\sigma_{wood})_{junction} = \frac{8}{15} \times 12.5 = 6.67 \text{ MPa} = \frac{20}{3} \text{ MPa}$$

$$m = \frac{E_s}{E_w} = \frac{200}{8} = 25$$

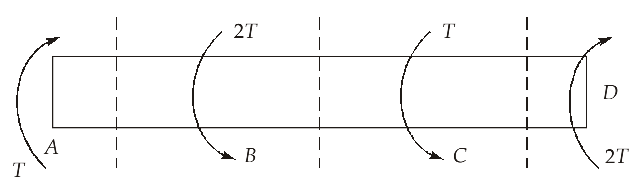
$$(\sigma_{steel})_{max} = 25 \times \frac{200}{3} = 166.67 \text{ MPa}$$

24. (d)

When a horizontal shaft is subjected to torsion, actual shear-stress is produced on the cross-section in circumferential direction.

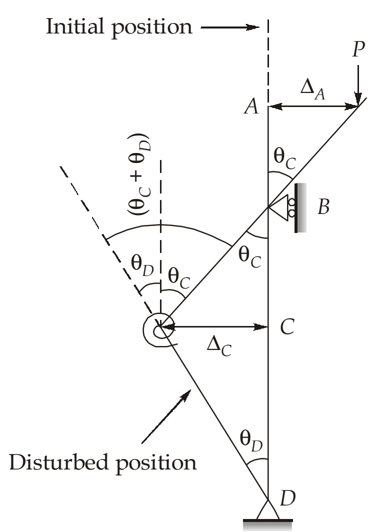
For a shaft subjected to torsion, the maximum shear-stress occurs at the surface of the shaft.

25. (d)

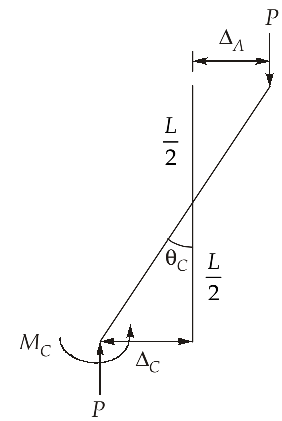


Portion *CD* is subjected to a maximum torque of 2*T*.

26. (d)



Free body diagram of *ABC* :



$$M_C = \beta(\theta_C + \theta_D)$$

$$\Delta_C = \theta_C \times \frac{L}{2} = \theta_D \times L$$

$$\Rightarrow \quad \theta_C = 2\theta_D$$

$$\therefore \quad M_C = \beta(3\theta_D)$$

For equilibrium,

$$P_{cr}(\Delta_A + \Delta_C) = M_C$$

$$\Delta_A = \Delta_C = \theta_C \times \frac{L}{2} = \theta_D L \quad \{\because \ \theta_C = 2\theta_D\}$$

$$\therefore \quad P_{cr}(\theta_D L + \theta_D L) = \beta(3\theta_D)$$

$$\Rightarrow \quad P_{cr} = \left(\frac{3}{2}\right)\left(\frac{\beta}{L}\right) = k\left(\frac{\beta}{L}\right)$$

$$\therefore \quad k = \frac{3}{2}$$

28. (a, b)

$$\tau_{max} = \frac{16PR}{\pi d^3} = \frac{16 \times 314 \times 60}{\pi \times 10^3}$$

$$\Rightarrow \quad \tau_{max} = 96 \text{ N/mm}^2$$

Exact solution:

$$\tau_{max} = \frac{16PR}{\pi d^3}\left(1 + \frac{d}{4R}\right) = \frac{16 \times 314 \times 60}{\pi \times 10^3}\left(1 + \frac{10}{4 \times 60}\right)$$

$$\Rightarrow \quad \tau_{max} = 100 \text{ N/mm}^2$$

29. (b, d)

In thick cylinder,

- The circumferential stress is tensile in nature and varies from maximum at inner surface to minimum at outer surface hyperbolically.
- The radial stress (fluid pressure) is compressive in nature and varies from maximum at inner surface to zero (which is minimum) at outer surface hyperbolically.

