LECTURE NOTES

ON

HYDRAULIC AND IRRIGATION ENGINEERING

Ganesh Institute of Engineering and Technology

SCTE &VT, BHUBANESWAR
ODISHA

4TH Semester Diploma in Civil Engineering

(As per Syllabus prescribed by SCTE&VT, Odisha)

By

Subject Coordinator: Er. Arasmita Dash

SR. LECTURER, CIVIL ENGINEERING

Hydrostatics :—

It is the branch of science which deals with study of fluids at rest.

Fluid :—

Any substance which is capable of flowing is called as a fluid.

Ex : liquid, gas

Properties of fluid :—

Density or mass density :—

(i) Density or mass density of a fluid is defined as the ratio of mass of fluid to its volume.

(ii) It is denoted as ρ (rho).

Mathematicaly $\rho = \frac{m}{v}$

The value of density of water is $1000 \, kg/m^3$.

Specific weight or weight density :—

(i) It is the ratio of weight of fluid to its volume.

(ii) It is denoted as γ (gamma).

Mathematically $\gamma = \frac{W}{V}$

$$\gamma = \frac{m}{v} = \frac{mg}{v} = \rho g$$

Specific Volume :—

It is the ratio of volume of liquid to the mass of liquid.

Mathematically, Specific volume $= \frac{V}{m} = \frac{1}{\frac{m}{v}} = \frac{1}{\rho}$

Specific Gravity :—

Specific gravity is defined as the ratio of weight density or density of a fluid to the weight density or density of a standard fluid. For liquid standard fluid is water, for gas standard fluid is air. Specific gravity is also known as relative density.

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$G_{mercury} = 13.6$

$$\rho_{mercury} = \frac{\text{Spe. Weight of mercury}}{\text{Sweight of water}}$$

$$\Rightarrow 13.6 = \frac{\text{density of mercury}}{1000}$$

$\Rightarrow$ Density of mercury $= 13600\ kg/m^3$

$W = m \times g$
$= 1 \times 9.81 = 9.81N$
$1kg = 9.81N$

Density of air $1.24\ kg/m^3$.

Q. Calculate the Specific weight, density and Specific gravity of 1 lt of a liquid which weighs 7N.

Ans Specific weight $= \gamma = \frac{w}{V}$

$$= \frac{7}{\frac{1}{1000}} = 7000\ N/m^3$$

Given data

$V = 1\ lt = \frac{1}{1000}\ m^3$

$W = 7N$

$\gamma = \rho g$

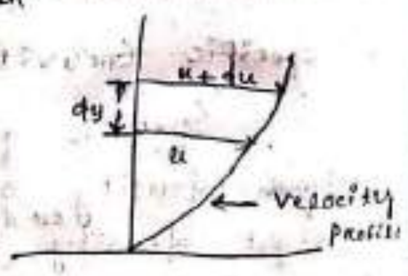
$$\rho = \frac{\gamma}{g} = \frac{7000}{9.81} = 713.55\ kg/m^3$$

$$G = \frac{\rho_l}{\rho_w} = \frac{713.55}{1000} = 0.713 \text{ (unitless)}$$

Viscosity :—

Viscosity is defined as the property of fluid which offers resistance to the movement of one layer of fluid over another adjecent layer of fluid.

The top layer causes a shear Stress (τ) on the adjecent bottom layer.



Newton's law of viscosity :—

According to this law, shear stress is directly proportional to velocity gradient $\left(\frac{dv}{dy}\right)$

Mathematically

$$\tau \text{ (Tau) } \propto \frac{dv}{dy}$$

$$\Rightarrow \tau = \mu \frac{dv}{dy} \quad \mu = mv$$

where τ (Tau) = shear stress in N/mm^2

μ (mu) = proportionality constant called co-efficient of dynamic viscosity or simply viscosity.

du = change velocity

dy = distance between two layers of fluid

$$\Rightarrow \mu = \frac{\tau}{\left(\frac{dv}{dy}\right)}$$

Unit of viscosity (μ) :—

$$\mu = \frac{\tau}{(dv/dy)} = \frac{N/mm^2}{\left(\frac{mm/sec}{mm}\right)} = \frac{N\text{-}sec}{mm^2}$$

Kinematic Viscosity :—

→ It is defined as the ratio between the dynamic viscosity (μ) and density of fluid (ρ).

→ It is denoted by ν (nu).

Mathematically

$$\boxed{\nu = \mu/\rho}$$

Unit of ν :—

$$\nu = \mu/\rho = \frac{N\text{-}sec}{m^2} \times \frac{1}{Kg/m^3}$$

[* unit of density is Kg/m^3

** $1N = 1\,\frac{Kg \cdot m}{s^2}$]

$$= \frac{Kg\text{-}m}{s^2} \times \frac{sec}{m^2} \times \frac{m^3}{kg}$$

$$= m^2/sec$$

1 poise = $1\,cm^2/sec$

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Problem-1

If the velocity distribution over a plate is given by $u = \frac{2}{3}y - y^2$ in which v is the velocity in m/sec at a distance y metre above the plate. Determine the shear stress at y = 0 and y = 0.15. Take dynamic viscosity of fluid as 8.63 poise.

Soln Given data

$$u = \frac{2}{3}y - y^2 \qquad \left(\frac{d}{dx} x^n = nx^{n-1}\right)$$

$$\frac{du}{dy} = \frac{2}{3}\frac{d(y)}{dy} - \frac{d}{dy}(y^2)$$

$$= \frac{2}{3} \times 1 - 2y$$

$$\mu = 8.63 \text{ poise} = 8.63 \text{ cm}^2/\text{sec}$$

$$= 8.63 \times 10^{-4} \text{ m}^2/\text{sec}$$

We know from newton's law of viscosity

$$\tau = \mu \frac{dv}{dy}$$

$$\tau_{y=0} = ? \quad \& \quad \tau_{y=0.15} = ?$$

$$\tau_{y=0} = \mu\left(\frac{dv}{dy}\right)_{y=0} = 8.63 \times 10^{-4} \times \left(\frac{2}{3} - 2 \times 0\right)$$

$$= 0.5754 \text{ N/m}^2$$

$$\tau_{y=0.15} = \mu\left(\frac{dv}{dy}\right)_{y=0.15} = 8.63 \times 10^{-4} \times \left(\frac{2}{3} - 2 \times 0.15\right)$$

$$= 0.3147 \text{ N/m}^2$$

Problem-2

A plate 0.025 mm distant from a fixed plate moves at 60 cm/sec and requires a force of 2 N/m² to maintain speed. Determine the fluid viscosity between the plates.

Soln Given data

$$dy = 0.025 \text{ mm}$$

$$= 0.025 \times 10^{-3} \text{ m}$$

$$du = 60 \text{ cm/sec} = 0.6 \text{ m/sec}$$

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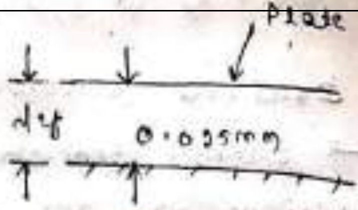
We know from newton's law of viscosity



$$\tau = \mu \cdot \frac{du}{dy} \quad \text{---- (1)}$$

τ given = 2 N/m²

putting the given values in eqⁿ (1)

$$2 = \mu \cdot \frac{0.6}{0.025 \times 10^{-3}}$$

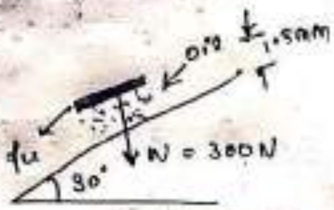
$$\Rightarrow \mu = 8.33 \times 10^{-5} \ N\cdot s/m^2$$

which is the required answer.

Problem - 3

Calculate the dynamic viscosity of an oil, which is used for lubrication between a square plate of size 0.8m x 0.8m and an inclined plate with angle of inclination 30° as shown in fig. The weight of the square plate is 300N and it slides down and inclined plate with a uniform velocity of 0.3m/sec. Thickness of oil film is 1.5mm.

Solⁿ Given data



Area of plate (A) = 0.8 × 0.8 = 0.64m²

$\theta = 30°$

$W = 300N$

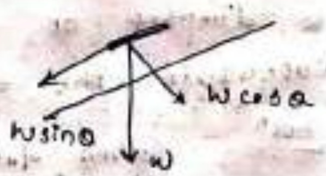
$du = 0.3$ m/sec

$dy = 1.5mm = 1.5 \times 10^{-3}$ m

Shear force (F) = W sin θ

= 300 sin 30°

= 150N



τ = Shear Stress =

$$= \frac{\text{Shear force}}{\text{shear area}} = \frac{150}{0.64}$$

We know from newton's law of viscosity

$$\tau = \mu \frac{du}{dy}$$

$$\Rightarrow \frac{150}{0.64} = \mu \cdot \frac{0.3}{1.5 \times 10^{-3}}$$

$\Rightarrow \mu = 1.17 \ N\text{-sec}/m^2$

Surface tension :—

→ Surface tension is defined as the tensile force acting on the surface of a liquid in contact with a gas or on the surface between two immiscible (unable to mix) liquids such that the contact surface behaves like a membrane under tension.

→ It is denoted as σ (sigma).

→ Unit is N/m

Surface tension of a liquid droplet :—

Let p = pressure intensity inside the droplet

σ = surface tension of liquid

d = dia of droplet

pressure force on area

$= \text{Stress or pressure} \times \text{Area}$

$= P \times \frac{\pi}{4}(d^2)$

Surface tension force = Surface tension × perimeter in N/m

$= \sigma \times \pi d$

Equating both

$$P \times \pi/4 \, (d)^2 = \sigma \times \pi d$$

$$\Rightarrow P = \frac{4\sigma}{d}$$

Problem-6

The surface tension of water in contact with air at 30°c is 0.0725 N/m. The pressure inside a droplet of water is to be 0.02 N/cm². Calculate the diameter of the droplet of water.

Sol^n Given data

$\sigma = 0.0725 \ N/m$

$P = 0.02 \ N/cm^2 = 0.02 \times 10^4 \ N/m^2$

$P = \frac{4\sigma}{d}$

$\Rightarrow 0.02 \times 10^4 = \frac{4 \times 0.0725}{d}$

$\Rightarrow d = 0.00145 m = 1.45 mm$

Surface tension of hollow soap bubble :-

A hollow bubble has two surface in contact with air

pressure force $= p \times \frac{\pi}{4} d^2$ (Same as previous case)

Surface tension force $= 2 \times \sigma \times \pi d$

Equating both we have

$$p \times \frac{\pi}{4}(d^2) = 2 \times \sigma \times \pi d$$

$$\Rightarrow p = \frac{8\sigma}{d}$$

Problem - 7

Find the surface tension in a soap bubble of 40mm diameter when the inside pressure is 2.5 N/m^2

Solⁿ Given data

$d = 40mm = 0.04m$

$P = 2.5 N/m^2$

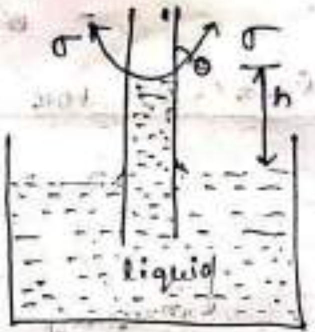
$$p = \frac{8\sigma}{d} \Rightarrow 2.5 = \frac{8 \times \sigma}{0.04}$$

$$\Rightarrow \sigma = 0.0125 \ N/m \quad \text{Ans}$$

Capillarity :-

Capillarity is defined as a phenomenon of rise or fall of a liquid surface in a small tube relative to the adjacent general level of liquid when the tube is held vertically in the liquid.

The rise of liquid surface is known as capillary depression.



Here in this figure

h = capillary rise

Unit

cm, m, mm etc.

Expression for finding capillary rise :-

$$h = \frac{4\sigma \cos\theta}{\rho g d}$$

Where,

σ = Surface tension in N/m

θ = Angle of contact

ρ = mass density of liquid

d = dia of tube

Problem-4

Calculate the capillary rise in a glass tube of 2.5 mm diameter when immersed vertically in (a) Water (b) Mercury.

Take surface tension σ = 0.725 N/m for water and σ = 0.52 N/m for mercury. Angle of contact for mercury = 130°. Specific gravity for mercury is 13.6 and for water is 1.0

Sol^n Case (a) For Water :

$d = 2.5\,mm = 2.5 \times 10^{-3}\,m$

$\sigma = 0.0725$ N/m

$\rho = 1000$ Kg/m 3

$g = 9.81$ m/sec^2

$$h = \frac{4\sigma \cos\theta}{\rho g d}$$

$$= \frac{4 \times 0.0725 \times \cos 0^\circ}{1000 \times 9.81 \times 2.5 \times 10^{-3}}$$

$= 0.0118\,m = 1.18\,cm$

Case (b) For mercury

$$h = \frac{4\sigma \cos\theta}{\rho g d}$$

$\sigma_{mercury} = 0.52$ N/m

$\theta = 130^\circ$

$\rho = 13.6 \times 1000$

$g = 9.81$ m/sec^2

(if not given in question, then you take $\theta = 130^\circ$ in case of mercury)

$d = 2.5$ mm $= 2.5 \times 10^{-3}$ m

$$h = \frac{4 \times 0.52 \times \cos 130^\circ}{13.6 \times 1000 \times 9.81 \times 2.5 \times 10^{-3}} = -0.004 \text{ m}$$

(-ve sign indicate capillary depression)

Problem - 5

Find out the minimum size of glass tube that can be used for measure water level if the capillary rise in the tube is restricted to 2 mm. Take σ of water in contact with air as 0.0735 N/m.

Sol^n Given data

$h = 2 \times 10^{-3}$ m

$\sigma = 0.0735$ N/m

$\theta = 0^\circ$ (for water)

$$h = \frac{4\sigma \cos\theta}{\rho g d}$$

$$\Rightarrow 2 \times 10^{-3} = \frac{4 \times 0.0735 \times \cos 0^\circ}{1000 \times 9.81 \times d}$$

$\Rightarrow d = 0.015$ m $= 1.5$ cm

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Chapter - 2

Pressure & its measurement :-

Pressure intensity :-

consider a small area dA in large mass fluid. If the fluid is stationary, then the force exerted by the surrounding fluid on the area will always be perpendicular to the surface dA. Let dF is the force acting on the area dA. Then the ratio of $\frac{dF}{dA}$ is known as pressure intensity.

→ It is represented by p.

Mathematically $p = \frac{dF}{dA} = \frac{\text{Force}}{\text{Area}}$

Unit :-

Force is in N, KN, Kg etc.

Area - is in cm^2, m^2, mm^2.

So p has a unit of N/mm^2 or KN/m^2 or Kg/cm^2 etc.

Pressure variation in fluid at rest :-

The pressure at any point in fluid at rest is obtained by the hydrostatic law which states the rate of change of pressure in vertically downward direction must be equal to specific weight of the fluid at that point.

Acc. to hydrostatic law.

$$\frac{dp}{dz} = \gamma = \rho g$$

$$\Rightarrow dp = \rho g \cdot dz$$

Integrating both sides

$$\int dp = \int \rho g \cdot dz = \rho g \int dz = \rho g z$$

$$\Rightarrow \boxed{p = \rho g z}$$

Problems

Q.1 Calculate the pressure due to a column of 0.3 of (a) water, (b) an oil of sp. gr. 0.8, and (c) mercury of sp. gr. 13.6. Take density of water $\rho = 1000\ kg/m^3$

Soln Given data,

Height of liquid column, $Z = 0.3m$

The pressure at any point in a liquid is given by

$$p = \rho g z$$

$$\rho = 1000 \ kg/m^3$$

$$p = \rho g z = 1000 \times 9.81 \times 0.3 = 2943 \ N/m^2$$

$$= \frac{2943}{10^4} \ N/cm^2 = 0.2943 \ N/cm^2$$

(b) For oil of sp. gr. = 0.8,

We know that the density of a fluid is equal to specific gravity of fluid multiplied by density of water.

$\therefore$ Density of oil,

ρ_0 = sp. gr. of oil $\times$ Density of water

$$= 0.8 \times \rho = 0.8 \times 1000 \quad (\rho_0 = \text{Density of oil})$$

$$= 800 \ kg/m^3$$

$$p = \rho_0 \times g \times z$$

$$= 800 \times 9.81 \times 0.3$$

$$= 2354.4 \ N/m^2 = \frac{2354.4}{10^4} \frac{N}{cm^2}$$

$$= 0.2354 \frac{N}{cm^2} \quad \text{Ans}$$

(c) For mercury, sp. gr. = 13.6

We know that the density of a fluid is equal to specific gravity of fluid multiplied by density of water.

$\therefore$ Density of mercury,

ρ_s = specific gravity of mercury $\times$ Density of water

$$= 13.6 \times 1000 = 13600 \ kg/m^3$$

$$p = \rho_s \times g \times z$$

$$= 13600 \times 9.81 \times 0.3$$

$$= 40025 \ N/m^2$$

$$= \frac{40025}{10^4} = 4.002 \frac{N}{cm^2} \quad \text{Ans}$$

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Q.2 The pressure intensity at a point in a fluid is given 3.924 N/cm². Find the corresponding height of fluid when the fluid is : (a) water, and (b) oil of sp. gr. 0.9.

Sol^n Given data,

pressure intensity, $p = 3.924 \frac{N}{cm^2}$

$= 3.924 \times 10^4 \frac{N}{m^2}$

The corresponding height, z, of the fluid is given

$$z = \frac{p}{\rho \times g}$$

(a) For water, $\rho = 1000 \ kg/m^3$

$$z = \frac{p}{\rho \times g} = \frac{3.924 \times 10^4}{1000 \times 9.81} = 4 \text{ m of water}$$

Ans

(b) For oil, sp. gr. = 0.9

Density of oil $\rho_o = 0.9 \times 1000 = 900 \ kg/m^3$

$$z = \frac{p}{\rho_o \times g} = \frac{3.924 \times 10^4}{900 \times 9.81} = 4.44 \text{ m of oil}$$ Ans

Q.3 An oil of sp. gr. 0.9 is contained in a vessel. At a point the height of oil is 40m. Find the corresponding height of water at the point.

Sol^n Given data,

Sp. gr. of oil, $S_o = 0.9$

Height of oil, $z_o = 40m$

Density of oil, ρ_o = Sp. gr. of oil × Density of water

$= 0.9 \times 1000 = 900 \ kg/m^3$

Intensity of pressure, $p = \rho_o \times g \times z_o$

$= 900 \times 9.81 \times 40 \frac{N}{m^2}$

Corresponding height of water $= \frac{p}{\text{Density of water} \times g}$

$= \frac{900 \times 9.81 \times 40}{1000 \times 9.81}$

$= 0.9 \times 40 = 36m$ of water Ans

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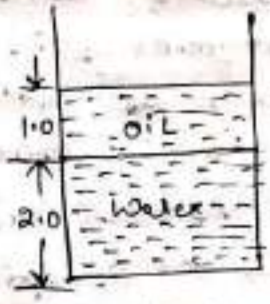
Q.4 An open tank contains water upto a depth of 2m and above it an oil of sp. gr. 0.9 for a depth of 1m. Find the pressure intensity i) at the interface of the two liquids, and ii) at the bottom of the tank.

Sol^n Given data,

Height of water, $Z_1 = 2m$

Height of oil, $Z_2 = 1m$

Sp. gr. of oil, $S_0 = 0.9$



Density of water, $\rho_1 = 1000 kg/m^3$

Density of oil, ρ_2 = Sp. gr. of oil × Density of water

$= 0.9 \times 1000 = 900 kg/m^3$

Pressure intensity at any point

$$P = \rho \times g \times Z$$

i) At interface, i.e. at A

$$P = \rho_2 \times g \times 1.0$$

$$= 900 \times 9.81 \times 1.0$$

$$= 8829 \frac{N}{m^2} = \frac{8829}{10^4}$$

$$= 0.8829 N/cm^2 \text{ Ans}$$

ii) At the bottom, i.e. at B

$$P = \rho_2 \times g Z_2 + \rho_1 \times g \times Z_1$$

$$= 900 \times 9.81 \times 1.0 + 1000 \times 9.81 \times 2.0$$

$$= 8829 + 19620$$

$$= 28449 N/m^2 = \frac{28449}{10^4} N/cm^2$$

$$= 2.8449 N/cm^2 \text{ Ans}$$

Absolute, Gauge, Atmospheric and vacuum pressure:-

The pressure on a fluid is measured in two different systems. In one system, it is measured above the absolute zero or complete vacuum and it is called the absolute pressure and in other system, pressure is measured above the atmospheric pressure and it is called gauge pressure. Thus:

1. Absolute pressure :-

→ Absolute pressure is defined as the pressure which is measured with reference to absolute vaccum pressure.

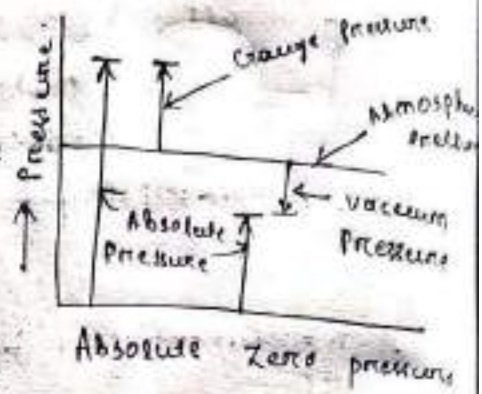
2. Gauge pressure :-

→ It is defined as the pressure which is measured with the help of a pressure measuring instrument, in which the atmospheric pressure is taken as datum. The atmospheric pressure on the scale is marked as zero.

3. Vaccum pressure :-

→ It is defined as the pressure below the atmospheric pressure.

→ The relationship between the absolute pressure, gauge pressure and vaccum pressure are shown in figure.



Mathematically :

(i) Absolute pressure = Atmospheric pressure + Gauge pressure

$$P_{ab} = P_{atm} + P_{gauge}$$

(ii) Vaccum pressure = Atmospheric pressure − Absolute Pressure.

Problems

Q.1 What are the gauge pressure and absolute pressure at a point 3 m below the free surface of a liquid having a density of 1.53×10^3 kg/m³ if the atmospheric pressure is equivalent to 750mm of mercury? The specific gravity of mercury is 13.6 and density of water = 1000 kg/m³.

Soln Given data,

Depth of liquid, $Z_1 = 3m$

Density of liquid, $\rho_1 = 1.53 \times 10^3$ kg/m³

Atmospheric pressure head, $Z_0 = 750$ mm of Hg

$= \frac{750}{1000} = 0.75m$ of Hg

Atmospheric pressure, $P_{atm} = \rho_0 \times g \times z_0$

where ρ_0 = Density of Hg = Sp. gr. of mercury × Density of water

$= 13.6 \times 1000$ kg/m3 ($\because z_0 = 0.75$)

$= 100062$ N/m²

pressure at a point, which is at a depth of 3m from the free surface of the liquid is given by, $p = \rho_1 \times g \times z_1$

$= (1.53 \times 1000) \times 9.81$

$= 45028$ N/m²

Gauge pressure, $p = 45028$ N/m² Ans

Now absolute pressure = Gauge pressure + Atmospheric ~~pressure~~ pressure

$= 45028 + 100062$

$= 145090$ N/m² Ans

Measurement of pressure :—

The pressure of a fluid is measured by the following devices:

1. Manometers 2. Mechanical gauges

Manometers :—

Manometers are defined as the devices used for measuring the pressure at a point in a fluid by balancing the column of the fluid by the same or another column of the fluid.

→ They are classified as

(a) Simple manometers

(b) Differential manometers.

(a) Simple manometers :—

A simple manometer consists of a glass tube having one of its ends connected to a point where pressure is to be measured and other end remains open to atmosphere.

→ common types of simple manometers are :

1. Piezometer
2. U-tube manometer

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Piezometer :—

→ It is the simplest from of manometer.

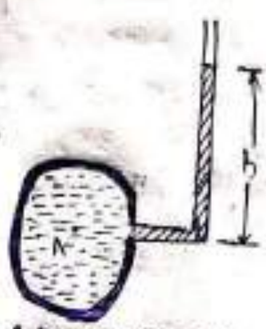
→ The rise of liquid gives the pressure head at thane point.

→ If at a point A, the height of liquid say water is h in piezometer tube, then

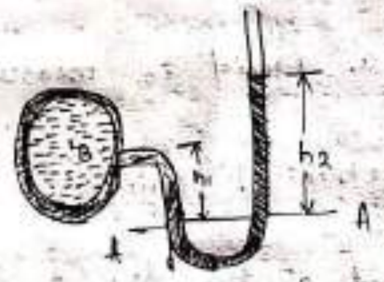
$$\text{pressure at } A = \rho \times g \times h \ \frac{N}{m^2}$$

U-tube manometer :—

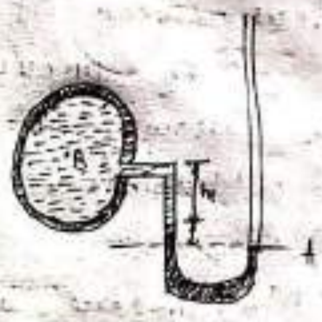
It consist of glass tube bent in U-shape, one end of which is connected to a point at which pressure is to be measured and other end remains open to the atmosphere.



(piezometer)



(a) For gauge pressure



(b) For Vacuum pressure

(a) For gauge pressure :—

Let B is the point at which pressure is to be measured, whose value is p.

→ The datum is A - A

h_1 = Height of light liquid above the datum line.

h_2 = Height of heavy liquid above the datum line.

ρ_1 = Density of light liquid $= 1000 \times S_1$

S_1 = sp. gr. of light liquid

S_2 = sp. gr. of heavy liquid

ρ_2 = Density of heavy liquid $= 1000 \times \rho_2$

As the pressure is the same for the horizontal surface. Hence pressure above the horizontal datum line A-A in the left column and in the right column of U-tube manometer should be same.

pressure above A-A in the left column of U-tube $= p + \rho_1 \times g \times h_1$

pressure above A-A in the right column $= \rho_2 \times g \times h_2$

Hence equating the two pressure $p + \rho_1 g h_1 = \rho_2 g h_2$

$$p = (\rho_2 g h_2 - \rho_1 \times g \times h_1).$$

(b) For vacuum pressure :—

For measuring vacuum pressure, the level of the heavy liquid in the manometer will be. Then

pressure above A-A in the left column =

$$\rho_2 g h_2 + \rho_1 g h_1 + p$$

Pressure head in the right column above A-A = 0

$$\rho_2 g h_2 + \rho_1 g h_1 + p = 0$$

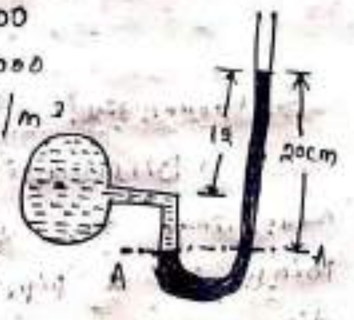
$$p = -(\rho_2 g h_2 + \rho_1 g h_1)$$

Q. The right of a simple U-tube manometer containing mercury is open to the atmosphere while the left limb is connected to a pipe in which a fluid of sp. gr. 0.9 is flowing. The centre of the pipe is 12 cm below the level of mercury in the right limb. Find the pressure of fluid in the pipe if the difference of mercury level in the two limbs is 20cm.

Soln. Given data,

sp. gr. of fluid, $s_1 = 0.9$

∴ Density of fluid, $\rho_1 = s_1 \times 1000$
$= 0.9 \times 1000$
$= 900\ kg/m^3$



sp. gr. of mercury, $s_2 = 13.6$

Density of mercury,

$\rho_2 = 13.6 \times 1000\ kg/m^3$

Difference of mercury level, $h_2 = 20cm = 0.2m$

Height of fluid form A-A, $h_1 = 20 - 12$
$= 8cm = 0.08m$

Let p = Pressure of fluid in pipe

Equating the pressure above A-A, we get

$$p + \rho_1 g h_1 = \rho_2 g h_2$$

$$p + 900 \times 9.81 \times 0.08 = 13.6 \times 1000 \times 9.81 \times 0.2$$

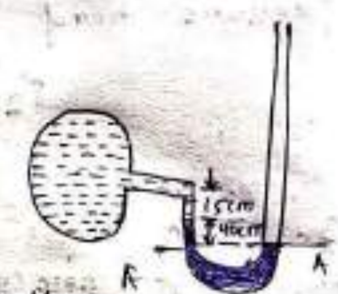
$$p = 13.6 \times 1000 \times 9.81 \times 0.2 - 900 \times 9.81 \times 0.08$$

$$= 26683 - 706 = 25977 \text{ N/m}^2$$

$$= 2.597 \text{ N/cm}^2 \text{ Ans}$$

Q. A simple U-tube manometer containing mercury is connected to a pipe in which a fluid of sp. gr. 0.8 and having vacuum pressure is flowing. The other end of the manometer is open to atmosphere. Find the vacuum pressure in pipe, if the difference of mercury level in the two limbs is 40 cm and the height of fluid in the left from the centre of pipe is 15 cm below.

<u>Soln</u> Given data,



Sp. gr. of fluid, $S_1 = 0.8$

Sp. gr. of mercury, $S_2 = 13.6$

Density of fluid, $\rho_1 = 800$

Density of mercury, $\rho_2 = 13.6 \times 1000$

Difference of mercury level, $h_2 = 40 \text{ cm} = 0.4 \text{ m}$.

