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ESE 2023 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Civil Engineering

Test-5

Flow of fluids, Hydraulic machines and Hydro power [All Topics]
Design of Concrete and Masonry Structures-1 [Part Syllabus]
+ Geo-technical & Foundation Engineering-2 [Part Syllabus]

Name : ....

Roll No :

Test Centres	Student's Signature
Delhi ☑ Bhopal ☐ Jaipur ☐ Pune ☐ Kolkata ☐ Bhubaneswar ☐ Hyderabad ☐	

Instructions for Candidates

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. There are Eight questions divided in TWO sections.
3. Candidate has to attempt FIVE questions in all in English only.
4. Question no. 1 and 5 are compulsory and out of the remaining THREE are to be attempted choosing at least ONE question from each section.
5. Use only black/blue pen.
6. The space limit for every part of the question is specified in this Question Cum Answer Booklet. Candidate should write the answer in the space provided.
7. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
8. There are few rough work sheets at the end of this booklet. Strike off these pages after completion of the examination.

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	27
Q.2	38
Q.3	—
Q.4	—
Section-B	
Q.5	37
Q.6	44
Q.7	29
Q.8	—
Total Marks Obtained	175

Signature of Evaluator: A. Kumar .... Cross Checked by ....

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IMPORTANT INSTRUCTIONS

CANDIDATES SHOULD READ THE UNDERMENTIONED INSTRUCTIONS CAREFULLY. VIOLATION OF ANY OF THE INSTRUCTIONS MAY LEAD TO PENALTY.

DONT'S

1. Do not write your name or registration number anywhere inside this Question-cum-Answer Booklet (QCAB).
2. Do not write anything other than the actual answers to the questions anywhere inside your QCAB.
3. Do not tear off any leaves from your QCAB, if you find any page missing do not fail to notify the supervisor/invigilator.
4. Do not leave behind your QCAB on your table unattended, it should be handed over to the invigilator after conclusion of the exam.

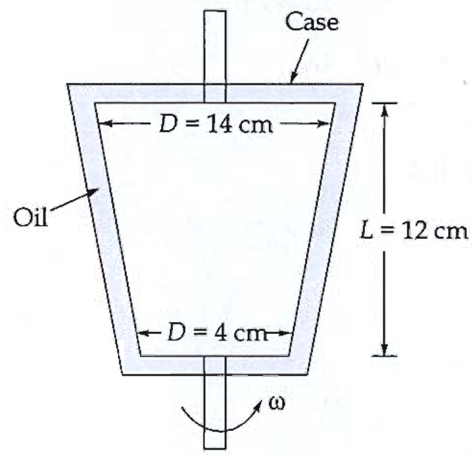
DO'S

1. Read the Instructions on the cover page and strictly follow them.
2. Write your registration number and other particulars, in the space provided on the cover of QCAB.
3. Write legibly and neatly.
4. For rough notes or calculation, the last two blank pages of this booklet should be used. The rough notes should be crossed through afterwards.
5. If you wish to cancel any work, draw your pen through it or write "Cancelled" across it, otherwise it may be evaluated.
6. Handover your QCAB personally to the invigilator before leaving the examination hall.

- Excellent work in Section-B
- presentation is good.
- Accuracy is good.
- Keep practising.

Section A : Flow of fluids, Hydraulic machines and Hydro power

Q.1 (a) A frustum-shaped body is rotating at a constant angular speed of 100 rad/s in a container filled with an oil of viscosity 0.099 Pa.s, as shown in figure. If the thickness of the oil film on all sides is 1.4 mm, determine the power required to maintain this motion.

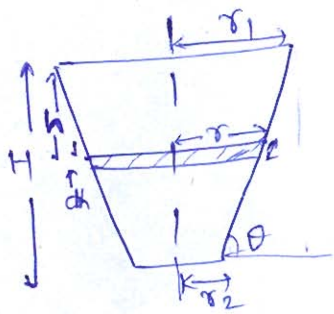


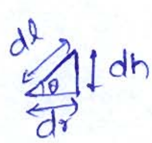
[12 marks]

$\omega = 100$ rad/s $\mu = 0.099$ Pa.sec

$t = 1.4$ mm. $r_1 = 7$ cm. $r_2 = 2$ cm $H = 12$ cm.

$\theta = \tan^{-1}\left(\frac{12}{5}\right) = 67.38^\circ$





$dl = \frac{dh}{\sin\theta}$

$r = r_1 - \left(\frac{r_1 - r_2}{L}\right) \cdot h$

$= 0.07 - \left(\frac{0.07 - 0.02}{0.12}\right) h$

$r = \left[0.07 - \frac{5}{12} h\right]$

(3)

Power required $dP = dT \cdot \omega$

$= dF \cdot r \cdot \omega = \tau \cdot dA \cdot r \cdot \omega$

$= \mu \cdot \frac{du}{dy} \cdot r \cdot \omega \cdot dA$

$= \mu \cdot \frac{(\omega r - 0)}{t} r \omega \cdot 2\pi r \cdot dl$

$dP = \frac{\mu \omega^2 \cdot 2\pi}{t} r^3 \cdot \frac{dh}{\sin\theta}$

$\Rightarrow \int dP = \frac{\mu \omega^2 2\pi}{t \sin\theta} \int_0^{0.12} \left[0.07 - \frac{5}{12} h\right]^3 dh$

$$P = \frac{0.099 \times 100^2 \times 2\pi}{1.4\times 10^{-3} \times \sin(67.38^\circ)} \times \left(\frac{-12}{5}\right) \times \frac{1}{4}\left[0.07 - \frac{5}{12}h\right]_0^{0.12}$$

$$= -2888024.083 \times [0.02 - 0.07)$$

$$P = 144401.2042\ W$$

$$\Rightarrow \boxed{P = 144.40\ kW}$$

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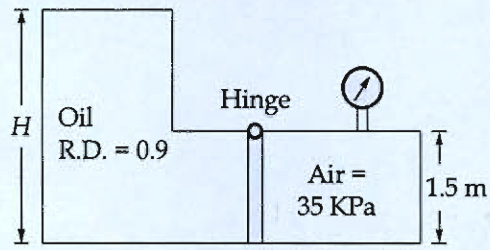
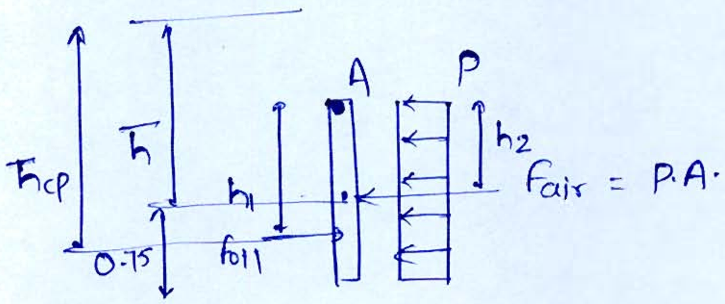
Q.1 (b) For the system shown in figure, calculate the height H of oil at which the rectangular hinged gate will just being to rotate counterclockwise.



[12 marks]



$\bar{h}$ = for oil free surface

$\bar{h} = (H-0.75)$

$\bar{h}_{cp} = \bar{h} + \frac{I_G \sin^2\theta}{A\bar{h}} = (H-0.75) + \frac{0.6\times(1.5)^3}{12 * 1.5\times0.6\times(H-0.75)}$

$\bar{h}_{cp} = (H-0.75) + \frac{0.1875}{(H-0.75)}$

$h_1 = \bar{h}_{cp} - (H-1.5)$

$= (H-0.75) + \frac{0.1875}{H-0.75} - H + 1.5$

$h_1 = \left[0.75 + \frac{0.1875}{H-0.75}\right]$

$F_{oil} = \rho_{oil} g \bar{h} A$

$= 900\times9.81\times(H-0.75)\times1.5\times0.6$

$F_{oil} = 7946.1(H-0.75)$ N

$F_{air} = P.A = 35\times10^3\times1.5\times0.6 = 31500$ N

$h_2 = \frac{1.5}{2} = 0.75$ m,

Taking Moment about Hinge point

$F_{oil} \times h_1 = F_{air} \times h_2$

$\Rightarrow 7946.1 \times (H - 0.75) \times \left[0.75 + \frac{0.1875}{H - 0.75}\right] = 31500 \times 0.75$

$\Rightarrow 5959.575H - 4469.68125 + 1489.89375 = 23625$

$\Rightarrow \boxed{H = 4.464 \text{ m.}}$

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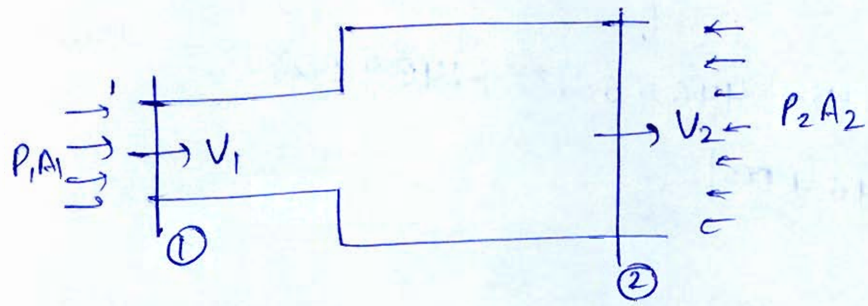
Q.1 (c) Determine the optimum ratio between the diameter of the pipe before expansion and the diameter of the pipe after expansion so that pressure rise may be maximum for sudden expansion in pipe flow. What will be the corresponding pressure rise?