30. (a)

Volumetric strain, $\in_V = \in_L + 2\in_h$

$$\in_h = \frac{\sigma_h}{E} - \frac{\mu\sigma_L}{E} = \frac{PD}{2tE} - \mu\left(\frac{PD}{4tE}\right) = \frac{PD}{4tE}(2 - \mu)$$

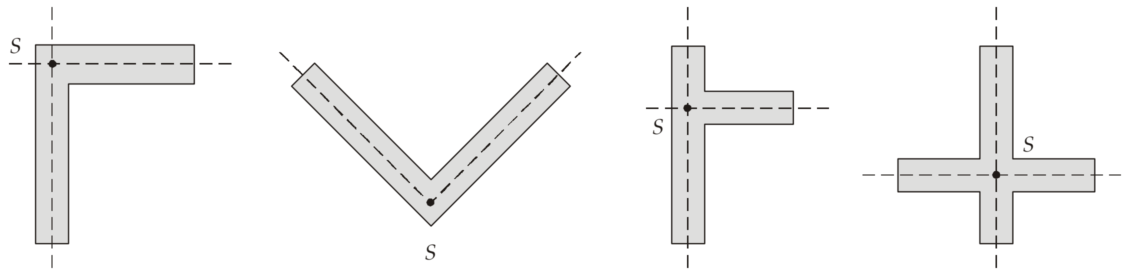
$$\in_L = \frac{\sigma_L}{E} - \frac{\mu\sigma_h}{E} = \frac{PD}{4tE} - \frac{\mu PD}{2tE} = \frac{PD}{4tE}(1 - 2\mu)$$

$$\in_V = \in_L + 2\in_h$$

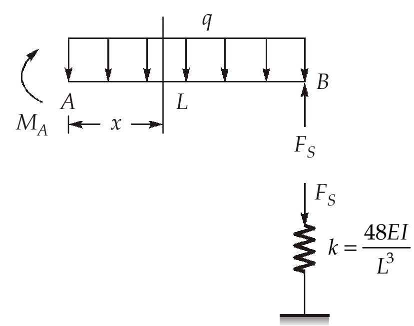
$$\Rightarrow \quad \in_V = \frac{PD}{4tE}(5 - 4\mu)$$

31. (b)

In case of sections consisting of two intersecting narrow rectangles, shear center lies at the point of intersection of the center lines of these legs.



32. (a)



$$\Sigma F_y = 0$$

$\Rightarrow$ $$F_s = qL$$

But $$F_s = k \times \delta_B$$

$\Rightarrow$ $$qL = \frac{48EI}{L^3}\delta_B$$

$\Rightarrow$ $$\delta_B = \frac{qL^4}{48EI} \quad \text{(downwards)}$$

$$\Sigma M_B = 0$$

$\Rightarrow$ $$M_A - \frac{qL^2}{2} = 0$$

$\Rightarrow$ $$M_A = \frac{qL^2}{2}$$

$$M_x = \frac{qL^2}{2} - \frac{qx^2}{2}$$

$\Rightarrow$ $$EI\frac{d^2y}{dx^2} = \frac{qL^2}{2} - \frac{qx^2}{2}$$

$\therefore$ $$EI\frac{dy}{dx} = \frac{qL^2}{2}x - \frac{qx^3}{6} + C_1$$

$$EI\,y = \frac{qL^2}{4}x^2 - \frac{qx^4}{24} + C_1x + C_2$$

At, $$x = 0, \frac{dy}{dx} = 0 \Rightarrow C_1 = 0$$

At, $$x = L, \frac{dy}{dx} = -\frac{qL^4}{48EI}$$

$$EI\left(-\frac{qL^4}{48EI}\right) = \frac{qL^4}{4} - \frac{qL^4}{x_1} + C_2$$

$$-\frac{qL^4}{48}+\frac{qL^4}{x_1}-\frac{qL^4}{4} = C_2$$

$$C_2 = \frac{(-1+2-12)qL^4}{48} = -\frac{11qL^4}{48}$$

$$y = \frac{1}{EI}\left[\frac{qL^2}{4}x^2-\frac{qx^4}{x_1}-\frac{11qL^4}{48}\right]$$

$$y = \frac{q}{48EI}\left[12L^2x^2-2x^4-11L^4\right]$$

$$y = -\frac{q}{48EI}\left[2x^4-12x^2L^2+11L^4\right]$$

33. (c)

At intermediate hinge, different slopes on either side of the hinge and deflection exists. At intermediate support, different shear force on either side of the support and bending moment exists.

