213/300

MADE EASY

Leading Institute for ESE, GATE & PSUs

ESE 2025 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Civil Engineering

Test-6

Section A : Flow of Fluids, Hydraulic Machines and Hydro Power [All Topics]

Section B : Water Resource Engineering and Hydrology [All Topics]

Name : ....

Roll No :

Test Centres			Student's Signature
Delhi ☑	Bhopal ☐	Jaipur ☐	
Pune ☐	Kolkata ☐	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	37
Q.2	28
Q.3	60
Q.4	
Section-B	
Q.5	47
Q.6	41
Q.7	
Q.8	
Total Marks Obtained	213/300

Signature of Evaluator ....

Cross Checked by ....

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.

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Section A : Flow of Fluids, Hydraulic Machines and Hydro Power

1 (a) A sphere 3 cm in diameter and of relative density 2.5 is attached to a string and is suspended from the roof of a wind tunnel. If an air stream of 25 m/s flows past the sphere then determine the inclination of the string to horizontal and the tension in the string. (Neglect the weight and drag of the string).

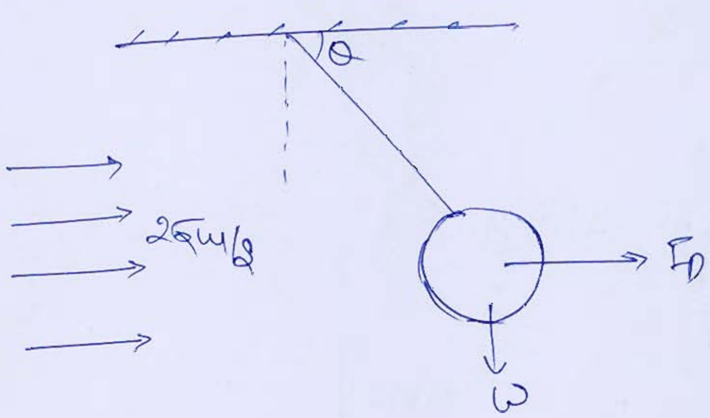
[Take : Mass density of air, ρ_{air} =1.25 kg/m^3, kinematic viscosity of air, ν_{air} = 1.40 × 10^{-5} m^2/s.]

Coefficient of drag

$$C_D = \begin{cases} 0.5 \text{ for } 10^4 < R_e \le 3\times10^5 \\ 0.2 \text{ for } R_e \ge 3\times10^5 \end{cases}$$

[12 marks]

Soln :-



Weight of sphere (W) = $\rho_s V g$

$= 2.5\times10^3 \times \frac{4}{3}\pi \left(\frac{1.5}{100}\right)^3 \times 9.81$

$= 0.3467$ N

Drag Force on sphere (F_D) := $\frac{1}{2} C_D \rho U^2 A$

C_D = Drag coefficient

Reynolds number $Re = \frac{\rho V D}{\mu} = \frac{VD}{\nu}$

$= \frac{25 \times 3\times10^{-2}}{1.40\times10^{-5}}$

$= 53571.428$

$= 5.357\times10^4$

Since, $Re = 5.357 \times 10^4$

$C_D = 0.5$

$F_D = \frac{1}{2} \times 0.5 \times 1.25 \times 25^2 \times \frac{\pi}{4} (3 \times 10^{-2})^2$

$= 0.138 \text{ N}$

$F_R = \sqrt{F_D^2 + W^2} = \sqrt{(0.138)^2 + (0.3467)^2}$

$= 0.373 \text{ N}$

So tension in string $(T) = \underline{0.373 \text{ N}}$

$\theta = \tan^{-1}\left(\frac{W}{F_D}\right) = \tan^{-1}\left(\frac{0.3467}{0.138}\right)$

$\theta = 68.295^\circ$

Angle of inclination of string to the horizontal $\theta = 68.295^\circ$

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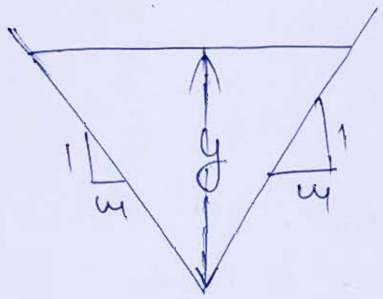
(b) Prove that the most efficient triangular cross-section channel is half of a square with its diagonal horizontal

[12 marks]

Sol^n :- Let's say we have triangular channel section with side slope of 1 in m



$A = my^2$

$P = 2y\sqrt{1+m^2}$

For most efficient channel section P should be minimum :-

$$P = 2y\sqrt{1+m^2} = 2\sqrt{\frac{A}{m}}\sqrt{1+m^2}$$

$$= 2\sqrt{A}\sqrt{\frac{1}{m}+m}$$

For P to be minimum :- $\frac{dP}{dm} = 0$

$$\frac{dP}{dm} = 2\sqrt{A}\,\frac{1}{2}\frac{1}{\sqrt{\frac{1}{m}+m}}\left(-\frac{1}{m^2}+1\right) = 0$$

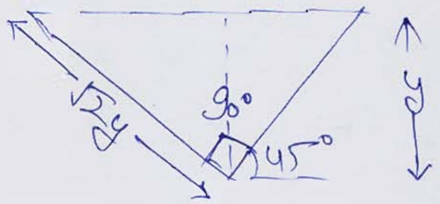
$$-\frac{1}{m^2}+1 = 0$$

$$m^2 = 1$$

$$m = \pm 1$$

So for most efficient triangular section $m = 1$ or side slope is $45°$.

If side slope is 45°



So it is clear than it is half of a square whose sides are √2y & one diagonal is vertical & one horizontal with length 2y.

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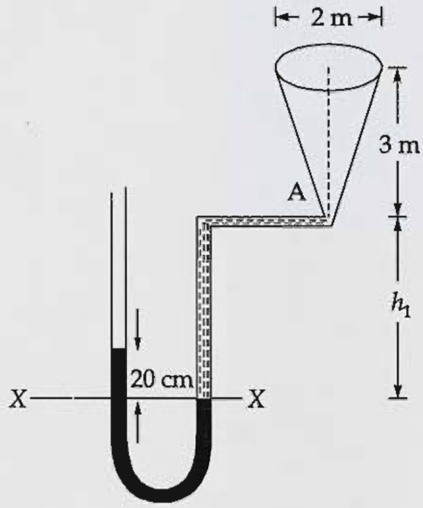
(c) Derive the expression for the efficiency of a Pelton turbine. Also determine the condition for maximum efficiency and obtain the expression for the maximum efficiency of turbine.

[12 marks]

(d) A conical vessel having its outlet at A to which a U-tube manometer is connected is shown in figure below. The reading of the manometer given in the figure shows when the vessel is empty. Find the reading of the manometer when the vessel is completely filled with water.