[12 marks]



Applying energy equation between ① & ②

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + z_2 + h_L$$

since $h_L = \frac{(V_1 - V_2)^2}{2g}$

$$\Rightarrow \frac{P_1}{\rho g} + \frac{V_1^2}{2g} = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + \frac{(V_1 - V_2)^2}{2g}$$

$$\Rightarrow \left(\frac{P_2}{\rho g} - \frac{P_1}{\rho g}\right) = \frac{V_1^2}{2g} - \frac{V_2^2}{2g} - \frac{(V_1 - V_2)^2}{2g} \quad -①$$

pressure rise

$$Q = A_1 V_1 = A_2 V_2$$

$$\Rightarrow \frac{\pi}{4} d_1^2 V_1 = \frac{\pi}{4} d_2^2 V_2$$

let $d_2 = k d_1$

$$\Rightarrow V_1 = \frac{d_2^2}{d_1^2} V_2$$

$$\Rightarrow V_1 = k^2 V_2$$

So by eqn ①

$$\frac{P_2 - P_1}{\rho g} = \frac{k^4 V_2^2}{2g} - \frac{V_2^2}{2g} - \frac{(k^2 V_2 - V_2)^2}{2g}$$

$$= \frac{V_2^2}{2g}\left[k^4 - 1 - k^4 - 1 + 2k^2\right]$$

$$\frac{P_2-P_1}{\rho g} = \frac{1}{2g}\left[V_1^2 - V_2^2 - V_1^2 - V_2^2 + 2V_1V_2\right]$$

$$= \frac{1}{2g}\left[2V_1V_2 - 2V_2^2\right]$$

$$= \frac{1}{g}\left[V_1V_2 - V_2^2\right]$$

$$= \frac{1}{g}\left[k^2V_2^2 -\right.$$

$$= \frac{16Q^2}{\pi^2 g}\left[\frac{1}{d_1^2 d_2^2} - \frac{1}{d_2^4}\right]$$

$$= \frac{16Q^2}{\pi^2 g}\left[\frac{1}{d_1^2 k^2 d_1^2} - \frac{1}{k^4 d_1^4}\right]$$

$$\frac{P_2-P_1}{\rho g} = \frac{16Q^2}{\pi^2 g . d_1^4}\left[\frac{1}{k^2} - \frac{1}{k^4}\right]$$

$$\left[\frac{Q^2}{d_1^2 d_2^2} - \frac{Q^2}{d_2^4}\right]$$

$$\left[\frac{1}{k^2 d_2^4} - \frac{1}{d_2^4}\right]$$

$$\frac{-2}{k^3} -$$

12

for Max^m pressure rise

$$\frac{d\left(\frac{P_2-P_1}{\rho g}\right)}{dk} = 0 \quad \Rightarrow \quad \frac{16Q^2}{\pi^2 g d_1^4}\left[\frac{-2}{k^3} + \frac{4}{k^5}\right] = 0$$

$$\Rightarrow -2k^5 + 4k^3 = 0$$

$$\Rightarrow k^3\left[k^2 - 2\right] = 0$$

$$\Rightarrow \boxed{k = \sqrt{2}}$$

So $\boxed{\frac{D_2}{D_1} = \sqrt{2}}$

Corresponding Max^m pressure rise

$$\frac{P_2-P_1}{\rho g} = \frac{16Q^2}{\pi^2 g d_1^4}\left[\frac{1}{2} - \frac{1}{4}\right]$$

$$\left(\frac{4Q}{\pi d_1^2}\right)^2 = V_1^2$$

$$\boxed{\left(\frac{P_2-P_1}{\rho g}\right)_{max^n} = \frac{V_1^2}{4g}}$$

Q.1 (d) (i) Explain cavitation in reaction turbine. What is Thoma's cavitation factor?

(ii) A conical draft tube having inlet and outlet diameters 0.8 m and 1.2 m respectively discharges water at outlet with a velocity of 3 m/sec. The total length of the draft tube is 8 m and 2 m of the length of draft tube is immersed in water. If the atmospheric pressure head is 10.3 m of water and loss of head due to friction in the draft tube is equal to 0.25 times the velocity head at outlet of the tube then find:

1. Pressure head at inlet.
2. Efficiency of the draft tube.

[4 + 8 marks]

Q.1 (e) (i) Write the assumptions made in the derivation of depth of hydraulic jump.

(ii) A sluice gate discharges water into a horizontal rectangular channel with a velocity of 10 m/s and depth of flow of 1 m. Determine the depth of flow after the jump and consequent loss in total head.

[12 marks]

Q.2 (a) (i) A siphon consisting of a pipe of 20 cm diameter is used to empty oil of relative density 0.85 from tank *A*. The siphon discharges to the atmosphere at an elevation of 2.00 m. The oil surface in the tank is at an elevation of 5.00 m. The centreline of the siphon pipe at its highest point C is at an elevation of 6.50 m. Estimate:

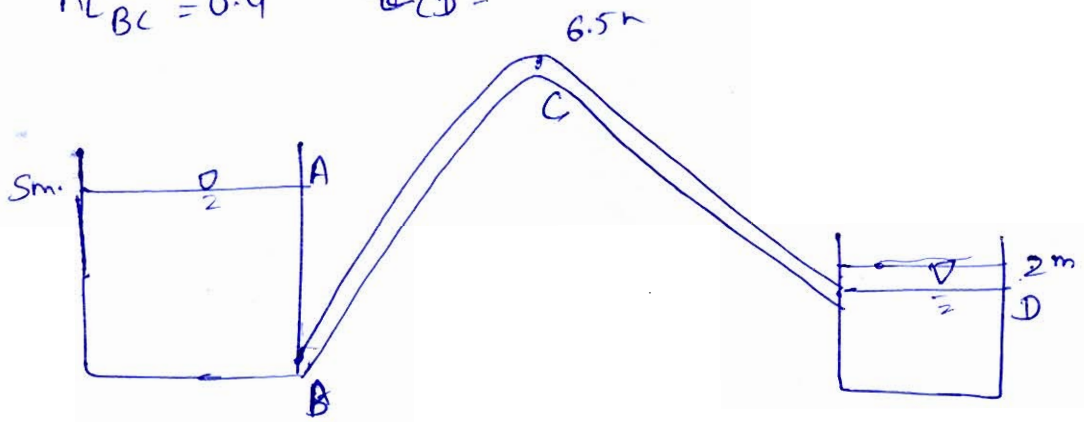
1. the discharge in pipe.
2. pressure at point C.

The losses in the pipe can be assumed to be 0.4 m up to the summit and 1.2 m from the summit to the outlet.

[12 marks]

$\rho = 850\ kg/m^3$ $d = 0.2 m.$

$h_{L_{BC}} = 0.4$ $h_{L_{CD}} = 1.2 m$



(i) Applying energy eqn b/w A & D

$$\frac{P_A}{\rho g} + \frac{V_A^2}{2g} + z_A = \frac{P_D}{\rho g} + \frac{V_D^2}{2g} + z_D + h_{L_{BC}} + h_{L_{CD}}$$

$$\Rightarrow 0 + 0 + 5 = 0 + 0 + 2 + 0.4 + 1.2 + \frac{V_D^2}{2g}$$

$$\Rightarrow V_D = 5.241\ m/s$$

Discharge in pipe $= A.V_D$

$= \frac{\pi}{4} \times 0.2^2 \times 5.241 \times 10^3$

$Q = 164.65\ l/s$

(ii) For pressure at C

Applying energy eq^n b/w A & C

$$\frac{P_A}{\rho g} + \frac{V_A^2}{2g} + Z_A = \frac{P_C}{\rho g} + \frac{V_C^2}{2g} + Z_C + h_{LBC}$$

$V_C = V_D$

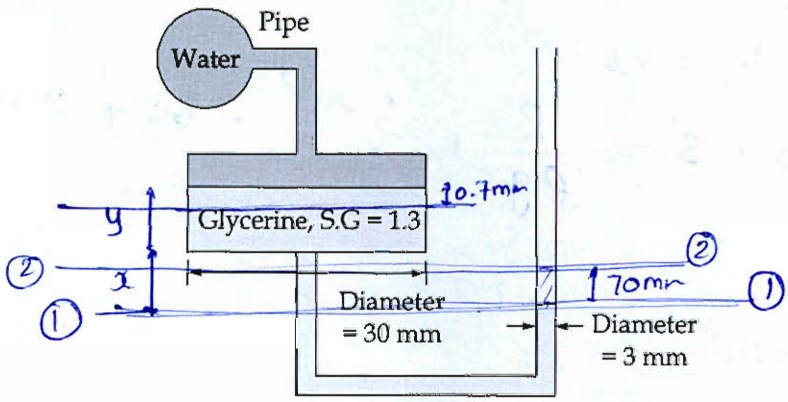
$$\Rightarrow 0 + 0 + 5 = \frac{P_C}{\rho g} + \frac{5.241^2}{2 \times 9.81} + 6.5 + 0.4$$

$$\Rightarrow \frac{P_C}{850 \times 9.81} = -3.3$$

$$\Rightarrow \boxed{P_C = -27517.08 \text{ Pa}}$$

12

Q.2 (a) (ii) The system shown in the figure is used to accurately measure the pressure changes when the pressure is increased by ΔP in the water pipe. Corresponding to a rise of 70 mm in the level of glycerin in the vertical pipe, what will be the change in the pipe pressure?