Height of fluid in left limb, $h_1 = 15 \text{ cm} = 0.15 \text{ m}$.

Let the pressure in pipe $= p$. Equating pressure above datum line A-A, we get

$$\rho_2 g h_2 + \rho_1 g h_1 + p = 0$$

$$p = -[\rho_2 g h_2 + \rho_1 g h_1]$$

$$= -[13.6 \times 1000 \times 9.81 \times 0.4 + 800 \times 9.81 \times 0.15]$$

$$= -[53366.4 + 1177.2]$$

$$= -54543.6 \text{ N/m}^2$$

$$= -5.454 \text{ N/cm}^2 \quad \text{Ans}$$

Differential Manometers :—

(Differential manometers are the devices used for measuring the difference of pressures between two points in a pipe or in two different pipes. A differential manometer consists of a U-tube, containing a heavy liquid, whose two ends are connected to the points, whose difference of pressure is to be measured. Most commonly types of differential manometers are :

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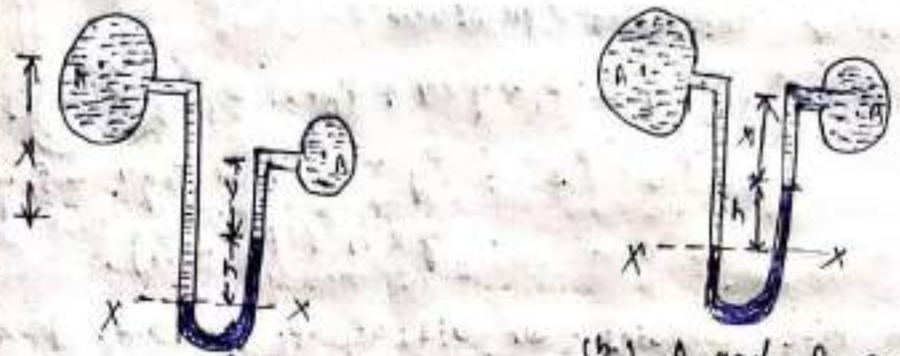
1. U-tube differential manometers and

2. Inverted U-tube differential manometer.

U-tube differential manometer :-



(a) Two points at different levels

(b) A and B are at the same level

(a), the two points A and B are at different level and also contains liquids of different sp. gr. These points are connected to the U-tube differential manometer. Let the pressure at A and B are P_A and P_B.

Let h = Difference of mercury level in the U-tube

y = distance of the centre of B, from the mercury level in the right limb.

x = Distance of the centre of A, from the mercury level in the right limb.

ρ_1 = Density of liquid at A.

ρ_2 = Density of liquid at B.

ρ_g = Density of heavy liquid or mercury

Taking datum line at X-X.

pressure above X-X in the left limb = $\rho_1 g(h+x) + P_A$

where P_A = pressure at A.

Equating the two pressure, we have

$$\rho_1 g(h+x) + P_A = \rho_g \times g \times h + \rho_2 g y + P_B$$

$$P_A - P_B = \rho_g \times g \times h + \rho_2 g y - \rho_1 g(h+x)$$

$$= h \times g(\rho_g - \rho_1) + \rho_2 g y - \rho_1 g x$$

Difference of pressure at A and B

$$= h \times g(\rho_g - \rho_1) + \rho_2 g y - \rho_1 g x$$

(b) the two points A and B are at the same level and contains the same liquid of density ρ_1. Then

Pressure above X-X in right limb

$$= \rho_g \times g \times h + \rho_1 \times g \times x + P_B$$

Pressure above X-X in left limb $= \rho_1 \times g \times (h+x) + P_A$

Equating the two pressure

$$\rho_g \times g \times h + \rho_1 \times g \times x + P_B = \rho_1 \times g \times (h+x) + P_A$$

$$P_A - P_B = \rho_g \times g \times h + \rho_1 g x - \rho_1 g (h+x)$$

$$= g \times h \, (\rho_g - \rho_1).$$

Q. A pipe contains an oil of sp. gr. 0.9. A differential manometer connected at the two points A and B shows a difference in mercury level as 15 cm. Find the difference of pressure at the two points.

Ans Given data :

Sp. gr. of oil, $S_1 = 0.9$

$\therefore$ Density, $\rho_1 = 0.9 \times 1000 = 900 \text{ kg/m}^3$

Difference in mercury level, $h = 15\text{ cm} = 0.15\text{ m}$

Sp. gr. of mercury, $S_g = 13.6$

$\therefore$ Density, $\rho_g = 13.6 \times 1000 \text{ kg/m}^3$

The difference of pressure is

$$P_A - P_B = g \times h \, (\rho_g - \rho_1)$$

$$= 9.81 \times 0.15 \, (13600 - 900)$$

$$= 18688 \text{ N/m}^2 \text{ Ans}$$

Q. A differential manometer is connected at the two points A and B of two pipes as shown in fig. The pipe A contains a liquid of sp. gr. = 1.5 while pipe B contains a liquid of sp. gr. = 0.9. The pressure at A and B are 1 kgf/cm² and 1.80 kgf/cm² respectively. Find the difference in mercury level in the differential manometer.

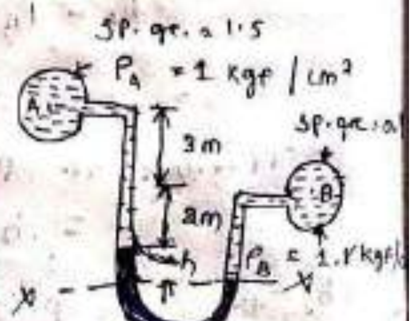
Soln Given data

Sp. gr. of liquid at A, $S_1 = 1.5$

$\therefore \rho_1 = 1500$

Sp. gr. of liquid at B, $S_2 = 0.9$

$\therefore \rho_2 = 900$



Pressure at A,

$p_A = 1 \text{ kgf}/cm^2$

$= 1 \times 10^4 \text{ kgf}/m^2$

$= 10^4 \times 9.81 \text{ N}/m^2 \quad (\because 1 \text{ kgf} = 9.81\text{N})$

pressure at B, $p_B = 1.8 \text{ kgf}/cm^2$

$= 1.8 \times 10^4 \text{ kgf}/m^2$

$= 1.8 \times 10^4 \times 9.81 \text{ N}/m^2$

Density of mercury $= 13.6 \times 1000 \text{ kg}/m^3$

Taking X-X as datum line.

pressure above X-X in the left limb

$= 13.6 \times 1000 \times 9.81 \times h + 1500 \times 9.81 \times (2+3) + p_A$

$= 13.6 \times 1000 \times 9.81 \times h + 7500 \times 9.81 + 9.81 \times 10^4$

pressure above X-X in the right limb =

$= 900 \times 9.81 \times (h+2) + p_B$

$= 900 \times 9.81 \times (h+2) + 1.8 \times 10^4 \times 9.81$

Equating the two pressure, we get

$13.6 \times 1000 \times 9.81 h + 7500 \times 9.81 + 9.81 \times 10^4 =$

$900 \times 9.81 \times (h+2) + 1.8 \times 10^4 \times 9.81$

Deviding by 1000×9.81, we get

$13.6h + 7.5 + 10 = (h+2.0) \times 0.9 + 18$

$\Rightarrow 13.6h + 17.5 = 0.9h + 1.8 + 18$

$\Rightarrow 13.6h + 17.5 = 0.9h + 19.8$

$\Rightarrow (13.6 - 0.9)h = 19.8 - 17.5$ or $12.7h = 2.3$

$\Rightarrow h = \frac{2.3}{12.7} = 0.181 m = 18.1 \text{ cm}$ Ans

Q. A differential manometer is connected at the two points A and B as shown in fig. At B air pressure is $9.81 \text{ N}/cm^2$ (abs), find the absolute pressure at A.

Soln Given data

Air pressure at B $= 9.81 \text{ N}/cm^2$

or, $p_B = 9.81 \times 10^4 \text{ N}/m^2$

Density of oil $= 0.9 \times 1000 = 900 \text{ kg}/m^3$

Density of mercury $= 13.6 \times 1000 \text{ kg}/m^3$

Let the pressure at A is p_A

Taking datum line at X-X

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Pressure above x-x in the right limb =

$= 1000 \times 9.81 \times 0.6 \times P_B$

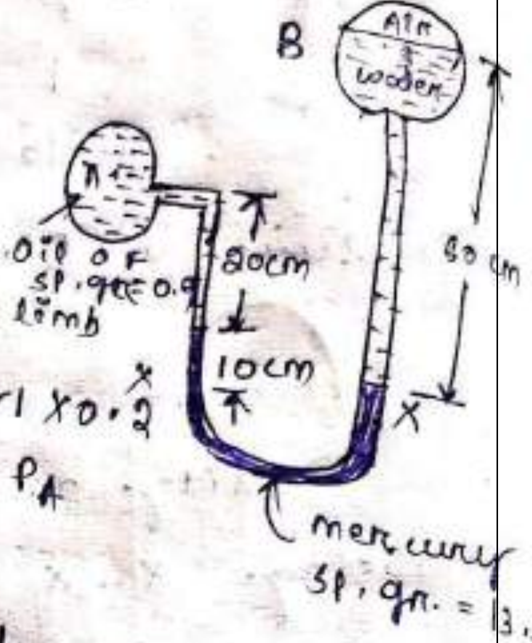
$= 5886 + \cancel{\quad} 98100$

$= 103986$

Pressure above x-x in the left limb

$= 13.6 \times 1000 \times 9.81 \times 0.1 + 900 \times 9.81 \times 0.2 + P_A$

$= 13341.6 + 1765.8 + P_A$



Equating the two pressure heads

$103986 = 13341.6 + 1765.8 + P_A$

$P_A = 103986 - 15107.4 = 88878.6$

$P_A = 88876.8 \ N/m^2$

$= \dfrac{88876.8 \ N}{10000 \ cm^2} = 8.8887 \ \dfrac{N}{cm^2}$

$\therefore$ Absolute pressure at A $= 8.8887 \ N/cm^2$ Ans

: Pressure exerted on immersed surfaces :

Total pressure :—

Total pressure is defined as the force exerted by a static fluid on a surface either plane or curved when the fluid comes in contact with the surfaces.

Center of pressure (CP) :—

centre of pressure is defined as the point of application of the total pressure on the surface.

Vertical plane surface submerged in liquid :—

consider a plane vertical surface immersed in liquid as shown below.

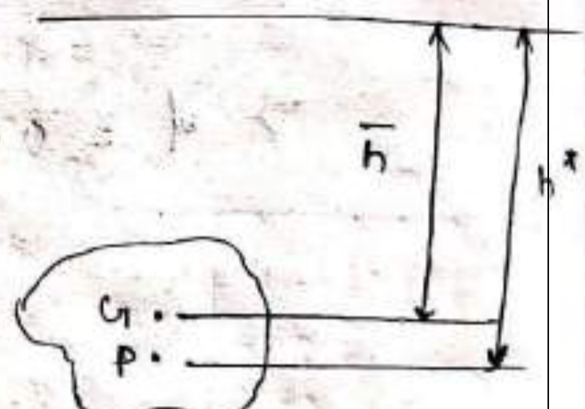
Let A = Total area of the surface

$\bar{h}$ = Distance of C.G from the free surface of liquid

G = Center of gravity

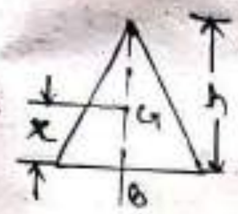
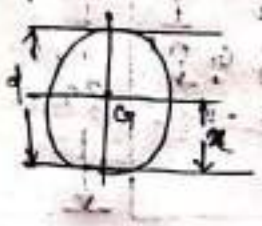
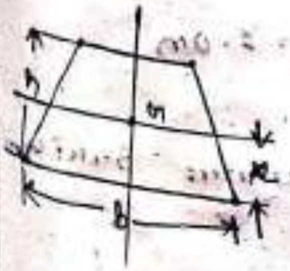
P = centre of pressure

h^* = Distance of centre of pressure (C.P) from free liquid surface.



Therefore total pressure $(P) = \rho g A \bar{h}$

centre of pressure (C.P) = $h^* = \dfrac{I_G}{A\bar{h}} + \bar{h}$

Plane surface	C.G from the base	Area	Moment of inertia about an axis passing through C.G. and parallel to base (I_G)	Moment of inertia about base
1. Rectangle 	$x = \frac{d}{2}$	bd	$\frac{bd^3}{12}$	$\frac{bd^3}{3}$
2. Triangle 	$x = \frac{h}{3}$	$\frac{bh}{2}$	$\frac{bh^3}{36}$	$\frac{bh^3}{12}$
3. Circle 	$x = \frac{d}{2}$	$\frac{\pi d^2}{4}$	$\frac{\pi d^4}{64}$	
4. Trapezium 	$x = \left[\frac{2a+b}{a+b}\right]\frac{h}{3}$	$\frac{a+b}{2} \times h$	$\left[\frac{a^2+4ab+b^2}{36(a+b)}\right] \times h^3$	

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Problem

A rectangular plane surface is 2m wide and 3m depth. It lies in vertical plane in water. Determine the total pressure and position of centre of pressure on the plane surface when its upper edge is horizontal and (a) coincide with water surface (b) 2.5m below the free water surface.

Sol^n

width of plane surface $= b = 2m$

Depth of plane surface $= d = 3m$

(a) Upper edge coincide with water surface

$$F = \rho g A \bar{h}$$

where $\rho = 1000\ kg/m^3$

$g = 9.81\ m/s^2$

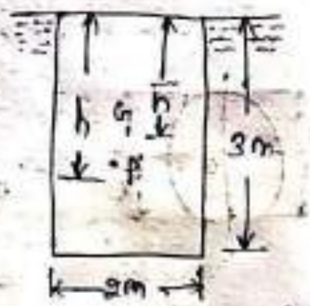
$A = 3 \times 2 = 6 m^2$

$\bar{h} = \frac{1}{2}(3) = 1.5\ m$

$F = 1000 \times 9.81 \times 6 \times 1.5$

$= 88290 N$ Ans

Depth of centre of pressure is given by equation



Free water surface

$$h^* = \frac{I_G}{A\bar{h}} + \bar{h}$$

where I_G = M.O.I. about C.G of the area of surface

$$= \frac{bd^3}{12} = \frac{2 \times 3^3}{12} = 4.5\ m^4$$

$$h^* = \frac{4.5}{6 \times 1.5} + 1.5 = 0.5 + 1.5 = 2.0m$$

(b) Upper edge is 2.5 m below water surface

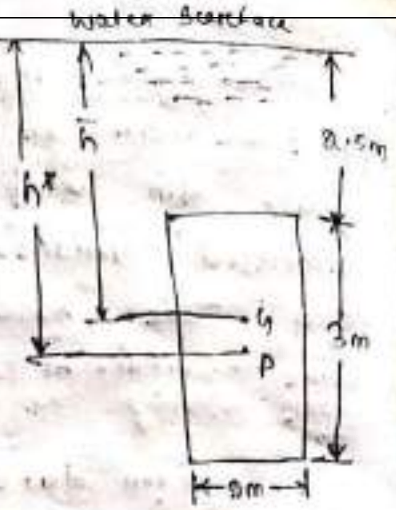
Total pressure (F) is given

$$F = \rho g A \bar{h}$$

where $\bar{h}$ = Distance of C.G from free surface of water $= 2.5 + \frac{3}{2} = 4.0m$

$F = 1000 \times 9.81 \times 6 \times 4.0$

$= 235440$ N **Ans**



centre of pressure is given by $h^* = \dfrac{I_G}{A\bar{h}} + \bar{h}$

where $I_G = 4.5$, $A = 6.0$,

$\bar{h} = 4.0$

$$h^* = \frac{4.5}{6.0 \times 4.0} + 4.0$$

$= 0.1875 + 4.0 = 4.1875 = 4.1875$ m **Ans**

Problem:

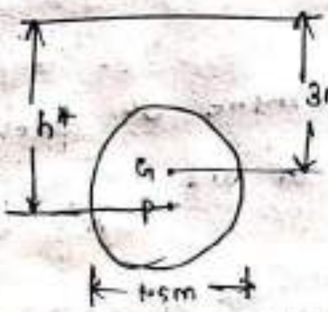
Determine the total pressure on a circular plate of diameter 1.5m which is placed vertically in water in such a way that the centre of the plate is 3m below the free surface of water. Find the position of centre of pressure also.

Sol^n Given data

Dia of plate $= d = 1.5$m

Area $= A = \dfrac{\pi}{4}(1.5)^2 = 1.767\text{ m}^2$

$\bar{h} = 3.0$m



Total pressure is given

$F = \rho g A\bar{h}$

$= 1000 \times 9.81 \times 1.767 \times 3$ N

$= 52002.81$ N **Ans**

Position of centre of pressure (h^*)

$$h^* = \frac{I_G}{A\bar{h}} + \bar{h}$$

Where $I_G = \dfrac{\pi d^4}{64} = \dfrac{\pi \times 1.5^4}{64} = 0.2485\text{ m}^4$

$$h^* = \frac{0.2485}{1.767 \times 3.0} + 3.0 = 0.0468 + 3.0$$

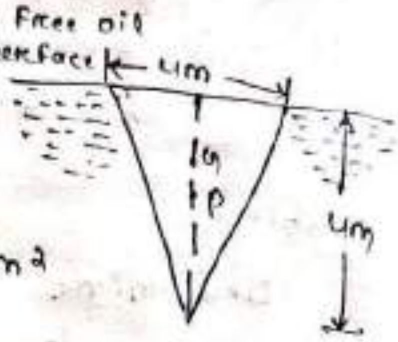
$= 3.0468$ m **Ans**

Problem.

Determine the total pressure and centre of pressure on an isoscales triangular plate of base 4m and altitude 4m where it is immersed vertically in an oil of specific gravity 0.9. The base of the plate coincides with the free surface of oil.

Sol^n

Given data



Base of plate $= b = 4m$

Height of plate $= h = 4m$

$\therefore$ Area, $A = \frac{b \times h}{2} = \frac{4 \times 4}{2} = 8m^2$

Specific gravity of oil

$s = 0.9$

Density of oil $\rho = 900\ kg/m^3$

The distance of C.G from free surface of oil,

$$\bar{h} = \frac{1}{3} \times h = \frac{1}{3} \times 4 = 1.33m$$

Total pressure (F) $= \rho g A\bar{h}$

$= 900 \times 9.81 \times 8.0 \times 1.33\ N$

$= 93941.6N$ Ans

Centre of pressure (h^*) from the free surface of oil.

$$h^* = \frac{I_G}{A\bar{h}} + \bar{h}$$

Where I_G = M.O.I of triangular section about it C.G $= \frac{bh^3}{36} = \frac{4 \times 4^3}{36} = 7.11\ m^4$

$$h^* = \frac{7.11}{8.0 \times 1.33} + 1.33$$

$= 0.6667 + 1.33 = 1.99m$ Ans

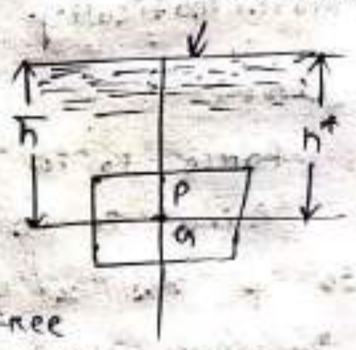
Horizontal plan surface submerged in liquid :—

consider a plane horizontal surface immersed in a static liquid. As every point of the surface is at the same depth from the free surface of the liquid, the pressure intensity will be equal on the entire surface and equal to $p = \rho g h$, where h is depth of surface.

Let,

A = Total area of surface

Then total force, F, on the surface



$= P \times \text{Area} = \rho g \times h \times A$

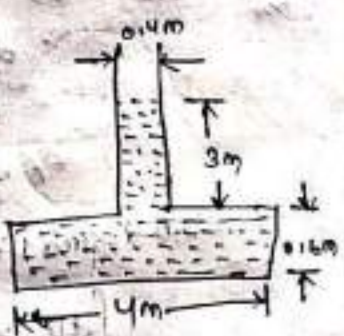
$= \rho g A \bar{h}$

Where $\bar{h}$ = Depth of C.G from free surface of liquid = h

Problem

figure shows a tank full of water. find (i) The Total pressure on the bottom of tank,

Sol^n Given data



Depth of water on bottom of tank $h_1 = 3 + 0.6 = 3.6$ m

width of tank = 2m

Length of tank at bottom = 4m

∴ Area at the Bottom

$A = 4 \times 2 = 8 m^2$

(i) Total pressure F on the bottom is

$F = \rho g A \bar{h} = 1000 \times 9.81 \times 3 \times 3.6$

$= 282528$ N Ans

-: Kinematics of fluid flow :-

RATE OF FLOW OR DISCHARGE (Q):-

It is defined as the quantity of a fluid flowing per second through a section of a pipe or a channel. For an incompressible fluid (or liquid) the rate of flow or discharge is expressed as the volume of fluid flowing across the section per second. For compressible fluids the rate of flow is usually expressed as the weight of fluid flowing across the section. Thus

(i) For liquids the units of Q are m^3/s or litres/s

ii) For gases the unit of Q is kgf/s or Newtons/s.

Consider a liquid flowing through a pipe in which

A = Cross-Sectional area of pipe.

V = Average Velocity of fluid across the Section.

The discharge $Q = A \times V$

CONTINUITY EQUATION :-

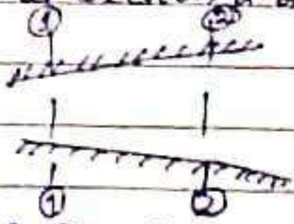
The equation based on the principle of conservation of mass is called continuity equation. Thus for a fluid flowing through the pipe at all the cross-section the quantity of fluid per second is constant. Consider two cross-section of a pipe as shown.

Let V_1 = Average Velocity at cross-Section 1-1.

ρ_1 = Density at Section 1-1

A_1 = Area of pipe at Section 1-1.

and V_2, ρ_2, A_2 are corresponding values at Section 2-2



Then rate of flow at Section 1-1 = $\rho_1 A_1 V_1$

Rate of flow at Section 2-2 = $\rho_2 A_2 V_2$

According to law of conservation of mass

Rate of flow at Section 1-1 = Rate of flow at Section 2-2

Or $\rho_1 A_1 V_1 = \rho_2 A_2 V_2$

Equation (5.2) is applicable to the compressible as well as incompressible fluid and is called continuity eq^n.

If the fluid is incompressible, then $\rho_1 = \rho_2$ and continuity equation (5.2) reduces to

$$A_1V_1 = A_2V_2$$

Problem :-

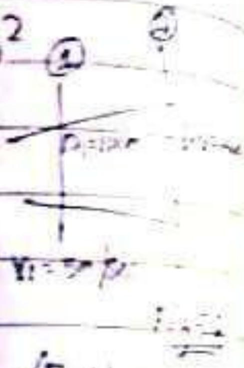
The diameters of a pipe at the section 1 and 2 are 10cm and 15cm respectively. Find the discharge through the pipe if the velocity of water flowing through the pipe at section 1 is 5m/s. Determine also the velocity at section 2.

Solution :-

At Section 1. $D_1 = 10cm = 0.1m$

$$A_1 = \frac{\pi}{4}(D_1^2) = \frac{\pi}{4}(.1)^2 = 0.007854 m^2$$

$V_1 = 5m/s$.



At Section 2. $D_2 = 15cm = 0.15m$.

$$A_2 = \frac{\pi}{4}(.15)^2 = 0.01767 m^2$$

i) Discharge through pipe is given by equation (5.1)

or $Q = A_1 \times V_1$

$= 0.007854 \times 5 = 0.03927 \ m^3/s$ Ans.

using eq. (5.3), We have $A_1V_1 = A_2V_2$

$= \cancel{0.007854 \times}$

$$V_2 = \frac{A_1V_1}{A_2} = \frac{0.007854 \times 5.0}{0.01767} = 2.22 m/s$$

problem :- A 30cm diameter pipe, conveying water, branches into two pipes of diameters 20cm and 15cm respectively. If the average velocity in the 30cm diameter pipe is 2.5m/s. Find the discharge in this pipe. Also determine the velocity in 15cm pipe if the average velocity in 20cm diameter pipe is 2 m/s.

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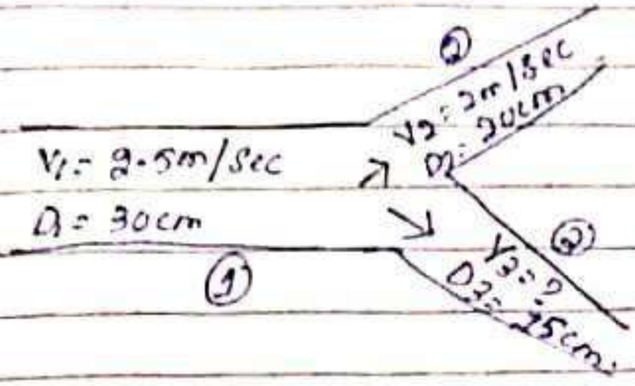
Solution :-



$D = 30cm = 0.30cm$

$A_1 = \frac{\pi}{4} D_1^2 = \frac{\pi}{4} \times .3^2 = 0.07068m^2$.

$V_1 = 2.5 m/s$.

$D_2 = 20cm = 0.20m$

$A_2 = \frac{\pi}{4}(.2)^2 = \frac{\pi}{4} \times .4 = 0.0314m^2$.

$V_2 = 2m/s$.

$D_3 = 15cm = 0.15m$.

$A_3 = \frac{\pi}{4}(.15)^2 = \frac{\pi}{4} \times 0.225 = 0.01767m^2$

Find i) Discharge in pipe 1 or Q_1

ii) Velocity in pipe of dia 15cm or V_3.

Let Q_1, Q_2, & Q_3 are discharge in pipe 1, 2 and 3 respectively.

Then according to continuity eq^n.

$Q_1 = Q_2 + Q_3$.

i) The discharge Q_1 in pipe 1 is give by

$Q_1 = A_1V_1 = 0.07068 \times 2.5 \ m^3/s = 0.1767 m^3/s$ Ans.

ii) Value of V_3.

$Q_2 = A_2V_2 = 0.0314 \times 2.0 = 0.0628 m^3/s$.

Substituting the values of Q_1 and Q_2 in eq^n (1).

$0.1767 = 0.0628 + Q_3$.

$Q_3 = 0.1767 - 0.0628 = 0.1139 m^3/s$.

But $Q_3 = A_3 \times V_3 = 0.01767 \times V_3$ or $0.1139 = 0.01767 \times V_3$.

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$$V_2 = \frac{0.1139}{0.01767} = 6.44\ m/s.\ \underline{Ans}$$

Problem :-

Water flows through a pipe AB 1.2 m diameter at 3 m/s and then passes through a pipe BC 1.5 m diameter. At C, the pipe branches. Branch CD is 0.8 m in diameter and carries one third of the flow in AB. The flow velocity in branch CE is 2.5 m/s. Find the volume rate of flow in AB, the velocity in BC, the velocity in CD and the diameter of CE.

Solution

Diameter of pipe $D_{AB} = 1.2m$.

Velocity of flow through AB $V_{AB} = 3.0 m/s$.

Dia of pipe BC $D_{BC} = 1.5 cm$

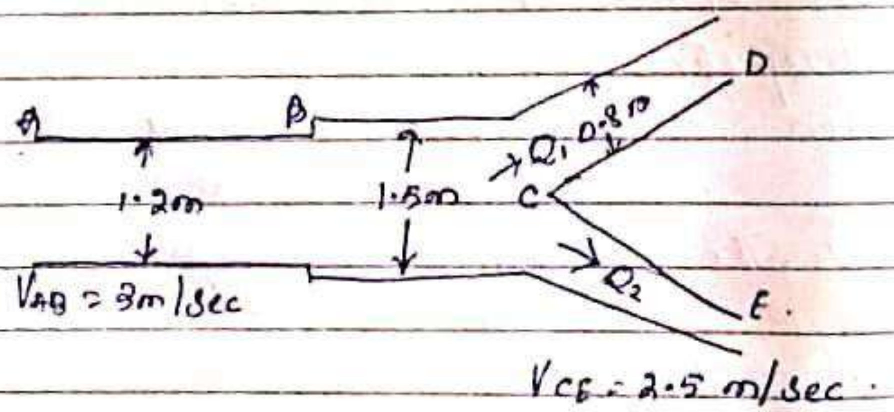
Dia of branched pipe CD. $D_{CD} = 0.8 m/s$

Velocity of flow in pipe CE. $V_{CE} = 2.5 m/s$

Let the flow rate in pipe $AB = Q\ m/s$

Velocity of flow in pipe. BC V_{BC} m/s

Velocity of flow in pipe $CD = V_{CD}$ m/s



Diameter of pipe $CE = D_{CE}$.

Then flow rate through $CD = Q/3$.

and flow rate through $CE = Q - Q/3 = \frac{2Q}{3}$.

i) Now Volume flow rate through AB = $Q = V_{AB} \times$ Area of AB

$$= 3.0 \times \frac{\pi}{4}(D_{AB})^2 = 3.0 \times \frac{\pi}{4}(1.2)^2$$

$$= 3.393\, m^3/s$$

ii) Applying continuity equation to pipe AB and pipe BC.