35. (a)

Both Statement-I and Statement-II are true and Statement-II is the correct explanation of Statement-I.

36. (c)

If an area is symmetric about an axis, the centroid must lie on that axis because first moment of area about an axis of symmetry always equals to zero.

37. (c)

Discharge through an artesian aquifer,

$$Q = \frac{2\pi kD(H-h)}{2.303\log_{10}\left(\frac{R}{r}\right)}$$

Here,

$$D = 7 \text{ m}$$

$$H - h = \text{Drawdown in well} = 3 \text{ m}$$

$$R = 100 \text{ m}$$

$$r = \frac{20}{2} = 10 \text{ cm} = 0.1 \text{ m}$$

$$k = 0.23\ l/\text{s/m}^2 = 0.23 \times 10^{-3} \text{ m/s} = 2.3 \times 10^{-4} \text{ m/s}$$

Substituting,

$$Q = 2\times\frac{22}{7}\times\frac{2.3\times10^{-4}\times7\times3}{2.303\times\log_{10}\left(\frac{100}{0.1}\right)}$$

$$\approx 4.4 \times 10^{-3} \text{ m}^3/\text{s} \approx 4.4\ l/\text{s}$$

38. (d)

Industry	Water requirements (in kL per unit)
Distillary (kilolitre)	122 – 170
Fertilizer (tonne)	80 – 200
Water (100 kg)	4
Paper (tonne)	200 – 400
Steel (tonne)	200 – 250
Sugar (tonne)	1 – 2
Petroleum (tonne)	1.5 – 2.0

39. (c)

A dead-end system requires more number of scour valves and less number is of cut-off valves as compared to grid-iron system because the flow is not multi-directional as it in grid-iron system.

40. (d)

Aeration of water decreases the carbon dioxide content of water and thereby reduces its corrosiveness and raises its pH value.

41. (b)

$$\text{Weight of carbonates} = 120 \text{ mg}$$

$$\text{Number of milli equivalents of carbonates} = \frac{\text{Weight (in mg)}}{\text{Equivalent weight (in g)}} = \frac{120}{30} = 4$$

$$\text{Weight of bi-carbonates} = 61 \text{ mg}$$

$$\text{Number of milli equivalents of bi-carbonates} = \frac{\text{Weight (in mg)}}{\text{Equivalent weight (in g)}} = \frac{61}{61} = 1$$

$$\text{Weight of hydroxide} = 34 \text{ mg}$$

$$\text{Number of milli equivalents of hydroxide} = \frac{\text{Weight (in mg)}}{\text{Equivalent weight (in g)}} = \frac{34}{17} = 2$$

$$\text{Total number of milli equivalents (in 500 ml)} = 4 + 1 + 2 = 7$$

$$\text{Total number of milli equivalents in 1 litre solution} = \frac{7}{500} \times 1000 = 14 \text{ milli equivalents}$$

$$= 14 \times 50 = 700 \text{ mg}/l \text{ as } CaCO_3$$

42. (c)

$$\text{Number of milli equivalents of } Ca^{2+} = \frac{40}{20} = 2$$

$$\text{Number of milli equivalents of } Mg^{2+} = \frac{48}{12} = 4$$

$$\text{Number of milli equivalents of } Na^{+} = \frac{69}{23} = 3$$

The number of milli equivalents of anions should also sum upto 9 to maintain the cation-anion balance. In all the options, sum of milli equivalents of anions is 9.

Also, we know that when Cl^- and SO_4^{2-} will be present, Na^+ will not combine with HCO_3^-, i.e. if 3 milli equivalents of Na^+ are present then maximum 6 milli equivalents of HCO_3^- can be present, with Cl^- and SO_4^{2-} being present in the sample.

$$6 \text{ milli equivalents } HCO_3^- = 6 \times 61 = 366 \text{ mg}/l$$

Thus concentration given in option (3) is not possible.