[8 marks]

~~$P_1 + \rho_{gly} \cdot g(y+x)\rho$~~

Above level ①-①

$P_1 + \rho_{g_1} g(y+x) = P_{atm}$ — ①

When pressure is increased to P_2

$A_1 h_1 = A_2 h_2$

$\Rightarrow \frac{\pi}{4} \times 30^2 \times h_1 = \frac{\pi}{4} \times 3^2 \times 70$

$\Rightarrow h_1 = 0.7\text{ mm}$

Above level ②-②

$P_2 + \rho_{gl} \cdot g(y - 0.7\times10^{-3} + x - 70\times10^{-3}) = P_{atm}$ — ②

eqⁿ ② − eqⁿ ①

$P_2 - P_1 + \rho_{g_1} g[y + x - 0.7\times10^{-3} - 70\times10^{-3}] - \rho_{g_1} g(y+x) = 0$

$\Rightarrow P_2 - P_1 = \rho_{g_1} \cdot g \cdot (0.7 + 70)\times10^{-3}$

$= 1300 \times 9.81 \times 70.7 \times 10^{-3}$

$P_2 - P_1 = 901.6371\ N/m^2$

Pressure rise = 901.6371 Pa

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Q.2 (b) Given the velocity distribution in a laminar boundary layer on a flat plate as

$$\frac{u}{U} = 2\left(\frac{y}{\delta}\right) - 2\left(\frac{y}{\delta}\right)^3 + \left(\frac{y}{\delta}\right)^4$$

Obtain expressions for the boundary layer thickness, shear intensity and force on one side of the plate.

[20 marks]

$$\frac{u}{U} = 2\left(\frac{y}{\delta}\right) - 2\left(\frac{y}{\delta}\right)^3 + \left(\frac{y}{\delta}\right)^4$$

According to Von Karman principle

$$\frac{\tau_0}{\rho U_\infty^2} = \frac{\partial \theta}{\partial x}$$

first Momentum Thickness

$$\theta = \int_0^\delta \frac{U}{U_\infty}\left(1 - \frac{U}{U_\infty}\right) dy$$

$$= \int_0^\delta \left[2\left(\frac{y}{\delta}\right) - 2\left(\frac{y}{\delta}\right)^3 + \left(\frac{y}{\delta}\right)^4\right]\left[1 - \frac{2y}{\delta} + 2\left(\frac{y}{\delta}\right)^3 - \left(\frac{y}{\delta}\right)^4\right] dy$$

$$= \int_0^\delta \left[\begin{array}{l} 2\left(\frac{y}{\delta}\right) - 4\left(\frac{y}{\delta}\right)^2 + 4\left(\frac{y}{\delta}\right)^4 - 2\left(\frac{y}{\delta}\right)^5 - 2\left(\frac{y}{\delta}\right)^3 + 4\left(\frac{y}{\delta}\right)^4 \\ - 4\left(\frac{y}{\delta}\right)^6 + 2\left(\frac{y}{\delta}\right)^7 + \left(\frac{y}{\delta}\right)^4 - 2\left(\frac{y}{\delta}\right)^5 + 2\left(\frac{y}{\delta}\right)^7 - \left(\frac{y}{\delta}\right)^8 \end{array}\right] dy$$

$$= \int_0^\delta \left[2\left(\frac{y}{\delta}\right) - 4\left(\frac{y}{\delta}\right)^2 - 2\left(\frac{y}{\delta}\right)^3 + 9\left(\frac{y}{\delta}\right)^4 - 4\left(\frac{y}{\delta}\right)^5 - 4\left(\frac{y}{\delta}\right)^6 + 4\left(\frac{y}{\delta}\right)^7 - \left(\frac{y}{\delta}\right)^8\right] dy$$

$$= \left(\frac{2y^2}{2\delta} - \frac{4y^3}{3\delta^2} - \frac{2y^4}{4\delta^3} + \frac{9}{5}\frac{y^5}{\delta^4} - \frac{4}{6}\frac{y^6}{\delta^5} - \frac{4}{7}\frac{y^7}{\delta^6} + \frac{4}{8}\frac{y^8}{\delta^7} - \frac{1}{9}\frac{y^9}{\delta^8}\right)_0^\delta$$

$$\theta = \left(1 - \frac{4}{3} - \frac{1}{2} + \frac{9}{5} - \frac{4}{6} - \frac{4}{7} + \frac{4}{8} - \frac{1}{9}\right)\delta$$

$$\Rightarrow \boxed{\theta = \frac{37}{315}\delta}$$

$$\tau_0 = \mu \left.\frac{\partial u}{\partial y}\right|_{y=0}$$

$$= \mu \left[U_\infty \left(\frac{2}{\delta} - 6\left(\frac{y}{\delta}\right)^2 + 4\left(\frac{y}{\delta}\right)^3 \right) \right]_{y=0}$$

$$\boxed{\tau_0 = \frac{2\mu U}{\delta}}$$

Now $\frac{\tau_0}{\rho U_\infty^2} = \frac{2\mu U}{\delta} \frac{\partial \theta}{\partial x}$

$$\Rightarrow \frac{2\mu U_\infty}{\delta \cdot \rho U_\infty^2} = \frac{2\mu U_\infty}{\delta \cdot \rho \cdot U_\infty^2} = \frac{\partial}{\partial x}\left(\frac{37}{315}\delta\right)$$

$$\Rightarrow \frac{37}{315}\int d\delta = \frac{2\mu}{\delta \cdot \rho U_\infty}\int dx$$

$$\Rightarrow \frac{37}{315}\int \delta \cdot d\delta = \frac{2\mu}{\rho U_\infty}\int dx$$

$$\Rightarrow \frac{37}{315 \times 2}\delta^2 = \frac{2\mu \cdot x \cdot x}{\rho U_\infty \cdot x} \qquad Re = \frac{\rho U_\infty x}{\mu}$$

$$\Rightarrow \frac{\delta^2}{x^2} = \frac{315 \times 2 \times 2}{37\, Re_x}$$

$$\Rightarrow \boxed{\frac{\delta}{x} = \frac{5.835}{\sqrt{Re_x}}} \quad \text{Boundary layer Thickness}$$

$$C_{f,x} = \frac{\tau_{0x}}{\frac{1}{2}\rho U_\infty^2} \qquad \tau_{0x} = \frac{2\mu U_\infty}{\delta}$$

$$\Rightarrow \tau_{0x} = \frac{2\mu \cdot U_\infty \sqrt{Re_x}}{5.835 \cdot x}$$

$$\tau_{0x} = \frac{2}{5.835}\sqrt{\frac{\rho U_\infty x \cdot U_\infty^2 \cdot \mu^2}{x^2}}$$

$$C_{f,x} = \frac{2\mu \cdot U_\infty \cdot \sqrt{Re_x}}{5.835 \cdot x \cdot \frac{1}{2}\rho U_\infty^2}$$

$$= \frac{4 \cdot \mu \cdot \sqrt{\frac{\rho U_\infty x}{\mu}}}{5.835\, \rho \cdot x \cdot U_\infty} = \frac{4}{5.835}\sqrt{\frac{\rho U_\infty x \cdot \mu^2}{\mu \cdot \rho^2 \cdot x^2 \cdot U_\infty^2}}$$

$$= \frac{4}{5.835\sqrt{Re_x}} \quad \Rightarrow \boxed{C_{f,x} = \frac{0.6855}{\sqrt{Re_x}}}$$

Shear Intensity

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$$\bar{C}_{f,x} = \frac{2\times 0.6855}{\sqrt{Re_x}} = \frac{1.371}{\sqrt{Re_x}}$$

Force on one side of wall

$$F = \frac{1}{2}\bar{C}_{f,x}\cdot \rho\cdot A\cdot U_\infty^2$$

$$= \frac{1}{2}\times \frac{1.371}{\sqrt{Re_L}}\cdot \rho\cdot L\cdot 1\cdot U_\infty^2$$

$$= \frac{1}{2}\times \frac{1.371}{\sqrt{\frac{\rho U_\infty L}{\mu}}}\cdot \rho\cdot L\cdot U_\infty^2$$

$$= U_\infty\, 0.6855 \sqrt{\frac{\rho\cdot L\cdot U_\infty}{\mu}\cdot \mu}$$

$$\boxed{F = 0.6855\, U_\infty\cdot \mu\cdot \sqrt{Re_L}}$$

20

Excellent

Q.2 (c) (i) A rectangular channel is 3 m wide and conveys a discharge of 15 m^3/sec at a depth of 2.5 m. It is proposed to reduce the width of the channel at hydraulic structure. Assuming the transition to be horizontal and the flow to be frictionless, determine the water surface elevations upstream and downstream of the constriction when the constricted width is 1.8 m.

[12 marks]

Q.2 (c) (ii) A 3.5 m wide rectangular channel carries a discharge of 15 m^3/sec at a depth of 2 m. Calculate the height and velocity of a surge produced when the flow is suddenly stopped completely by the full closure of a sluice gate at the downstream end.

[8 marks]

Q.3 (a) (i) An inward flow turbine (reaction type with radial discharge) with an overall efficiency of 85% is required to develop 160 kW power. The head is 8 m; peripheral velocity of the wheel is $0.96\sqrt{2gH}$; the radial velocity of the flow is $0.36\sqrt{2gH}$. The wheel is to make 160 rpm and the hydraulic losses in the turbine are 24% of the available energy.

Determine:

1. The angle of the guide blade at inlet.
2. The wheel vane angle at inlet.
3. The diameter of the wheel.
4. The width or the wheel at inlet.

[15 marks]

Q.3 (a) (ii) What is an air vessel? Describe the function of the air vessel for reciprocating pumps.

[5 marks]

Q.3 (b) (i) A 3.0 long conical diffuser 30 cm in diameter at the upstream end has 90 cm diameter at the downstream end. At a certain instant the discharge through the diffuser is observed to be 300 L/s of water and is found to increase uniformly at the rate of 60 L/s per second. Estimate the local, convective and total acceleration at a section 1.5 m from the upstream end.

[12 marks]

Q.3 (b) **(ii)** A proposed model of a river stretch of 20 km is to have a horizontal scale of $\frac{1}{250}$ and vertical scale of $\frac{1}{50}$. If the normal discharge, width and depth of the river are 150 m^3/s, 100 m and 4 m respectively, estimate the corresponding model quantities. Also calculate the Manning's roughness 'n' to be provided in the model to represent a prototype roughness value of 0.030.