[12 marks]

Sol:- Assuming the manometric fluid to be mercury

$\rho_{Hg} = 13.6 \times 10^3$ kg/m³

Case ①:- When vessel was empty

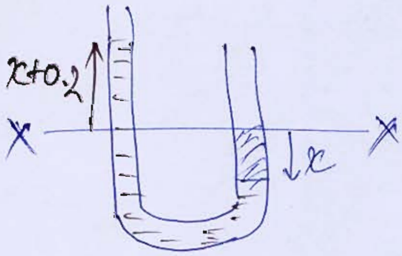
$P_{xx} = \rho_{Hg}\, g \times \left(\frac{20}{100}\right) = \rho_w\, g \times h_1$

$13.6 \times 10^3 \times \frac{20}{100} = 10^3 \times h_1$

$h_1 =$ ~~2.72 m~~ 2.72 m

Case ②:- When vessel is completely filled :-

So due to rise in pressure in right tube water will move downward & mercury will shift upward.



So now :-

$$P_{xx} = \rho_w \times g \times (3 + h_1 + x) = \rho_{Hg} \times g \times (0.2 + x)$$

$$10^3 \times g \times (3 + 2.72 + x) = 13.6 \times 10^3 \times (0.2 + x)$$

$$5.72 + x = 2.72 + 13.6x$$

$$12.6x = 3$$

$$x = 0.238 \text{ m}$$

So final reading will be $= 2x + 0.2$

$= 0.676$ m

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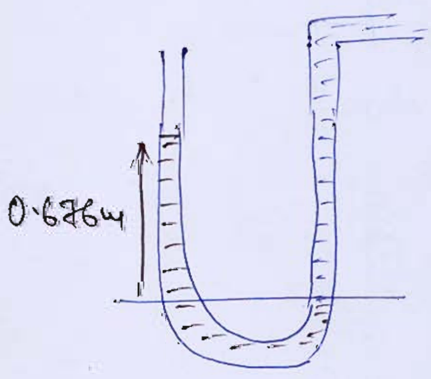

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(e) A 30 cm × 15 cm venturimeter is provided in a vertical pipe line carrying oil of specific gravity 0.9, the flow being upwards. The difference in elevation of the throat section and entrance section of the venturimeter is 30 cm. The differential U-tube mercury manometer shows a gauge deflection of 25 cm. Calculate:

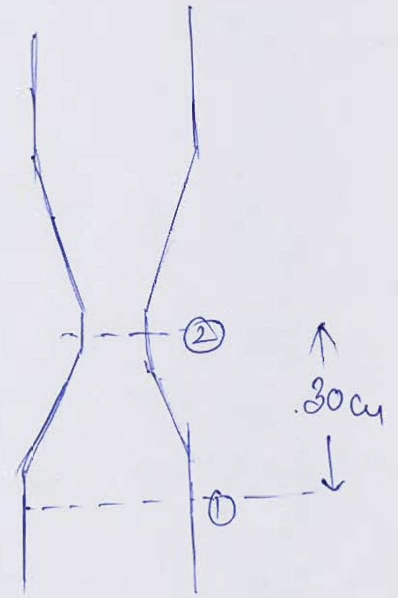
(i) The discharge of oil

(ii) The pressure difference between the entrance section and the throat section. Take the coefficient of venturimeter as 0.98 and specific gravity of mercury as 13.6.

[12 marks]

Soln :-

30 cm × 15 cm venturimeter



$D_1 = 30$ cm $\qquad D_2 = 15$ cm

(i)

$$Q_{act} = \frac{C_d A_1 A_2}{\sqrt{A_1^2 - A_2^2}} \sqrt{2gh}$$

h = difference in piezometric head @ section ① & throat section ②

$$h = x\left(\frac{S_M}{S} - 1\right) = \frac{25}{100}\left(\frac{13.6}{0.9} - 1\right) = 3.5278 \text{ m}$$

$C_d = 0.98$

$$Q_{act} = \frac{0.98 \times (\pi/4 \times 0.3^2) \times (\pi/4 \times 0.15)^2 \times \sqrt{2 \times 9.81 \times 3.5278}}{\sqrt{(\pi/4 \times 0.3^2)^2 - (\pi/4 \times 0.15^2)^2}}$$

$$= 0.1488 \text{ m}^3/\text{s}$$

(ii) $h = \left(\frac{P_1}{\rho g} + z_1\right) - \left(\frac{P_2}{\rho g} + z_2\right) = 3.5278$

$$\left(\frac{P_1 - P_2}{\rho g}\right) + (z_1 - z_2) = 3.5278$$

$$\frac{P_1 - P_2}{\rho g} + (0 - 0.3) = 3.5278$$

$$\Delta P = 3.8278 \times 10^3 \times 9.81$$

$$= 37.55 \text{ kPa}$$

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Q.2 (a) A body has the cylindrical upper portion of 3 m diameter and 1.8 m deep. The lower portion is a curved one, which displaces a volume of 0.6 m^3 of water. The centre of buoyancy of the curved portion is at a distance of 1.95 m below the top of the cylinder. The centre of gravity of the whole body is 1.20 m below the top of the cylinder. The total displacement of water is 3.9 tonnes. Find the meta-centric height of the body.

[20 marks]

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(b) Air is flowing over a flat plate 500 mm long and 500 mm wide with a velocity of 5 m/s. The kinematic viscosity of air is 0.1×10^{-4} m²/s. Determine:

(i) the boundary layer thickness at the end of the plate.

(ii) shear stress at the end of the plate.

The velocity profile over the plate is $\frac{U}{U_\infty} = \sin\left(\frac{\pi y}{2\delta}\right)$ and density of air is 1.2 kg/m³.

[20 marks]

Soln :-

$$Re_x = \frac{\rho V x}{\mu} = \frac{Vx}{\nu} = \frac{5 \times 0.5}{0.1 \times 10^{-4}}$$

$$= 250000 < (Re_{x_{cr}} = 5 \times 10^5)$$

Flow is laminar

(i) As per Blasius results :-

$$\frac{\delta}{x} = \frac{5}{\sqrt{Re_x}}$$

$$\delta = \frac{5 \times 0.5}{\sqrt{250000}} = 5 \times 10^{-3} \text{ m}$$

$$\delta = 5 \text{ mm}$$

Velocity profile :- $\frac{u}{u_\infty} = \sin\left(\frac{\pi y}{2\delta}\right)$

$$\theta = \int_0^\delta \frac{u}{u_\infty}\left(1 - \frac{u}{u_\infty}\right) dy = \int_0^\delta \left(\sin\left(\frac{\pi y}{2\delta}\right) - \sin^2\left(\frac{\pi y}{2\delta}\right)\right) dy$$

$$= \int_0^\delta \sin\left(\frac{\pi y}{2\delta}\right) dy - \int_0^\delta \frac{1 - \cos\left(\frac{2\pi y}{2\delta}\right)}{2} dy$$

$$\Rightarrow -\frac{2\delta}{\pi} \cos\left(\frac{\pi y}{2\delta}\right)\Big|_0^\delta - \left(\frac{y}{2} - \frac{1}{2}\sin\left(\frac{\pi y}{\delta}\right)\frac{\delta}{\pi}\right)_0^\delta$$

$$\Rightarrow -\frac{2\delta}{\pi}(0 - 1) - \left(\frac{\delta}{2} - 0\right) + \frac{1}{2}\frac{\delta}{\pi}(0 - 0)$$