$V_{AB} \times$ Area of pipe AB = $V_{BC} \times$ Area of pipe BC.

or $\quad 3.0 \times \frac{\pi}{4}(D_{AB})^2 = V_{BC} \times \frac{\pi}{4}(D_{BC})^2$.

or $\quad 3.0 \times (1.2)^2 = V_{BC} \times (1.5)^2$

or $\quad V_{BC} = \frac{3 \times 1.2^2}{1.5^2} = 1.92\, m/s$ Ans.

iii) The flow rate through pipe

$$CD = Q_1 = \frac{Q}{3} = \frac{3.393}{3} = 1.131\, m^3/s.$$

$$Q_1 = V_{CD} \times \text{Area of pipe } CD \times \frac{\pi}{4}(D_{CD})^2$$

$$1.131 = V_{CD} \times \frac{\pi}{4} \times 0.8^2 = 0.5026\, V_{CD}.$$

$$V_{CD} = \frac{1.131}{0.5026} = 2.25\, m/s \text{ Ans.}$$

iv) Flow rate through CE,

$$Q_2 = Q - Q_1 = 3.393 - 1.131 = 2.262\, m^3/s.$$

$$Q_2 = V_{CE} \times \text{Area of pipe } CE = V_{CE}\, \frac{\pi}{4}(D_{CE})^2.$$

$$2.263 = 2.5 \times \frac{\pi}{4} \times (D_{CE})^2$$

$$D_{CE} = \sqrt{\frac{2.263 \times 4}{2.5 \times \pi}} = \sqrt{1.152} = 1.0735\, m$$

$\therefore$ Diameter of pipe CE = 1.0735 m Ans.

BERNOULLI'S EQUATION FROM EULER'S EQUATION:-

Bernoulli's equation is obtained by integrating the euler's equation of motion (6.3) as.

$$\int \frac{dp}{\rho} + \int g dz + \int V dV = \text{constant}$$

If flow is incompressible, ρ is constant and

$$\therefore \frac{p}{\rho} + gz + \frac{V^2}{2} = \text{constant}$$

or $$\frac{p}{\rho g} + z + \frac{V^2}{2g} = \text{constant}$$

or $$\frac{p}{\rho g} + \frac{V^2}{2g} + z = \text{constant}$$

Equation (iv) is a Bernoulli's equation in which,

$\frac{p}{\rho g}$ = pressure energy per unit weight of fluid or pressure head.

$V^2/2g$ = kinetic energy per unit weight or kinetic head.

z = potential energy per unit weight or potential head

Assumptions:- The following are the assumption made in the derivation of Bernoulli's eqn.

i) The fluid is ideal i.e. viscosity is zero
ii) The flow is steady.
iii) The flow is incompressible.
(iv) The flow is irrotational.

Problem:- Water is flowing through a pipe of 5cm diameter under a pressure of 29.43 N/cm^2 and with mean velocity of 2.0 m/s. Find the total head or total energy per unit weight of the water at cross-section which is 5m above the datum line.

Solution:-

Diameter of pipe = 5cm = 0.5 m

pressure, $p = 29.43\ N/cm^2 = 29.43 \times 10^4\ N/m^2$

Velocity $\quad V = 2.0$ m/s.

Datum head $\quad Z = 5$m.

Total head $\quad$ = pressure head + kinetic head + datum head

pressure head $= \frac{P}{\rho g} = \frac{29.43 \times 10^4}{1000 \times 9.81} = 30$m $\left\{ \rho \text{ for water} = 1000 \frac{Kg}{m^3} \right.$

Kinetic head $= \frac{V^2}{2g} = \frac{2 \times 2}{2 \times 9.81} = 0.204$m.

$\therefore$ Total head $= \frac{P}{\rho g} + \frac{V^2}{2g} + Z = 30 + 0.204 + 5 = 35.204$m Ans.

Problem :- A pipe, through which water is flowing, is having diameter 20cm and 10cm of at the cross-section 1 and 2 respectively. The velocity of water at section 1 is given 4.0m. Find the velocity head at section 1 and 2 also rate of discharge.

Solution :-

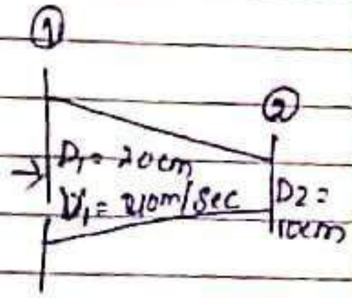
$D_1 = 20cm = 0.2m$

$\therefore$ Area $A_1 = \frac{\pi}{4} D_1^2 = \frac{\pi}{4}(.2)^2 = 0.0314 m^2$

$V_1 = 4.0$ m/s

$D_2 = 0.1m$

$\therefore A_2 = \frac{\pi}{4}(.1)^2 = .00785 m^2$.



i) Velocity head at section 1.

$= \frac{V_1^2}{2g} = \frac{4.0 \times 4.0}{2 \times 9.81} = 0.815m$ Ans.

ii) Velocity head at section 2 $= V_2^2/2g$.

To find V_2 apply continuity equation at 1 or 2.

$A_1V_1 = A_2V_2$ or $V_2 = \frac{A_1V_1}{A_2} = \frac{.0314}{.00785} \times 4.0 = 16.0$m/s.

$\therefore$ Velocity head at section 2 $= \frac{V_2^2}{2g} = \frac{16.0 \times 16.0}{2 \times 9.81}$

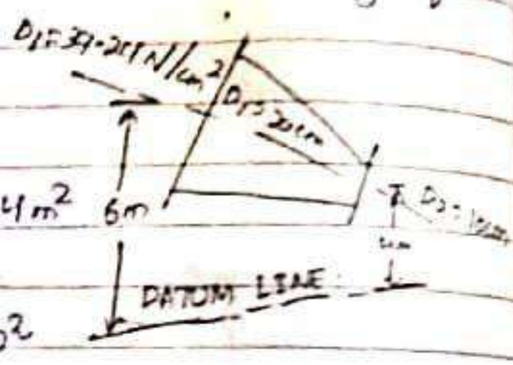
$= 13.047$m Ans.

iii) Rate of discharge $= A_1V_1$ or A_2V_2

$= 0.0314 \times 4.0 = 0.1256\ m^3/s$

$= 125.6$ liters/s **Ans.**

Problem :- The water is flowing through a pipe having diameter 20cm and 10 cm at section 1 and 2 respectively. The rate of flow through pipe is 35 liters. The section 1 is 6 m above datum and section 2 is 4m above datum. If the pressure at section 1 is 39.24 N/cm², Find the intensity of pressure at section 2.



Solution :-

$D_1 = 20cm = 0.2m$

At section 1 $A_1 = \frac{\pi}{4}(2)^2 = .0314\ m^2$

$P_1 = 39.24\ N/cm^2$

$= 39.24 \times 10^4\ N/m^2$

$Z_1 = 6.0m$.

At section 2 $D_2 = 0.10m$.

$A_2 = \frac{\pi}{4}(0.1)^2 = .00785\ m^2$

$Z_2 = 4m$.

$P_2 = ?$.

Rate of flow, $Q = 35\ lit/s = \frac{35}{1000} = .035\ m^3/s$

Now. $Q = A_1V_1 = A_2V_2$

$\therefore$ $V_1 = \frac{Q}{A_1} = \frac{.035}{.0314} = 1.114\ m/s$

and $V_2 = \frac{Q}{A_2} = \frac{.035}{.00785} = 4.456\ m/s$.

applying Bernoulli's eqⁿ at section 1 & 2 we get

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2$$

or $\frac{39.24 \times 10^4}{1000 \times 9.81} + \frac{(1.114)^2}{2 \times 9.81} + 6.0 = \frac{P_2}{1000 \times 9.81} + \frac{(4.456)^2}{2 \times 9.81}$

Or $\quad 40 + 0.063 + 6.0 \quad \frac{P_2}{9810} + 1.012 + 4.0$

or $\quad 46.063 = \frac{P_2}{9810} + 5.012$.

$\therefore \quad \frac{P_2}{9810} = 46.063 - 5.012 = 41.051$.

$P_2 = 41.051 \times 9810 \ N/m^2$

$= \frac{41.051 \times 9810}{10^4} \ N/cm^2 = 40.27 \ N/cm^2$ Ans.

problem :- A pipe of diameter 400mm carries water at a velocity of 25m/s. The pressure at the points A & B are given as 29.43 N/cm² and 22.563 N/cm² respectively while the datum head at A and B are 28 m and 30m. Find the loss of head between A & B.

Solution :-

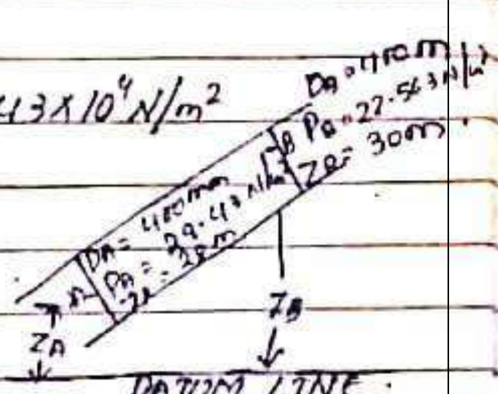
Dia of pipe $\quad D = 400mm = 0.4$

Velocity $\quad V = 25 \ m/s$.

At point A, $\quad P_A = 29.43 \ N/cm^2 = 29.43 \times 10^4 \ N/m^2$

$Z_A = 28m$

$V_A = V = 25m/s$



$\therefore$ Total energy at A

$E_A = \frac{P_A}{\rho g} + \frac{V_A^2}{2g} + Z_A$.

$= \frac{29.43 \times 10^4}{1000 \times 9.81} + \frac{25^2}{2 \times 9.81} + 28$

$= 30 + 31.85 + 28 = 89.85m$.

At point B, $\quad P_B = 22.563 \ N/cm^2 = 22.563 \times 10^4 \ N/m^2$.

$Z_B = 30m$

$V_B = V = V_A = 25 \ m/s$.

Total energy at B, $\quad E_B = \frac{P_B}{\rho g} + \frac{V_B^2}{2g} + Z_B$

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$$= \frac{22.563 \times 10^4}{1000 \times 9.81} + \frac{25^2}{2 \times 9.81} + 30 = 23 + 31.85 + 30$$

$$= 84.85m.$$

Loss of energy $= E_A - E_B = 89.85 - 84.85 = 5.0m$ Ans.

PRACTICAL APPLICATIONS OF BERNOULLI'S EQUATION.

Bernoulli's eqn is applied in all problems of incompressible fluid flow where energy considerations are involved. But we shall consider its application to the following measuring devices:

1. Venturimeter
2. Orifice meter
3. Pitot - tube

Venturimeter :- A venturimeter is a device used for measuring the rate of a flow of a fluid flowing through a pipe. It consist of three parts.

i) A short converging part. ii) Throat.
iii) Diverging part. It is based on the principle of Bernoulli eqn.

Expression for rate of flow through venturimeter.

Consider a venturimeter fitted in a horizontal pipe through which a fluid is flowing as shown in

Let d_1 = diameter at inlet or at section

P_1 = pressure at section

V_1 = Velocity of fluid at section.

a = area at section (1) $= \frac{\pi}{4} d_1^2$

d_2, P_2, V_2, a_2 are corresponding values at section (2)

Applying Bernoulli eqn at section (1) & (2) we get

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2 .$$

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As pipe is horizontal hence $z_1 = z_2$.

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} \quad \text{or} \quad \frac{P_1 - P_2}{\rho g} = \frac{V_2^2}{2g} - \frac{V_1^2}{2g}$$

But $\frac{P_1 - P_2}{\rho g}$ is the difference of pressure heads at section 1 and 2 and it is equal to h or $\frac{P_1 - P_2}{\rho g} = h$

Substituting the value of $\frac{P_1 - P_2}{\rho g}$ in the above eq^n,

$$h = \frac{V_2^2}{2g} - \frac{V_1^2}{2g}.$$

Now applying continuity equation at section 1 & 2.

$$a_1 V_1 = a_2 V_2 \text{ or } V_1 = \frac{a_2 V_2}{a_1}$$

Substituting the value of V_1 in eq^n

$$h = \frac{V_2^2}{2g} - \frac{\left(\frac{a_2 V_2}{a_1}\right)^2}{2g} = \frac{V_2^2}{2g}\left[1 - \frac{a_2^2}{a_1^2}\right] = \frac{V_2^2}{2g}\left[\frac{a_1^2 - a_2^2}{a_1^2}\right].$$

$$= V_2^2 = 2gh \frac{a_1^2}{a_1^2 - a_2^2}$$

$$V_2 = \sqrt{2gh \frac{a_1^2}{a_1^2 - a_2^2}} = \frac{a_1}{\sqrt{a_1^2 - a_2^2}} \sqrt{2gh}$$

∴ Discharge $\quad Q = a_2 V_2$.

$$= a_2 \cdot \frac{a_1}{\sqrt{a_1^2 - a_2^2}} \times \sqrt{2gh} = \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \times \sqrt{2gh}.$$

Equation gives the discharge under ideal conditions and is called , theoretical discharge Actual

$$Q_{act} = C_d \times \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \times \sqrt{2gh}$$

Where C_d = Co-efficient of venturimeter & its value is less than 1.

Value of h given by differential U-tube manometer

Case-1:- Let the differential manometer contains a liquid which is heavier than the liquid flowing through the pipe

S_h = Sp. gravity of the heavier liquid

S_o = sp. gravity of the liquid flowing through pipe

x = Difference of the heavier liquid column in U-tube

Then $h = x\left[\frac{S_h}{S_o} - 1\right]$.

Case II :- If the differential manometer contains a liquid which is lighter than the liquid flowing through the pipe ; the value of h is given by

$$h = x\left[1 - \frac{S_l}{S_o}\right].$$

Where S_l = Sp. gr. of lighter liquid in U-tube

S_o = Sp. gr. of fluid flowing through pipe

x = Difference of the lighter liquid column in U-tube.

Problem :- A horizontal venturimeter with inlet and throat diameter 30cm and 15cm respectively is used to measure the flow of water. The reading of differential manometer connected to the inlet and the throat is 20 cm of mercury. Determine the rate of flow. Take $C_d = 0.98$.

Solution :-

Dia of inlet $d_1 = 30cm$.

∴ Area at inlet $a_1 = \frac{\pi}{4} d_1^2 = \frac{\pi}{4}(30)^2 = 706.85 cm^2$.

Dia. of throat $d_2 = 15cm$.

$a_2 = \frac{\pi}{4} \times 15^2 = 176.7 cm^2$

$C_d = 0.98$.

Reading of differential manometer $= x = 20cm$ of

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mercury.

∴ Difference of pressure head is given by.

or $h = x\left[\frac{S_h}{S_o} - 1\right]$.

Where S_h = Sp. gravity of mercury = 13.6, S_o = Sp. gravity of Water = 1

$= 20\left[\frac{13.6}{1} - 1\right] = 20 \times 12.6\,cm = 252.0\,cm$ of Water

The discharge through Venturimeter is given by eqn.

$$Q = C_d \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \times \sqrt{2gh}$$

$$= 0.98 \times \frac{706.85 \times 176.7}{\sqrt{(706.85)^2 - (176.7)^2}} \times \sqrt{2 \times 981 \times 252}$$

$$= \frac{86067593.36}{\sqrt{499636.9 - 31222.7}} = \frac{86067593.36}{684.4}$$

$= 125756\,cm^3/s = \frac{125756}{1000}$ lit/s $= 125.756$ lit/s

Problem :- An oil of Sp. gr. 0.8 is flowing through a Venturimeter having inlet diameter 20cm and throat diameter 10cm. The oil-mercury differential manometer shows a reading of 25cm. Calculate the discharge of oil through the horizontal Venturimeter. Take $C_d = 0.98$.

Solution :

Sp. gr. of oil, $S_o = 0.8$ Reading of differential

Sp. gr. of mercury $S_h = 13.6$ manometer = x = 25cm

Difference ~~Reading~~ of pressure head $h = x\left[\frac{S_h}{S_o} - 1\right]$.

$= 25\left[\frac{13.6}{0.8} - 1\right]$ cm of oil $= 25[17-1] = 400$ cm of oil.

Dia at inlet , $d_1 = 20cm$

$$a_1 = \frac{\pi}{4} d_1^2 = \frac{\pi}{4} \times 20^2 = 314.16 cm^2.$$

$$d_2 = 10cm.$$

$$a_2 = \frac{\pi}{4} \times 10^2 = 78.54 cm^2.$$

$$Cd = 0.98.$$

∴ The discharge Q is given by eq?

$$Q = Cd \cdot \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \times \sqrt{2gh}.$$

$$= 0.98 \times \frac{314.16 \times 78.54}{\sqrt{(314.16)^2 - (78.54)^2}} \times \sqrt{2 \times 981 \times 400}$$

$$= \frac{21421375.68}{\sqrt{98696 - 6168}} = \frac{21421375.68}{304} cm^3/s$$

$$= 70465 \, cm^3/s = 70465 \text{ liters } \underline{\underline{Ans}}.$$

Problem :- A horizontal venturimeter with inlet diameter 20cm and throat diameter 10cm is used to measure the flow of oil sp.gr. 0.8. The discharge of oil through venturimeter is 60 liters/s. Find the reading of the oil – mercury differential manometer. Take $Cd = 0.98$.

Solution :

$$d_1 = 20cm$$

$$a_1 = \frac{\pi}{4} 20^2 = 314.16 cm^2.$$

$$d_2 = 10cm.$$

$$a_2 = \frac{\pi}{4} \times 10^2 = 78.54 cm^2$$

$$Cd = 0.98.$$

$$Q = 60 \text{ liters/s} = 60 \times 1000 \, cm^3/s.$$

using the equation $Q = Cd \cdot \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \times \sqrt{2gh}.$

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Or $\quad 60 \times 1000 = 9.81 \times \dfrac{314.16 \times 78.54}{\sqrt{(314.16)^2 - (78.54)^2}} \times \sqrt{2 \times 981 \times h} =$

$$\frac{1071068.78\sqrt{h}}{304}$$

Or $\quad \sqrt{h} = \dfrac{304 \times 60000}{1071068.78} = 17.029.$

$$h = (17.029)^2 = 289.98 \text{ cm of oil}$$

But $\quad h = x\left[\dfrac{S_h}{S_o} - 1\right].$

Where $\quad S_h = $ Sp. gr. of mercury $= 13.6$.
$S_o = $ Sp. gr. of oil $= 0.8$.
$x = $ Reading of manometer.

$\therefore \quad 289.98 = x\left[\dfrac{13.6}{0.8} - 1\right] = 16x.$

$$x = \frac{289.98}{16} = 18.12 \text{ cm}$$

$\therefore$ Reading of oil - mercury differential manometer $= 18.12$ cm Ans.

Problem :- A horizontal Venturimeter with inlet diameter 20cm and throat diameter 10cm is used to measure the flow of water. The pressure at inlet is 17.658 N/cm² and the vacuum pressure at the throat is 30 cm of mercury. Find the discharge of water through Venturimeter. Take $C_d = 0.98$.

Solution :-

Dia. at inlet $\quad d_1 = 20$cm.

$\therefore \quad a_1 = \dfrac{\pi}{4} \times (20)^2 = 314.16 \text{ cm}^2.$

Dia. at throat $\quad d_2 = 10$cm

$$a_2 = \frac{\pi}{4} \times 10^2 = 78.54 \text{ cm}^2.$$

$$P_1 = 17.658 \text{ N/cm}^2 = 17.658 \times 10^4 \text{ N/m}^2$$

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ρ for Water $= 1000 \frac{Kg}{m^3}$ and $\therefore \frac{P_1}{\rho g} = \frac{17.658 \times 10^4}{9.81 \times 1000}$

$= 18m$ of water

$\frac{P_2}{\rho g} = -30cm$ of mercury.

$= -0.30$ m of mercury $= -0.30 \times 13.6 = -4.08m$ of water

$\therefore$ Differential head

$= h = \frac{P_1}{\rho g} - \frac{P_2}{\rho g} = 18 - (-4.08).$

$= 18 + 4.08 = 22.08$ m of Water $= 2208$ cm Water.

The discharge Q is given by equation

$$Q = Cd \cdot \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \times \sqrt{2gh}.$$

$$= 0.98 \times \frac{314.16 \times 78.54}{\sqrt{(314.16)^2 - (78.74)^2}} \times \sqrt{2 \times 981 \times 2208}$$

$$= \frac{50328837.21}{304} \times 165555 \ cm^3/s = 165.555 \ lit/s.$$

Orifice meter or orifice plate :- It is a device used for measuring the rate of flow of a fluid through a pipe. It is a cheaper device as compared to venturimeter. It also works on the same principle as that of Venturimeter. It consist of a flat circular plate which has a circular sharp edged hole called Orifice which is concentric with the pipe. The Orifice diameter is kept generally 0.5 times the diameter of the pipe, though it may vary from 0.4 to 0.8 times the pipe diameter.

Let P_1 = pressure at Section (1)

V_1 = Velocity at Section (1)

a_1 = area of pipe at Section (1).

Discharge $(Q) = \frac{C_d a_0 \sqrt{2gh}}{\sqrt{1-\left(\frac{a_0}{a_1}\right)^2}} = \frac{C_d a_0 a_1 \sqrt{2gh}}{\sqrt{a_1^2 - a_0^2}}$

a_0 = area of orifice.

h = head.

Where C_d = Co-efficient of discharge for orifice meter.
The Co-efficient of discharge for orifice meter is much smaller that for a venturimeter.

problem :- An orifice meter with orifice diameter 10cm is inserted in a pipe of 20cm diameter. The pressure gauges fitted upstream and downstream of the orifice meter gives reading of 19.62 N/cm^2 and 9.81 N/cm^2 respectively. Co-efficient of discharge for the orifice meter is given as 0.6. Find the discharge of water through pipe

Solution :-

Dia of orifice $d_0 = 10cm$.

$\therefore$ Area, $a_0 = \frac{\pi}{4}(10)^2 = 78.54 cm^2$

Dia of pipe, $d_1 = 20cm$.

$\therefore$ Area $a_1 = \frac{\pi}{4}(20)^2 = 314.16 cm^2$.

$P_1 = 19.62 N/cm^2 = 19.62 \times 10^4 N/m^2$.

$\frac{P_1}{\rho g} = \frac{19.62 \times 10^4}{1000 \times 9.81} = 10m$ of water.

$h = \frac{P_1}{\rho g} - \frac{P_2}{\rho g} = 20.0 - 10.0 = 10m$ of water
$= 1000$ cm of water.

$C_d = 0.6$.

The discharge Q is given by equation

$$Q = C_d \cdot \frac{a_0 a_1}{\sqrt{a_1^2 - a_0^2}} \times \sqrt{2gh}$$

$$= 0.6 \times \frac{78.54 \times 314.16}{\sqrt{(314.16)^2 - (78.54)^2}} \times \sqrt{2 \times 981 \times 1000}$$

$$= \frac{20736838.02}{304} = 68213.28 \text{ cm}^3/s$$

$$= 68.21 \text{ liters}/s \quad \text{Ans}$$

Pitot - tube :- It is a device used for measuring the velocity of flow at any point in a pipe or a channel. It is based on the principle that if the velocity of flow at a point becomes zero the pressure there is increased due to the conversion of the kinetic energy into pressure energy. The liquid rises up in the tube due to the conversion of kinetic energy into pressure energy. The velocity is determined by measuring the rise of liquid in the tube.

Considerd two points (1) and (2) at the same level in such a way that point (2) is just as the inlet of the pitot - tube and point 1) is far away from the tube.

P_1 = Intensity of pressure at point (1)
V_1 = Velocity of flow at (1)
P_2 = Pressure at point (2)
V_2 = Velocity at point (2) which is zero
H = depth of tube in the liquid.
h = rise of liquid in the tube above the free surface.

Applying Bernoulli's eq^n at point (1) x (2)

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2,$$

But $Z_1 = Z_2$ as points (1) & (2) are on the same line and $V_2 = 0$

$\frac{P_1}{\rho g}$ = pressure head at (1) = H.

$\frac{P_2}{\rho g}$ = pressure head at (2) = (h+H).

Substituting these values, we get

$$H + \frac{V_1^2}{2g} = (h+H) \quad \therefore h = \frac{V_1^2}{2g} \text{ or } V_1 = \sqrt{2gh}.$$

This is theoretical velocity, Actual velocity is given by:

$$(V_1)_{act} = C_v \sqrt{2gh}.$$

Where C_v = co-efficient of pitot-tube.

$\therefore$ Velocity at any point

$$V = C_v \sqrt{2gh}.$$

Problem :- A pitot-static tube placed in the centre of a 300 mm pipe line has one orifice pointing upstream and other perpendicular to it. The mean velocity in the pipe is 0.80 of the central velocity. Find the discharge through through the pipe if the pressure difference between the two orifice is 60mm of water. Take the co-efficient of pitot tube as $C_v = 0.98$.

Solution :-

Dia of pipe $d = 300mm = 0.30m$.

Diff. of pressure head $h = 60mm$ of water $= .06m$ of water.

$C_v = 0.98$

Mean velocity. $\bar{V} = 0.80 \times$ central velocity.

Central Velocity is given by eqn.

$$= C_v \sqrt{2gh} = 0.98 \sqrt{2 \times 9.81 \times .06} = 1.063 \, m/s$$

$$\bar{V} = 0.80 \times 1.063 = 0.8504 \, m/s.$$

Discharge Q = Area of pipe $\times \bar{V}$

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$$= \frac{\pi}{4} d^2 \times \bar{V} = \frac{\pi}{4} (.30)^2 \times 0.8504 = 0.06 m^3/s$$

Problem :- Find the velocity of the flow of an oil through a pipe, when the difference of mercury level in a differential U-tube manometer connected to the two tappings of the pitot-tube is 100mm. Take co-efficient of pitot-tube 0.98 and sp. gr. of oil = 0.8.

Solution:

Diff. of mercury level $x = 100mm = 0.1m$.

Sp. gr. of oil $S_o = 0.8$

Sp. gr. of mercury $S_g = 13.6$

$C_v = 0.98$

Diff. of pressure head. $h = x\left[\frac{S_g}{S_o} - 1\right] = 1\left[\frac{13.6}{0.8} - 1\right]$

$= 1.6m$ of oil.

$\therefore$ Velocity of flow $C_v\sqrt{2gh} = 0.98\sqrt{2 \times 9.81 \times 1.6}$

$= 5.49$ m/s Ans.

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Module - 2 :— chapter-2 :—

Flow over Notches and Weirs :—

Notch :—

A notch is a device used for measuring rate of ~~flowing~~ flow of a liquid through a small channel or a tank.

Weir :—

A weir is a concrete or masonary structure placed in an open channel over which the flow occurs. It is generally in the form of vertical wall, with a sharp edge at the top.

Types of Notches :—

According to the shape of the opening notches are classified into

(a) Rectangular notch
(b) Triangular notch
(c) Trapizoidal notch
(d) Stepped notch

Types of weirs :—

(1) According to shape of the opening

(a) Rectangular weir
(b) Trelangular weir
(c) Trapizoidal weir

(2) According to the shape of crest

(a) Sharp - crested weir
(b) Broad - crested weir
(c) Narrow - crested weir
(d) Ogee - shaped weir

Discharge over a Rectangular notch or weir :—

$$\text{Discharge } (Q) = \frac{2}{3} C_d \cdot L\sqrt{2g} \cdot H^{3/2}$$

where, C_d = Co-efficient of discharge
L = Length of notch or weir
H = Head of water over crest

Q.1 Find the discharge of water flowing over a rectangular notch of 2m length when the constant head over the notch is 300mm. Take C_d = 0.60

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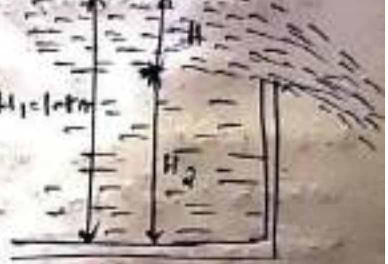
Sol^n Given data :—

$$L = 2.0\,m$$
$$H = 300\,mm = 0.3\,m$$
$$C_d = 0.60$$

$$Q = \frac{2}{3} \times C_d \cdot L \cdot \sqrt{2g} \cdot H^{3/2}$$
$$= \frac{2}{3} \times 0.6 \times 2 \times \sqrt{2 \times 9.81} \times 0.3^{3/2}$$
$$= 0.582\ m^3/sec$$

Q.2 Determine the height of a rectangular weir of length 6 m to be built across a rectangular channel. The maximum depth of water on the upstream side of the weir is 1.8 m and discharge is 2000 lit/sec. Take $C_d = 0.6$.

Sol^n Given data :—



$$L = 6\,m$$
$$H_1 = 1.8\,m$$

Height of weir = H_2

Head of water = H

$$H_1 - H_2 = H$$
$$H = ?$$

Putting the given values in below formula

$$Q = \frac{2}{3} C_d \cdot L\sqrt{2g} \cdot H^{3/2}$$
$$\Rightarrow 2 = \frac{2}{3} \times 0.6 \times 6 \times \sqrt{2 \times 9.81} \times H^{3/2}$$
$$\Rightarrow H = 0.328\ m$$

$1m^3 = 1000\,lit$
$1\,lit = \frac{1}{1000} m^3$
$2000\,lit = \frac{2000}{1000} m^3 = 2m^3$

Height of weir $\Rightarrow H_2 = H_1 - H$
$$= 1.8 - 0.328$$
$$= 1.472\ m$$

Discharge over a triangular notch or weir :—

$$\text{Discharge } (Q) = \frac{8}{15} \times C_d \times \tan\frac{\theta}{2} \times \sqrt{2g} \times H^{5/2}$$

θ = angle of notch

H = Head of water above V-notch

C_d = Co-efficient of discharge

Q.3 Find the discharge over a triangular notch of angle 60° when the head over the V-notch is 0.3 m. Take $C_d = 0.6$.