[8 marks]

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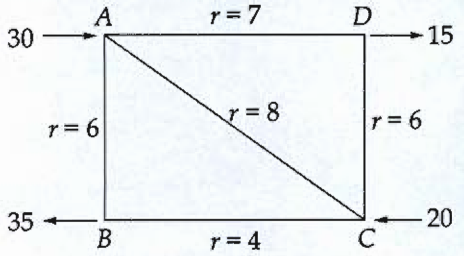
Q.3 (c) For the network shown in figure, the head loss is given by $h_f = rQ^2$. The values of r for each pipe, and the discharge into or out of various nodes are shown in the sketch. The discharges are in arbitrary unit. Obtain the distribution of discharge in the network.



[20 marks]

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Q.4 (a) (i) A 4 m wide rectangular channel has a Manning's coefficient of 0.025. For a discharge of 6 m^3/sec, identify and draw the possible types of GVF profiles produced in the following break in grades:

1. $S_{01} = 0.0004$ to $S_{02} = 0.005$.
2. $S_{01} = 0.015$ to $S_{02} = 0.0045$.

[12 marks]

Q.4 (a) (ii) A 1.5 m wide rectangular channel carries a discharge of 5.0 m^3/s at a depth of 1.5 m. At a section the channel undergoes transition to a triangular section of side slopes 2 H : 1 V. If the flow in the triangular section is to be critical without changing the upstream water surface, find the location of the vertex of triangular section relative to the bed of rectangular channel. What is the drop/rise in the water surface at the transition? (Assume zero energy loss at the transition)

[8 marks]

Q.4 (b) **(i)** An open cylinder 30 cm in diameter and 50 cm high is filled with water and rotated about its axis. Calculate the amount of water spilled when the speed of rotation is (*a*) 150 rpm and (*b*) 250 rpm.

[12 marks]

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Q.4 (b) **(ii)** In a turbulent flow through a pipe of radius r_0, at what distance from the boundary would the local velocity

1. be equal to the mean velocity?
2. be equal to half the mean velocity if the shear velocity is 1/10 of the mean velocity?

[8 marks]

Q.4 (c) A centrifugal pump operates against a manometric head of 30 m with a manometric efficiency of 80%. The pressure rise through the impeller is 60% of the total head developed by the pump. The radial velocity of flow which is constant is 3.5 m/s. The outer diameter of the impeller is 450 mm and the width at outlet is 15 mm. The blades at inlet are curved backwards at 60° to the wheel tangent.

Calculate:

(i) the discharge in liters per minute.

(ii) speed of the pump.

(iii) blade angle at outlet.

(iv) diameter of impeller at inlet.

[20 marks]

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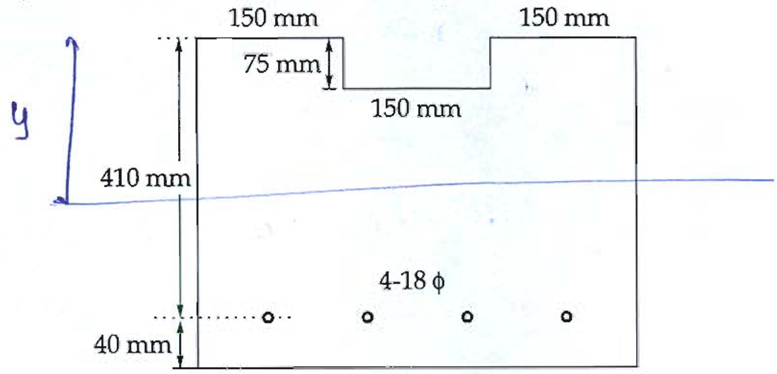
Section B : Design of concrete and Masonry Structures-1 + Geo-technical & Foundation Engineering-2

Q.5 (a) The beam section shown in the figure is subjected to a bending moment of 50 kN-m. Determine the maximum compressive stress in concrete and the tensile stress in steel. (Take m = 13.33 and assume cracked section)



[12 marks]

$A_{st} = 4 \times \frac{\pi}{4} \times 18^2 = 1017.876\ mm^2$

$BM = 50\ kN\text{-}m.$ $m = 13.33$

Neutral Axis

$(\cancel{y-75}\ 75) \times 150 \times 2 \times \left(y - \frac{75}{2}\right) + (y-75) \times 450 \times \left(\frac{y-75}{2}\right) = 13.33 \times A_{st} \times (410 - y)$

$\Rightarrow 22500y - 843750 + \cancel{450} \ 225y^2 - 33750y + 1265625 = -13568.28768y + 5562997.703$

$\Rightarrow 225y^2 + 2318.287y - 5171122.703 = 0$

$\Rightarrow y = 146.536mm$

Neutral Axis is at a distance of $x_a = 146.536$ mm from top

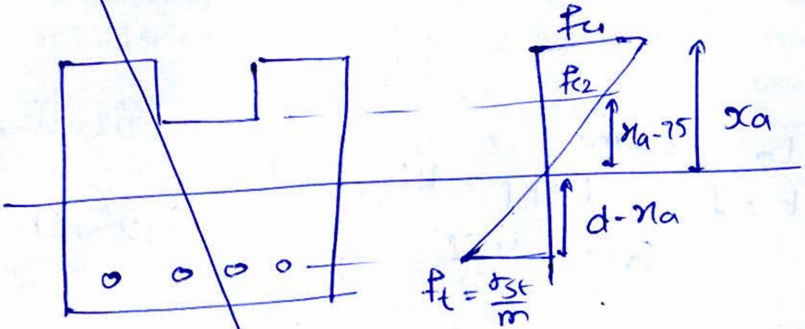
Now

$BM = \sigma_{st} A_{st} (d - x_a)$

$\Rightarrow 50 \times 10^6 = \sigma_{st} \times 1017.876 \times (410 - 146.536)$

$\Rightarrow \boxed{\sigma_{st} = 186.446\ N/mm^2}$

For Max^m compressive stress in steel



$f_{c1} \rightarrow$ Max^m compressive stress

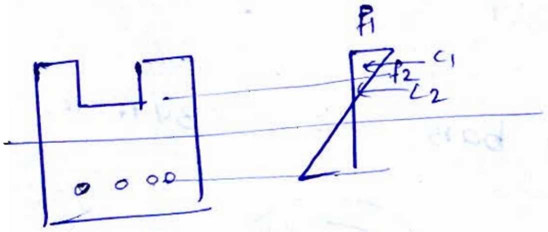
$$\frac{f_{c1}}{x_a} = \frac{f_t}{(d - x_a)}$$

$$\Rightarrow \frac{f_{c1}}{146.536} = \frac{186.446}{13.3 \times (410 - 146.536)}$$

$$\Rightarrow \boxed{f_{c1} = 7.797\ N/mm^2}$$

$$f_2 = \frac{f_1 \times 71.536}{146.356}$$

$$f_2 = 0.488 f_1$$



$$C_1 = 2 \times 75 \times 150 \times \left(\frac{f_1 + f_2}{2}\right)$$

$$C_1 = 16740 f_1$$

$$C_2 = 71.536 \times 450 \times \frac{f_2}{2} = 7854.0528 f_1$$

$$x_1 = \left(\frac{2f_2 + f_1}{f_2 + f_1}\right) \times \frac{75}{3} = 33.199\ mm$$

$$x_2 = 75 + \frac{(146.536 - 75)}{3} = 98.845\ mm$$

12

$$\bar{x} = \frac{C_1 x_1 + C_2 x_2}{C_1 + C_2} = 54.164\ mm$$

$$BM = \sigma_{st} \cdot A_{st} (d - \bar{x})$$

$$\Rightarrow \sigma_{st} = \frac{50 \times 10^6}{1017.876 \times (410 - 54.164)} = \boxed{138.046\ N/mm^2}$$

Max^m Tensile Stress

$$\frac{f_{c1}}{x_a} = \frac{f_t}{d - x_a} \Rightarrow f_{c1} = \frac{138.046 \times 146.536}{13.33 \times (410 - 146.536)}$$

$$\boxed{f_{c1} = 5.76\ N/mm^2}$$

Max^m compressive stress

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Q.5 (b) A circular column of 400 mm diameter is subjected to a factored load of 1500 kN. The column has an unsupported length of 3.2 m. The column is held in position but not restrained against rotation at both ends. Design the helical reinforcement. Use M25 grade concrete and Fe415 grade steel.

[12 marks]

$D = 400$ mm. $\quad L_o = 3.2$ m.

$P_u = 1500$ kN $\quad k = 1 \quad L_{eff} = kL_o = 3.2$ m.

M-25 Fe415 $\quad S_r = \frac{L_{eff}}{D} = \frac{3200}{400} = 8 < 12 \rightarrow$ Short column

For Hellical R/F^n

$P_u = 1.05(0.4 f_{ck} A_c + 0.67 f_y A_{sc})$

first check $\quad e_{min} = \left\{ \frac{3200}{500} + \frac{400}{30} = 19.73 \text{mm} \right.$ max 20mm

$e_{min} = 0.05D = 20$mm

$e = 20$mm

So safe

Use formula given

$\Rightarrow 1500 \times 10^3 = 1.05 \times \left[0.4 \times 25 \times \left(\frac{\pi}{4} \times 400^2 - A_{sc}\right) + 0.67 \times 415 A_{sc}\right]$

$\Rightarrow A_{sc} = 641.426$ mm^2

$(A_{sc})_{min}$

provide 6 # 12mm dia bars $= 678.584$ mm^2

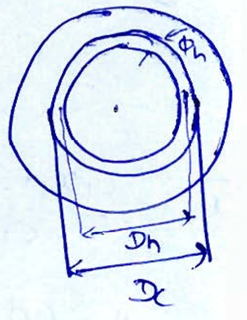
Let NC = 40mm.