Do not write in this margin

$$\Rightarrow \frac{2\delta}{\pi} + \frac{\delta}{2} = 1.1266\,\delta$$

As per von Karman integral momentum eqn :-

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

Incomplete

8

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(c) (i) The velocity potential function for a two-dimensional flow is given by

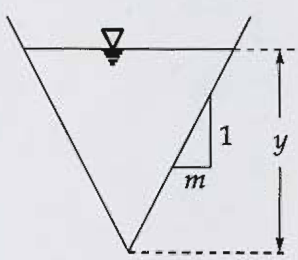
$$\phi = (x^2 - y^2) + 3xy.$$

Determine

1. The stream function
2. The flow rate between the streamlines passing through points (1, 1) and (1, 2).

(ii) Show that in a triangular channel, the Froude numbers F_1 and F_2 corresponding to alternate depths y_1 and y_2 respectively are related as

$$\left(\frac{F_1}{F_2}\right)^2 = \left(\frac{4+F_1^2}{4+F_2^2}\right)^5$$



[10 + 10 = 20 marks]

(i)

Sol^n:

$$\phi = (x^2 - y^2) + 3xy$$

$$u = -\frac{\partial \phi}{\partial x} = -(2x - 0 + 3y) = -2x - 3y$$

$$v = -\frac{\partial \phi}{\partial y} = -(-2y + 3x) = 2y - 3x$$

$$u = -2x - 3y = -\frac{\partial \psi}{\partial y}$$

$$(2x + 3y)\,dy = \partial\psi$$

$$\psi = 2xy + 3y^2/2 + f(x)$$

$$v = \frac{\partial \psi}{\partial x} = 2y - 3x$$

$$\Rightarrow \frac{\partial \psi}{\partial x} = 2y + f'(x) = 2y - 3x$$

$$f'(x) = -3x$$

$$f(x) = -\frac{3x^2}{2}$$

So :- $\psi = 2xy + 3y^2/2 - 3x^2/2$

b) Flow rate b/w (1,1) & (1,2)

$$\psi_{(1,1)} = 2(1.1) + 3\,1^2/2 - 3\,1^2/2 = 2$$

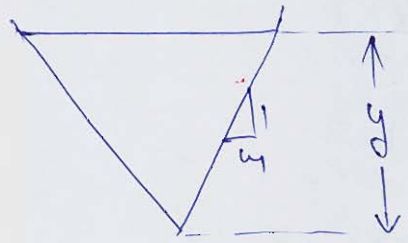
$$\psi(1,2) = 2.1.2 + 3.2^2/2 - 3.1^2/2 = 8.5$$

discharge per unit width $= \psi(1,2) - \psi(1,1)$

$= 8.5 - 2 = 6.5$ unit

(10)

Sol 4 :-



$A = my^2 \qquad P = 2y\sqrt{1+m^2}$

Alternate depth y_1 & y_2

$F_r = \frac{V}{\sqrt{gD}} \Rightarrow F_r^2 = \frac{Q^2 T}{gA^3} = \frac{Q^2 (2my)}{g(my^2)^3}$

$F_r^2 = \frac{2Q^2}{g m^2 y^5}$

$F_{r1}^2 = \frac{2Q^2}{g m^2 y_1^5} \qquad F_{r2}^2 = \frac{2Q^2}{g m^2 y_2^5}$

Equating energy :-

$E_1 = E_2$

$y_1 + \frac{V_1^2}{2g} = y_2 + \frac{V_2^2}{2g}$

$y_1 + \frac{Q^2}{2gA_1^2} = y_2 + \frac{Q_2^2}{2gA_2^2}$

$y_1 + \frac{Q^2}{2gm^2 y_1^4} = y_2 + \frac{Q^2}{2gm^2 y_2^4}$

$\frac{2gm^2 y_1^5 + Q^2}{2gm^2 y_1^4} = \frac{2gm^2 y_2^5 + Q^2}{2gm^2 y_2^4}$

From Froude's no' → $g\omega^2 y^5 = \frac{2Q^2}{f_r^2}$

$$\frac{2\times\left(\frac{2Q^2}{f_1^2}\right)+Q^2}{y_1^4} = \frac{2\times\left(\frac{2Q^2}{f_2^2}\right)+Q^2}{y_2^4}$$

$$\frac{\frac{4}{f_1^2}+1}{y_1^4} = \frac{\frac{4}{f_2^2}+1}{y_2^4}$$

$$\frac{4+f_1^2}{4+f_2^2} = \frac{y_1^4}{y_2^4}\frac{f_1^2}{f_2^2}$$

$$\left(\frac{y_1}{y_2}\right)^5 = \left(\frac{f_2}{f_1}\right)^2$$

So → $$\frac{4+f_1^2}{4+f_2^2} = \left(\frac{f_2}{f_1}\right)^{2/5\times 4}\left(\frac{f_1}{f_2}\right)^2$$

$$\frac{4+f_1^2}{4+f_2^2} = \left(\frac{f_1}{f_2}\right)^{0.4}$$

$$\left(\frac{4+f_1^2}{4+f_2^2}\right)^5 = \left(\frac{f_1}{f_2}\right)^2$$

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Hence proved

Q.3 (a) Two large plane surfaces are 2.4 cm apart. The space between the surfaces is filled with glycerine. What force is required to drag a very thin plate of surface area 0.5 square metre between the two large plane surfaces at a speed of 0.6 m/s, if:

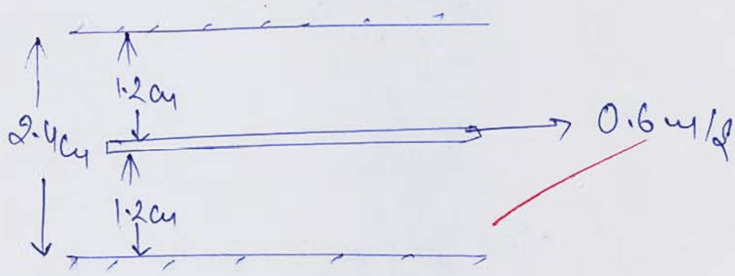
(i) The thin plate is in the middle of the two plane surfaces, and

(ii) The thin plate is at a distance of 0.8 cm from one of the plane surface? Take dynamic viscosity of glycerine as 8.10×10^{-1} Ns/m^2.