Sol^n Given data, Angle of notch $(\theta) = 60°$

$H = 0.3 m$

$C_d = 0.6$

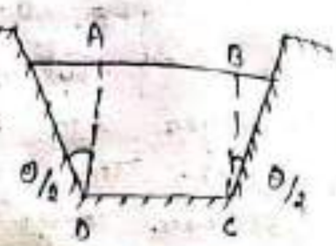
Discharge $(Q) = \frac{8}{15} \times C_d \times \tan\frac{\theta}{2} \times \sqrt{2g} \times H^{5/2}$

$= \frac{8}{15} \times 0.6 \times \tan\frac{60°}{2} \times \sqrt{2\times9.81} \times 0.3^{5/2}$

$= 0.040 \ m^3/sec$

Discharge over a trapezoidal notch or weir :-

Trapezoidal weir or notch is a combination of a rectangular and triangular notch or weir.



$Q_{trapezoidal} = Q_{rectangular} + Q_{triangular}$

Discharge $(Q) = \frac{2}{3} C_{d_1} \cdot L\sqrt{2g} \cdot H^{3/2} + \frac{8}{15} C_{d_2} \cdot \tan\frac{\theta}{2} \cdot \sqrt{2g} \cdot H^{5/2}$

Q.4 Find the discharge through a trapezoidal notch which is 1m wide at the top and 0.40m at the bottom and is 30cm in height. The head of water on the notch is 20 cm. Assume C_d for rectangular portion $= 0.62$ while for triangular portion $= 0.60$.

Soln Given data :-

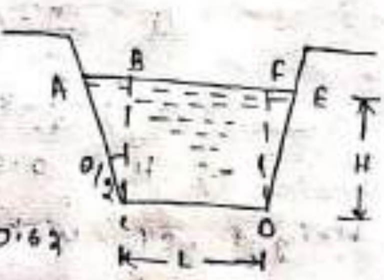
Top width , $AE = 1m$

Base width , $CD = L = 0.4m$

Head of water, $H = 0.20m$

For rectangular portion, $C_{d_1} = 0.62$

For triangular portion, $C_{d_2} = 0.60$



From Δ ABC , we have

$\tan\frac{\theta}{2} = \frac{AB}{BC} = \frac{(AE - CD)/2}{H}$

$= \frac{(1.0 - 0.4)/2}{0.3} = \frac{0.6/2}{0.3} = \frac{0.3}{0.3} = 1$

Discharge through trapezoidal notch is given

$Q = \frac{2}{3} C_{d_1} \times L \times \sqrt{2g} \times H^{3/2} + \frac{8}{15} C_{d_2} \times \tan\frac{\theta}{2} \times \sqrt{2g} \times H^{5/2}$

$= \frac{2}{3} \times 0.62 \times 0.4 \times \sqrt{2\times9.81} \times (0.2)^{3/2} + \frac{8}{15} \times 0.60 \times 1 \times \sqrt{2\times9.81} \times (0.2)^{5/2}$

$= 0.06549 + 0.02535$

$= 0.09084 \ m^3/s = 90.84$ lit/s Ans

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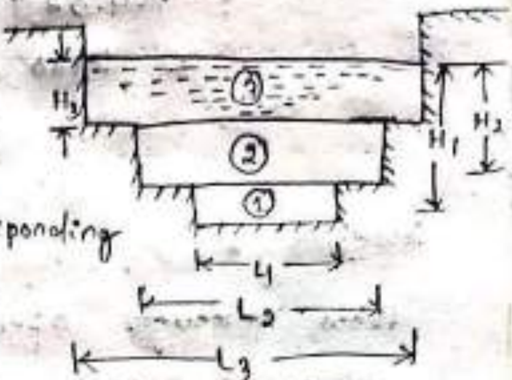
Discharge over a stepped notch :—

A stepped notch is a combination of rectangular notches. The discharge through stepped notch is equal to the sum of the discharges through the different rectangular notches.

consider a stepped as shown in figure.



Let H_1 = Height of water above the crest of notch 1.

L_1 = Length of notch 1,

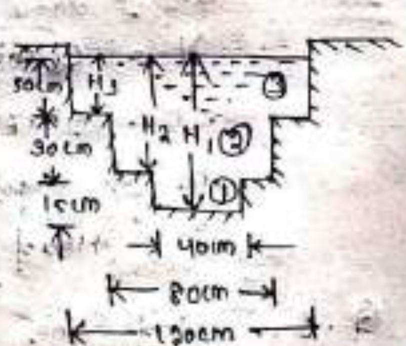
H_2, L_2 and H_3, L_3 are corresponding values for notches 2 and 3 respectively.

C_d = co-efficient of discharge for all notches

Total discharge $Q = Q_1 + Q_2 + Q_3$

$$Q = \frac{2}{3} \times C_d \times L_1 \times \sqrt{2g} \left(H_1^{3/2} - H_2^{3/2} \right) + \frac{2}{3} C_d \times L_2 \times \sqrt{2g} \left(H_2^{3/2} - H_3^{3/2} \right) + \frac{2}{3} C_d \times L_3 \times \sqrt{2g} \times H_3^{3/2}$$

Q.5 Figure shows a stepped notch, find the discharge through the notch if C_d for all section = 0.62.



Sol^n Given data,

$L_1 = 40$ cm

$L_2 = 80$ cm

$L_3 = 120$ cm

$H_1 = 50 + 30 + 15 = 95$ cm

$H_2 = 80$ cm, $H_3 = 50$ cm

$C_d = 0.62$

Total discharge $Q = Q_1 + Q_2 + Q_3$

$$Q_1 = \frac{2}{3} \times C_d \times L_1 \times \sqrt{2g} \left(H_1^{3/2} - H_2^{3/2} \right)$$

$$= \frac{2}{3} \times 0.62 \times 40 \times \sqrt{2 \times 981} \times \left[95^{3/2} - 80^{3/2} \right]$$

$$= 732.26 \,(925.94 - 715.54)$$

$$= 154067 \text{ cm}^3/\text{s} = 154.067 \text{ lit/s}$$

$$Q_2 = \frac{2}{3} \times C_d \times L_2 \times \sqrt{2g} \times \left(H_2^{3/2} - H_3^{3/2} \right)$$

$$= \frac{2}{3} \times 0.62 \times 80 \times \sqrt{2 \times 981} \times \left(80^{3/2} - 50^{3/2} \right)$$

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$= 1464.52\,(715.54 - 353.55)\ cm^3/s$

$= 530141\ cm^3/s = 530.144\ lit/s$

and $Q_3 = \frac{2}{3} \times C_d \times L_3 \times \sqrt{2g} \times H_3^{3/2}$

$= \frac{2}{3} \times 0.62 \times 120 \times \sqrt{2 \times 981} \times 50^{3/2}$

$= 776771\ cm^3/s = 776.771\ lit/s$

$\therefore\ Q = Q_1 + Q_2 + Q_3$

$= 154.067 + 530.144 + 776.771$

$= 1460.98\ lit/s$ Ans

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Module - 2 Chapter - 3

Types of flow through the pipes :—

Steady flow :—

Steady flow is defined as that type of flow in which the fluid characteristics like velocity, pressure, density etc at a point do not change with time.

$$\frac{\partial v}{\partial t} = 0 \;,\; \frac{\partial p}{\partial t} = 0$$

Unsteady flow :—

Unsteady flow is that types of flow in which velocity, pressure and density at a point changes with respect to time.

$$\frac{\partial v}{\partial t} \neq 0 \;,\; \frac{\partial p}{\partial t} \neq 0$$

Uniform flow :—

Uniform flow is defined as the type of flow in which the velocity at any given time does not change with respect to space i.e. length of direction of flow.

$$\frac{\partial v}{\partial s} = 0$$

Non - Uniform flow :—

Non uniform flow is that type of flow in which the velocity at any given time changes with respect to space.

$$\frac{\partial v}{\partial s} \neq 0$$

Reynold's Number :—

→ For a pipe flow the type of flow is determined by a non-dimensional number called Reynold's number.

→ It is denoted by Re.

Mathematically, $R_e = \frac{\rho V D}{\mu}$

where ρ = Density of fluid

V = velocity of fluid flow
D = Dia of pipe
μ = dynamic viscosity of fluid

Laminar flow :—
→ Laminar flow is defined as that type of flow in which the fluid particles move along well defined path.
→ For a laminar flow $Re < 2000$

Turbulent flow :—
→ Turbulent flow is that types of flow in which the fluid particles move in zig-zag way. Due to zig-zag way movement of fluid, heavy energy loss occurs.
→ For turbulent flow to be possible $Re > 4000$

Kinematic viscosity (ν) :—
It is defined as the ratio of dynamic viscosity (μ) to the density of fluid (ρ) flowing.
Mathematically, $\nu = \mu / \rho$

Q. Water flowing in a pipe of diameter 300 mm at a velocity of 3 m/sec. Find the type of flow whether it is laminar or turbulent. Take ν = 0.001 stoke.

Sol^n Given data,
Dia. of pipe (D) = 300 mm = 0.3 m
Velocity of pipe (V) = 3 m/sec
Kinematic viscosity (ν) = 0.01 stoke
= 0.01 cm²/sec
= 0.01×10^{-4} m²/sec

$Re = \frac{\rho V D}{\mu}$

$\nu = \mu / \rho$
$\Rightarrow \mu = \nu \times \rho = 0.01 \times 10^{-4} \times 1000$
$= 0.001 \ \frac{N\text{-}s}{m^2}$

$= \frac{1000 \times 3 \times 0.3}{0.001}$
$= 900000 > 4000$

∴ As $Re > 4000$ flow is turbulent.

Module - 2 : —

Chapter - 4 : —

Loss of energy in pipes :—

When a fluid is flowing through a pipe, the fluid experiences some resistance due to which some of the energy of fluid is lost. This loss of energy is classified as :

Energy losses

1. Major energy losses
   This is due to friction and it is calculated by the following formulae :
   (a) Darcy - Weisbach formula
   (b) Chezy's formula.

2. Minor energy losses
   This is due to
   (a) Sudden expansion of pipe
   (b) Sudden contraction of pipe
   (c) Bend in pipe
   (d) Pipe fittings etc.
   (e) An obstruction in pipe.

Loss of Energy (or head) Due to Friction :—

(a) Darcy - Weisbach Formula :—

The loss of head (or energy) in pipes due to friction is calculated from Darcy-Weisbach equation which has been derived in chapter 10 and is given by

$$h_f = \frac{4.f.L.V^2}{d \times 2g}$$

h_f = loss of head due to friction

f = co-efficient of friction which is a function of Reynold's number

$$= \frac{16}{R_e} \text{ for } R_e < 2000 \text{ (viscous flow)}$$

$$= \frac{0.079}{R_e^{1/4}} \text{ for } R_e \text{ varying from } 4000 \text{ to } 10^6$$

L = Length of pipe,

V = mean velocity of flow,

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d = diameter of pipe

Chezy's formula for finding head loss due to friction in pipe :—

$$\text{Velocity } (V) = C\sqrt{mi}$$

where, C = chezy's constant

m = hydraulic radius

i = head loss per unit length

$m = \dfrac{A}{P}$ A = Area of flow

P = perimeter

$i = \dfrac{h_f}{L}$ h_f = head loss

L = Length of flow

For pipe carrying full flow

$$m = \frac{A}{P} = \frac{\frac{\pi}{4}d^2}{\pi d} = \frac{d}{4}$$

Power Requirement (P) :—

$$P = \frac{\rho g Q h_f}{1000} \text{ in K.W}$$

ρ = density of fluid in kg/m^3

g = Acceleration due to gravity m/sec^2

Q = Rate of flow m^3/sec

h_f = head loss in m.

Q.1 Find the head lost due to friction in a pipe of diameter 300 mm and length 50m, through which water is flowing at a velocity of 3m/s using (i) Darcy formula (ii) Chezy's formula for which $C = 60$. Take ν for water = 0.01 stoke.

Soln Given data,

Dia of pipe, d = 300 mm = 0.30 m

Length of pipe, L = 50 m

Velocity of flow, V = 3 m/s

Chezy's constant, C = 60

Kinematic viscosity, ν = 0.01 stoke = 0.01 cm^2/s

$= 0.01 \times 10^{-4}$ m^2/s.

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(i) Darcy formula is given by (eq) →

$$h_f = \frac{4 \cdot f \cdot L \cdot V^2}{d \times 2g}$$

where 'f' = co-efficient of friction is a function of Reynold's number, R_e

But R_e is given by $R_e = \frac{V \times d}{\nu} = \frac{3.0 \times 0.30}{0.01 \times 10^{-4}}$

$= 9 \times 10^5$

∴ Value of $f = \frac{0.079}{R_e^{1/4}} = \frac{0.079}{(9 \times 10^5)^{1/4}} = 0.00256$

∴ Head lost, $h_f = \frac{4 \times 0.00256 \times 50 \times 3^2}{0.3 \times 2.0 \times 9.81} = 0.7828\,m$ Ans

(ii) Chezy's formula,

$$V = C\sqrt{mi}$$

where $C = 60$, $m = \frac{d}{4} = \frac{0.30}{4} = 0.075\,m$

∴ $3 = 60\sqrt{.075 \times i}$ or $i = \left(\frac{3}{60}\right)^2 \times \frac{1}{0.075}$

$= 0.0333$

But, $i = \frac{h_f}{L} = \frac{h_f}{50}$

Equating the two values of i, we have $\frac{h_f}{50} = .0333$

∴ $h_f = 50 \times .0333 = 1.665\,m$. Ans

Q.2 An oil of sp. gr. 0.7 is flowing through a pipe of diameter 300mm at the rate of 500 lit/s. Find the head lost due to friction and power required to maintain the flow for a length of 1000 m. Take $\nu = .29$ stokes.

Soln:- Given data,

Sp. gr. of oil, $S = 0.7$

Dia of pipe, $d = 300mm = 0.3m$

Discharge, $Q = 500\,lit/s = 0.5\,m^3/s$

Length of pipe, $L = 1000m$

Velocity, $V = \frac{Q}{Area} = \frac{0.5}{\frac{\pi}{4} d^2} = \frac{0.5 \times 4}{\pi \times 0.3^2}$

$= 7.073\,m/s$

∴ Reynold's number, $R_e = \frac{V \times d}{\nu} = \frac{7.073 \times 0.3}{0.29 \times 10^{-4}}$

$= 7.316 \times (10.3)^4$

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$\therefore$ Co-efficient of friction, $f = \frac{.079}{R_e^{1/4}}$

$$= \frac{0.79}{(7.316 \times 10^4)^{1/4}} = 0.0048$$

$\therefore$ Head loss due to friction, $h_f = \frac{4 \times f \times L \times v^2}{d \times 2g}$

$$= \frac{4 \times 0.0048 \times 1000 \times 7.073^2}{0.3 \times 2 \times 9.81} = 163.18 \text{ m}$$

Power required $= \frac{\rho g \cdot Q \cdot h_f}{1000} \times \text{kW}$

where ρ = density of oil $= 0.7 \times 1000 = 700 \text{ kg/m}^3$

Power required $= \frac{700 \times 9.81 \times 0.5 \times 163.18}{1000}$

$= 560.28$ kW. Ans

Minor Energy (Head) Losses :—

The loss of head or energy due to friction in a pipe is known as major loss while the loss of energy due to change of velocity of the following fluid in magnitude or direction is called minor loss of energy. The minor loss of energy includes the following cases :

1. Loss of head due to sudden enlargement,
2. Loss of head due to sudden contraction,
3. Loss of head at the entrance of a pipe,
4. Loss of head at the exit of a pipe,
5. Loss of head due to an obstruction in a pipe,
6. Loss of head due to bend in the pipe,
7. Loss of head in various pipe fittings.

Q.1. A crude oil of kinematic viscosity 0.4 stoke is flowing through a pipe of diameter 300 mm at the rate of 300 litres per sec. Find the head lost due to friction for a length of 50 m of the pipe.

Soln Given data,

Kinematic viscosity, $\nu = 0.4$ stoke

$= 0.4 \text{ cm}^2/\text{s} = .4 \times 10^{-4} \text{ m}^2/\text{s}$

Dia of pipe, $d = 300 \text{ mm} = 0.30 \text{ m}$

Discharge, $Q = 300 \text{ lit/s} = 0.3 \text{ m}^3/\text{s}$

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Length of pipe, $L = 50m$

velocity of flow, $V = \frac{Q}{Area} = \frac{0.3}{\frac{\pi}{4}(0.3)^2} = 4.24\ m/s$

$\therefore$ Reynolds number, $Re = \frac{V \times d}{\nu} = \frac{4.24 \times 0.30}{0.4 \times 10^{-4}}$

$= 3.18 \times 10^4$

As Re lies between 4000 and 100000, the value of $f = \frac{0.079}{(Re)^{1/4}} = \frac{0.079}{(3.18 \times 10^4)^{1/4}} = 0.00591$

$h_f = \frac{4f \cdot L \cdot V^2}{d \times 2g} = \frac{4 \times 0.00591 \times 50 \times 4.24^2}{0.3 \times 2 \times 9.81}$

$= 3.61m$

Hydraulics and total energy lines :—

The concept of hydraulic gradient line and total energy line is very useful in the study of flow of fluids through pipes. They are defined as :

Hydraulic Gradient Line :—

~~It is defined as the line which gives the sum of pressure head~~ $\cancel{\left(\frac{p}{w}\right)}$ ~~and datum head~~ $\cancel{(z)}$ ~~of the~~

→ showing the pressure head (P/w) of a flowing fluid in a pipe from the centre of the pipe.

Total Energy Line :—

It is defined as the line which gives the sum of pressure head, datum head and kinetic head of a flowing fluid in a pipe with respect to some reference line. ~~It~~ ~~to~~ ~~also~~.

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Module - 2 :— chapter - 5 :—

Flow through open channels :—

Flow in open channels is defined as the flow of a liquid with a free surface. A free surface is a surface having constant pressure such as atmospheric pressure. Thus a liquid flowing at atmospheric pressure through a passage is known as flow in open channels.

Discharge through open channel by chezy's formula :—

$$Q = A.V$$

$$V = C\sqrt{mi}$$

C = chezy's constant.

m = hydraulic mean radius.

i = Head loss per meter length of flow

Q.1. find the velocity of flow and rate of flow of water through a rectangular channel of 6m wide and 3m deep, when it is running full. The channel is having bed slope as 1 in 2000. Take chezy's constant C = 55.

Soln Given data

Width of rectangular channel, b = 6m

Depth of channel, d = 3m

∴ Area, $A = 6 \times 3 = 18 m^2$

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Bed slope, $i = 1$ in $2000 = \frac{1}{2000}$

chezy's constant, $C = 55$

perimeter, $P = b + 2d = 6 + 2 \times 3 = 12m$

$\therefore$ Hydraulic mean depth, $m = \frac{A}{P} = \frac{18}{12} = 1.5m$

velocity of flow is

$$V = C\sqrt{mi} = 55\sqrt{1.5 \times \frac{1}{2000}} = 1.506 m/s$$

Rate of flow, $Q = V \times$ Area $= V \times A$

$= 1.506 \times 18 = 27.108 m^3/s$

Q.2 Find the slope of the bed of a rectangular channel of width 5m when depth of water is 2m and rate of flow is given as $20 m^3/s$. Take chezy's constant, $C = 50$.

Soln Given data,

width of channel, $b = 5m$

Depth of water, $d = 2m$

Rate of flow, $Q = 20 m^3/s$

chezy's constant, $C = 50$

Let the bed slope $= i$

~~Using equation~~ we have $Q = AC\sqrt{mi}$

where A = Area $= b \times d = 5 \times 2 = 10 m^2$

$$m = \frac{A}{P} = \frac{10}{b + 2d} = \frac{10}{5 + 2 \times 2} = \frac{10}{5+4} = \frac{10}{9} m$$

$$20.0 = 10 \times 50 \times \sqrt{\frac{10}{9} \times i} \quad \text{or} \quad \sqrt{\frac{10}{9} i} = \frac{20}{500} = \frac{2}{50}$$

Squaring both side, we have $\frac{10}{9} i = \frac{4}{2500}$

$$i = \frac{4}{2500} \times \frac{9}{10} = \frac{36}{25000} = \frac{1}{\frac{25000}{36}} = \frac{1}{694.44}$$

$\therefore$ Bed slope is 1 in 694.44.

Q.3 A flow of water of 100 lits per second flows down in a rectangular flume of width 600mm and having adjustable bottom slope. If chezy's constant C is 56, find the bottom slope necessary for uniform flow with a depth of flow of 300mm. Also find the conveyance K of the flume.

Soln Given data,

Discharge, $Q = 100\ lit/s = \frac{100}{1000} = 0.10 m^3/s$

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$b = 600\,mm = 0.60\,m$

$d = 300\,mm = 0.30$

Area of flow, $A = b \times d = 0.6 \times 0.3 = 0.18\,m^2$

Chezy's constant, $C = 56$

Let the slope of bed $= i$

Hydraulic mean depth, $m = \frac{A}{P} = \frac{0.18}{b+2d}$

$$= \frac{0.18}{0.6+2\times0.30} = \frac{0.18}{1.2} = 0.15\,m$$

We have, $Q = AC\sqrt{mi}$ or $\sqrt{0.15 i} = \frac{0.10}{0.18\times56}$

$$0.10 = 0.18 \times 56 \times \sqrt{0.15 \times i}$$

Squaring both sides, we have $0.15\, i = \left(\frac{0.10}{0.18\times 56}\right)^2$

$$= 0.000098418$$

$$i = \frac{0.000098418}{0.15} = 0.0006512 = \frac{1}{\frac{1}{0.0006512}}$$

$$= \frac{1}{1524} \quad \text{Ans}$$

Q. 4 Find the discharge through a trapezoidal channel of width 8m and side slope of 1 horizontal to 3 vertical. The depth of flow of water is 2.4m and value of chezy's constant, c = 50. The slope of the bed of the channel is given 1 in 4000.

__Sol__ⁿ Given data,

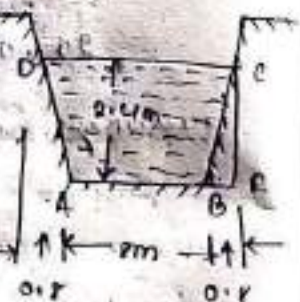
$b = 8m$

Side slope = 1 hori. to 3 vertical

$d = 2.4m$

$C = 50$

Bed slope, $i = \frac{1}{4000}$



depth, $CE = 2.4$,

Horizontal distance, $BE = 2.4 \times \frac{1}{3} = 0.8\,m$

∴ Top width of the channel,

$$CD = AB + 2 \times BE$$

$$= 8.0 + 2\times0.8 = 9.6\,m$$

Area of trapezoidal channel, ABCD is

$$A = (AB + CD) \times \frac{CE}{2} = (8 + 9.6) \times \frac{2.4}{2}$$

$$= 17.6 \times 1.2 = 21.12\,m^2$$

Wetted perimeter, $P = AB + BC + AD = AB + 2BC$

$$BC = \sqrt{BE^2 + CE^2} = \sqrt{(0.8)^2 + (2.4)^2} = 2.529 \text{ m} \quad (\because BC = AD)$$

$$P = 8.0 + 2 \times 2.529 = 13.058 \text{ m}$$

Hydraulic mean depth, $m = \dfrac{A}{P} = \dfrac{21.12}{13.058} = 1.617 \text{ m}$

The discharge, Q is given

$$Q = AC\sqrt{mi}$$

$$= 21.12 \times 50 \sqrt{1.617 \times \frac{1}{4000}} = 21.23 \text{ m}^3/\text{s} \quad \underline{\text{Ans}}$$

Discharge of open channel using manning's Formula :—

$$Q = A \cdot V$$

V = Velocity

A = Area of Flow

$$V = C\sqrt{mi}$$

$$C = \frac{1}{N} m^{1/6}$$

Where N = Manning's constant

m = hydraulic radius

$m = \dfrac{A}{P}$ A = Area of Flow

P = Wetted perimeter

Q. 5 Find the discharge through a rectangular channel 2.5 m wide, having depth of water 1.5 m and bed slope as 1 in 2000. Take the value of K = 2.36 in Bazin's Formula.

<u>Ans</u> Given data

$b = 2.5$ m

$d = 1.5$ m

Area, $A = b \times d = 2.5 \times 1.5 = 3.75 \text{ m}^2$

Wetted perimeter, $P = d + b + d$

$= 1.5 + 2.5 + 1.5 = 5.5$ m

Hydraulic mean depth, $m = \dfrac{A}{P} = \dfrac{3.75}{5.50} = 0.682$

Bed slope, $i = \dfrac{1}{2000}$

Bazin's constant, $K = 2.36$

Using Bazin's Formula $C = \dfrac{157.6}{1.81 + \dfrac{K}{\sqrt{m}}} = \dfrac{157.6}{1.81 + \dfrac{2.36}{\sqrt{0.682}}}$

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= 33.76

Discharge, $Q = AC\sqrt{mi}$

$= 3.75 \times 33.76 \times \sqrt{0.682 \times \frac{1}{2000}} = 2.337\,m^3/s$

Q.6 Find the discharge through a rectangular channel 4m wide, having depth of water 3m and bed slope 1 in 1500. Take the value of $N = 0.03$ in the Kutter's formula.

Sol^n Given data

$b = 4m$

$d = 3m$

Bed slope, $i = \frac{1}{1500} = 0.000667$

Kutter's constant, $N = 0.03$

Area of flow $= A = b \times d = 4 \times 3 = 12m^2$

wetted perimeter, $P = d + b + d = 3+4+3 = 10m$

Hydraulic mean depth, $m = \frac{A}{P} = \frac{0.12}{10} = 1.2m$

Using Kutter's formula,

$$C = \frac{23 + \frac{0.00155}{i} + \frac{1}{N}}{1 + \left(23 + \frac{0.00155}{i}\right) \times \frac{N}{\sqrt{m}}} = \frac{23 + \frac{0.00155}{0.000667} + \frac{1}{0.03}}{1 + 23 + \frac{0.00155}{0.000667} \frac{0.03}{\sqrt{1.2}}}$$

$$= \frac{23 + 2.3238 + 33.33}{1 + (23 + 2.3238) \times 0.3286} = \frac{58.623}{1.832} = 32.01$$

Discharge, $Q = AC\sqrt{mi} = \sqrt{12 \times 0.000667} = 10.867\,m^3/s$

Q.7 Find the discharge through a rectangular channel of width 2m, having a bed slope of 4 in 8000. The depth of flow is 1.5m and take the value of N in manning's formula as 0.012.

Sol^n Given data,

$b = 2m$

$d = 1.5m$

Area of flow, $A = b \times d = 2 \times 1.5 = 3.0\,m^2$

wetted perimeter, $P = b + d + d = 2 + 1.5 + 1.5 = 5m$

Hydraulic mean depth, $m = \frac{A}{P} = \frac{3}{5} = 0.6$

Bed slope, $i = 4$ in $8000 = \frac{4}{8000} = \frac{1}{2000}$

Value of $N = 0.012$

Using manning's formula,

$$C = \frac{1}{N} m^{1/6} = \frac{1}{0.012} \times 0.6^{1/6} = 76.54$$

Discharge, $Q = AC\sqrt{mi}$

$$= 3.0 \times 76.54 \sqrt{0.6 \times \frac{1}{2000}} \; m^2/s$$

$$= 3.977 \; m^3/s$$

Most economical section of channels :—

A section is said to be most economical when the cost of construction of the channel is minimum. Most economical section is also called the best section or most efficient section.

The condition to be most economical for the following shapes of the channels are

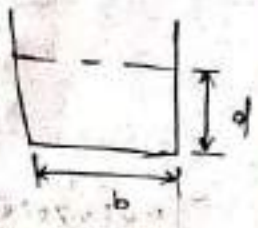
1. Rectangular section
2. Trapezoidal section
3. Circular section

Rectangular Section :—

The condition for most economical section is $\boxed{b = 2d}$ which implies

$$m = \frac{A}{P} = \frac{b \times d}{b + 2d} = \frac{2d \times d}{2d + 2d} = \frac{d}{2}$$

$$\Rightarrow \boxed{m = \frac{d}{2}}$$



Q. 8 A rectangular channel of width, 4m is having a bed slope of 1 in 1500. Find the maximum discharge through the channel. Take value of C = 50.

Sol? Given data,

$$b = 4m$$

Bed slope, $i = \frac{1}{1500}$

chezy's constant, $C = 50$

Discharge will be maximum, when the channel is most economical. The conditions for most economical rectangular channel are :

(i) $b = 2d$ or, $d = \frac{b}{2} = \frac{4}{2} = 2m$.