$D_c = D - 2NC = 400 - 2 \times 40$

$\Rightarrow D_c = 320$mm.

Let $\phi_h = 8$mm.

$\Rightarrow D_h = D_c - \phi_h = 312$ mm.



$\frac{0.36 f_{ck}}{f_y}\left[\frac{A_g}{A_c} - 1\right] \le \frac{V_h}{V_c}$

$\Rightarrow \frac{0.36 \times 25}{415}\left[\frac{\frac{\pi}{4} \times 400^2}{\frac{\pi}{4} \times 320^2} - 1\right] \le \frac{\frac{1000}{p} \times \frac{\pi}{4} \times 8^2 \times 2\pi \times \frac{312}{2}}{1000 \times \frac{\pi}{4} \times 320^2}$

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$\Rightarrow p \leq 50.21$ mm

$p \not> \frac{D_c}{6} = \not> \frac{320}{6} = \not> 53.33$ mm

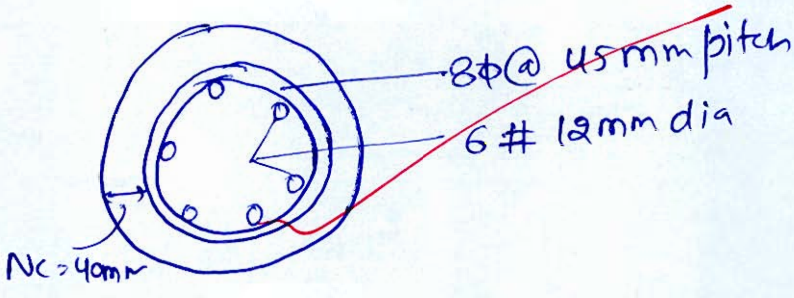
$\not< 3\phi_h \not< 3 \times 8 = \not< 24$ mm

$\not> 75$ mm

$\not< 25$ mm

so provide 8 mm dia hellical reinforcement at 45 mm pitch

(8)



Q.5 (c) Explain the following terms:

(i) Arching effect in sand.

(ii) Anchored bulkhead.

(iii) Coffer dams.

(iv) Geocells and Geogrids.

[3 + 3 + 3 + 3 marks]

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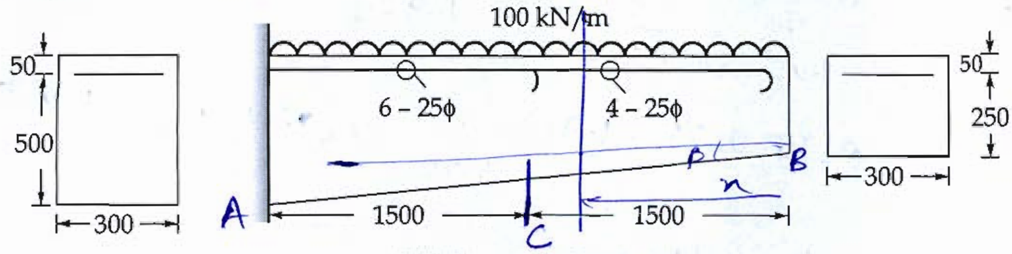
Q.5 (d) Design shear reinforcement for a tapered cantilever beam of span 3 m, having a section of 250 mm effective depth and 300 mm width at the free end, and 500 mm effective depth and 300 mm width at the support as shown in figure. The beam has to support a factored uniform load of 100 kN/m, including its self weight. Assume an effective cover of 50 mm, Fe415 steel and M20 concrete. Use 2-legged 8 mm-ϕ stirrups.



(All dimension in mm)

Design shear stress of M20 concrete is given in table below:

$\%P_t = \frac{A_{st}}{bd} \times 100$	$\tau_c\ (\text{N/mm}^2)$
≤ 0.15	0.28
0.25	0.36
0.50	0.48
0.75	0.56
1.00	0.62
1.25	0.67
1.50	0.72
1.75	0.75
2.00	0.79

[12 marks]

$D_x = 300 + \left(\frac{550-300}{3000}\right)x$

$D_x = \left(300 + \frac{x}{12}\right)$ or $d_x = \left(250 + \frac{x}{12}\right)$

$d_c = 250 + \frac{1500}{12} = 375$ mm

$\tan\beta = \frac{550-300}{3000} = \frac{1}{12}$

BM at end A $BM_u = 100 \times 3 \times \frac{3}{2} = 450$ kN-m

$V_u = 100 \times 3 = 300$ kN

$\tau_v = \frac{V_u - \frac{M_u}{d}\tan\beta}{Bd}$

$$\tau_v = \frac{\left(300 - \frac{450}{0.5} \times \frac{1}{12}\right) \times 10^3}{300 \times 500} = 1.5 \text{ N/mm}^2$$

$$\% p_t = \frac{6 \times \frac{\pi}{4} \times 25^2 \times 100}{300 \times 500} = 1.963\%$$

$$\tau_c = \left(\frac{1.963 - 1.75}{2 - 1.75}\right) \times (0.79 - 0.75) + 0.75$$

$$\tau_c = 0.784 \text{ N/mm}^2$$

$$V_s = (\tau_v - \tau_c) B \cdot d = (1.5 - 0.784) \times 500 \times 300$$

$$V_s = 107.376 \text{ kN}$$

$$S_v = \frac{0.87 f_y A_{sv} d}{V_s} = \frac{0.87 \times 415 \times 2 \times \frac{\pi}{4} \times 64 \times 500}{107.376 \times 10^3}$$

$$S_v = 169.016 \text{ mm}$$

$$\text{Minimum Spacing} = \frac{0.87 f_y A_{sv}}{0.4 B}$$

$$= \frac{0.87 \times 415 \times 2 \times \frac{\pi}{4} \times 64}{0.4 \times 300}$$

$$= 362.47 \text{ mm}$$

$$\text{Max}^m \text{ spacing} = 0.75d = 0.75 \times 500 = 375 \text{ mm}$$

$$300 \text{ mm}$$

provide 2-legged 8mm dia bars @ 165 mm c/c between AC portion

At C

$BM_c = 100 \times 1.5 \times \frac{1.5}{2} = 112.5$ kN-m

$V_c = 100 \times 1.5 = 150$ kN

$$\tau_v = \frac{V_u - \frac{M_u}{d_c}\tan\beta}{Bd_c} = \frac{\left(150 - \frac{112.5}{0.375} \times \frac{1}{12}\right)\times 10^3}{300 \times 375} =$$

$\tau_v = 1.11$ N/mm²

$$\% p_t = \frac{4 \times \frac{\pi}{4} \times 25^2 \times 100}{375 \times 300} = 1.745\%$$

$\tau_c = 0.749$ N/mm²

$V_s = (\tau_v - \tau_c)Bd = 40.563$ kN

$$S = \frac{0.87 \times 415 \times 2 \times \frac{\pi}{4} \times 64 \times 375}{40.563 \times 10^3} = 333.785 \text{ mm}$$

$$S_{min} = \frac{0.87 \times 415 \times 2 \times \frac{\pi}{4} \times 64 \times 8}{0.4 \times 300} = 302.47 \text{ mm}$$

So provide 2-legged 8 mm dia stirrups @ 300 mm c/c in CB portion

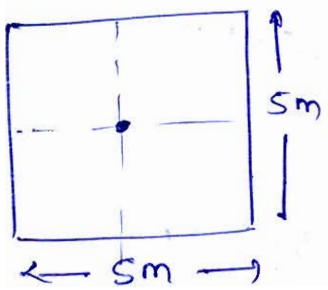
11

Q.5 (e) Determine the immediate settlement beneath the centre of (i) 5 m size square flexible footing (ii) 4.5 m size square rigid footing, resting at 1 m depth and applying a stress of 125 kN/m^2 in dry dense sand with an average E value of 30×10^3 kN/m^2 upto a depth of 10 m and an average value of 60×10^3 kN/m^2 for a depth between 10 m and 25 m. The soil is having a Poisson's ratio of 0.35.

(Consider Influence factor, I_f for $\frac{L}{B} = 1$ at centre as 1.12 for flexible footing)

[12 marks]

(i) (e)



Flexible footing

$\frac{L}{B} = 1$

$I_f = 1.12$

$S = \frac{qB(1-\mu^2)I_f}{E_s}$ — 1m

$S = \frac{125 \times 5 \times (1-0.35^2) \times 1.12}{E_s}$

$E = \frac{E_1 d_1 + E_2 d_2}{d_1 + d_2} = \frac{30 \times 10^3 \times 10 + 60 \times 10^3 \times 15}{25}$

$= 48 \times 10^3$ kN/m²

6

$\Rightarrow$ Settlement $= \frac{125 \times 5 \times (1-0.35)^2 \times 1.12}{48 \times 10^3}$

Settlement = 12.796 mm

(ii) Below 4.5m size square rigid footing

for Rigid footing $I_{f_2} = 0.8\, I_{flexib}$

$= 0.8 \times 1.12 = 0.896$

Settlement $= \frac{qB(1-\mu^2) I_{f_2}}{E_s}$

$$S = \frac{125 \times 4.5 \times (1 - 0.35^2) \times 0.896}{48 \times 10^3}$$

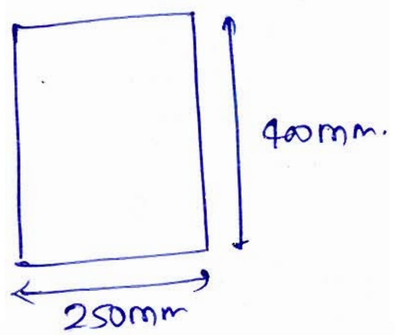
Settlement = 9.213 mm

Q.6 (a) A rectangular RC beam is 25 cm wide and 40 cm deep (overall). The beam is simply supported over an effective span of 4 m. The superimposed load over the beam is 50 kN/m. Using M20 grade concrete and Fe415 grade steel, design the beam for flexure only. Consider an effective cover of 40 mm.