In option (4), Cl^- and SO_4^{2-} are missing, so Na^+ can combine with HCO_3^- and 9 milli equivalents of HCO_3^- will be present.

$$9 \text{ milli equivalents } HCO_3^- = 9 \times 61 = 549 \text{ mg}/l$$

$\therefore$ Options (1), (2) and (4) are possible values of the concentrations of the given anions.

Option (c) is the right answer.

43. (b)

$Cl_2 \rightarrow pH < 5$

$NH_2Cl \rightarrow pH > 7.5$

$NHCl_2 \rightarrow 5 < pH < 7$

$HOCl \rightarrow 5 < pH < 7$ (Predominates as compared to OCl^-)

$OCl^- \rightarrow pH > 8$ (Predominates as compared to HOCl)

$NCl_3 \rightarrow pH < 4.4$

44. (c)

For chimney emitting SO_2,

Height of chimney, $h = 14\,(Q_s)^{1/3}$ metres

$Q_s = SO_2$ emission in kg/hr

Here, $Q_s = \dfrac{648}{24} = 27$ kg/hr

$h = 14\,(27)^{1/3} = 14 \times 3 = 42$ m

45. (d)

As per Noise Pollution (Regulation and Control) Rules, 2000

Category of Area / Zone	(Limits in dB)	
	Day time	Night time
Industrial area	75	70
Commercial area	65	55
Residential area	55	45
Silence zone	50	40

Note: Also, refer table 2 of IS : 4954 - 1968, Page 6

46. (c)

$$\text{Sound pressure level (dB)} = 20\log_{10}\left(\frac{P}{P_0}\right)$$

$$P_0 \text{ (Reference pressure)} = 2 \times 10^{-5} \text{ N/m}^2$$

$$P \text{ (Sound pressure)} = 4000 \ \mu \text{ bar}$$
$$= 4000 \times 10^{-6} \times 10^{5} \text{ N/m}^2$$
$$= 400 \text{ N/m}^2$$
$$\text{SPL} = 20\log_{10}\left(\frac{400}{2\times10^{-5}}\right)$$
$$= 20 \log_{10} (2 \times 10^7)$$
$$= 20 [(\log_{10} 2) + 7]$$
$$= 20 \times 7.3 = 146 \text{ dB}$$

47. (b)

Effective diameter 'D_{10}' → 0.45 to 0.7 mm

Rate of filtration → 3000 to 6000 litres/hr/m^2 or 50 to 100 litres/min/m^2

Depth of sand → 0.6 to 0.75 m

Uniformity coefficient → 1.2 to 1.7

48. (d)

London Smog is also known as Classical Smog. It is formed in the months of winter, particularly in the morning hours when temperature is low.

49. (b)

$$\text{Water obtained} = 2 \times 10^6 \text{ m}^3$$
$$\text{Volume of aquifer drained} = 200 \times 10^4 \times 5 \text{ m}^3$$
$$\text{Specific yield} = \frac{2\times10^6}{200\times10^4\times5} = 0.2$$
$$\text{Porosity} = \text{Specific yield + Specific retention}$$
$$\Rightarrow \quad 0.35 = 0.2 + \text{Specific retention}$$
$$\Rightarrow \quad \text{Specific retention} = 0.15$$

50. (b)

Efficiency of a filter in bacterial removal 'η' = 90% = 0.9

If N filters are arranged in series then,

$$\text{Overall efficiency } '\eta_0' = \eta + \eta(1-\eta) + \eta(1-\eta)(1-\eta) \text{ .... } N \text{ terms}$$
$$\Rightarrow \quad \eta_0 = \frac{\eta(1-(1-\eta)^N)}{1-(1-\eta)} = 1-(1-\eta)^N$$

But, $$\eta_0 = 99.99\% = \frac{99.99}{100} = 0.9999$$

and $$\eta = 0.9$$

Putting values,

$$0.9999 = 1 - (1-0.9)^N$$
$$\Rightarrow \quad (0.1)^N = 0.0001$$
$$\Rightarrow \quad N = 4$$

So, 4 filters are required to be provided in series.