[20 marks]

Soln. –

(i)



Surface area of plate = 0.5 m^2

μ glycerine = 8.10×10^{-1} Pa-s

As per Newton's law of viscosity :-

$$\tau = \mu \frac{du}{dy} = \mu \left(\frac{u-0}{h}\right)$$

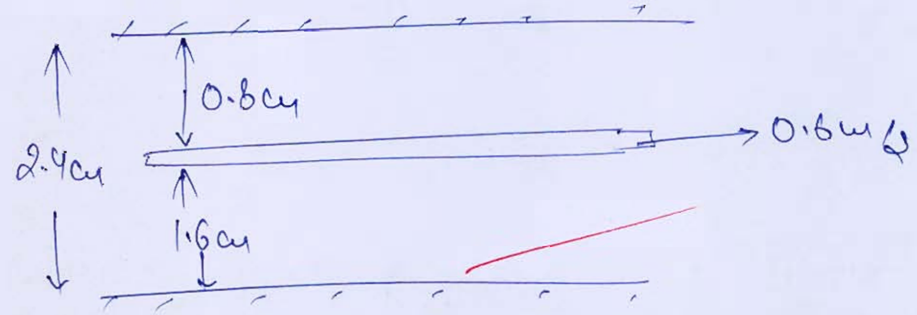
$$F_D = \tau A \times 2$$

$$= \mu \left(\frac{u-0}{h}\right) A \times 2$$

$$= 8.10 \times 10^{-1} \frac{Ns}{m^2} \left(\frac{0.6\ m/s - 0}{1.2 \times 10^{-2} m}\right) \times 0.5 m^2 \times 2$$

$$F_D = 40.5\ N$$

(ii)



$$F_D = \tau_1 \times A + \tau_2 \times A$$

$$= 8.1 \times 10^{-1} \left(\frac{0.6-0}{0.8 \times 10^{-2}}\right) \times 0.5 + 8.1 \times 10^{-1} \left(\frac{0.6-0}{1.6 \times 10^{-2}}\right) \times 0.5$$

$$= 45.5625\ N$$

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(b) A horizontal pipe line 40 m long is connected to a water tank at one end and discharges freely into the atmosphere at the other end. For the first 25 m of its length from the tank, the pipe is 150 mm in diameter and its diameter is suddenly enlarged to 300 mm thereafter. The height of water level in the tank is 8 m above the centre line of the pipe. Considering all losses of head which occur, determine the rate of flow. Take coefficient of friction, $f = 0.01$ for both sections of the pipe.

[20 marks]

Sol^n :- 40 m long pipe

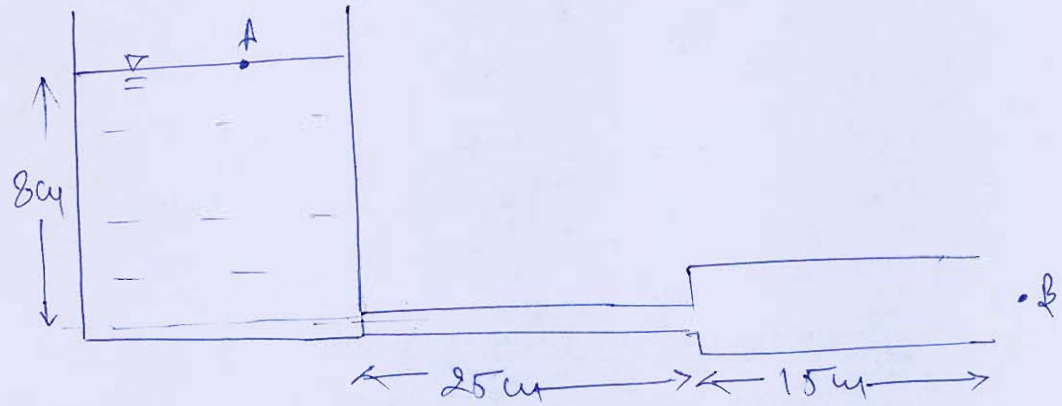
For :- 25m length

dia = 150mm = 0.15m

For remaning 15m length

dia = 300mm = 0.3m

$f' = 0.01$ $\quad f = 4f' = 0.04$



Point A : at free surface level
Point B : at exit of pipe

Apply energy eqn b/w A & B :-

$$\frac{P_A}{\rho g} + \frac{V_A^2}{2g} + Z_A = \frac{P_B}{\rho g} + \frac{V_B^2}{2g} + Z_B + h_L$$

$$h_L = Z_A - Z_B = 8\text{ cm}$$
(head loss)

major head loss (due to friction)

$$h_f = \frac{8Q^2}{\pi^2 g}\frac{fL}{D^5}$$
or
$$h_f = \frac{fLV^2}{2gD}$$

minor head loss :-

① At entry :- $0.5V^2/2g$

② Due to sudden expansion $(V_1 - V_2)^2/2g$

③ At exit $= V^2/2g$

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$$h_L = 8m = \frac{f L_1 V_1^2}{2g D_1} + \frac{f L_2 V_2^2}{2g D_2} + \frac{0.5 V_1^2}{2g} + \frac{(V_1 - V_2)^2}{2g} + V_2^2/2g$$

$$= \frac{0.04 \times 25 V_1^2}{2 \times 9.81 \times 0.15} + \frac{0.04 \times 15 \times V_2^2}{2 \times 9.81 \times 0.2} + \frac{0.5 V_1^2}{2 \times 9.81} + \frac{(V_1 - V_2)^2}{2 \times 9.81} + V_2^2/2g$$

Apply continuity :- $Q = A_1 V_1 = A_2 V$

$$\pi/_4 (0.15)^2 V_1 = \pi/_4 (0.3)^2 V_2$$

$$V_1 = 4 V_2$$

$$8m = \frac{0.04 \times 25 \times (4V_2)^2}{2 \times 9.81 \times 0.15} + \frac{0.04 \times 15 \; V_2^2}{2 \times 9.81 \times 0.2} + \frac{0.5 \times (4V_2)^2}{2 \times 9.81} + \frac{(4V_2 - V_2)^2}{2 \times 9.81} + \frac{V_2^2}{2 \times 9.81}$$

$$8m = 6.456 \, V_2^2$$

$$V_2 = 1.113 \; m/s$$

So $= Q = AV = \pi/_4 \times 0.3^2 \times 1.113$

$= 0.07868 \; m^3/s$

$= 78.685 \; l/s$

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(c) The resistance R experienced by a partially submerged body depends upon the velocity V, length of the body l, dynamic viscosity of the fluid μ, density of the fluid ρ and gravitational acceleration g. Obtain a dimensionless expression of R. Also relate R to some special dimensionaless numbers.