Stress-strain values for Fe415

	Maximum Design stress	Total strain
	$0.8\times0.87f_y$	0.00144
	$0.925\times0.87f_y$	0.00217
	$0.950\times0.87f_y$	0.00241
347.51 =	$0.9625\times0.87f_y$	0.00259
352.02 =	$0.975\times0.87f_y$	0.00276
	$0.9875\times0.87f_y$	0.00328
	$1.0\times0.87f_y$	0.00380

[20 marks]



$L_{eff} = 4m.$
$LL = 50$ kN/m
M-20 , Fe415
$E_c = 40mm$
$d = 400 - 40 = 360mm$
$K = 0.48$, $j = 0.84$

$DL = 25\times0.25\times0.4\times1 = 2.5$ kN/m
$W_u = 1.5(2.5+50) = 78.75$ kN/m
$M_u = \frac{W_u . L_{eff}^2}{8} = \frac{78.75\times4^2}{8} = 157.5$ kN-m

$x_{ulim} = 0.48d = 0.48\times360 = 172.8$ mm
$M_R = 0.138 f_{ck} Bd^2 = 0.138\times20\times250\times360^2 = 89.424$ kN-m
Since $M_u > M_R$
so Design Doubly Reinforced section
For M_R → Balanced section
~~M_R~~ $= A_{st_1} = \frac{M_R}{0.87f_y jd}$
$A_{st_1} = \frac{89.424\times10^6}{0.87\times415\times0.84\times360} = 819$ mm2

$$A_{st_2} = \frac{M_u - M_R}{0.87 f_y (d - d_c)}$$

$$= \frac{157.5 \times 10^6 - 89.424 \times 10^6}{0.87 \times 415 \times (360 - 40)}$$

$$A_{st_2} = 589.219 \text{ mm}^2$$

$$A_{st} = A_{st_1} + A_{st_2} = 589.219 + 819 = 1409 \text{ mm}^2$$

provide

$$A_{sc} = \frac{M_u - M_R}{f_{sc}(d - d_c)}$$

$$\varepsilon_{sc} = \frac{0.0035 (x_{u_{lim}} - d_c)}{x_{ulim}} = \frac{0.0035 \times (172.8 - 40)}{172.8}$$

$$\varepsilon_{sc} = 2.6898 \times 10^{-3}$$

from table

$$f_{sc} = \left(\frac{2.6898 \times 10^{-3} - 0.00259}{0.00276 - 0.00259}\right)(352.62 - 347.51) + 347.51$$

$$f_{sc} = 350.157 \text{ N/mm}^2$$

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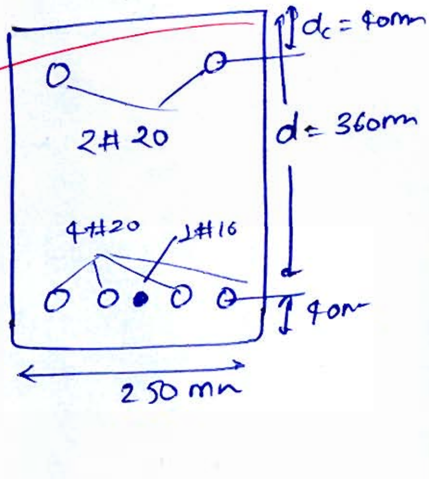
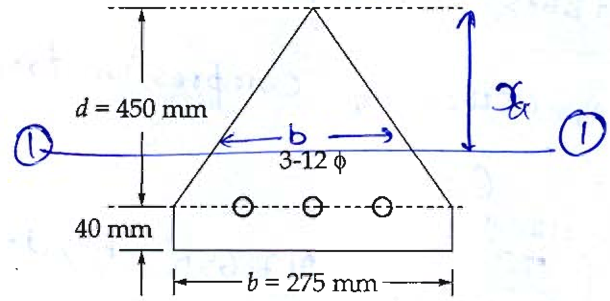
$$\text{so } A_{sc} = \frac{(157.5 - 89.424) \times 10^6}{350.157 \times (360 - 40)} = 607.55 \text{ mm}^2$$

$A_{st} = 1409 \text{ mm}^2 = 4\#20 + \#16$

$A_{sc} = 607.55 \text{ mm}^2 = 2\# 20\text{mm}$



Q.6 (b) A triangular reinforced concrete beam section is as shown in the figure. Find the depth of neutral axis and the moment of resistance of the beam section. Safe stresses in concrete and steel are 7 N/mm² and 230 N/mm² respectively. (Take $m = 13.33$)



$A_{st} = 339.292$ mm²

[20 marks]

Considering cracked section

$\frac{x_a}{b} = \frac{450}{275} \Rightarrow b = \frac{11}{18} x_a$

Taking Moment about ① - ①

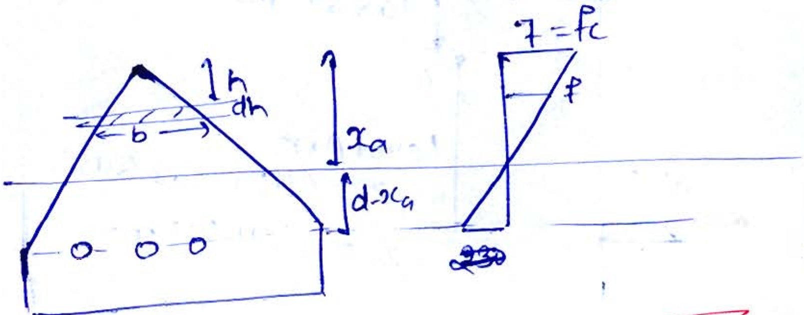
$\frac{1}{2} x_a b \times \frac{x_a}{3} = m A_{st} (d - x_a)$

$\Rightarrow \frac{11}{18 \times 6} x_a^3 = 13.33 \times 339.292 \times (450 - x_a)$

$\Rightarrow x_a^3 + 44405.30317 x_a - 19982386.43 = 0$

$\boxed{x_a = 217.69 \text{ mm}}$ Neutral Axis

If $\sigma_{cbc} = 7$ N/mm²
then $\sigma_{st} = \frac{13.33 \times 7 \times 217.69}{(450 - 217.69)}$
$= 99.576$ N/mm² < 230 N/mm²
so safe



$\frac{h}{b} = \frac{450}{275} \Rightarrow b = \frac{11}{18} h$

$f = \frac{7}{217.69} \times (217.69 - h)$

$dC = f \cdot b \cdot dh = \frac{7}{217.69} (217.69 - h) \cdot \frac{11}{18} h \cdot dh$

$\Rightarrow \int dC = \int_0^{217.69} \frac{77}{18 \times 217.69} (217.69h - h^2)\, dh$

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$$C = \frac{77}{18\times217.69}\left[\frac{217.69\times h^2}{2} - \frac{h^3}{3}\right]_0^{217.69}$$

$$\boxed{C = 33786.55629\ \text{kN}} = 33.786\ \text{kN}$$

Now Line of action of compressive force

$$\int dC\cdot h = C\cdot\bar{h}$$

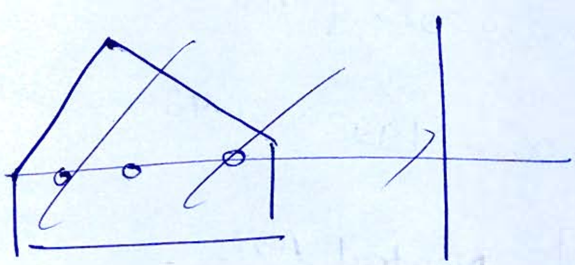
$$\Rightarrow C\cdot\bar{h} = \int_0^{217.69}\frac{77}{18\times217.69}\left(217.69h^2 - h^3\right)dh$$

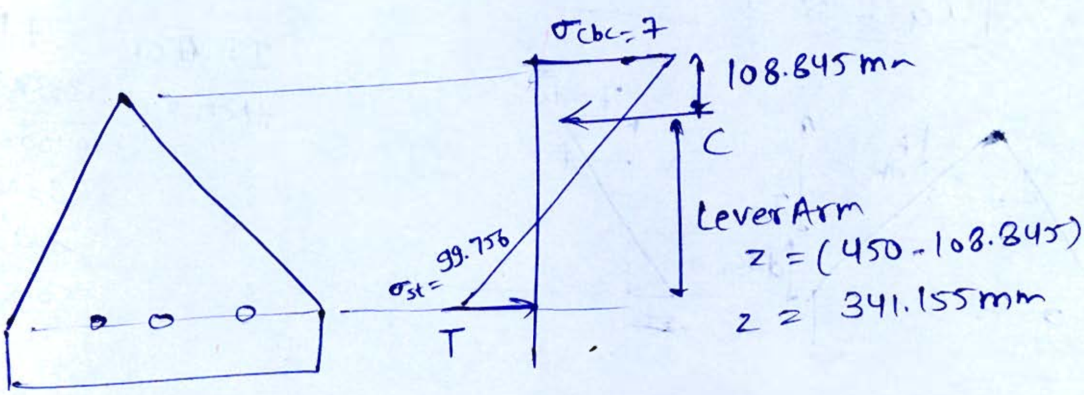
$$\Rightarrow C\bar{h} = \frac{77}{18\times217.69}\left(\frac{217.69h^3}{3} - \frac{h^4}{4}\right)_0^{217.69}$$

$$\boxed{\bar{h} = 108.845\ \text{mm}}$$

Good

20





So Moment of Resistance of Section

$$M_R = C\cdot z$$

$$= 33786.55629 \times 341.155 \times 10^{-6}\ \text{kN-m}$$

$$\boxed{M_R = 11.526\ \text{kN-m}}$$

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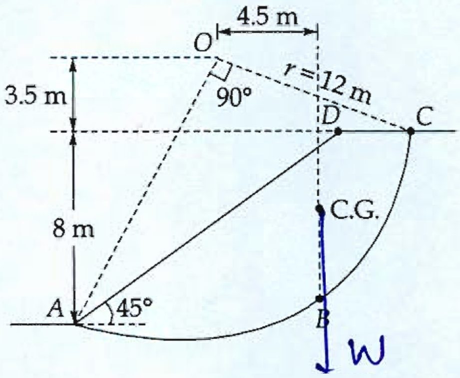
$T = \sigma_{st} A_{st}$

$= 99.576 \times 339.292 \times 10^{-3} = 33.785$ kN

Q.6 (c) (i) A 45° slope has been excavated to a depth of 8 m in a saturated clay having cohesion of 60 kN/m^2, angle of internal friction as zero and unit weight of 20 kN/m^3. Area of the failure wedge (*ABCD*) is taken as 70 m^2. Determine (*a*) the factor of safety for the trial failure surface specified in the figure. (*b*) The minimum value of factor of safety for the given slope.