(ii) $m = \frac{d}{2} = \frac{2}{2} = 1m$

∴ Area of most economical rectangular channel,

$$A = b \times d = 4 \times 2 = 8 \; m^2$$

Discharge $Q = AC\sqrt{mi} = 8 \times 5 \times \sqrt{1.0 \times \frac{1}{1500}} = 10.328 \; m^3/s.$

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Q.9 A rectangular channel carries water at the rate of 400 lit/s when bed slope is 1 in 2000. Find the most economical dimensions of the channel if C = 50.

Soln Given data,

Discharge, $Q = 400$ lit/s $= 0.4\ m^3/s$

Bed slope, $i = \frac{1}{2000}$

Chezy's constant, $C = 50$

For the rectangular channel to be most economical,

(i) width, $b = 2d$

(ii) Hydraulic mean depth, $m = \frac{d}{2}$

∴ Area of flow, $A = b \times d = 2d \times d = 2d^2$

Discharge, $Q = AC\sqrt{mi}$

$$0.4 = 2d^2 \times 50 \times \sqrt{\frac{d}{2} \times \frac{1}{2000}}$$

$$= 2 \times 50 \times \sqrt{\frac{1}{2 \times 2000}}\ d^{5/2} = 1.581\ d^{5/2}$$

$$d^{5/2} = \frac{0.4}{1.581} = 0.253$$

$$d = (0.253)^{2/5} = 0.577\ m.$$

$$b = 2d = 2 \times 0.577 = 1.154\ m \quad \underline{\text{Ans}}$$

Trapezoidal Section :—

The condition for most economical trapezoidal section is $\boxed{\frac{b + 2nd}{2} = d\sqrt{n^2+1}}$ — (1)

where b = width of channel

n = side slope

d = depth of water

$$m = \frac{A}{P} = \left\{ \begin{array}{l} A = \left(\frac{\text{bottom width} + \text{top width}}{2}\right) \text{depth} \\ = \left(\frac{b + b + 2nd}{2}\right) d = (b + nd)d \\ P = b + 2d\sqrt{n^2+1} \end{array} \right.$$

$$\Rightarrow m = \frac{(b+nd) \cdot d}{b + 2d\sqrt{n^2+1}}$$

Using eqn (1), $2d\sqrt{n^2+1} = b + 2nd$

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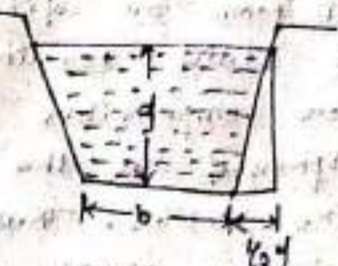
$$m = \frac{(b+nd)d}{b+b+2nd} = \frac{(b+nd)d}{2(b+nd)} = \frac{d}{2}$$

$$\Rightarrow \boxed{m = \frac{d}{2}}$$

2.10 A trapezoidal channel has side slopes of 1 horizontal to 2 vertical and the slope of the bed is 1 in 1500. The area of the section is $40 m^2$. Find the dimensions of the section if it is most economical. Determine the discharge of the most economical section if $C = 50$.

Soln Given data,



Side slope, $n = \frac{\text{Horizontal}}{\text{Vertical}} = \frac{1}{2}$

Bed slope, $i = \frac{1}{1500}$

Area of section, $A = 40 m^2$

Chezy's constant, $C = 50$

For the most economical section,

$$\frac{b+2nd}{2} = d\sqrt{n^2+1} \text{ or } \frac{b+2\times\frac{1}{2}d}{2} = d\sqrt{(1/2)^2+1}$$

$$\text{or } \frac{b+d}{2} = d\sqrt{\frac{1}{4}+1} = 1.118d$$

or $b = 2\times1.118d - d = 1.236d$,

But area of horizontal section,

$$A = \frac{b+(b+2nd)}{2}\times d = (b+nd)d$$

$$= (1.236d + 1/2d)d \quad (\because b = 1.236d \text{ and } n = 1/2)$$

$$= 1.736d^2$$

But $A = 40 m^2$,

$$40 = 1.736d^2$$

$$d = \sqrt{\frac{40}{1.736}} = 4.80m \text{ Ans}$$

Substituting the value of d,

$$b = 1.236\times4.80 = 5.933 m.$$

Discharge for most economical section, Hydraulic mean depth for most economical section is

$$m = \frac{d}{2} = \frac{4.80}{2} = 2.40 m$$

Centrifugal Pumps :—

Introduction :—

→ The hydraulic machines which convert the mechanical energy into hydraulic energy are called pumps.

→ The hydraulic energy is in the form of pressure energy.

→ If the mechanical energy is converted into pressure energy by means of centrifugal force acting on the fluid, the hydraulic machine is called centrifugal pump.

Main parts of a centrifugal pump :—

The following are the main parts of a centrifugal pump :

1. Impeller
2. Casing
3. Suction pipe with a foot valve and a strainer.
4. Delivery pipe

1. Impeller :—

→ The rotating part of a centrifugal pump is called impeller.

→ It consists of a series of backward curved vanes.

→ The impeller is mounted on a shaft which is connected to the shaft of an electric motor.

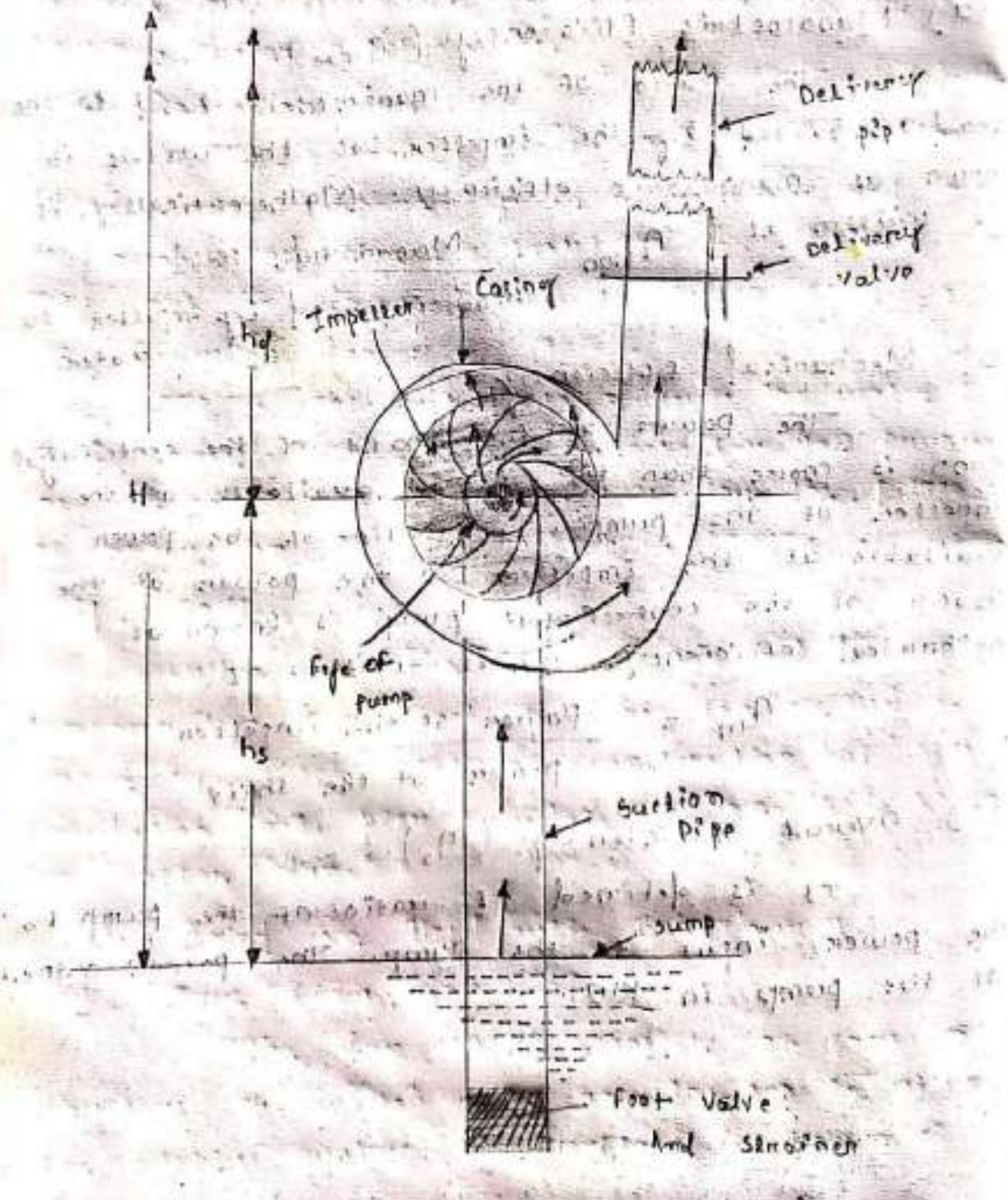
2. Casing :—

→ The casing of a centrifugal pump is similar to the casing of a reaction turbine.

→ It is an air tight passage surrounding the impeller and is designed in such a way that the kinetic energy of the water discharged at the outlet of the impeller is converted into pressure energy before the water leaves the casing and enters the delivery pipe. The following three types of the casings are commonly adopted :

a) Volute Casing:-

Figure shows the volute casing, which surrounds the impeller. It is of spiral type in which area of flow increases gradually. The increase in area of flow decreases the velocity of flow. The decrease in velocity increases the pressure of the water flowing through the casing. It has been observed that in the case of volute casing, the efficiency of the pump increases slightly as a large amount of energy is lost due to the formation of eddies in this type of casing.



Main parts of a centrifugal pump

3. Suction pipe with a foot valve and a strainer :—

→ A pipe whose one end is connected to the inlet of the pump and other end dips into water in a sump is known as suction pipe.

→ A foot valve which is a non-return valve or one-way type of valve is fitted at the lower end of the suction pipe.

→ The foot valve opens only in the upward direction.

→ A strainer is also fitted at the lower end of the suction pipe.

4. Delivery pipe :—

A pipe whose one end is connected to the outlet of the pump and other end delivers the water at a required height is known as delivery pipe.

Definations of heads and efficiencies of a centrifugal pump :—

1. Suction Head (h_s) :—

It is the vertical height of the centre line of the centrifugal pump above the water surface in the tank or pump from which water is to be ~~for~~ lifted as shown in figure. This height is also called suction lift and is denoted by 'h_s'.

2. Delivery Head (h_d) :—

The vertical distance between the centre line of the pump and the ~~a~~ water surface in the tank to which water is delivered is known as delivery head.

→ This is denoted by 'h_d'.

3. Static Head (H_s) :—

The sum of suction head and delivery head is known as static head.

→ This is represented by 'H_s' and is written as $H_s = h_s + h_d$.

5. Efficiencies of a centrifugal pump :-

In case of a centrifugal pump, the power is transmitted from the shaft of the electric motor to the shaft of the pump and then to the impeller. From the impeller, the power is given to the water. Thus power is decreasing from the shaft of the pump to the impeller and then to the water. The following are the important efficiencies of a centrifugal pump : (a) Manometric efficiency (η_{man})

(b) Mechanical efficiency (η_m)

(c) Overall efficiency (η_o).

(a) Manometric Efficiency (η_{man}) :-

The ratio of the manometric head to the head imparted by the impeller to the water is known as manometric efficiency. Mathematically, it is written as

$$\eta_{man} = \frac{\text{Manometric head}}{\text{Head imparted by impeller to water}}$$

(b) Mechanical Efficiency (η_m) :-

The power at the shaft of the centrifugal pump is more than the power available at the impeller of the pump. The ratio of the power available at the impeller to the power at the shaft of the centrifugal pump is known as mechanical efficiency. It is written as

$$\eta_m = \frac{\text{Power at the impeller}}{\text{Power at the shaft}}$$

(c) Overall Efficiency (η_o) :-

It is defined as ratio of the pump to the power input to the pump. The power output of the pump in KW.

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Irrigation :—

The process of artificial application of water to the soil for the growth of agricultural crops is termed as irrigation. It is practically a science of planning and designing a water supply system for the agricultural land to protect the crops from bad effects of low rainfall. It includes the construction weirs, dams, barrages, canal system for regular supply of water to culturable cultivated land.

Necessity of Irrigation :—

Followings are the factors which govern the necessity of irrigation :

(1) Insufficient rainfall

(2) Uneven distribution of rainfall

(3) Improvement of perennial crop throughout the year.

(4) Development of agriculture in desert area.

Benefits of irrigation :—

Followings are the important benefits of irrigation

(1) Yield of crops

(2) Improvement of cash crops like vegetable, fruits etc.

(3) Nevegation i.e. communication and transportation of agricultural goods.

(4) Hydroelectric power generation

(5) Water supply

(6) Prosperity of farmers i.e farmers may or money and improve their living standard by painting two or more crops on the same land.

(7) Source of revenue i.e cultivator may give some taxes by taking water from the canal.

(8) General communication i.e the inspection road along the canal bank may surve as communication road.

Gross command Area :-

The whole area enclosed between an imaginary boundary land which can be included in an irrigation project for supplying water to the agricultured land by network of canal is known as gross command area (G.C.A)

G.C.A = culturable area + unculturable area

Unculturable area :-

The area where agriculture can be done and crops can be grown satisfactorily is called as culturable area.

(C.C.A) Culturable Command area :-

The total area within an irrigation project where the cultivation can be done and crops can be grown is known as culturable command area. Again C.C.A may be of two categories

(1) culturable cultivated area
(2) culturable uncultivated area

Culturable Uncultivated area :-

It is the area within the C.C.A where cultivation is possible but it is not being cultivated at present due to non-availability fund etc.

Culturable cultivated area :-

It is the area within the C.C.A where cultivation is possible but it is not being cultivated at present due to non-availability fund etc.

Intensity of irrigation :-

Intensity of irrigation may be defined as a ratio of cultivated land for a perticular crop to the total culturable command area. It is expressed as a percentage of C.C.A

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Ex: If total culturable command area is 100 hectre where wheat is cultivated in 25 hectre then intensity of irrigation for wheat

$$= \frac{25}{100} \times 100 = 25\%$$

Q. The gross command area of an irrigation is 1 lakh hectre. The culturable command area is 75% of gross command area. The intensity of irrigation for rice and wheat are 50% and 55% respectively. Find the area of each crop where the particular crop has been grown.

Ans Given data

$$G.C.A = 1 \text{ lakh hectre}$$
$$= 100000 \text{ hectre}$$

$$C.C.A = 100000 \times \frac{75}{100}$$
$$= 75000 \text{ hectre}$$

intensity of irrigation

Rice

$$\frac{\text{Area of rice}}{C.C.A} \times 100 = 50$$

$$\Rightarrow \frac{\text{Area of rice}}{75000} \times 100 = 50$$

$$\Rightarrow \text{Area of rice} = 50 \times 750 = 37500 \text{ hectre}$$

Wheat

$$\frac{\text{Area of wheat}}{75000} \times 100 = 55$$

$$\Rightarrow \text{Area of wheat} = 55 \times 750 = 41250 \text{ hectre}$$

Crop Season :—

The period during which some particular type of crop grown every year on the same land is known as crop season. Followings are the main crop seasons (a) Khariff
(b) Rabi

Khariff Season :—

This Season ranges from june to october. The crops are Sown in the very beginning of monsoon and harvested at the end of the autumn.

The major khariff crops are rice, millet, maize, Jute, groundnut.

Rabi Season :—

This Season ranges from october to march. The crops are Sown in the very beginning of winter and harvested at the end of the Spring Season.

The major rabi crops are wheat, gram, Mustard, Pulses, onion.

Again their are several crops which are not included in either Khariff or in rabi Season, but they require more time and they cover both the main Season (Khariff & rabi).

Ex : Cotton is a 8 months crop, Sugarcane is a 12 months crop (perennial)

Crop Ratio :—

It is defined as the ratio of the areas of two main Season.

Ex : If the area under Khariff crop is 5000 hectre and area under Rabi crop is 10000 hectre then ~~the~~ crop ratio is 1:2

Cash Crop :—

The crops which are cultivated by the Farmers to sell in the open market to meet their financial requirement are known as cash crops.

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Ex: Vegitables, Fruits etc.

Crop period :—

The crop period is defined as the total period from the time of sowing a crop to the time of harvesting. In other words it is the period in which crop remains in the field.

Number of watering :—

The total depth of water required by a crop is not supplied at a time. but it is supplied over the base period by stages depending upon the requirement.

Ex: Rice requires 190 cm of water, If watering depth applied at each stage is 10cm, then number of watering $\frac{190}{10} = 19$ times.

Paleo Irrigation :—

The Initial watering which is done to provide moisture to the soil just before sowing any particular crop is known as paleo irrigation.

Kor Watering :—

The ~~first~~ watering is done when the crop has grown to about 3 cm. The watering is known as kor watering.

The number of watering depends on type of soil (Moisture retainning property), soil condition, climate condition.

Base period :→

(i) Base period is defined as the period from 1st watering to last watering of a crop. It is also known as base.

(ii) It is denoted by 'B' and expressed number of days.

Ex:

Crop	Base
(i) Rice	120 days
(ii) Wheat	120 days
(iii) cotton	200 days
(iv) Sugercane	320 days

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Delta (Δ) :—

Each crop required shorten amount of water for its growth and development. If the total amount of water supplied to the crop (1st watering to last watering) is stored on the land without any loss there will be a thick layer of water standing on that land. This depth of water layer is known as delta for that crop. It is denoted as 'Δ'. and expressed in cm.

Ex :

Crop	Delta
1. Rice	125 cm
2. wheat	40 cm
3. Ground nut	80 cm

Duty (D) :—

(i) The duty of water is defined as number of hectres that can be irrigated by constant supply of water at the rate 1 cumec (1 m^3/sec) throughout the base period.

(ii) It is expressed in hectre/cumec and is denoted by 'D'.

Ex :

Crop	Duty
1. Rice	$B = 120,\ \Delta = 125\text{cm} = 1.25\text{m}$ $D = \frac{8.64 \times 120}{1.25} = 829.44$ hec/cumec (900 hec/cum)
2. Wheat	$B = 120,\ \Delta = 40\text{cm} = 0.4\text{m}$ $D = \frac{8.64 \times 120}{0.4} = 2592$ (1800 hec/cum)

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Relation between Base (B), Delta (Δ), Duty (D) :-

Let D = Duty in hectre/ cumec

Δ = Delta in metre

B = Base period in days

From defination of duty 1 cumec of water, flowing continuous for 'B' days gives depth of water 'Δ' over 'D' hectre

$1 m^3/sec \times B \times 24 \times 3600$ sec

$= 86400 B\ m^3$ (water applied)

$D \times 10000 \times \Delta$ (water stored)

Equating water applied = water stored, we have

$$86400\ B m^3 = D \times 10000 \times \Delta$$

$$\Rightarrow \frac{8.64 \times B}{\Delta} = D$$

Discharge required of a canal :-

Discharge can be calculated for a crop by deviding area of that particular crop with its duty.

$$Q = \frac{A}{D}$$

where A = Area of crop in hectre

D = Duty of crop in hec/cum

Q = Discharge

Q. A ~~cano~~ channel is to be design for irrigating 5000 hectres in Khariff crop and 4000 hecs in rabi crop. The water requirement for Khariff and rabi are 60 cm and 25 cm respectively. The ~~crop~~ base period / kor period for khariff is 3 weeks and rabi is 4 week. Determine the discharge of the channel for which it is to be design!

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Given data -

Khariff crop

$\Delta_{rice} = 60\ cm = 0.6m$

$B_{rice} = 3\times7 = 21$ days

$A_{rice} = 5000$ hectre

$$Duty\ (D) = \frac{8.64\times B}{\Delta}$$

$$= \frac{8.64\times21}{0.6}$$

$$= 302.4\ hec/cumec$$

$$Q_K = \frac{A}{D} = \frac{5000}{302.4} = 16.53\ cumec$$

Rabi crop

$\Delta_{wheat} = 25\ cm = 0.25m$

$B_{wheat} = 4\times7 = 28$ day

$A_{wheat} = 4000$ hectre

$$Duty\ (D) = \frac{8.64\times B}{\Delta}$$

$$= \frac{8.64\times28}{0.25}$$

$$= 967.68\ hec/cumec$$

$$Q_R = \frac{A}{D} = \frac{4000}{967.68} = 4.13\ cumec$$

So the channel is to be design for the maximum discharge of 16.53 cumec.

Q. Find the delta for a crop when its duty is 864 hec/cumec, the base period of this crop is 120 days?

Ans Given data

$\Delta = ?$

$D = 864$ hec/cumec

$B = 120$ day

$$D = \frac{8.64 \times B}{\Delta}$$

$$\Rightarrow 864 = \frac{8.64 \times 120}{\Delta}$$

$$\Rightarrow \Delta = \frac{8.64 \times 120}{864} = 1.2 \text{ m}$$

Q. Find the delta for sugarcane when duty is 780 hec/cumec on the field and the base period of the crop being 140 days?

Ans Given dat

$D = 780$ hec/cumec

$B = 140$ days

$\Delta = ?$

$$D = \frac{8.64 \times B}{\Delta}$$

$$\Rightarrow 780 = \frac{8.64 \times 140}{\Delta}$$

$$\Rightarrow \Delta = \frac{8.64 \times 140}{780} = 1.55 \text{ m}$$

Q. The gross command area of an irrigation project is 1 lakh hectres. the culturable command area is 75% of G.C.A. The intensities of irrigation for Kharif and rabi are 50% and 55% respectively. If the duties for Kharif and rabi are 1200 hec/cumec and 1400 hec/cum respectively, determine the discharge at the head of the canal considering 20% provisions for transmition loss, overlap allowance, evaporation loss etc.

Ans Given data

G.C.A = 1 lakh hectres

= 100000 hectre

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$$C.C.A = 100000 \times \frac{75}{100}$$

$$= 75000 \text{ hectare}$$

intensities of irrigation

Khariff

$$\frac{\text{Area for Khariff}}{C.C.A} \times 100 = 50$$

$$\Rightarrow A_K = \frac{C.C.A \times 50}{100}$$

$$= 75000 \times \frac{50}{100}$$

$$= 37500 \text{ hectare}$$

Rabi crop

$$\frac{A_{rabi}}{C.C.A} \times 100 = 55$$

$$\Rightarrow A_{Rabi} = \frac{55}{100} \times C.C.A$$

$$= \frac{55}{100} \times 75000$$

$$= 41250 \text{ hectare}$$

Duties for Khariff = 1200 hec/cum

$$Q_K = \frac{A_K}{D_K} = \frac{37500}{1200} = 31.25$$

Duties for rabi = 1400 hec/cum

$$Q_R = \frac{A_R}{D_R} = \frac{41250}{1400} = 29.46 \text{ cumec}$$

considering losses 20% extra amount of water is need

$$31.25 \times \frac{20}{100} = 6.25 \text{ cumec}$$

$$\therefore Q \text{ required} = 31.25 + 6.25 = 37.5 \text{ cumec}$$

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Q. Determine the discharge of a canal from the following data :

Crop	Base period in days	Area in hectare	Duty in hec/cumec
Rice	120 days	4000	1500
Wheat	120 days	3500	2000
Sugarcane	310 days	3000	1200

Ans :- Given data

For rice

$B = 120$ day

$A = 4000$ hectare

$D = 1500$ hec/cumec

$$Q_R = \frac{A}{D} = \frac{4000}{1500} = 2.66 \text{ cumec}$$

For wheat

$B = 120$ days

$A = 3500$ hectare

$D = 2000$ hec/cum

$$Q_W = \frac{A}{D} = \frac{3500}{2000} = 1.75 \text{ cumec}$$

For sugercane

$B = 310$ days

$A = 3000$ hec

$D = 1200$ hec/cumec

$$Q_S = \frac{A}{D} = \frac{3000}{1200} = 2.5 \text{ cumec}$$

$$Q_{Kharif} = Q_R + Q_S$$
$$= 2.66 + 2.5 = 5.16 \text{ cumec}$$

$$Q_{Rabi} = Q_W + Q_S$$
$$= 1.75 + 2.5 = 4.25 \text{ cumec}$$

Therefore required canal discharge = maximum (5.16, 4.25)

= 5.16 cumec

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Overlap allowance :-

Sometimes a crop of one season may overlap the next crop season by a few days more which it requires to mature. During this period of overlaping the irrigation water is to be supplied simultaneously to the crops both the season. Due to this extra demand discharge of the canal is to be increased. This provision of increasing demand is adjusted by adopting appropriate overlap allowance. This is expressed in percentage.

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: Water logging and Drainage :—

Introduction :—

(i) In agricultural land when the pores within the root zone are gets saturated due to the subsoil water or ground water the air circulation within the soil pores are gets stop. This phenomena is called as water logging.

(ii) Due to water logging fertility of the land is reduced yield of crop is stop.

Causes of water logging :—

Following are the main causes of water logging

(i) Over Irrigation :—

Inundation Irrigation System, since there is no control over water supply it may causes over Irrigation.

(ii) Seepage from canals :—

In unlined canal system water percolates through the bank of canals. Thus ground water table gets rised.

(iii) Nature of soil :—

The soil having low permiability like black cotton soil (More plasticity) does not allow water to percolates water through it. Thus it lead to water logging.

(iv) Excessive rainfall :—

If the rainfall is excessive water gets no time to drained at completely. There by a pool of stagnant water is formed which to water logging.

(v) Topography of land :—

If the agricultural land is flat with depression and undulations this leads to water logging.

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(vi) Poor irrigation Management :—

If the main canal is kept open for a long period unnecessarily without computing the total water requirement, leads to over irrigation which results into water logging.

(vii) Seepage from reservoir :—

If the reservoir basin consist of permiable zones, cracks which were not detected during the construction of dam these may cause seepage of water.

(viii) Flood :—

If an area gets affected by flood and their is no proper drainage system the water table gets rised these causes water logging.

(ix) Obstruction in natural water course :—

If the bridges or culverts are constructed across a water course with the opening with ~~different~~ insufficient discharge capacity the upstream area gets flooded and this causes water logging.

Obstruction in sub soil Drainage :—

If some impermeable zone exist at a lower depth below the ground surface, then the movement of sub soil water gets obstructed and causes water logging in the area.

Efects of Water logging :—

Followings are the effects of water logging

(i) Salinization of Soil :—

Due to waterlogging the dissolved salts like sodium carbonate, sodium chloride and sodium sulphate come to the surface of the soil. When the water evaporates from the surface, the salts are deposited there. This process is known as salinization of soil. Excessive concentration of salt makes the land alkaline. It does not allow the plants to thrive and thus the yield

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of crop is reduced. This process is also known as Salt efflorescence.

(2) Lack of aeration :—

The crops require some nutrients for their growth which are supplied by some bacteria or micro-organisms by breaking the complex nitrogenous compounds into simple compounds which are consumed by the plants for their growth. But the bacteria required oxygen for their life and activity. When the aeration in the soil is stopped by water-logging, these bacteria cannot survive without oxygen and the fertility of the land is lost which results in reduction of yield.

(3) Fall of soil temperature :—

Due to water logging, the agricultural land is ~~converted~~ lowered. At low temperature of the soil the activity of the bacteria becomes very slow and consequently the plants do not get the requisite amount of food in time. Thus growth of the plants is hampered and the yield also is reduced.

(4) Growth of weeds and aquatic plants :—

Due to water logging, the agricultural land is converted to marshy land and the weeds and aquatic plants are grown in plenty. These plants consume the soil foods in advance and thus the crops are destroyed.

(5) Diseases of crops :—

Due to low temperature and poor aeration, the crops get some diseases which may destroy the crops or reduce the yield.

(6) Difficulty in cultivation :—

In water logged area it is very difficult to carry out the operation of cultivation such as tilling, ploughing, etc.

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Restriction of Root growth :—

When the water table rises near to root zone the soil gets saturated. The growth of the roots is confined only to the top layer of the soil. So, the crops cannot be matured properly and the yield is reduced.

Control of Water logging (i.e. anti water logging measures) :—

The following measures may be taken to control water logging :—

(1) Prevention of percolation from canals :—

The irrigation canals should be lined with impervious lining to prevent the percolation of water through the bed and banks of the canals. Thus the water logging may be prevented.

Intercepting drains may be provided along the course of the irrigation canals in places where the percolation of water is detected. The percolating water is intercepted by the drains and the water is carried to other natural water course.

(2) Prevention of percolation from reservoirs :—

During the construction of dam, the geological survey should be conducted on the reservoir basin to detect the zone of permeable formations through which water may percolate. These zones should be treated to prevent seepage. If afterwards it is found that there is still leakage of water through some zone, then sheet piling should be done to prevent the leakage.

(3) Control of intensity of irrigation :—

The intensity of irrigation may cause water logging so, it should be controlled in a planned way

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that there is no possibility of water logging in a particular area.

(4) Economical use of water :—

If the water is used economically, then it may control the water logging and the yield of crops may be high. So, Special training is required to be given to the cultivators to realise the benefits of economical use of water. It helps them to get more crops by eliminating the possibility of water logging.

(5) Fixing of crop pattern :—

Soil survey should be conducted to fix the crop pattern. The crops having high rate of evapotranspiration should recommended for the area susceptible to water logging.

(6) Providing drainage system :—

Suitable drainage system should be provided in the low lying areas so that the rain water does not stand for long days. A net work of sub-surface drains are provided which are connected to the surface drains. The surface drains discharge the water to the river or any water course.