[20 marks]

Soln! —

$$R = f(V, l, \mu, \rho, g)$$

No. of π terms = $m - n$

m = total no. of variables = 6

n = no. of fundamental units involved = 3

no. of π terms = $6 - 3 = 3$

$$\pi_1 = l^a V^b \rho^c \mu$$

$$\pi_2 = l^a V^b \rho^c g$$

$$\pi_3 = l^a V^b \rho^c R$$

$\pi_1 = l^a v^b \rho^c \mu$

using dimensional analysis :-

$M^0L^0T^0 = [L]^a [LT^{-1}]^b [ML^{-3}]^c [ML^{-1}T^{-1}]$

$a+b-3c-1=0$ $\quad c=-1$

$-b -1 = 0$ $\quad b=-1$

$c+1=0$ $\quad a=-1$

$$\pi_1 = \frac{\mu}{\rho v l}$$

$\pi_2 = l^a v^b \rho^c g$

$M^0L^0T^0 = [L]^a [LT^{-1}]^b [ML^{-3}]^c [LT^{-2}]$

$a+b-3c+1=0$

$-b-2=0$

$c=0$ $\quad b=-2$ $\quad a=1$

$$\pi_2 = \frac{lg}{v^2}$$

$\pi_3 = l^a v^b \rho^c R$

$M^0L^0T^0 = [L]^a [LT^{-1}]^b [ML^{-3}]^c [MLT^{-2}]$

$a+b-3c+1=0$ $\quad b=-2$

$-b-2=0$ $\quad c=-1$

$c+1=0$ $\quad a=-2$

$$\pi_3 = \frac{R}{l^2 v^2 \rho}$$

$\pi_1 = \frac{\mu}{\rho V l}$ $\pi_2 = \frac{lg}{V^2}$ $\pi_3 = \frac{R}{\rho V^2 l^2}$

As per Buckingam π method

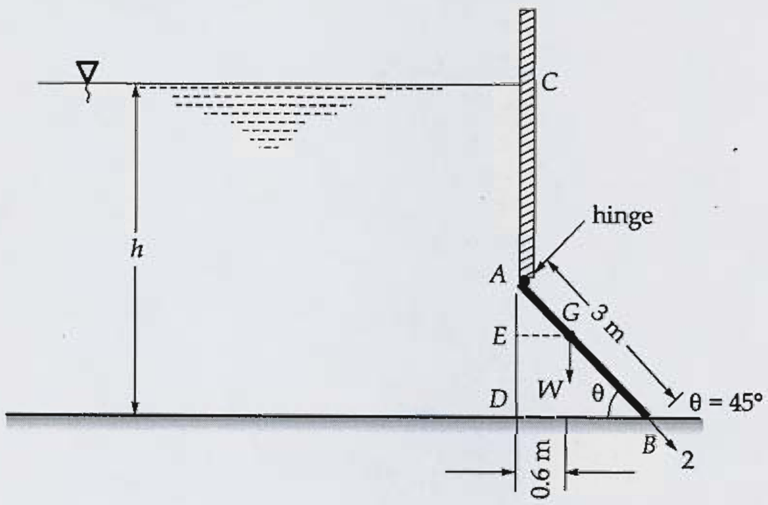
$$f(\pi_1, \pi_2, \pi_3) = 0$$

$$f\left(\frac{\mu}{\rho V l}, \frac{lg}{V^2}, \frac{R}{\rho V^2 l^2}\right) = 0$$

$$\frac{R}{\rho V^2 l^2} = K f\left(\frac{\mu}{\rho V l}, \frac{lg}{V^2}\right)$$

20

Q.4 (a) A rectangular sluice gate *AB*, 2 m wide and 3 m long is hinged at *A* as shown in figure. It is kept closed by a weight fixed to the gate. The total weight of the gate and weight fixed to the gate is 343350 N. Find the height of the water '*h*' which will just cause the gate to open. The centre of gravity of the weight and gate is at *G*.



[20 marks]

(b) **(i)** Explain radial flow reaction turbine. Describe its main components with the help of schematic diagram.

(ii) A Francis turbine with an overall efficiency of 75% is required to produce 150 kW power. It is working under a head H of 7.5 m. The peripheral velocity = $0.25\sqrt{2gH}$ and the radial velocity of flow at inlet is $0.95\sqrt{2gH}$. The wheel runs at 160 rpm and hydraulic losses in the turbine are 20% of the available energy. Assuming radial discharge, determine:

1. The guide blade angle
2. The wheel angle at inlet
3. Diameter of wheel at inlet, and
4. Width of the wheel at inlet

[10 + 10 = 20 marks]

(c) Find the convective acceleration at the middle of a pipe which converges uniformly from 0.4 m diameter to 0.2 m diameter over 2 m length. The rate of flow is 20 lit/s. If the rate of flow changes uniformly from 20 lit/s to 40 lit/s in 30 seconds, find the total acceleration at the middle of the pipe at 15^{th} second.

[20 marks]

Section B : Water Resource Engineering and Hydrology

Q.5 (a) For a catchment area of 12 km^2, a 7 hr storm pattern is as follows:

Time (h)	1	2	3	4	5	6	7
Precipitation (mm)	20	40	0	30	50	40	5

The discharge observed at the gauging site is as follows:

Time(h)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Discharge(Q)(m^3/s)	0	8	19	34	68	58	48	40	25	19	15	11	6	3	0

Assume the evaporation loss to be 3 mm and the seepage loss equal to 50% of the evaporation loss. Calculate ϕ-index and w-index.

[12 marks]

Soln. :- Catchment area = 12 Km²

Total rainfall (P) = 20 + 40 + 30 + 50 + 40 + 5
= 165 mm

Total runoff depth = Runoff volume (Area of hydrograph) / Catchment area

$$= \frac{\Sigma Q_i t_i}{CA}$$

$$= \frac{(0+8+19+34+68+58+48+40+25+19+15+11+6+3+0) \times 60 \times 60}{12 \times 10^6}$$

= 106.2 mm

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evaporation loss = 3 mm
seepage loss = 0.5×3 = 1.5 mm
total loss (ΔL) = 4.5 mm

$$W\text{index} = \frac{P - R - \Delta L}{7} = \frac{185 - 106.2 - 4.5}{7}$$

$$= 10.614 \text{ mm/hr}$$

ϕ index ≥ W index

$$\phi\text{index} = \frac{(20 + 40 + 30 + 40 + 50) - 106.2}{5}$$

$$= 14.76 \text{ mm/hr}$$

(from effective rainfall)

11

(b) A tube well penetrates fully into a confined aquifer. The following data was collected during observations. Calculate the discharge from the well.