(Assuming that the depth factor is zero)



[14 marks]

$C = 60\ kN/m^2 \quad \phi = 0$

$\gamma = 20\ kN/m^3$

Arc ABC; $L = \theta \cdot R = \frac{\pi}{2} \times 12 = (6\pi)$ m.

(i) $FOS = \frac{(C \cdot L) R}{W \cdot \bar{x}} = \frac{60 \times 6\pi \times 12}{70 \times 1 \times 20 \times 4.5} = 2.15$

Write properly in steps.

4

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Q.6 (c) (ii) Briefly explain the assumptions of Rankine's earth pressure theory and Coulomb's earth pressure theory.

[6 marks]

Rankine's Assumption →

① Wall is frictionless, Vertical.

② Backfill is Cohesionless

③ Back·

1

Q.7 (a) Design a wall of a rectangular water tank to resist a pull of 60 kN and a bending moment of 7.5 kN-m/m width. Use M30 concrete and Fe 415 grade steel.

Effective cover = 30 mm.

Permissible stress in direct tension in concrete = 1.5 MPa.

Permissible stress in bending tension in concrete = 2 MPa.

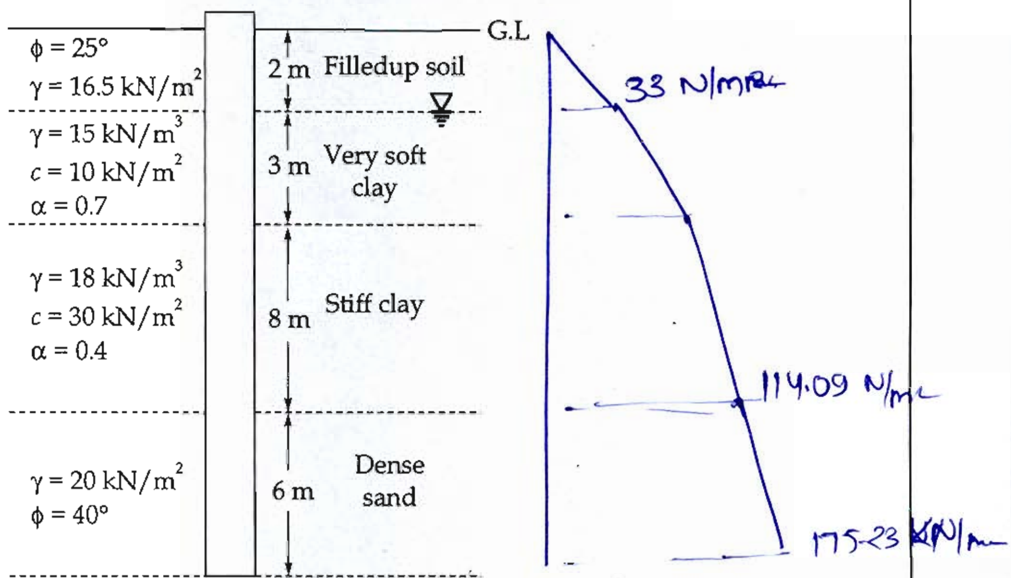
Permissible stress in bending compression in concrete = 10 MPa.

Modular ratio, $m = 9.33$.

Permissible stress in steel = 130 MPa.

[20 marks]

Q.7 (b) At a particular site, the soil profile consists of four different layers as shown in the figure below with respective soil properties. The water table is at 2 m below the ground level.



A pile of diameter 600 mm and length 19 m is bored through the soil. Calculate the safe load that can be carried by the pile with a factor of safety of 2.5.
(Take, $N_q = 140$ and $N_\gamma = 152$)

[20 marks]

Assume $\delta = \phi$

For filledup soil

$q_{nf_1} = (K_a \tan\delta)\,\bar{\sigma}_{avg}$

$K = \frac{1-\sin\phi}{1+\sin\phi} = \frac{1-\sin 20}{1+\sin 20} = 0.49$

$q_{nf} = 0.49 \times \tan 20° \times \frac{33}{2} = 2.944\ kN/m^2$

~~$Q_{nf_1} = q_{s_1} A_{s_1} =$~~

$\Rightarrow Q_{nf_1} = q_{nf_1} A_{s_1} = 2.944 \times \pi \times 0.6 \times 2 = 11.1\ kN$

For Very Soft Clay

$q_{nf_2} = \alpha c' = 0.7 \times 10 = 7\ kN/m^2$

$Q_{nf_2} = q_{nf_2} A_{s_2} = 7 \times \pi \times 0.6 \times 3 = 39.584\ kN$

For Stiff Clay

$q_{sf_3} = \alpha c = 0.4 \times 30 = 12\ kN/m^2$

$Q_{sf_3} = q_{sf_3} \times A_3 = 12 \times \pi \times 0.6 \times 8 = 180.955\ kN$

for Dense sand

$q_{sf_4} = K(\bar{\sigma}_{avg}) \tan\delta$

$K = \frac{1-\sin 40}{1+\sin 40} = 0.217$

$\Rightarrow q_{sf_4} = 0.217 \times \left(\frac{114.09+175.23}{2}\right) \times \tan 40^\circ = 26.394 \text{ kN/m}^2$

$Q_{sf_4} = q_{sf_4} A_s = 26.394 \times \pi \times 0.6 \times 6 = 298.51 \text{ kN}$

~~$Q_{eb} = \frac{\pi}{4}$~~

$q_{eb} = (q N_q + 0.3 B \gamma N_\gamma)$

$= 175.23 \times 140 + 0.3 \times 0.6 \times (20-9.81) \times 152$

$q_{eb} = 24810.9984 > 1100 \text{ kN/m}^2$

So take $q_{eb} = 1100 \text{ kN/m}^2$

Now for Boring pile. $q_{eb} = \frac{1}{3}(q_{eb})_{\text{end bearin}}$

So $Q_{eb} = (q_{eb})_{bored} \times \frac{\pi}{4} d^2$

$Q_{eb} = \frac{1}{3} \times 1100 \times \frac{\pi}{4} \times 0.6^2 = 1036.725 \text{ kN}$

19

Total Load capacity.

$Q = -q_{nf_1} - q_{nf_2} + q_{sf_3} + q_{sf_4} + Q_{eb}$

$= -11.1 - 39.584 + 180.955 + 298.51 + 1036.725$

$Q = 1465.505 \text{ kN}$

Safe load that can be carried

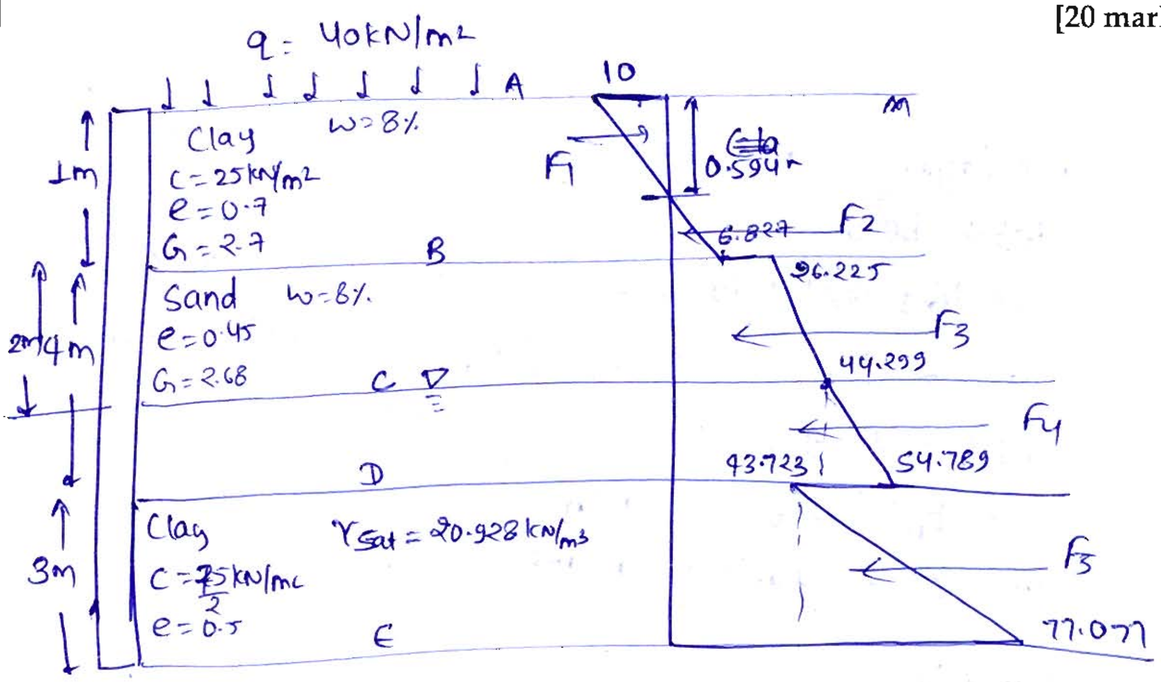
$Q_{safe} = \frac{Q}{FOS} = \frac{1465.505}{2.5} = 586.202 \text{ kN}$

Q.7 (c) A retaining wall of 8 m height has backfill soil in three different layers. Top 1 m and bottom 3 m clay layer has unconfined compressive strengths equal to 50 kN/m^2 and 75 kN/m^2 respectively. The void ratio of top and bottom-most clay is 0.7 and 0.5 respectively. Middle 4 m sand layer has a void ratio of 0.45 and when tested in tri-axial test the confining pressure comes out to be 300 kN/m^2 and deviator pressure comes out to be 350 kN/m^2.