(7) Improvement of natural drainage :—

Sometimes, the natural drainage may be completely silted up or obstructed by weeds, aquatic plants, etc. The affected section of the drainage should be improved by excavating and clearing the obstructions.

(8) Pumping of ground water :—

A number of open wells or tube wells are constructed in the water logged area and the ground water is pumped out until the water table goes down to a safe level. The lifted ground water may be utilised for irrigation or may be discharged to the river or any water course.

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(9) Construction of Sump well :—

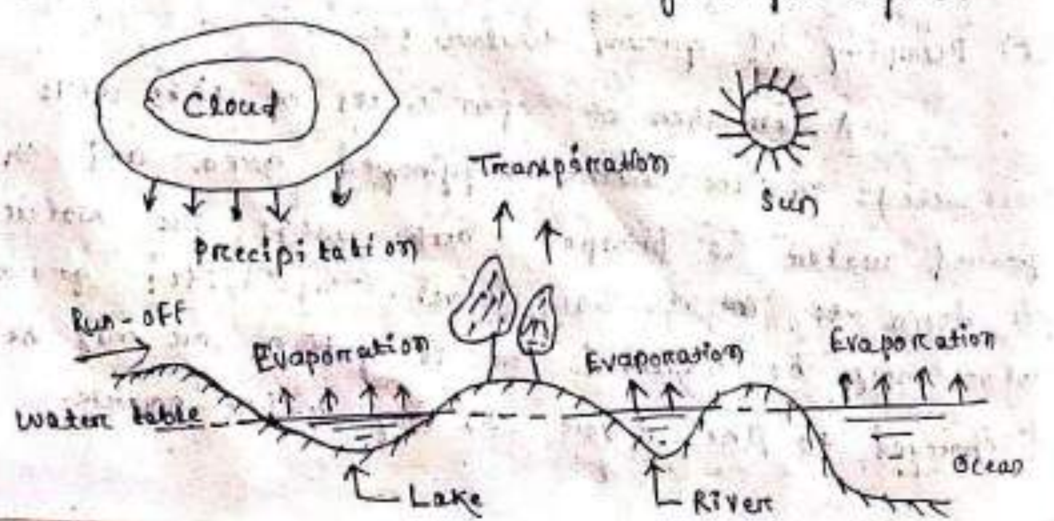
Sump wells may be constructed within the water logged area and they help to collect the surface water. The water from the sump wells may be pumped to the irrigable lands or may be discharged to any river.

— : Hydrology : —

The science of study the different forms of water available above the earth surface and below the earth surface is known as hydrology.

Hydrologic cycle or Water cycle :—

The water of the universe always changes from one state to other under the effect of sun. The water from the surface sources like lakes, rivers, ocean, etc. converts to vapour by evaporation due to solar heat. The vapour goes on accumulating continuously in the atmosphere. This vapour is again condensed due to the sudden fall of temperature and pressure. Thus clouds are formed. These clouds again causes the precipitation (i.e. rainfall). Some of the vapour is converted to ice at the peak of the mountains. The ice again melts is summer and flows as rivers to meet the sea or ocean. These processes of evaporation, precipitation and melting of ice go on continuously like an endless chain and thus a balance is maintained in the atmosphere. This phenomenon is known as hydrologic cycle.



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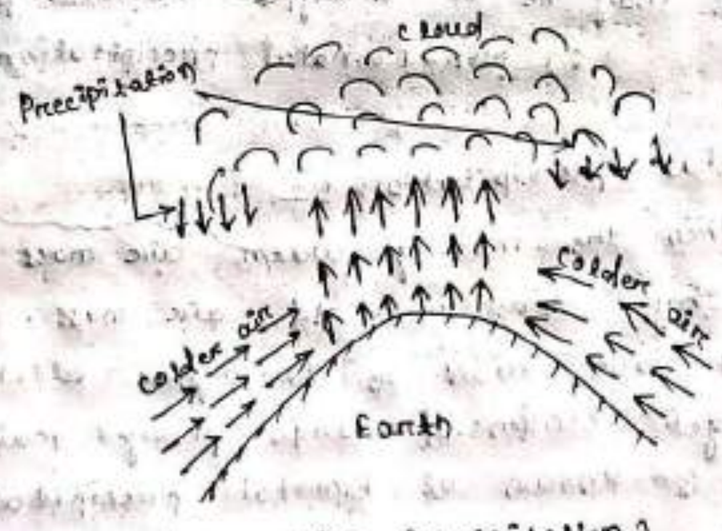
. The water vapour goes on collecting in the atmosphere up to a certain limit. When this limit exceeds and the atmospheric temperature and pressure fall to a certain value, the water vapour will get condensed and thereby cloud is formed. ultimately droplets are formed and returned to earth in the form of rain, snowfall, hail, etc. This is known as precipitation.

Types of precipitation or Rainfall :-

Depending upon the various atmospheric conditions the precipitation may be of the following types.

1. Convective precipitation :-

In tropical countries, when on a particular hot day the ground surface gets heated unequally, the warm air is lifted to high altitude and the cooler air takes its place with high velocity. Thus, the warm moist air mass is condensed at the high altitude causing heavy rainfall. This is known as convective precipitation.



(Convective precipitation)

3. Orographic precipitation :-

The moving warm moist air when obstructed by some mountain rises up to a high altitude. It then gets condensed and precipitation occurs. This is known as orographic precipitation.

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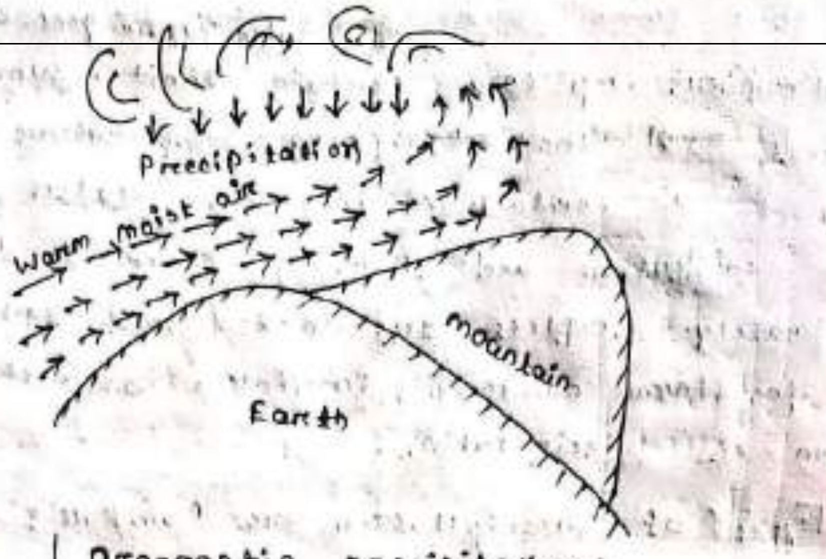


(Orographic precipitation)

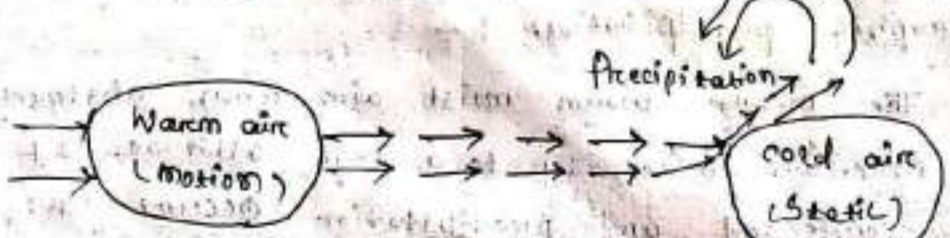
Cyclonic precipitation :—

This type of precipitation caused by difference of pressure within the air mass on the surface of earth. If low pressure is generated at some place the warm air from the surrounding area ~~crosses~~ ~~to~~ rushes to the zone of low pressure. The warm air rises up with whirling motion and get condensed at higher altitude and ultimately heavy rainfall occures. This may be of 2 types (1) frontal precipitation (2) Non-frontal precipitation

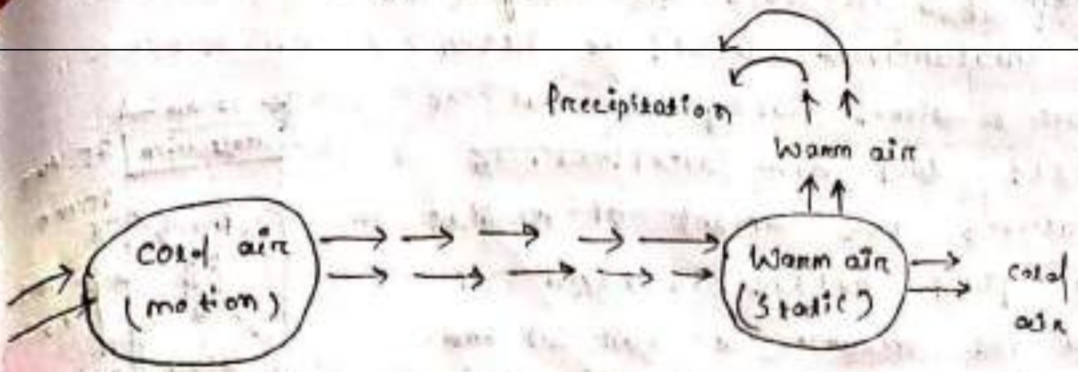
Frontal precipitation :—

When the moving warm air mass is obstructed by zone of cold air mass, the warm moist air rises up to higher altitude where it get condensed and heavy rainfall occurs this is known as frontal precipitation.

frontal precipitation is of 2 types



(Hot air frontal precipitation)



(Cold air frontal precipitation)

Non - Frontal precipitation :—

When the warm air rushes to the zone of low pressure air pocket is form and the warm air rises up like a chimney. At higher altitude this air may get condensed and heavy rainfall occurs. This is known as non-frontal precipitation.

Measurement of Rainfall (i.e. Precipitation) :—

This instrument which is used to measure the amount of rainfall is known as raingauge. The principle of raingauge is the amount of rainfall in a small area will represent the amount of rainfall in a large area provided the meteorological characteristics of both small and large area are similar. The raingauges are of the following types.

1. Non - Recording type raingauge :—

Simon's raingauge is a non - recording type of raingauge which is most commonly used. It consists of metal casing of diameter 127mm which is set on a concrete foundation. A glass bottle of capacity about 100mm of rainfall is placed within the casing. A funnel with brass rim is placed on the top of the bottle.

The rainfall is recorded at every 24 hours. Generally, the measurement is taken at 8.30 a.m.

everyday. In case of heavy rainfall the measurement should be taken 2 or 3 times daily so that the bottle does not overflows. To measure the amount of rainfall the glass bottle is taken off and the ~~amount of rainfall the glass bottle~~ collected water is measured in a measuring glass, and recorded in the raingauge record book. When the glass bottle is taken off it is immediately re-placed with a new bottle of some capacity.

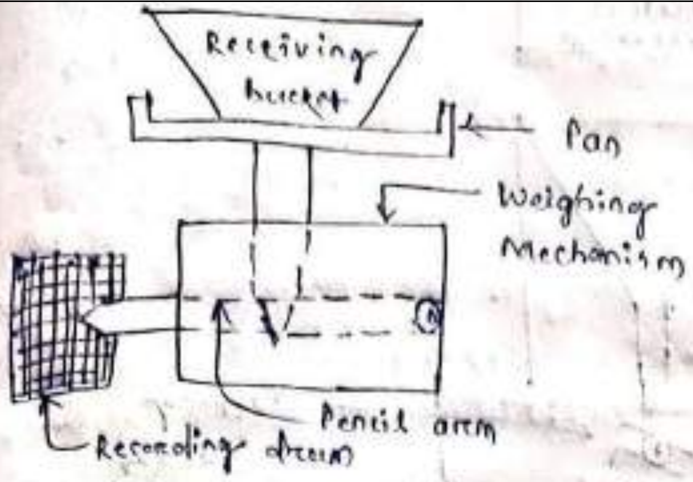
600 x 600 x 600mm
[simons raingauge]

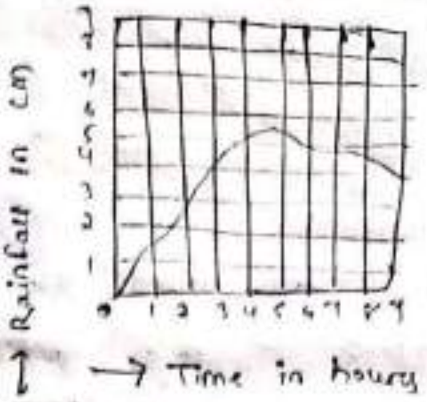
2. Recording type Raingauge :—

In this type of raingauge, the amount of rain-fall is automatically recorded on a graph paper by some mechanical device. Hence, no person is required for measuring the amount of rainfall from the containere in which the rain water is collected. The recording type raingauge may be of 3 types.

(a) Weighing Bucket Raingauge :—

This type of raingauge consists of a receiving bucket which is placed on pan. The pan is again filled with some weighing mechanism. A pencil arm is pivoted with the weighing mechanism in such a way that the movement of the bucket can be traced by a pencil on a moving recording drum. So, when the water is collected in the bucket the increasing weight of water is transmitted through the pencil which traces a curve on the recording drum. The raingauge produces a graph of cumulative rainfall versus time and hence it is some times called integrating raingauge. The graph is known as the mass curve of rainfall.





(Weighing bucket raingauge)

Tipping Bucket raingauge :—

It consist of a circular collector of diameter 30 cm in which the rain water is initially collected. The rain water then passes through a funnel fitted to the circular collector and gets collected in two compartment tipping buckets pivoted below the funnel.

When 0.25 mm rain water is collected in one bucket then it tips and discharge the water in a reservoir kept below the bucket. At the same time the other bucket comes below the funnel and the rain water goes on collecting in it. When the requisite amount of rain water is collected. It also tips and discharge the water in the reservoir. In this way, a circular motion is generated by the buckets. This circular motion is transmitted to a pen or pencil which traces a wave like curve on the sheet mounted on a revolving drum. The total rainfall may be ascertained from the graph. There is an opening with stop cock at the bottom of the reservoir for discharging the collected rainwater. Sometimes a measuring glass is provided to verify the result shown by the graph.

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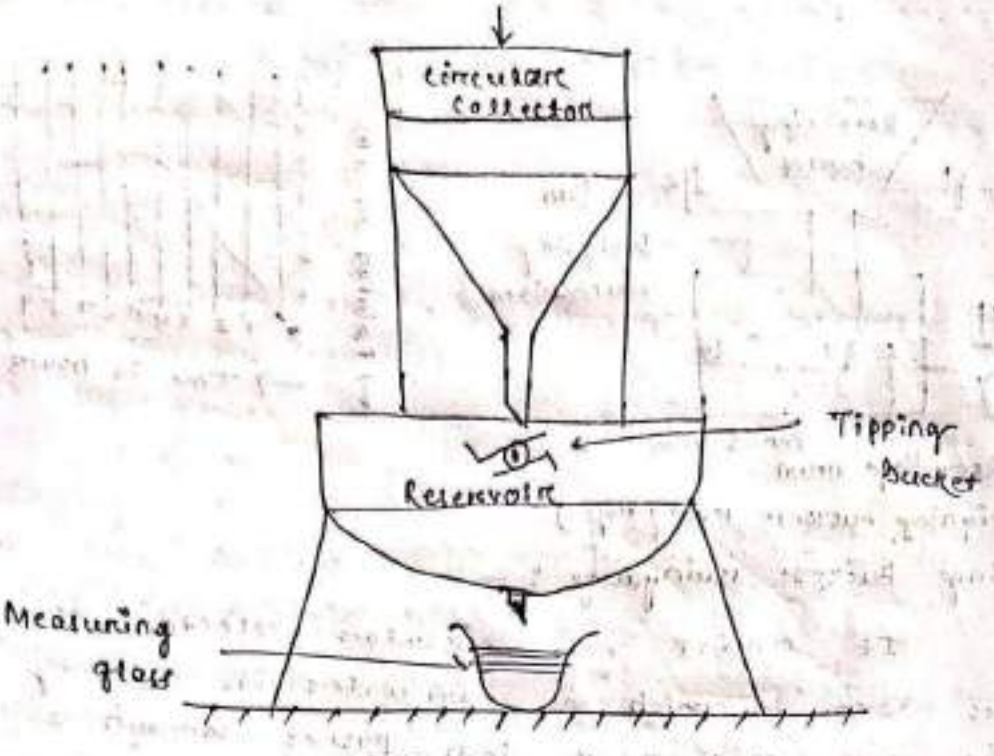
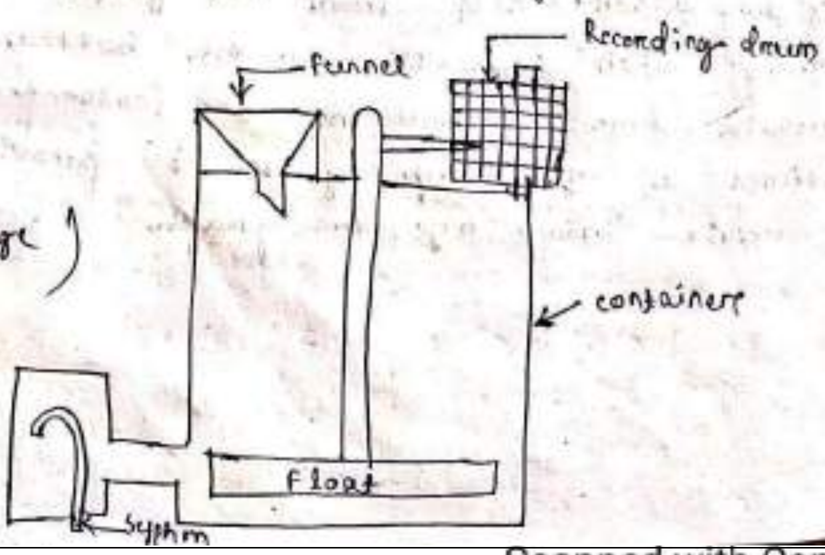
(C) Float



(Tipping Bucket raingauge)

Float type raingauge :—

In this type of raingauge, a funnel is provided at one end of a rectangular container and a rotating recording drum is provided at the other end. The rain water enters the container through the funnel. A float is provided within the container which rises up a rain water gets collected there. The float consist of a rod which contains a pen arm for recording the amount of rainfall on the graph paper wrapped on the recording drum. It consists of a syphon which starts functioning when the float rises to some definite height and the container goes on emptying gradually.



(Float type raingauge)

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Average depth of precipitation :—

One raingauge station cannot represent a large basin. So, a basin is always composed of many raingauge stations which are evenly distributed throughout the whole basin. Again, the amount of rainfall may not be equal in all raingauge stations. Since the average rainfall of the basin is required for estimating the run-off from the basin it is customary to apply any suitable method to determine the average depth of precipitation. The following three methods are generally adopted to calculate the average depth of precipitation.

1. Arithmetic Mean Method :—

This method is very simple. In this method the rainfall values obtained from all the raingauge stations are added and devided by the number of stations to get the average value. Suppose, N is the number of stations and $R_1, R_2, R_3, \ldots$ etc are the rainfall values obtained from the stations. Then, average depth of precipitation =

$$\frac{R_1 + R_2 + R_3 + \cdots}{N}$$

2. Thiessen Polygon Method :—

This method is highly suitable for large areas. It is based on the assumption that each raingauge stations has its own domain within the basin area. That domain may be defined by geometrical construction as follows.

(i) Suppose A, B, C, D, E & F are the raingauge stations. All the stations are joined by dotted lines to form a number of triangles.

(ii) The ⊥lar bisectors are drawn to each sides of the triangles. Thus a closed polygon abcde is formed which indicates the domain of the raingauge station F.

(iii) Similarly, all the other raingauge stations within

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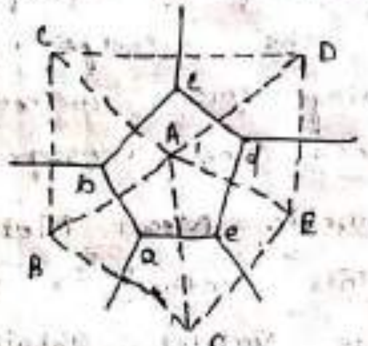
the basin are joined to form triangles. The ⊥lar bisects are drawn as above. Thus, a number of polygons are formed.

(iv) Geometrically, it can be proved that each polygon represents the domains of each raingauge station.

(v) The area of each polygon is measured by graph paper or by planimeter.

(vi) The result is then tabulated as follows.



Station (1)	Rainfall in cm (2)	Area of Polygon in sq. km (3)	Product of rainfall and area (4) = (2)×(3)
A	10.5	120	1260.0
B	12.0	95	1140.0
C	9.5	105	997.5
D	8.0	125	1000.0
E	11.5	98	1127.0
F	7.5	100	750.0
G	6.0	100	630.0
		Σ 748.0	Σ 6904.5

Average depth of precipitation $= \frac{6904.5}{748.0} = 9.2$ cm

(3) Iso-hyetal Method :—

A iso-hyetal line represents a line joining the points of equal depth of precipitation. So, it is just like a contour line. In this method all the raingauge stations are located within the map of the required basin. Then depth of precipitation of all stations are noted at the respective station point.

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Now, the iso-hyetal lines are drawn at 1 cm intervals by the method of interpolation. The area enclosed between the two successive Iso-hyet lines is found out by graph paper or by planimeter. The result is tabulated as shown to get the average depth of precipitation.

Iso-hyetal interval	Average depth	Area betn two successive Iso-hyet lines	Average depth × area
(1)	(2)	(3)	(4) = (2)×(3)
10 – 9	9.5	a	9.5 × a
9 – 8	8.5	b	8.5 × b
8 – 7	7.5	c	7.5 × c
7 – 6	6.5	d	6.5 × d
		ΣA (say)	ΣB (say)

average depth of precipitation =

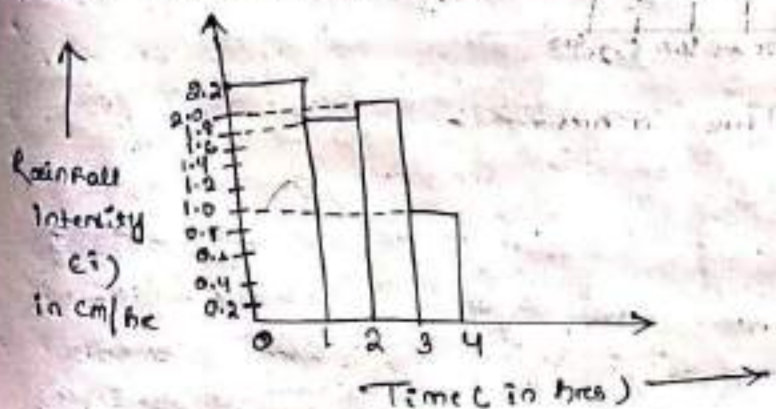
$$\frac{\Sigma B}{\Sigma A} = x \text{ cm (say)}$$

Rainfall Hyetograph :—

It is the graphical representation of rainfall intensity in y-axis (ordinate) verses time in hours in abscissa axis (x-axis).

$$\left(\text{intensity} = \frac{\text{Rainfall}}{\text{Time}} \right)$$

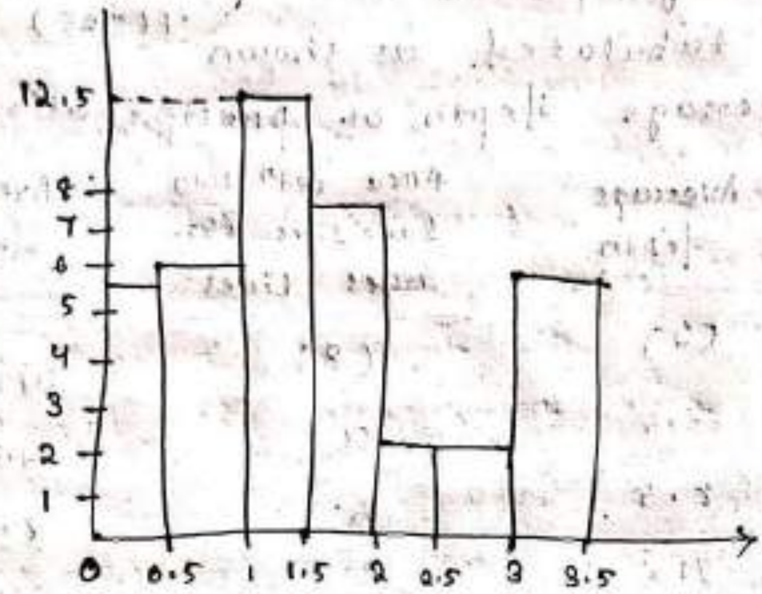
For example :—



Total Rainfall = 2.2×1 + 1.8×1 + 2×1 + 1×1

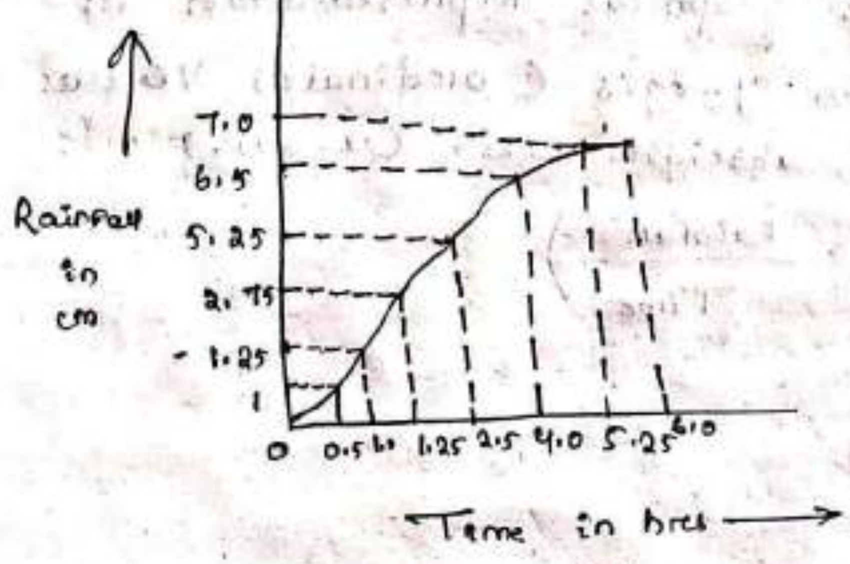
= 7 cm Rainfall

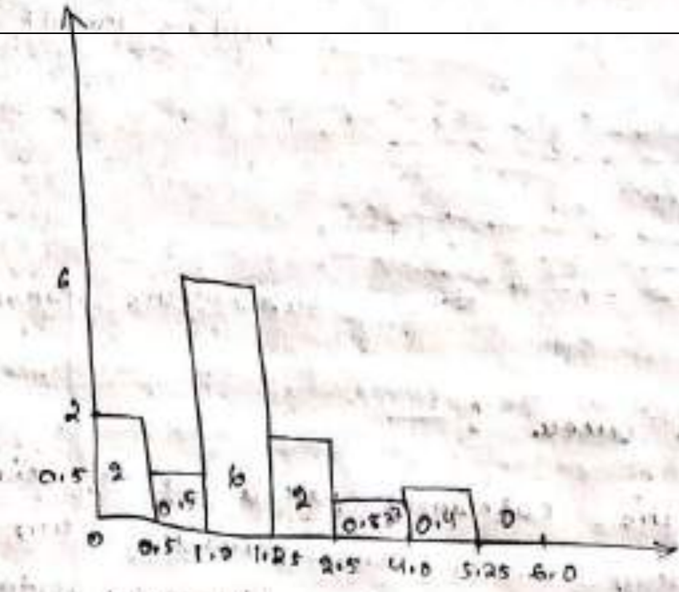
Q.1 The following are the rates of rainfall for successive 30 mins period for a storm direction of 210 mins. (5.5, 6.0, 12.5, 8.0, 3.25, 3.25, 6.5 cm/hr) Find the total rainfall.



$$\text{Total rainfall} = 5.5 \times 0.5 + 6.0 \times 0.5 + 12.5 \times 0.5 + 8.0 \times 0.5 + 3.25 \times 1 + 6.5 \times 0.5$$
$$= 22.5 \text{ cm/hr}$$

Q.2 Draw the rainfall hyetograph from the rainfall mass curve given below.





$$i_1 = \frac{1}{0.5} = 2 \text{ cm/hr}$$

$$i_2 = \frac{0.25}{0.5} = 0.5 \text{ cm/hr}$$

$$i_3 = \frac{1.5}{0.25} = 6 \text{ cm/hr}$$

$$i_4 = \frac{2.5}{1.25} = 2 \text{ cm/hr}$$

$$i_5 = \frac{1.25}{1.5} = 0.833 \text{ cm/hr}$$

$$i_6 = \frac{0.5}{1.25} = 0.4 \text{ cm/hr}$$

$$i_7 = \frac{0}{0.75} = 0 \text{ cm/hr}$$

$$\text{Total rainfall} = 2 \times 0.5 + 0.5 \times 0.5 + 6 \times 0.25 + 2 \times 1.25 + 0.8333 \times 1.5 + 0.4 \times 1.25 + 0 \times 0.75$$
$$= 6.9995 = 7 \text{ cm}$$

Run off :—

Whenever it rains part of the rainwater goes deep below the ground and finally reaches to ground water, some part loses due to natural process like evaporation, transpiration, interception and remaining water after considering the losses flows over and under the ground surface. This water is known as runoff.