52. (b)

$$\text{Population} = 100000 = 100 \text{ thousands}$$

As per Kuchling's formula,

$$Q_k = 3182\sqrt{P}\ l/\text{min}$$
$$= 3182\sqrt{100} = 31820\ l/\text{min}$$

As per Freeman's formula,

$$Q_f = 1136\left[\frac{P}{5}+10\right] = 1136\left[\frac{100}{5}+10\right] = 34080\,l/\text{min}$$

53. (b)

Discharge, Q = 6 MLD

$= 6 \times 10^6\ l/\text{day}$

Alum dose = 37 mg/l

Total amount of alum required = $37 \times 6 \times 10^6$ mg = 37×6 kg

$Al_2(SO_4)_3 \cdot 18\ H_2O + 3Ca(HCO_3)_2 \rightarrow 2Al(OH)_3 + 3CaSO_4 + 6CO_2 + 18H_2O$

666 g of alum produced 156 g of $Al(OH)_3$

For 37 × 6 kg of alum, $Al(OH)_3$ produced = $\frac{156}{666} \times 37 \times 6 = 52$ kg

54. (d)

Settling velocity 'V_s' will be 4 times only when both the particle undergo laminar settling.

For instance if 'd' is 0.08 mm, $2d$ will be 0.16 mm and laminar settling will not take place for particle of '$2d$' diameter.

55. (d)

In Baylis turbidimeter, light intensity is measured in the direction of incident light, while in nephlometer, light intensity is measured at right angles to the incident ray. Hence Baylis turbidimeter is based on absorption principle, while nephlometer is based on scattering principle.

57. (c)

Flow always takes place along the flow lines and perpendicular to equipotential lines.

58. (d)

$$i = (G - 1)(1 - n)$$

But, $$i = \frac{\gamma'}{\gamma_w}$$

$\Rightarrow$ $$i = \frac{\gamma_{sat} - \gamma_w}{\gamma_w}$$

59. (c)

$$RD = \frac{e_{max} - e}{e_{max} - e_{min}}$$

$$\gamma_d = \frac{\gamma}{1+w} = \frac{1.95}{1+0.2} = \frac{1.95}{1.2} = 1.625 \text{ g/cc}$$

Also, $$\gamma_d = \frac{G\gamma_w}{1+e}$$

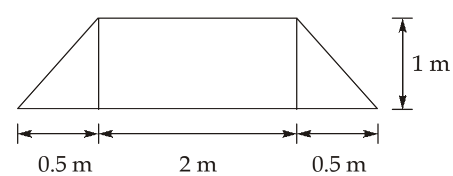
$\Rightarrow$ $$1 + e = \frac{2.65 \times 1}{1.625}$$

$\Rightarrow$ $$e = 0.63$$

$\therefore$ $$RD = \frac{0.9 - 0.63}{0.9 - 0.5} = \frac{0.27}{0.4} = 0.675 \text{ or } 67.5\%$$

60. (d)

$$\Delta\sigma = \frac{q \times L \times B}{(B+1)(L+1)}$$



$\Rightarrow$ $$\Delta\sigma = \frac{60 \times 2 \times 4}{(2+1)(4+1)}$$

$\Rightarrow$ $$\Delta\sigma = \frac{60 \times 8}{3 \times 5} = 32 \text{ kN/m}^2 \text{ or } 32 \text{ kPa}$$

62. (b)

$$I_{P_1} = 48 - 24 = 24\%$$

$$I_{P_2} = 0.73\,(w_L - 20)$$

$$= 0.73\,(48 - 20) = 20.44\%$$

$$I_{P_1} > I_{P_2} \Rightarrow \text{Clay i.e. C}$$

Also, $50\% > w_L > 35\% \Rightarrow$ I

Group symbol is CI i.e. clay of intermediate compressibility.