Radius of tube well = 20 cm

Thickness of confined aquifer = 25 m

Drawdown = 4 m

Radius of circle of influence = 300 m

Coefficient of transmissibility = 125×10^{-4} m^2/sec.

Also calculate the coefficient of permeability. **[12 marks]**

As per Theis theory :-

For confined aquifers :- $Q = \dfrac{2\pi K b\,(h_2 - h_1)}{\ln(r_2/r_1)}$

$r_w = 20\text{cm} = 0.2\text{m}$

$b = 25\text{m}$

$S_w = 4\text{m}$

$R = 200\text{m}$

Coefficient of transmissibility $(T) = KH = 125\times10^{-4}\,\text{m}^2/\text{s}$

$K = \dfrac{125\times10^{-4}\,\text{m}^2/\text{s}}{25\text{m}} = 5\times10^{-4}\,\text{m/s}$

$Q = \dfrac{2\pi\times5\times10^{-4}\times25\times(H - h_w)}{\ln(R/r_w)}$

$= \dfrac{2\pi\times5\times10^{-4}\times25\times4}{\ln(200/0.2)}$

10

$Q = 0.04295\,\text{m}^3/\text{s}$

$= 42.958\ \text{l/s}$

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(c) Explain the advantages and disadvantages of canal lining in irrigation canal.

[12 marks]

Sol^n:- Canal lining is done as per IS 10430 : 2000

Advantage of canal lining:-

(i) With the help of canal lining seepage losses can be prevented upto a significant amount

(ii) Maintainance cost of lined canals is very low as compared to unlined canals.

(iii) High velocity of flow can be permitted through lined canals without any problem of scouring.

(iv) Lined canals provide less friction as compared to unlined canals so frictional losses will be less.

(v) Lined canals will act as rigid boundary canals, so no change in shape & size.

Disadvantage :-

(1) Lining is costly.

(2) Skilled manpower is req.

6

other points ??

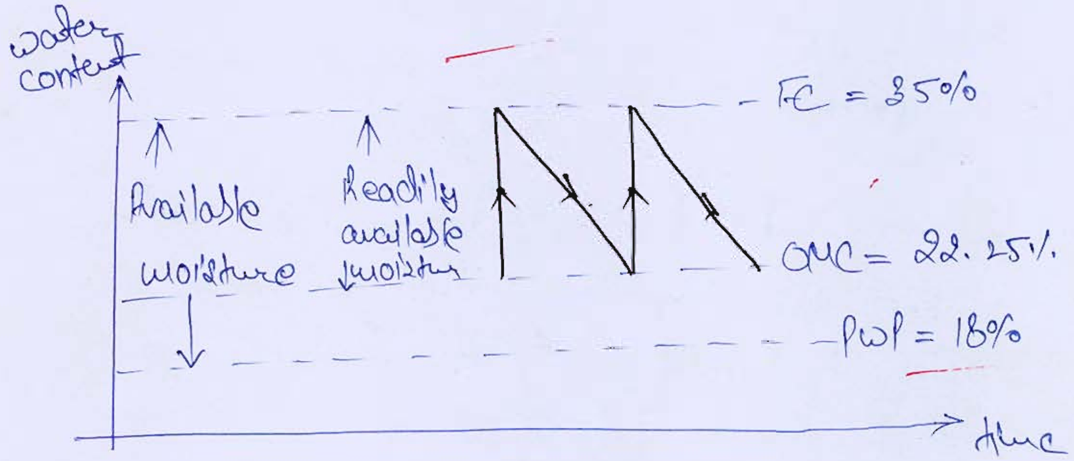
(d) Determine the frequency of irrigation from the following data:
Field capacity of soil = 35%
Permanent wilting point = 18%
Density of soil = 1.5 g/cm³
Depth of root zone = 70 cm
Daily consumptive use of water = 17 mm
(Take: Readily available moisture as 75% of the available moisture.)

[12 marks]

Soln: — FC = 35% PWP = 18%

root zone depth = 70 cm

C_u = 17 mm



OMC = 35% − 0.75(35 − 18) = 22.25%

Depth of water available for use by plants $= \left(\frac{\gamma_d}{\gamma_w}\right) d \times (FC - OMC)$

$= \left(\frac{1.5}{1}\right) \times 70 \times (0.35 - 0.2225)$

= 13.3875 cm

frequency of irrigation $= \frac{\text{depth of water available}}{\text{consumptive use}}$

$= \frac{13.3875 \times 10}{17}$

≃ 7.875 days ≃ 7 days.

12

Do not write in this margin

(e) Compares Kennedy's theory and Lacey's theory for the design of alluvial canals. Also discuss about the major drawbacks of Lacey's theory in the design of stable channels in alluvial soils.

[12 marks]

Kennedy's Theory :-	Lacey's theory :-
(i) It is based on iterative approach	It is based on direct approach
(ii) Kennedy assumed that eddies from the side slope doesn't have silt supporting power	Eddies from the entire wetted perimeter have silt supporting power
(iii) Didn't give any eq^n to find m	Give well defined eq^n for f
(iv) Silt charge & silt grade was not considered	Silt charge was not taken into account
(v) Regime channel is trapezoidal	Regime channel was semi-elliptical but for simplification of calculations it was considered to be trapezoidal.

Drawbacks of Lacey's Theory :-

① Lacey's theory doesn't consider silt charge & it is only applicable when silt charge is b/w 500 − 5000 mg/l.

② Lacey's assumed the section to be semi elliptical but doesn't provide any mathematical eqⁿ for it.

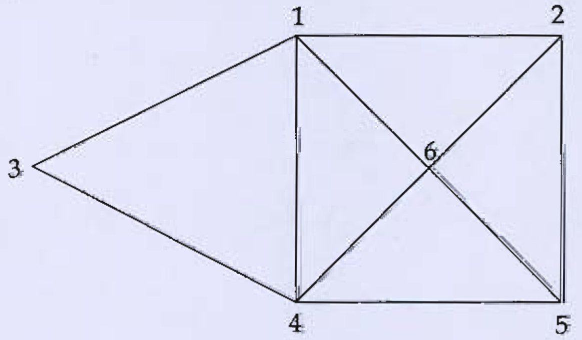
③ Lacey doesn't considered the increase in silt charge due to evaporation & seepage losses.

④ It is only applicable for canals in alluvial soil.

⑤ It is empirical theory based on experiments in small region.

8

Q.6 (a) (i) Calculate the mean precipitation for the area sketched below by Thiessen's polygon method. The area is composed of a square plus an equilateral triangle of side 8 km. Rainfall reading in cm at the various stations are given in table below.