Runoff can be of 2 form

(1) Surface runoff

(2) Sub surface runoff

Catchment area :—

The catchment area of a river means the area from where the surface run off flows to the river through the streams, springs, tributaries etc. catchment area is also known as watershed.

Estimation of flood discharge :—

Flood discharge can be estimated by

(a) Dicken's Formula :—

$$Q = C \times A^{3/4}$$

where Q = Discharge in cumec (m^3/sec)

A = catchment area in sq km

C = A constant depending upon the factors affecting the flood.

* Dicken's formula is used for catchments in North India and Central India.

(b) Ryve's Formula :—

$$Q = C \times A^{2/3}$$

Where Q = flood discharge in cumec

A = Catchment area in sq km

C = A constant depending upon the factors affecting the flood.

Q. Find the flood discharge of an area using Dicken's formula and Ryve's formula. The constant C in Ryve's formula and Dicken's formula may be taken as 6.8, 11.5 respectively. The area of catchment may be taken as

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1000 ~~100000~~ hectre.

<u>Ans</u> Given data

$$A = 100000 \text{ hec}$$

$$1 \text{ hectre} = 10000 m^2$$

$$100000 = 100000 \times 10000 m^2$$

$$= 10^9 m^2$$

$$1 km^2 = 1 km \times 1 km$$

$$= 1000 m \times 1000 m$$

$$1 km^2 = 10^6 m^2$$

$$\frac{1}{10^6} km^2 = 1 m^2$$

$$10^3 km^2 = 10^9 m^2$$

$$C_D = 11.5$$

$$C_R = 6.8$$

According to Dicken's formula

$$Q = C \cdot A^{3/4}$$

$$= 11.5 \times (10^3)^{3/4}$$

$$= 2045.02 \text{ cumec}$$

According to Ryve's formula

$$Q = C \cdot A^{2/3}$$

$$= 6.8 \times (10^3)^{2/3}$$

$$680 \text{ cumec}$$

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Cross drainage works :—

Necessity of cross drainage works :

In an irrigation project canals may have to cross natural drainages like rivers, streams etc. The crossing of the canals with such obstacles can't be avoided. So suitable structure must be constructed at the crossing point for the easy flow of water of the canal and drainage in their respective direction. These structures are known as cross drainage works.

Necessity of cross drainage works :—

The following factors justify the necessity of cross drainage work :

(i) At the crossing point the water of the canal and drainage will get intermixed. For smooth running of the canal and drainage water CD work is required.

(ii) The sight condition of the crossing point may be such that without any suitable structure the water of the canal and drainage can be diverted to their natural direction. So cross drainage works must be provided to maintain their natural direction of flow.

Types of cross-drainage works :—

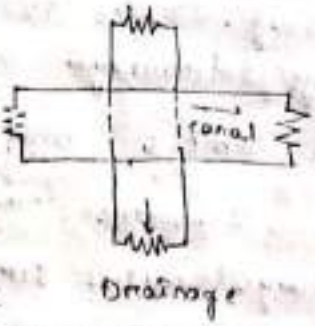
According to the relative bed levels, maximum water levels and relative discharge of the canals and drainages the cross drainage works may be of the following types.

Type-1 Irrigation canal passes over the drainage :—

This condition involves the construction of following :

(a) Aqueduct :—

The hydraulic structure in which the irrigation canal is taken over the drainage (such, river, stream, etc). is known as aqueduct. This structure is suitable when bed level of canal is above the highest flood level of drainage. In this case, the drainage water passes clearly below the canal.



(b) Siphon Aqueduct :—

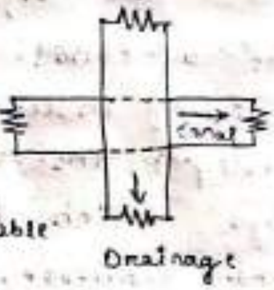
In a hydraulic structure where the canal is taken over the drainage, but the drainage water cannot passes clearly below the canal. It flows under siphonic action. so, it is known as siphon aqueduct. This structure is suitable when the level of canal is below the highest flood level of the drainage.

Type - II Drainage passes over the irrigation canal :—

This condition involves the construction of the following :

(a) Super passage :—

The hydraulic structure in which the drainage is taken over the irrigation canal is known as super passage. The structure is suitable when the bed level of ~~the canal~~ drainage is above the full supply level of the canal. The water of the canal passes clearly below the drainage.



(b) Siphon Super passage :—

The hydraulic structure in which the drainage is taken over the irrigation canal, but the canal water passes below the drainage under siphonic action is known as siphon super passage. This structure is suitable when the bed level of drainage is below the full supply level of the canal.

Type - III Drainage and canal intersection each other at the same level :—

This condition involves the construction of the following :

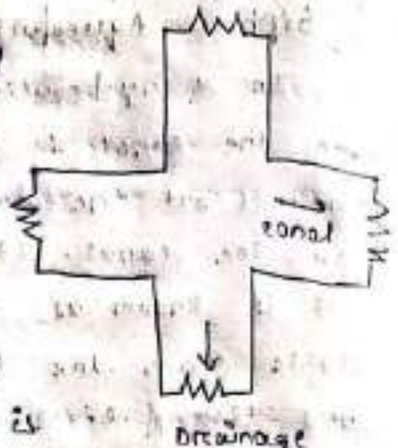
(a) Level crossing :—

When the bed of the drainage and canal are practically at the same level, then a hydraulic

Structure is constructed which is known as crossing. This is suitable for the crossing of large drainage with main canal.

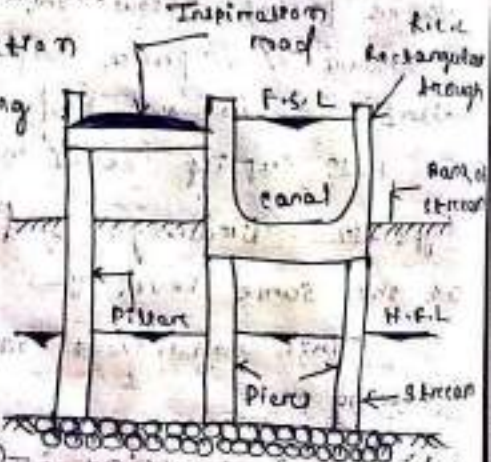
(b) Inlet and outlet :—

In the crossing of small drainage with small channel no hydraulic structure is constructed. simple openings are provided for the flow of water in their respective directions. This arrangement is known as inlet and outlet.



Aqueduct :—

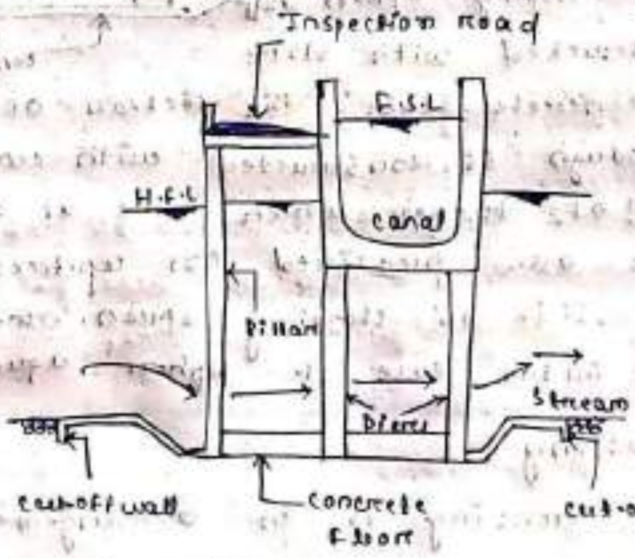
The aqueduct is just like a bridge where a canal is taken over the deck supported by piers instead of a road or railway. Generally, the canal is in the shape of a rectangular trough which is constructed with reinforced cement concrete. Sometimes, the trough may be of trapezoidal section. An inspection road is provided along the side of the trough. The bed and banks of the drainage below the trough is protected by boulder pitching with cement grouting. The section of the trough is designed according to the full supply discharge of the canal. A free board of about 0.50m should be provided. The height and section of piers are designed according to the highest flood level and velocity of flow of the drainage. The piers may be of brick masonary, stone masonary or reinforced cement concrete. Here, deep foundation (like well foundation) is not necessary for the piers. The concrete foundation may be done by provided



the depth of foundation according to the availability of hard soil.

Siphon Aqueduct :-

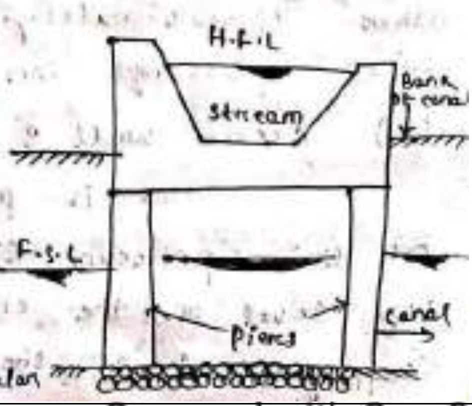
The siphon aqueduct, the bed of the drainage is depressed below the bottom level of the canal trough by providing sloping apron on both sides of the crossing. The slopping apron may be constructed by stone pitching or cement concrete. The section of the drainage below the canal trough is constructed with cement concrete in the form of tunnel. This tunnel acts as a siphon. Cut off walls are provided on both sides of the apron to prevent scouring. Boulder pitching should be provided on the upstream and downstream of the cut off walls. The other components like canal trough, piers, inspection road, etc. should be designed according to the methods adopted in case of aqueduct.



(Siphon acqueduct)

Super passage :-

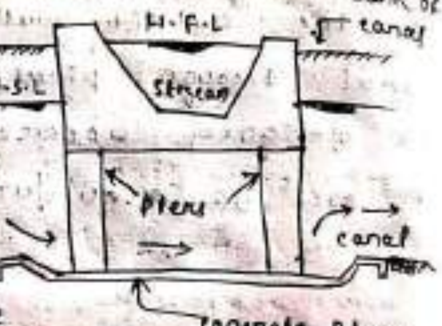
The supper passage is just opposite of the aqueduct. In this case, the bed level of the drainage is above the fully supply level of the canal. The drainage is taken through a rectangular



or trapezoidal trough of channel which is constructed on the deck supported by piers. The section of the drainage through depends on the high flood discharge. A free board of about 1.5m should be provided for safety. The trough should be constructed of reinforced cement concrete. The bed and banks of the canal below the drainage through should be protected by boulder pitching or lining with concrete slabs. The foundation of the piers will be same as in the case of acqueduct.

Siphon supper passage :—

It is just opposite siphon aqueduct. In this case, the canal passes below the drainage trough. The section of the trough is designed according to high flood discharge. The bed of the canal is depressed below the bottom level of the drainage trough by providing sloping apron on both sides of the crossing. The sloping apron may be constructed with stone pitching or concrete slabs.



The section of the canal below the trough is constructed with cement concrete in the form of tunnel which acts as siphon. cut-off walls are provided on upstream and down stream side of slopping apron. other components are same as in the case of siphon aqueduct.

Level crossing :—

Level crossing is an arrangement provided to regulate the flow of water through the drainage and the canal when they cross each other approximately at the same bed level. The level crossing consist of the following components.

(i) Crest wall :—

It is provided across the drainage just at the upstream side of the ~~co~~ crossing point. The top level of the crest wall is kept at the full supply level of the canal.

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(2) Drainage Regulator :—

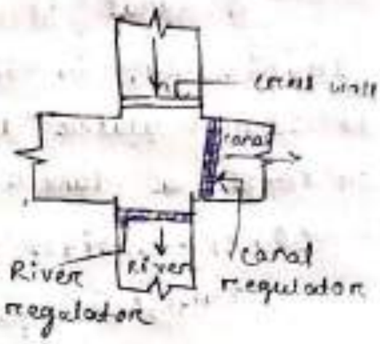
It is provided across the drainage just at the down-stream side of the crossing point. The regulator consists of adjustable shutters at different tiers.

(3) Canal regulator :—

It is provided across the canal just at the downstream side of the crossing point. This regulator also consists of adjustable shutters at different tiers.

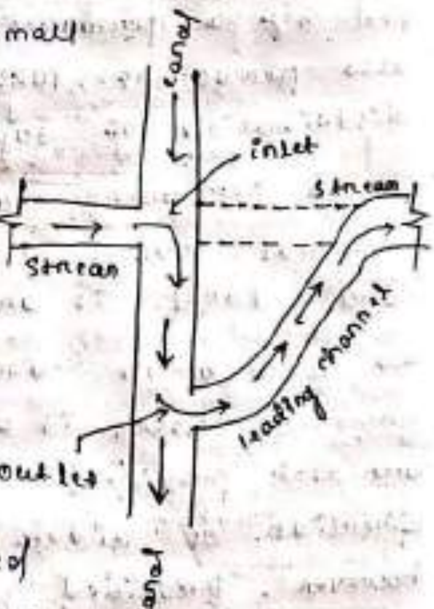
Operation :—

In dry season when the discharge of the drainage is very low the drainge regulator is kept closed and the canal water is allowed to flow as usual. In rainy season, when the discharge of the drainage is very high, the drainage regulator is kept completely open and the canal regulator is adjusted according to the requirement. The level crossing is recommended for the crossing of main canal with large drainage.



Inlet and outlet :—

In case of crossing of a small irrigation channel with a small drainage. no hydraulic structure is constructed. Because, the discharges of the drainage and the channel are practically low and these can be easily tackled by easy system like inlet and outlet arrangement. In this system an inlet is provided in the channel bank simply by open cut and the drainage water is allowed to join the channel. Then at a suitable point on the down stream side of the channel an outlet is provided by open cut



and the water from the irrigation channel is allowed to flow through a leading channel toward the original course of the drainage are protected by stone pitching. The bed and banks of the irrigation channel between inlet and outlet point should also be protected by stone pitching.

Flow Irrigation :—

Canals :—

A canal is an artificial channel, generally trapizoidal in shape constructed on the ground. to carry water to the fields either from the river or from a tank or reservoir.

Classification of canals :—

Canals can be classified in following ways

(a) classification based on the nature of source of supply :

(1) Permanent canal

(2) Inundation canal

A canal is said to be permanent when it is fed by a permanent source of supply. It has also permanent masonry words for regulation and distribution of supplies.

A permanent canal is also sometimes known as perennial canal when the sources from which canal takes is an ice fed perennial river.

→ Inundation canals usually draw their rivers whenever there is a high stage in the river. They are not provided with any head works for diversion of river water to the canal. they are however, provided with a canal head regulator.

(b) Classification based on financial out put :

(1) Productive canal

(2) Protective canal

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→ productive canals are those which yield a net revenue to the nation after full development of irrigation in the area.
→ protective canal is a sort of relief work constructed with the idea of protecting a particular area from famine.

(c) Classification based on the function of the canal:
(1) Irrigation canal
(2) Carrier canal
(3) Feeder canal
(4) power canal

→ A irrigation canal carries water to the agricultural fields.
→ A carrier canal besides doing irrigation, carries water for another canal.
→ A feeder canal is constructed with the idea of feeding two or more canals.

(d) Classification based on boundary surface of the canal:
(1) Alluvial canal :—
→ An alluvial canal is the one which is excavated in alluvial soils, such as silt.
(2) Non - alluvial canals :—
A non - alluvial canal is the one which is excavated in non - alluvial soils, such as loam, clay, hard soil (murram)
(3) Rigid boundary canals :—
Rigid boundary canals are those which have rigid sides and rigid base, such as lined canals.

(e) Classification based on the discharge and its relative importance in a given network of canals:
(1) Main canal :—
main canal generally carries water directly from the river or reservoir. Such a canal

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carries heavy supplies and is not used for direct irrigation except in exceptional circumstances. Main canals act as water carrier carriers to feed supplies to branch canals and major distributaries.

(2) Branch canal :—

Branch canals are the branches of the main canal in either direction taking of at regular intervals. In general, branch canals also do not carry out any direct irrigation, but at times direct outlets may be provided. Branch canals are usually feeder channels for major and minor distributaries. They usually carry a discharge of over 5 cumecs.

(3) Major distributary :—

Major distributaries usually called Rajbha, take off from a branch canal. They may also sometimes take off from the main canal, but their discharge is generally lesser than branch canal. They are real irrigation channels in the sence that they supply water for irrigation to the field through outlets provided along them.

→ Their discharge varies from 1/4 to 5 cumecs.

(4) Minor distributary :—

Minor distributaries are minor takes off from branch canals or from distributaries. Their discharge is usually less than 1/4 cumecs. They supply water to the water courses through outlets provided along them.

(5) Water course :—

A water course or field channel is a small channal which ultimately feeds the water to irrigation fields. Depending upon the size and extent of the irrigation scheme, a field

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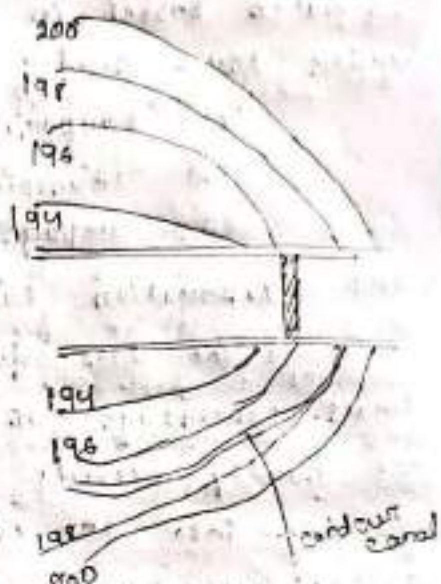
channel may take off from a distributary or minors. Sometimes, it may even take off from the branch channel, for the field situated very near the branch canal.

(c) Classification based on canal alignment :—

According to the alignment a canal may be classified such follow.

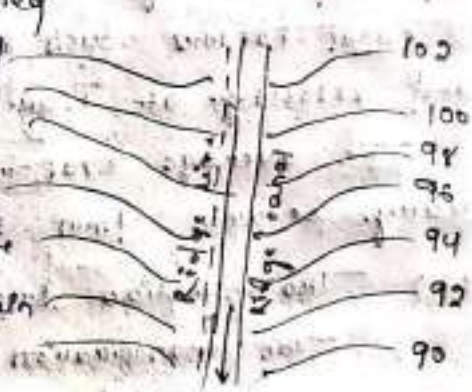
(1) contour canal :—

The canal which is aligned approximately parallel to the contour lines is known as contour canal. This canal can irrigate the areas on one side only. This canal may cross natural drainage and hence cross drainage works are necessary.



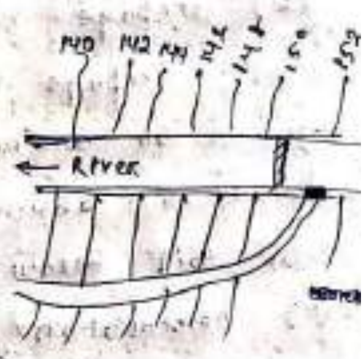
(2) Ridge canal or watershed canal :—

The canal which is aligned along the ridge line (watershed line) is known as ridge canal or watershed canal. The advantage of this type of canal is that it can irrigate the areas on both sides. Again there is no possibility of crossing any natural drainage and hence no cross-drainage work is necessary.



(3) Side - slope canal :—

The canal which is aligned approximately at right angle to the contour line is known as side slope canal. It can irrigate the areas on one side only. Again, it does not cross any natural drainage and hence are the cross drainage work are not necessary.



Losses in canals :—

When water continuously flows through a canal losses take place due to seepage, deep percolation and evaporation. These losses are sometimes known as transmission losses. These losses should be properly accounted for, otherwise lesser quantity water will be available for cultivation at the tail end.

→ Water losses in canals can be broadly classified under three head :

(1) Evaporation losses
(2) Transpiration losses
(3) Seepage losses

(1) Evaporation losses :—

The loss due to evaporation is generally small percentage of the total loss in unlined canal. It hardly exceeds 1 to 2 percent of the total water entering into the canal. The evaporation depend on
(i) climatic factor such as temperature, humidity and wind velocity.
(ii) canal factors such as surface, water depth and velocity of flow.

The average evaporation loss per day may be vary between 4mm to 10mm.

(2) Transpiration losses :—

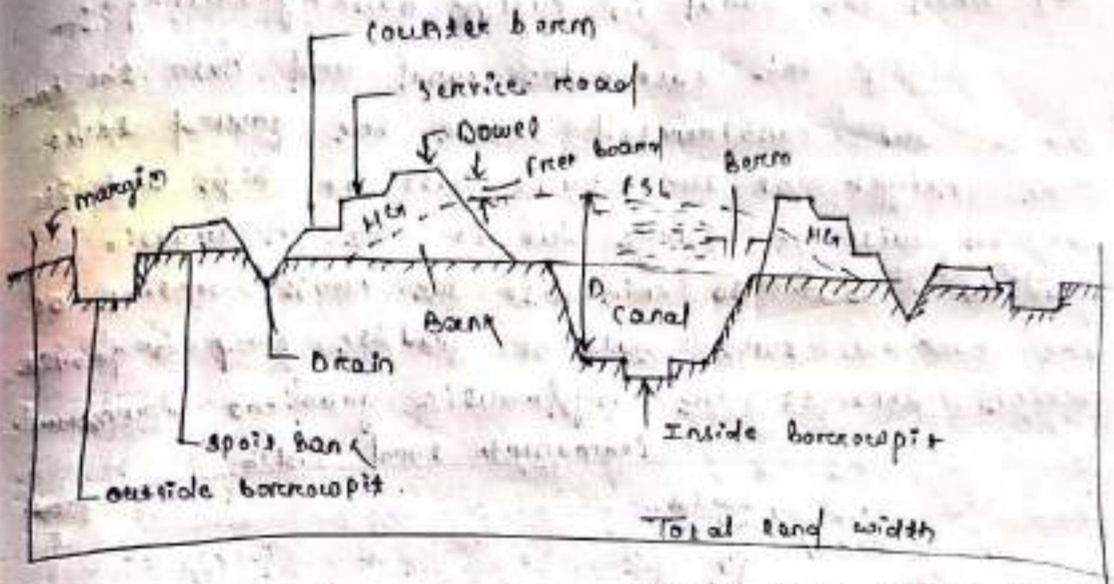
The transpiration loss takes place through lot of vegetation and weed growth along the bank of canal. However, this form a extremely small part of total loss.

(3) Seepage losses :—

Seepage losses constitute major portion of loss in an unlined canal. The seepage losses are due to (i) absorption of water in the upper layer of soil below the canal bed.
(ii) percolation of water into the water table, thus raising the water table.

If however water table is much lower, seepage losses are only due to absorption, percolation losses are always much more than the absorption losses.

Different components of irrigation canal and their Function :—



FSL = Full supply level
D = Full supply depth

Canal Bank :—

The canal bank is necessary to retain water in the canal to the full supply level. But the section of the canal bank is different for different site condition.

(a) When the canal fully in cutting :—

In this case the banks are constructed on both sides of the canal to provide only a inspection road. Here, the ~~hydraulic~~ hydraulic gradient has no function so the height of the bank will be low and the top width will be minimum just to provide the road way. The side slope will be 1.5 : 1 or 2 : 1 according to the nature of the soil.

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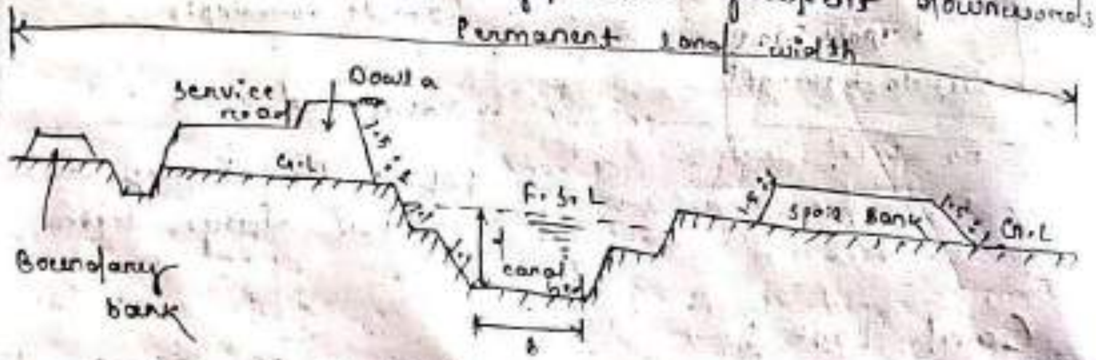
(b) when the canal in partial cutting and banking (filling) :—

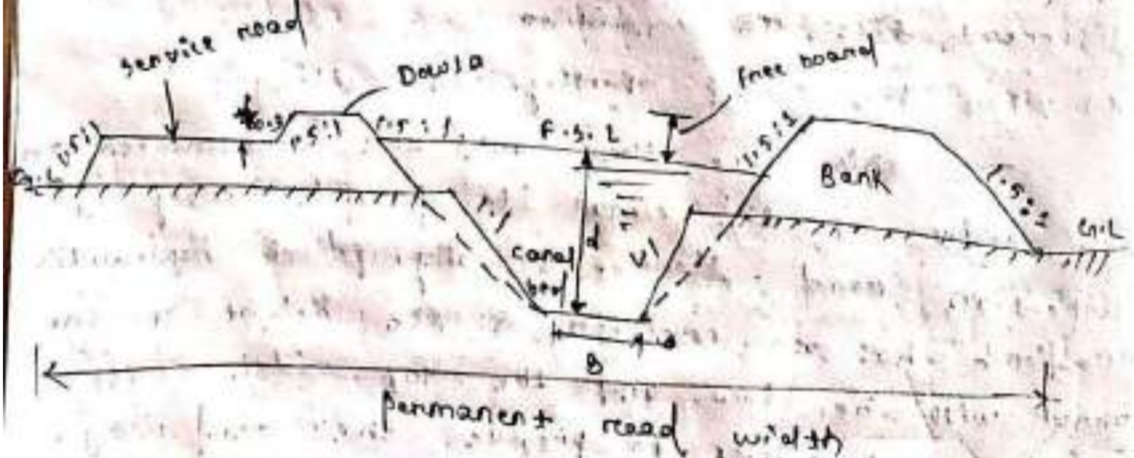
In this case the banks are constructed on side of the canal to retain water. The height of the banks depends on the fully supply level of the canal. Again, the section of the canal depends on the hydraulic gradient. The top width and the side slope of the bank should be such that hydraulic gradient should have a minimum ~~cover~~ cover of 0.5m.

(c) when the canal in full ~~of~~ banking (filling) :—

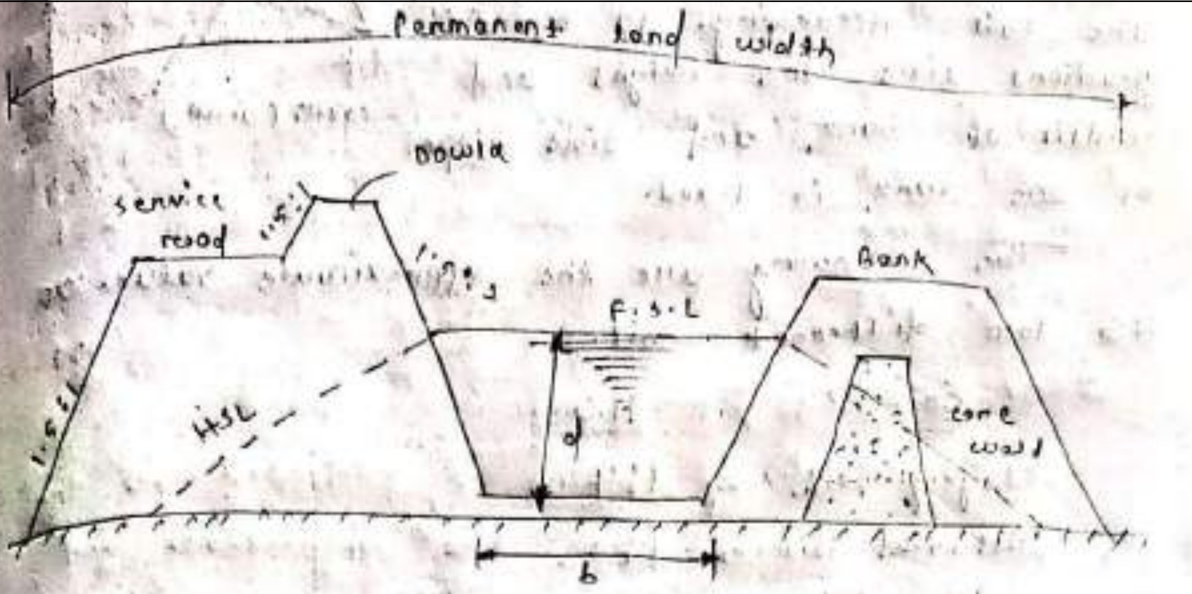
In this case, the canal and both the canal banks are constructed above the ground level. The height of the bank will be high and its section will be large due to the hydraulic gradient. But to minimise the cross section of the bank a core wall of puddle clay is provided which deflects the hydraulic gradient downwards.