63. (a)

$$i_{exit} = \frac{\Delta H}{l} = \frac{\frac{H}{N_d}}{l}$$

$\Rightarrow$ $$i_{exit} = \frac{\left(\frac{8}{8}\right)}{0.8} = \frac{1}{0.8} = 1.25$$

64. (a)

$$H_C = \frac{4C}{\gamma\sqrt{k_a}} = \frac{4\times 20}{20\sqrt{1}} = 4 \text{ m}$$

$$F = \frac{1}{2}k_a\gamma H^2 - 2C\sqrt{k_a}\,H$$

$\Rightarrow$
$$F = \frac{1}{2}\times 1\times 20\times 4^2 - 2\times 20\times\sqrt{1}\times 4$$
$$= 160 - 160 = 0$$

65. (c)

$$C_c = \frac{D_{30}^2}{D_{60}\times D_{10}} = \frac{0.48\times 0.48}{0.12\times 0.72} = 2.67$$

$$C_u = \frac{D_{60}}{D_{10}} = \frac{0.72}{0.12} = 6$$

For well-graded gravel

$$1 < C_c < 3$$
$$C_u > 4$$

For well-graded sand

$$1 < C_c < 3$$
$$C_u > 6$$

66. (d)

$$k = \frac{al}{At}\ln\frac{h_1}{h_2}$$

For the same sample

$$\frac{1}{t_1}\ln\left(\frac{h_1}{h_2}\right) = \frac{1}{t_2}\ln\left(\frac{h_2}{h_3}\right)$$

$$\frac{1}{t}\ln\left(\frac{h}{\frac{3h}{4}}\right) = \frac{1}{\frac{t}{2}}\ln\left(\frac{\frac{3h}{4}}{h'}\right)$$

$$\ln\frac{4}{3} = 2\ln\left(\frac{3h}{4h'}\right)$$

$$\frac{4}{3} = \left(\frac{3h}{4h'}\right)^2$$

$$h'^2 = \frac{27h^2}{64}$$

$$h' = \frac{3\sqrt{3}}{4\sqrt{4}}h = \frac{3}{4}\sqrt{\frac{3}{4}}h$$

67. **(c)**

For a soil,

Void ratio : $e > 0$

Porosity : $0 < n < 100\%$

Degree of Saturation : $0 \le S \le 1$

Water content : $w \ge 0$

68. **(a)**

$$e = \frac{V_v}{V_s}$$

$$\frac{V_v + V_s}{V_s} = e + 1$$

$$\frac{V_T}{V_s} = 1 + e \quad \Rightarrow \quad V_T \propto 1 + e$$

$$\frac{V_{T_1}}{V_{T_2}} = \frac{1+e_1}{1+e_2}$$

$$\frac{8}{20} = \frac{1+e_1}{1+e_2}$$

$$e = \frac{n}{1-n} = \frac{0.18}{1-0.18} = 0.219$$

$$\frac{8}{20} = \frac{1+0.219}{1+e_2}$$

$$e_2 = 2.048$$

69. **(a)**

For a saturated clay water undrained condition,

$$\phi_u = 0°$$

$$\tau_u = C_u + \sigma \tan \phi_u$$

$$\tau_u = C_u$$

70. **(b)**

$$F_a = \frac{k_a \gamma H^2}{2} - 2c\sqrt{k_a}\, H + \frac{2c^2}{\gamma}$$

$$k_a = 1 \text{ (soft clay)}$$

$$F_a = \frac{1}{2} \times 18 \times 8^2 - 2 \times 20 \times 8 + \frac{2 \times 20^2}{18}$$

$$= 576 - 320 + 44.444 = 300.44 \text{ kN/m}$$

71. (c)

$$m_V = \frac{a_v}{1+e_0} \rightarrow \frac{m^2}{N}$$

$$m_V \rightarrow \frac{m^2}{kg \times \frac{m}{s^2}}$$

$$m_V \rightarrow \frac{ms^2}{kg}$$

$$m_V \rightarrow \frac{LT^2}{M}$$

72. (c)

Pneumatic tyred rollers can be used for gravel, sand, clayey soils, silts.

73. (a)

$$e \times s = wG$$

$$e = \frac{0.15 \times 2.8}{0.84} = 0.5$$

$$\gamma_d = \frac{G\gamma_w}{1+e} = \frac{2.8 \times 1}{1.5} = 1.86 \text{ g/cc}$$

74. (c)

Transformed section never shows the true picture of flow net. True picture can only be obtained by analyzing the flow in original conditions.

75. (c)

A sand soil becomes quick when the flow is upward only under a hydraulic gradient which reduces the effective stress to zero.

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