Calculate the line of action of the total active earth pressure force from the bottom of wall, if water table exists at a depth of 3 m from the top of wall and a surcharge of 40 kN/m^2 is applied at the ground level.

(Take specific gravity of clay, G_{clay} = 2.7, Specific gravity of sand, G_{sand} = 2.68, Water content of clay above water table = 8%, Water content of sand above water table = 8%)

[20 marks]



For Clay in top 1m layer

$$\gamma = \left(\frac{wG_s + G_s}{1+e}\right)\gamma_w = \left(\frac{0.08\times 2.7 + 2.7}{1+0.7}\right)\times 9.81 = 16.827 \text{ kN/m}^3$$

For Sand →

$$\gamma = \frac{(wG_s + G_s)}{1+e}\gamma_w = \left(\frac{0.08\times 2.68 + 2.68}{1+0.45}\right)\times 9.81 = 19.582 \text{ kN/m}^3$$

$$\gamma_{sat} = \left(\frac{e+G_s}{1+e}\right)\gamma_w = \left(\frac{2.68+0.45}{1+0.45}\right)\times 9.81 = 21.176 \text{ kN/m}^3$$

~~For Bot~~ $\sigma_1 = \sigma_3 \tan^2(45+\phi/2)$

$\Rightarrow (300+350) = 300 \tan^2(45+\phi/2)$

$\Rightarrow \boxed{\phi = 21.618^\circ}$

$$K_a = \frac{1-\sin\phi}{1+\sin\phi} = 0.4615$$

In Top Clay layer $K_a = 1$

At z depth below

$\bar{\sigma} = \gamma_1 z + q = (40 + 16.827z)$

$p = K_a\bar{\sigma} - 2c\sqrt{K_a}$

$= 40 + 16.827z - 2\times25 = (16.827z - 10)\ kN/m^2$

At top $z_1 = 0$, $p_A = -10\ kN/m^2$

$z_1 = 1m$, $p_B = 6.827\ kN/m^2$

where $p = 0$ $z = \frac{10}{16.827} = 0.594\ m.$

In sand layer above WT

At z depth below

$\bar{\sigma} = 40 + 16.827\times1 + 19.582z = 56.827 + 19.582z$

$p = K_a\bar{\sigma} - 2c\sqrt{K_a} = 0.4615(56.827 + 19.582z) - 0$

$p = 26.225 + 9.037z$

At $z = 0$, $p_B = 26.225\ kN/m^2$

$z = 2m$, $p_C = 44.299\ kN/m^2$

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~~In Bottom Cla~~

In Sand layer Below WT

At z depth below

$\bar{\sigma} = 56.827 + 19.582\times2 + (21.176 - 9.81)z$

$\bar{\sigma} = 95.991 + 11.366z$

$p = K_a\bar{\sigma} - 2c\sqrt{K_a} = 0.4615(95.991 + 11.366z) - 0$

$p = 44.299 + 5.245z$

At $z = 0$, $p_C = 44.299\ kN/m^2$

$z = 2m$, $p_D = 54.789\ kN/m^2$

In Bottom Clay layer

At z depth below

$\bar{\sigma} = 95.991 + 11.366 \times 2 + (20.928 - 9.81)z$

$\bar{\sigma} = 118.723 + 11.118z$

$p = K_a \bar{\sigma} - 2C\sqrt{K_a}$

$= 118.723 + 11.118z - 2 \times \frac{75}{2}$

$p = 43.723 + 11.118z$

At $z = 0$, $p_D = 43.723$ kN/m2

$z = 3$m, $p_E = 77.077$ kN/m

$F_1 = \frac{1}{2} \times 10 \times 0.594 = 2.97$ kN/m

$h_1 = 4 + 3 + 1 ~~-0.594~~ ~~+0~~ \; 1 - 0.594 + \frac{0.594 \times 2}{3} = 7.802$ m

$F_2 = \frac{1}{2} \times 6.827 \times (1 - 0.594) = 1.385$ kN/m

$h_2 = 4 + 3 + \left(\frac{1 - 0.594}{3}\right) = 7.135$ m.

$F_3 = \frac{1}{2} \times 2 \times (26.225 + 44.299) = 70.524$ kN/m

$h_3 = 3 + 2 + \left(\frac{2 \times 26.225 + 44.299}{26.225 + 44.299}\right) \times \frac{2}{3} = 5.914$ m.

$F_4 = \frac{1}{2} \times 2 \times (44.299 + 54.789) = 99.088$ kN/m

$h_4 = 3 + \left(\frac{2 \times 44.299 + 54.789}{44.299 + 54.789}\right) \times \frac{2}{3} = 3.964$ m

$F_5 = \frac{1}{2} \times 3 \times (43.723 + 77.077) = 181.2$ kN/m

$h_5 = \left(\frac{2 \times 43.723 + 77.077}{43.723 + 77.077}\right) \times \frac{3}{3} = 1.362$ m

Total Force $= F_2 + F_3 + F_4 + F_5 - F_1$

$F = 349.227$ kN/m length of wall

line of action of force $h = \dfrac{F_2 h_2 + F_3 h_3 + F_4 h_4 + F_5 h_5 - F_1 h_1}{F_2 + F_3 + F_4 + F_5 - F_1}$

$h = 2.987$ m. above bottom of wall

Q.8 (a) Design a waist slab type dog-legged staircase for a building given the following data:

Height between floors = 2.7 m

Riser = 150 mm

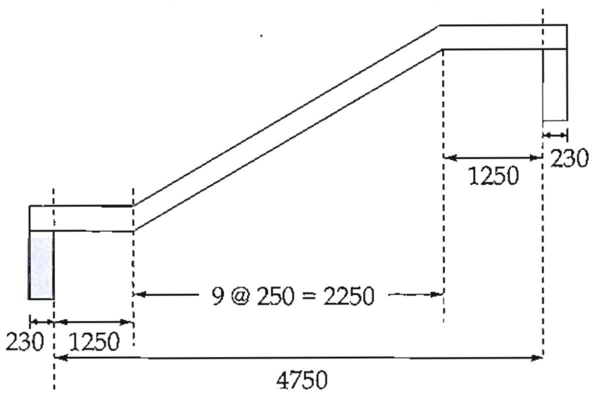
Tread = 250 mm

Width of flight and landing width = 1.25 m

Imposed load = 4.0 kN/m^2

Floor finishes = 0.6 kN/m^2

Assume that the stair is to be supported on 230 mm wide beam at the outer edges of the landing, parallel to the risers as shown in figure. Use M20 concrete and Fe415 grade steel. Assume any other data suitably.



(All dimension in 'mm')

[20 marks]

Q.8 (b) A square footing, placed at a depth of 1.4 m below the ground surface, carrying a safe load of 1050 kN. The soil beneath the footing is having void ratio of 0.64, specific gravity of 2.67, cohesion as 12 kN/m^2 and angle of internal friction of 30°. The soil upto 1.4 m depth is having void ratio of 0.55, degree of saturation 50% (above water table) specific gravity 2.79, cohesion as 10 kN/m^2 and angle of internal friction 32°. The bearing capacity factors for respective friction angles are given as :

ϕ	N_c	N_q	N_γ
30°	37.2	22.5	19.7
32°	44.14	28.5	27.5

Find the size of the footing if the desired factor of safety is 3. (Water table is present at 0.5 m depth from the ground level).

[20 marks]

Q.8 (c) (i) Discuss in brief about the various types of soil samplers.

(ii) Write a short note on pressuremeter test.

[12 + 8 marks]

Space for Rough Work

Space for Rough Work

$$\frac{d_2}{d_1} = K$$

$$V_1 V_2 - V_2^2$$

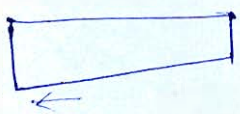
$$\frac{16 Q^2}{\pi^2}\left[\frac{1}{d_1^2 d_2^2} - \frac{1}{d_2^4}\right]$$

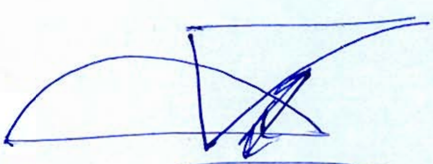
$$\left[\frac{1}{d_1^2 \cdot K^2 d_1^2} - \frac{1}{K^4 d_1^4}\right] \qquad \frac{1}{dk}\left[\frac{1}{k^2} - \frac{1}{k^4}\right]$$

$$\frac{-2}{k^3} + \frac{4}{k^5} = 0$$

$$\frac{1}{2}\left(1 + \frac{B}{L}\right) \qquad 1 - \frac{0.2B}{L}$$

$$\frac{0.8}{2} \quad 0.4$$





$$\frac{V_u - \frac{M_u}{d}\tan\beta}{Bd}$$