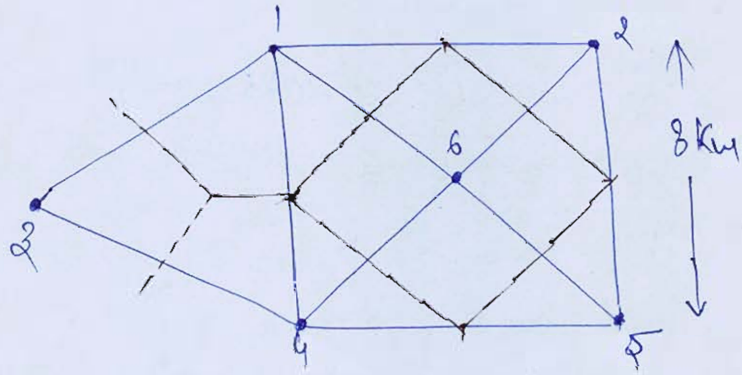
Rain gauge	1	2	3	4	5	6
Rainfall reading	10 cm	6 cm	3 cm	12 cm	3.6 cm	8.4 cm

(ii) Discuss different forms of precipitation. How measurement of precipitation is done?

[12 + 8 = 20 marks]

Sol 4:-

(a)



$$A_6 = \frac{8 \times 8}{2} = 32 \text{ Km}^2$$

$$A_2 = A_5 = \frac{8 \times 8 - 32}{4} = 8 \text{ Km}^2$$

$$A_3 = \frac{1}{2}\left(\sqrt{2}\, a^2/_4\right) = \frac{1}{2}\left(\sqrt{2} \times \frac{8^2}{4}\right) = 9.238 \text{ km}^2$$

$$A_1 = A_4 = 8 + 9.238 = 17.238 \text{ km}^2$$

As per Thiessen's Polygon method :-

$$P_{avg} = \frac{P_1 A_1 + P_2 A_2 - - - P_4 A_4}{A}$$

$$= \frac{(17.238 \times 10) + (8 \times 6) + (9.238 \times 3) + (17.238 \times 12) + (8 \times 3.6) + 32 \times 8.4}{91.7128}$$

$$P_{avg} = 8.21 \text{ cm}$$

12

b) Precipitation :- Any form in which water reaches earth surface from atmosphere is known as precipitation.

Different forms of precipitation involves :-

① Rain :- It denotes water droplets whose size varies b/w 0.5mm to 6mm.

② Snow :- It denotes crystal of ice having density of 0.5 gm/cm³

③ Drizzle :- It denotes fine water droplets having size less than 0.5mm & intensity less than 1mm/hr

④ Glaze :- When water droplets comes into contact with cold ground surface it converts into ice known as glaze.

⑤ Sleets :- It denotes frozen water droplets which are transparent in nature.

⑥ Hails :- It denotes lumps of ice whose size is more than 8mm as per IMD.

Measurement of precipitation:-

Precipitation is measured with the help of raingauge. To measure precipitation in any area a network of raingauges is established & data is recorded.

There are 2 types of raingauges:-

(i) Recording type
(ii) Non recording type

7

At least 10% of rain gauges must be recording type.

(b) (i) In a wide stream, a suspended load sample taken at a height of 0.6 m from the bed indicated a concentration of 1200 mg/l of sediment by weight. The stream is 6 m deep and has a bed slope of 1/5000. The bed material can be assumed to be of uniform size with a fall velocity of 4 cm/s. Determine the concentration of the suspended load at 2 m below top surface. Assume Von Karman's constant = 0.40.

(ii) Table below gives the details for a certain crop. Using Blaney-Criddle equation and a crop factor K = 0.80, determine the following :

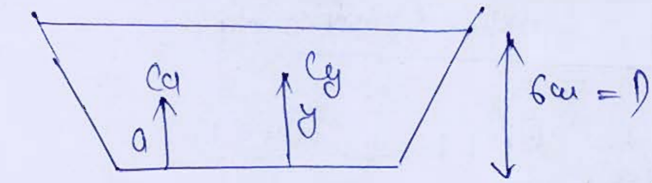
1. consumptive use
2. consumptive irrigation requirement
3. field irrigation requirement, if water application efficiency is 0.75. The latitude of the place is 30° N.

Month	Monthly Temp. (°C)	Monthly (%) of day time hours of the year	Useful rainfall (cm)
August	22	7.20	–
September	19	7.18	1.5
October	18.5	7.50	0.6
November	16	7.30	–

(iii) Write a short note on quality of irrigation water.

[10 + 6 + 4 = 20 marks]

Sol 4:— (i)



$S_0 = 1/5000$

$a = 0.6m$ $C_a = 1200\ mg/l$

$w = \text{fall velocity} = 4cm/s = 4\times10^{-2}\ m/s$

Karman constant $k = 0.4$

$y = 6-2 = 4m$

$$C_y/C_a = \left(\frac{a}{y}\frac{(D-y)}{(D-a)}\right)^{w/kV^*}$$

$$V^* = \text{shear velocity} = \sqrt{\frac{\tau_0}{\rho}} = \sqrt{\frac{\gamma_w R S}{\rho}}$$

$$= \sqrt{g\times D\times S} = \sqrt{9.8\times6\times 1/5000} = 0.1084$$

$$\frac{C_y}{1200\ mg/l} = \left(\frac{0.6\times(6-4)}{4\times(6-0.6)}\right)^{\frac{4\times10^{-2}}{0.10849\times0.4}}$$

$C_y = 88.6\ mg/l$

10

ii) As per Blaney - Criddle eq^n: -

$$C_u = \frac{kp}{40}(1.8t + 32)$$

a) Consumptive use = C_u aug + C_u sep. + C_u oct + C_u Nov

$$= \frac{0.8 \times 7.2}{40}(1.8 \times 22 + 32) + \frac{0.8 \times 7.18}{40}(1.8 \times 13 + 32)$$

$$+ \frac{0.8 \times 7.5}{40}(1.8 \times 16.5 + 32) + \frac{0.8 \times 7.3 \times}{40}(1.8 \times 16 + 32)$$

$$= 28.466 \text{ cm}$$

b) Consumptive irrigation req.

$$CIR = C_u - P_{eff} = 28.488 - 1.5 - 0.6$$

$$= 26.388 \text{ cm}$$

c) Assuming LR = PSR = 0   CIR = NIR

$$FIR = \frac{CIR}{\eta_a} = \frac{26.388}{0.75} = 48.517 \text{ cm}$$

6

(iii) Quality of irrigation water

① pH should be b/w 6 – 8.5

② TDS conc should not be more than 2100 mg/l

③ Boron concn < 2 mg/l

④ Sodium Absorption ratio = $\frac{Na^+ \times 100}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$ in med/l

④ Concn of salts is measured in terms of electrical conductivity.

2

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(c) A 12-hour storm rainfall with the following depths (in cm) occurred over a basin :
2.0, 2.5, 7.6, 3.8, 10.6, 5.0, 7.0, 10.0, 6.4, 3.8, 1.4 and 1.4
The surface runoff resulting from the above storm is equivalent to 27.5 cm of depth over basin. Calculate the average infiltration index for the basin.
Also calculate the average depth of hourly rainfall excess for a basin of area of 150 hectares. The basin consists of area A_1, A_2 and A_3 having average infiltration indices as given below :

Area	A_1	A_2	A_3
Area (hectares)	40	60	50
Infiltration index (cm/hr)	7.5	4	0.8

[20 marks]

Sol :-

Time	Rainfall (cm)
0	0
1	2
2	2.5
3	7.6
4	3.6
5	10.6
6	5
7	7
8	10
9	6.4
10	3.8
11	1.4
12	1.4

Total rainfall (P) = 61.5 cm

Runoff (R) = 27.5 cm

$$W \text{ index} = \frac{P-R}{12} = 2.833 \text{ cm/hr}$$

ϕ index ≥ W index

$$\phi_{index} = \frac{(7.6 + 8.8 + 10.6 + 5 + 7 + 10 + 6.4 + 8.8) - 27.5}{8}$$

$= 2.2275$ cm/hr

Incorrect approach

4

.7 (a) A masonry dam 10 m high is trapezoidal in section with top width of 1 m and bottom width of 8.25 m. The face exposed to water has a batter of 1:10. Depth of water at upstream level is 10 m. Calculate:

1. Factor of safety against overturning
2. Factor of safety against sliding
3. Shear friction factor

Assume coefficient of friction as 0.75, unit weight of masonry as 2240 kg/m^3.

Permissible shear stress of joint = 14 kg/cm^2. Based on the results give your remarks.

[Neglect uplift pressure and water level at downstream side]

[20 marks]

(b) (i) Describe various methods of surface irrigation with their advantages and disadvantages.

(ii) For a river, the estimated flood peaks for two return periods by the use of Gumbel's method, are given below.

Return period (years)	Peak flood (m^3/s)
100	485
50	445

What flood discharge in this river will have a return period of 1000 years?

[10 + 10 = 20 marks]

(c) (i) What do you meant by 'Stage' of a river? List the different methods of measurement of stage of a channel, by distinguishing it from gauge height.

(ii) Compute the flood discharge in a stream by the slope-area method for the following data:

	Area of cross-section (m^2)	Wetted perimeter (m)	Roughness coefficient (n)
Section 1-1	206	65	0.045
Section 2-2	200	53.8	0.045

The drop in head and length between the two sections are 0.98 m and 125 m, respectively.

[6 + 14 = 20 marks]

8 (a) (i) The base period, intensity of irrigation and duty of various crops under a canal system are given in the table below. Calculate the reservoir capacity if the canal losses are 25% and the reservoir losses are 10%.

Crop	Base Period (days)	Duty at the field (hectare / cumec)	Area under the crop (hectares)
Wheat	110	1600	4800
Sugarcane	360	720	5800
Cotton	200	1800	2500
Rice	140	1000	3600
Vegetable	180	800	1500

(ii) Define the following terms :

1. Effective rainfall
2. Consumptive irrigation requirement
3. Net irrigation requirement
4. Field irrigation requirement
5. Gross irrigation requirement

[15 + 5 = 20 marks]

(b) (i) Explain the term "Exit Gradient". Using Khosla's theory, estimate the value of exit gradient for a weir with a horizontal floor on a permeable foundation having width b = 10m, and depth of downstream sheet pile = 1.5 m. Given the difference between upstream and downstream water levels is 4 m.

(ii) What do you understand by river training? State its objectives and also write in brief about groynes, their types and support your answer with suitable sketches.

(iii) Design a regime channel for a discharge of 50 m^3/s and silt factor 1.1 using Lacey's Theory.

[Assume any other data suitably]

[4 + 4 + 12 = 20 marks]

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(c) In Muskingum method by McCarthy, the storage in a stream is given by $S = K[xI + (1 - x)O]$ where K is storage constant. Also, basic routing equation written for discrete time is

$$\left(\frac{I_1 + I_2}{2}\right)t - \left(\frac{O_1 + O_2}{2}\right)t = (S_2 - S_1)$$

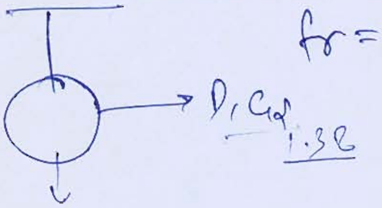
Derive from these the Muskingum equation of flood routing and determine the coefficients therein. What is the sum of these coefficients?

[20 marks]

Space for Rough Work

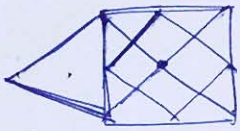
Space for Rough Work

Space for Rough Work



$Fr = \frac{Q^2 T}{g A^3} \Rightarrow Q^2$

$Re = \frac{\rho V D}{\mu} \to \frac{VD}{\nu} \Rightarrow$



$\frac{1}{2} C_D \rho u^2 A$

$Cd = 0.9$

$Mg = \rho V g = 346.71 P$

$W \Rightarrow 2.6 \times 10^3 \frac{4}{3}\pi r^3 \times 9.81$

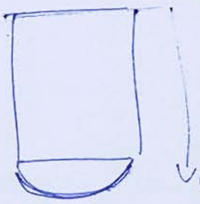
0.3461

0.138

$MG \to BM - BG$

$\frac{1+u^2}{u}$

$\frac{1}{u} + u - \frac{1}{u}$



$F \to m r a$

V, d, μ, ρ, g

$-2y + 3x$

$R = f(d, V, g, \mu, \rho)$

$2y - 3x = \frac{\partial \varphi}{\partial x}$

$6 - 3 = 3$

$\pi_1 = d^a V^b \rho^c \mu$

$\pi_2 = d^a V^b \rho^c g$

$\pi = d^a V^b \rho^c R$

$a + b - 3c - 1 = 0$

$-b - 1 = 0$, $b = -1$

$c + 1 = 0$, $c = -1$, $a = -1$

$c = 0$, $a + b - 3c - 2 = 0$, $-b - 2 = 0$, $b = -2$, $a = 4$

$c = 1$, $a + b - 3c + 1 = 0$, $-b - 2 = 0$, $b = -2$, $a = -2$

$\pi_1 = \frac{\mu}{\rho V h}$

$\pi_2 = \frac{g d^4}{V^2}$

$\pi_3 = \frac{R}{\rho d^2 V^2}$