((a) canal section in full cutting)



((b) canal section partialy cutting and filling)



Berm :—

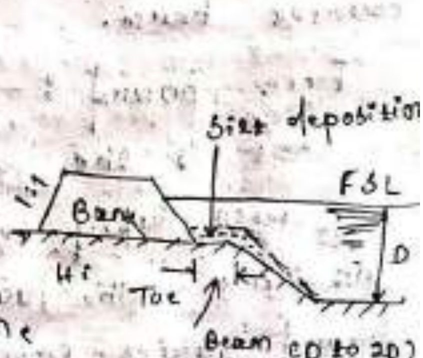
The distance between the toe of the bank and the top edge of cutting is termed as berm. The berm is provided for the following reasons.

(1) To protect the bank from erosion.
(2) To provide a space for widening the canal section in future if necessary.
(3) To protect the bank from sliding down towards the canal section.
(4) The silt deposition on the berm makes an impervious lining.
(5) If necessary borrowpit can be excavated on the berm.

The width of the berm varies from D to 2D where D is the full supply depth of the canal.

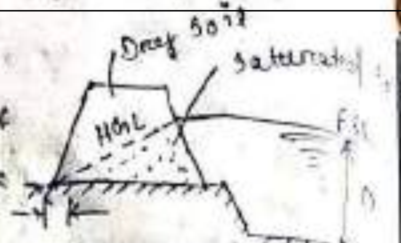
Hydraulic Gradient :—

When the water is termed by the canal bank, the seepage occurs through the body of the bank. Due to the resistance of the soil, the saturation line forms a sloping line which may pass through country side of the bank. This sloping line is known as the hydraulic gradient or



Saturation gradient.

The hydraulic gradient depends on the permeability of the soil. According to hydraulic gradient line the height and width of bank and side slope of ~~the~~ bank is fixed.

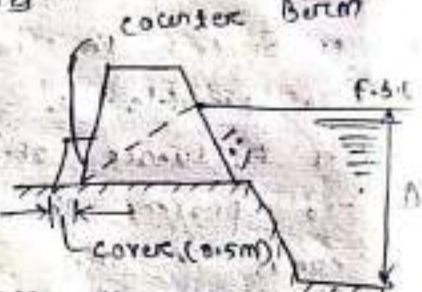


The following are the approximate value of H.G for different soil.

Soil	H.G
Clayey soil	1:4
Alluvial soil	1:5
Sandy soil	1:6

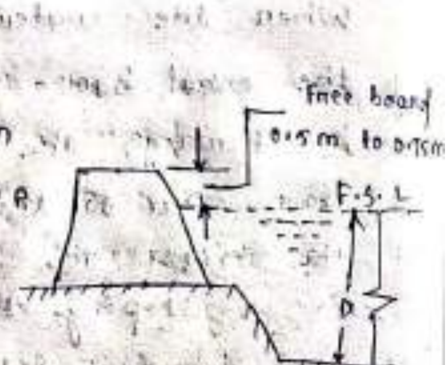
Counter Berm :—

When the water is retained by a canal the hydraulic gradient line passes through the body of the bank. For stability of the bank, this gradient should not intersect the outer side at the bank. It should pass through the base and a minimum cover of 0.5m should always be maintained. Sometimes, it may occur that the hydraulic gradient line intersect the outer side of the bank, In that case, a ~~__~~ projection is provided on the bank to obtain minimum cover. This projection is known as counter berm.



Free Board :—

It is the distance between the full supply level and top of the bank. The amount of free board varies from 0.6m to 0.75m.



It is provided for the following (Free board) reasons.

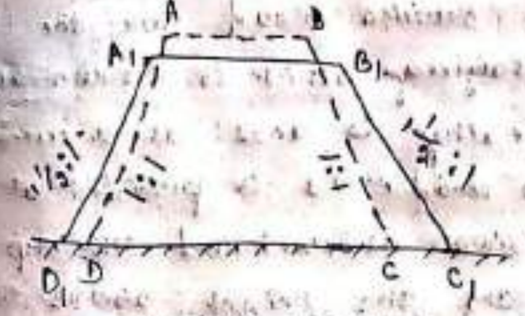
(a) To keep a sufficient margin so that the canal water does not overtop the bank, in case of heavy rainfall or fluctuation in water supply.
(b) To keep the saturation gradient much below the top of the bank.

Side Slope :—

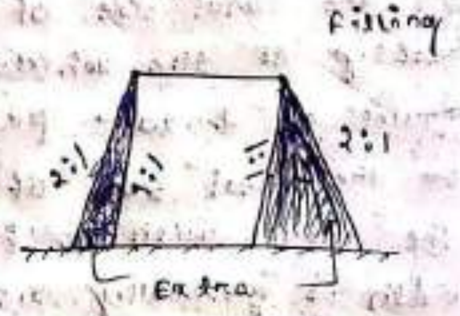
The side slopes of the canal bank and canal section depend on the angle of repose of the soil existing on the site. So, to determine the side slopes of different sections, the soil samples should be collected from the site, and should be tested in the soil testing laboratory. The necessity of such test is that if the permissible slope (to maintain angle of repose) is not provided in an embankment or cutting, then the soil in that place will go on sliding gradually until the angle of repose for that particular soil is attained.

For instance, suppose an embankment was constructed with side slope 1:1 but according to the nature of the soil, the side slope should be 1½:1. Then the initial shape ABCD will automatically take the final shape A_1, B_1, C_1, D_1 after slide in the due course.

Again, an opposite incident may occur, suppose an embankment was constructed with side slope 2:1, but latter it was found that the side slope of 1:1 was sufficient to maintain the angle of repose for that soil. In this case, an unnecessary earthwork was done.



Sliding of bank



Extra earthwork

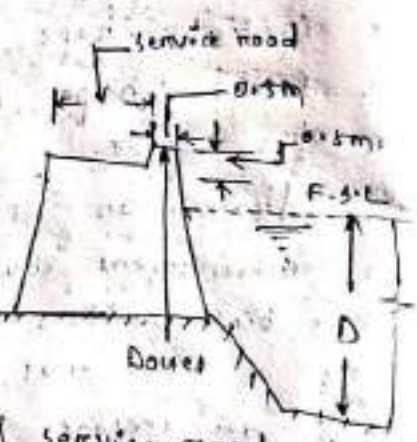
The permissible side slopes for some soil are given in the following table :

Type of soil	Side slope in cutting	Side slope banking
clayey soil	1:1	1½ : 1
Alluvial soil	1:1	2:1
sandy loam	1½:1	2:1
Sandy soil	2:1	3:1

Service Road :—

The roadway which is provided on the top of the canal bank for inspection and maintenance works is known as service road or inspection road. For main canal, the service roads are provided on both bath banks. But for branch canals, the road is provided on one bank only. The width of the service roads for main canal varies from 4 to 6m. The width of the road for the branch canal varies from 3 to 4m.

The initial purpose of the service road is to conduct the inspection and maintenance works. But finally these road serve the purpose of communication between the different villages and for transporting agricultural goods. Therefore it becomes necessary to construct metalled (service road and dowel) road to serve these purposes.

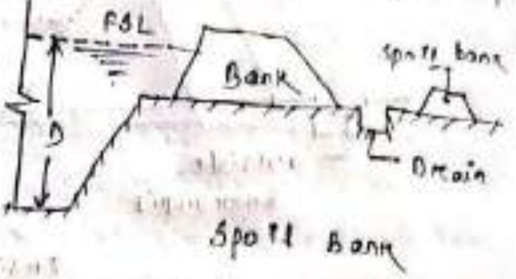


Dowel or Dowla :—

The protective small embankment which is provided on the canal side of the service road for the safety of the vehicle plying on it is known as dowel or dowla. practically it acts as a curb on the canal side of the road. It is provided above the F.S.L. with a provision of freeboard. The top width is generally 0.5m and the height above the road level is about 0.5 m. The side slope is similar to the side slope of the bank.

Spoil Bank :—

When the canal is constructed in full cutting, excavated earth may not be completely required for forming the bank. In such a case, the earth is deposited in the form of small banks which are known as spoil banks. The spoil banks are provided on one side or both sides of the canal bank depending on the quality of excess earth and the available space. The spoil banks run parallel to the main bank. But are not continuous, sufficient spaces are left between the adjacent spoil banks for proper drainage.



Spoil Bank

Borrowpit :—

When the canal is constructed in partial cutting and partial banking, the excavated earth may not be sufficient for forming the required bank. In such a case, the extra earth required for the construction of banks is taken from some pits which are known as Borrowpits. The borrowpits may be inside or outside the canal.

The inside borrowpit may be located at the centre of the canal. The width of the borrowpit should be half of the base width of canal. The maximum depth should be 1m. The excavation is done in a number of borrowpits leaving a gap between them. The gap is generally half of the length of each borrowpit. The idea behind this is that the borrowpits will act as water pockets where the silt will be deposited and ultimately the canal bed will get levelled up.

The outer borrowpit may be adjacent to the heel of the bank with a clearance of 1m between the heel and edge of borrowpit. But the outer borrowpit may create some inconvenience. So it is better to borrow earth from the barren lands is far away from the canal.

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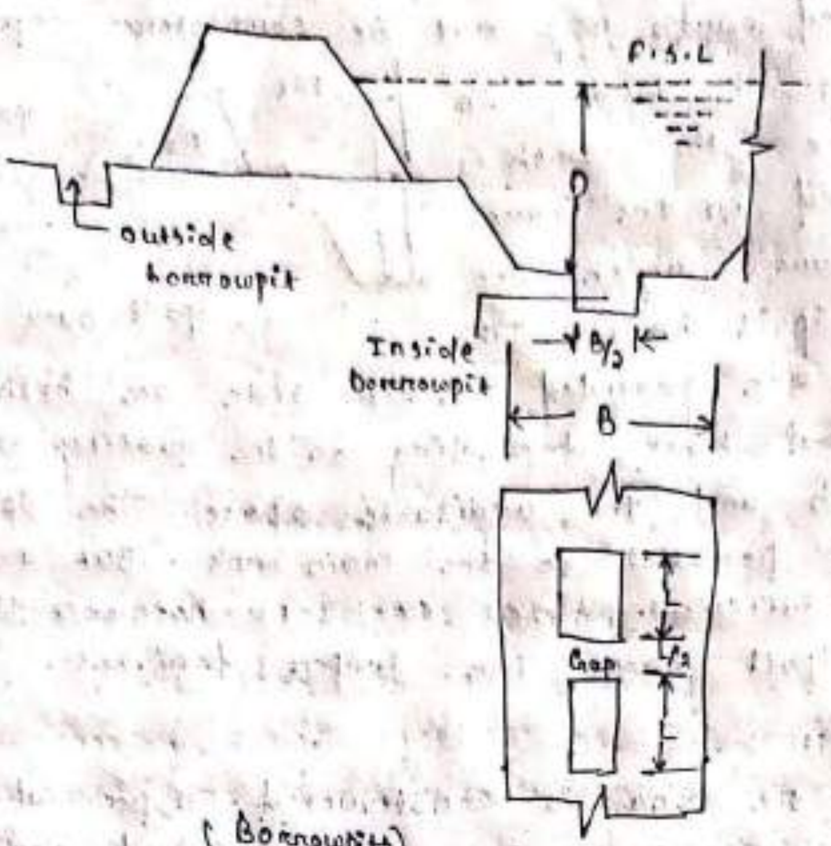

(Borrowpits)

Land Width :—

The total land width required for the construction of a canal depends on the nature of the site condition, such as fully in cutting or fully in banking or partly in cutting and partly in banking. These conditions arise according to the designed bed level of the canal and the natural ground surface. So, total land width differs with the site condition. However, to determine the total land width the following dimensions should be added.

1. Top width of the canal.
2. Twice the berm width.
3. Twice the bottom width of banks.
4. A margin of one metre from the heel of the bank on both sides.
5. width of external borrowpit if any.
6. A margin of 0.5m from the outer edge of borrowpit on both sides. If external borrowpit becomes necessary.

Types of lining :—

The following are the different types of lining which are generally recommended according to the various site conditions :

1. cement concrete lining
2. pre-cast concrete lining
3. cement mortar lining
4. Lime concrete lining
5. Brick lining
6. Boulder lining
7. shot crete lining
8. Asphalt lining
9. Bentonite and clay lining
10. Soil-cement lining

Cement concrete lining :—

This lining is recommended for the canal in full banking. The cement concrete lining (cast-in-situ) is widely accepted as the best impervious lining. It can resist the effect of scouring and erosion very efficiency. The velocity of flow may be kept above 2.5 m/sec. It can eliminate completely growth of weeds. The lining is done by the following steps.

(a) Preparation of sub-grade :—

The sub-grade is prepared by ramming the surface properly with a layer of sand. Then a slurry of cement and sand (1:3) is spread uniformly over the prepared bed.

(b) Laying of concrete :—

The cement concrete of grade M15 is spread uniformly according to the desired thickness (generally the thickness varies from 100m to 150mm). After laying the concrete is tapped gently until the slurry comes on the top. The curing is done for two weeks. As the concrete is liable to get damaged by the change of temperature, the expansion joints are provided at appropriate places. Normally no re-inforcement is required for this cement concrete but in special cases, a network of 6mm diameter rods may be provided with spacing 10cm centre to centre.

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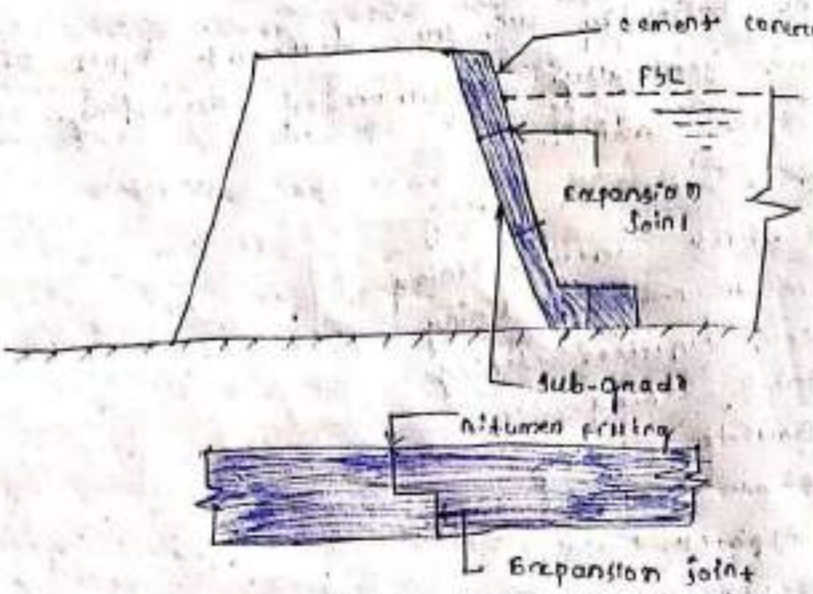
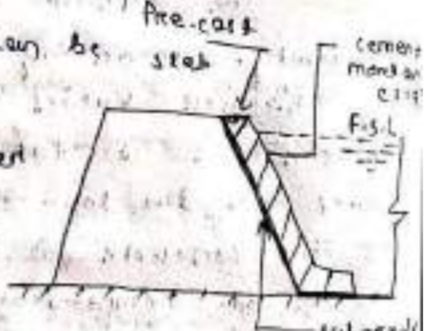


(Cement concrete lining)

Pre - cast concrete lining :-

This line is recommended for the canal full banking. It consist of pre-cast concrete slabs of size 60cm x 60cm x 5cm which are set along the canal bank and bed with cement mortar (1:6). A network of 6mm diameter rod is provided in the slab with spacing 10cm centre of centre. The proportion of the concrete is recommended as 1:2:4. Rebates are provided on all the four sides of the slab so that proper joints may be obtained when they are placed side by side. The joints are finished with cement mortar (1:3). Expansion joints are provided at a suitable interval. The slabs are set in the following sequence

(a.) The sub grade is prepared by properly ramming the soil with a layer of sand. The bed is levelled so that the slabs can be placed easily

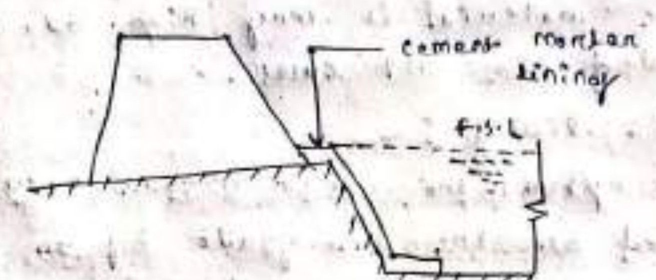


(b) The slabs are stacked as per estimate along the course of the canal. The slabs are placed with cement mortar (1:6) by setting the rebates properly. The joints are finished with cement mortar (1:3).

(c) The curing is done for a week.

Cement mortar Lining :—

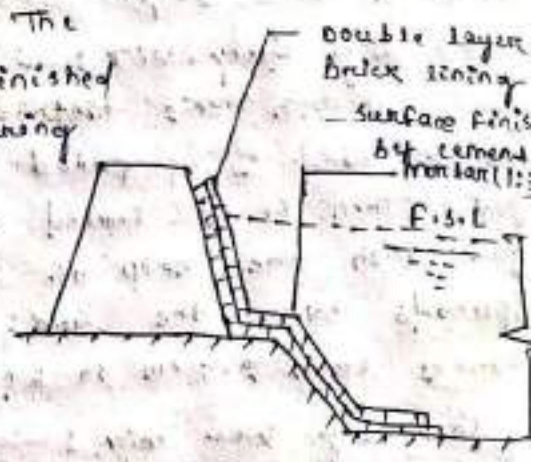
This type of lining is recommended for the canal fully in cutting where hard soil or clayey soil is available. This thickness of the cement mortar (1:4) is generally 2.5 cm. The sub-grade is prepared by ramming the soil after cutting. Then, over the compacted sub-grade, the cement mortar is laid uniformed and the surface is finished with neat cement polish. This lining is impervious, but its not durable. The curing should be done properly.



Lime concrete lining :—

The lining is prepared by the double layer brick flat soling laid with cement mortar (1:6) over the compacted sub-grade. The first class bricks should be recommended for the work. The surface of the lining is finished with cement plaster. The curing should be done perfectly.

This lining is always preferred for the following reasons:



(Brick lining)

a) This lining is economical.
b) work can be done very quickly.
c) Expansion joints are not required.
d) Repair works can be done easily.
e) Bricks can be manufactured from the excavated earth near the site. However this lining has certain disadvantages,
(a) It is not completely impervious.
(b) It has low resistance against erosion.
(c) It is not so much durable.

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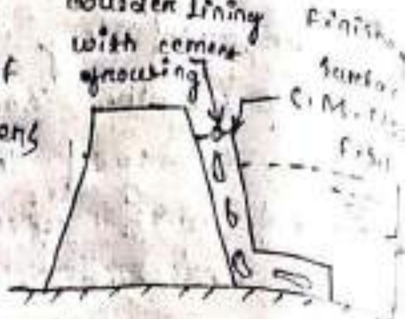
Boulder Lining :—

In hilly areas where the boulders are available in plenty, this type of lining is generally recommended. The boulders are laid in single or double layer maintaining the slope of the banks and the bed level of the canal. The joints of the boulders are grouted with cement mortar (1 : 6). The surface is finished with cement mortar (1 : 3).



Curing is necessary in this lining too. This lining is very durable and impervious. But the transportation cost of the material is very high. So, it cannot be recommended for all cases.

Shot crete linings :—

In this system, the cement mortar (1:4) is directly applied on the sub-grade by an equipment known as cement gun. The mortar is termed as shot crete and the lining is known as shot crete lining. The process is also known as guniting, as a gun is used for laying the mortar. Sometimes, this lining is known as gunited lining. The lining is done in two ways.

(a) By dry mix :—

In this method, a mixture of cement and moist sand is prepared and loaded in the cement gun. Then it is forced through the nozzle of the gun with the help of compressed air. The mortar spreads over the sub-grade to a thickness which varies from 2.5 cm to 5 cm.

(b) By wet mix :—

In this process, the mixture of cement, sand and water is prepared according to the approved consistency. The mixture is loaded in the gun and forced on the sub-grade.

This type of lining is very costly and it is not durable. It is suitable for resurfacing and old cement concrete lining.

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Asphalt lining :—

This lining is prepared by spraying (i.e. bitumen) at a very high temperature (about 150°C) on the subgrade to a thickness varies from 3 mm to 6mm. The hot asphalt when becomes cool forms a water proof membrane over the sub-grade. This membrane is covered with a layer of earth and gravel. The lining is very cheap and can control the seepage of water very effectively but it cannot control the growth of weeds.

Bentonite and clay lining :—

In this lining a mixture of bentonite and clay are mixed thoroughly to form a sticky mass. This mass is spread over the sub-grade to form an impervious membrane which is effective in controlling the seepage of water, but it cannot control the growth of weeds. This lining is generally recommended for small channels.

Soil-cement lining :—

This line is prepared with a mixture of soil and cement. The usual quantity of cement is 10% of the weight of dry soil. The soil and cement are thoroughly mixed to get an uniform texture. The mixture is laid on the sub-grade and it is made thoroughly compact. The lining is efficient to control the seepage of water, but it cannot control the growth of weeds. So, this is recommended for small channels only.

Advantages and Disadvantages of canal lining :—

Advantages :—

1. It reduces the loss of water due to seepage and hence the duty is enhanced.
2. It controls the water logging and hence the bad effects of water-logging are eliminated.
3. It provides smooth surface and hence the velocity of flow can be increased.
4. Due to the increased velocity the discharge capacity of a canal is also increased.
5. Due to the increased velocity, the evaporation loss

also be reduced.

6. It eliminates the effect of scouring in the canal bed.

7. The increased velocity eliminates the possibility of silting in the canal bed.

8. It controls the growth of weeds along the canal sides and bed.

9. It provides the stable section of the canal.

10. It reduces the requirement of land width of the canal, because smaller section of the canal can produce greater discharge.

11. It prevents the sub-soil salt to come in contact with the canal water.

12. It reduces the maintenance cost for the canal.

Disadvantages :—

1. The initial cost of the canal linings is very high. So, it makes the project very expensive with respect to the output.

2. It involves much difficulties for repairing the damaged section of lining.

3. It takes too much time to complete the project work.

4. It becomes difficult if the outlets are required to be shifted or new outlets are required to be provided, because the dismantling of the lined section is difficult.

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— : DAM : —

Introduction :—

→ An impervious / high barrier which is constructed across a river valley to form a deep storage reservoir is known as dam. It is suitable in hilly region where a deep gorge section is available for the storage reservoir. The dam is meant for serving multipurpose functions such as, (a) Irrigation
(b) Hydroelectric power generation,
(c) Flood control,
(d) Water supply,
(e) Fishery,
(f) Recreation

A. Based on materials of construction :—

1. Rigid dam :—

It is constructed with rigid materials like masonary, concrete, steel or timber. It is designated as, (a) masonary dam, (b) concrete dam, (c) Steel dam, (d) timber dam.

2. Non - rigid dam :—

It is constructed with non-rigid materials such as earth, clay, rock materials, etc. It is designated as, (a) earthen dam; (b) rock - fill dam, (c) composite dam.

B. Based on structural Behaviour :—

1. Solid gravity dam :—

It is constructed with masonarry or concrete It resists the forces acting on it by its own weight. It is approximately triangular in section.

2. Arch dam :—

It is a curved masonary or concrete dam which resists the forces acting on it by the principle of arch action.

3. Buttress dam :—

It behaves like a retaining wall. It consists of sloping deck on the upstream side which is supported by a number of buttress in the form of wall or counterforts. ... reinforced concrete

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4. Embankment dam :—

It is non-rigid dam constructed simply by earth work in trapezoidal section. Sometimes it may be of earth work with clay core or rock fill. It resists forces acting on it by its shear strength.

C. Based on functions :—

1. Storage dam :—

It is constructed to form a reservoir in which the water is stored during the period of rainy season or flood and utilised for the irrigation in the period of draught. The water is also utilised for the generation of hydro electric power, water supply, etc.

2. Detention dam :—

It is mainly constructed to detain the flood water temporarily in a reservoir and then released gradually so that the downstream area may not be damaged due to sudden flood water.

3. Diversion dam :—

It is constructed to divert the water from a perennial river to a channel for the purpose of irrigation or to a conduit for the purpose of generation of hydroelectric power.

4. Coffer dam :—

When an area in the river bed is enclosed temporarily by sheet pilings for excluding water for the sake of construction of well foundation (i.e. pier foundation) then it is known as coffer dam.

D. Based on Hydraulic Behaviour :—

1. Over flow dam :—

The dam which consists of crests or shutters of waste weirs on the top to allow the surplus water to overflow is known as overflow dam.

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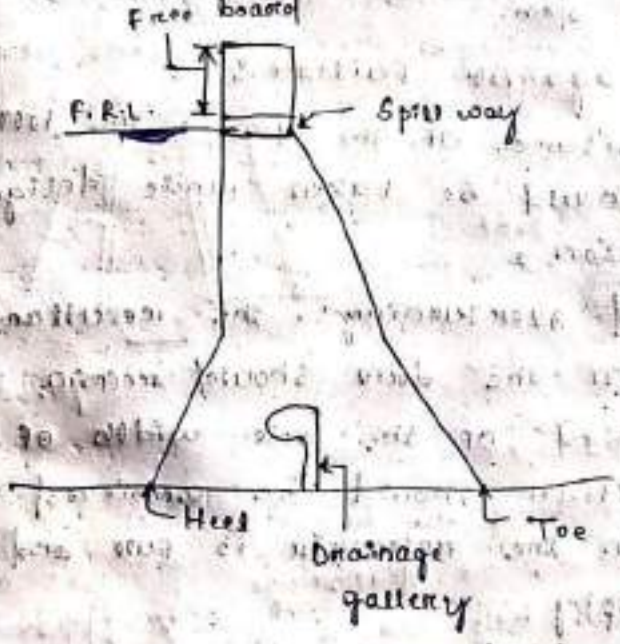
2. Non overflow dam :-

The dam in which spill ways are provided to discharge the surplus water is not allowed to flow over the crest, is known as non-overflow dam.

Solid gravity Dam :-

The solid gravity dam may be constructed with rubble masonry or concrete. The rubble masonry is done according to the shape of the dam with rich cement mortar. The upstream and downstream faces are finished with rich cement mortar. ~~The upstream and downstream faces are finished with rich cement mortar~~

Now-a-days, concrete gravity dams are preferred, because they can be easily constructed by laying concrete layer by layer with construction joints.



(Solid gravity dam)

Causes of failure of gravity dam :-

1. By over turning :-

The solid gravity dam may fail by over turning at its toe when the total horizontal forces acting on the dam are greater than the total vertical force. In such a case, the resultant force passes through a point outside the middle-third of the base of the dam.

2. By sliding :—

The total horizontal forces acting on a dam tend to slide the entire dam at its base or along any horizontal section of the dam.

3. By over stressing :—

If the permissible working compressive stress of concrete or masonry exceeds due to some adverse conditions, then the dam may fail by crushing due to overstressing of the concrete or masonry.

4. By cracking :—

The tensile stresses should not be allowed to develop on the upstream face of the dam. If due to some reasons, the tension is developed in the dam section, crack will from in the body of the dam and ultimately this will cause the failure of the dam.

Precautions against Failure :—

To avoid failure of the dam, the following precautions should be taken while designing the dam section,

1. To avoid overturning, the resultant of all forces acting on the dam should remain within the middle - third of the base width of the dam. This condition should be achieved in both the cases, when the reservoir is full and also when it is empty.

2. In this dam, the sliding should be fully resisted when the condition for no sliding exists in the dam section.

The condition for no sliding is given by

$$\tan\theta = \frac{\Sigma P}{\Sigma W}$$

and $\tan\theta < \mu$

where, ΣP, sum of horizontal forces, ΣW = sum of vertical forces, μ = coefficient of friction of the materials of dam.

3. In the dam section, the compressive stresses of concrete or masonry should not exceed the permissible working stresses to avoid failure due to crushing.

4. There should be no tension in the dam section to avoid the formation of cracks. This condition may be achieved by maintaining the middle-third rule.

5. The factor of safety should be taken 4 to 5.

Earthen dam :—

Earthen dams are constructed purely by earth work in trapezoidal section. These are most economical and suitable for weak foundation. Earthen dams are classified as follows :

Based on method of construction :—

Rolled fill Dam :—

In this method, the dam is constructed in successive layers of earth by mechanical compaction. The selected soil is transported from borrowpits and laid on the dam section, to layers of about 45 cm. The layers are thoroughly compacted by rollers of recommended weight and type.

Hydraulic fill dam :—

In this method, the dam section is constructed with the help of water. Sufficient water is poured in the borrowpit and by pugging thoroughly, slurry is formed. This slurry is transported to the dam site by pipe line and discharged near the upstream and downstream faces of the dam. The coarser material get deposited near the face and the finer material moves towards the centre and get deposited there.

Semi-hydraulic fill dam :—

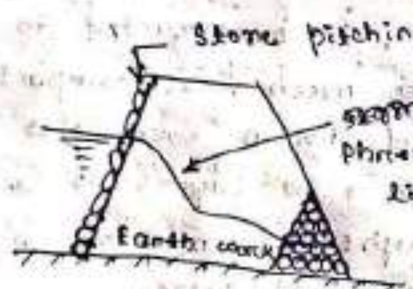
In this method the selected earth is transported from the borrowpit and dumped within the section of the dam, as done in the case of rolled fill dam. While dumping no ~~water~~ water is used.

Homogeneous types Dam :—

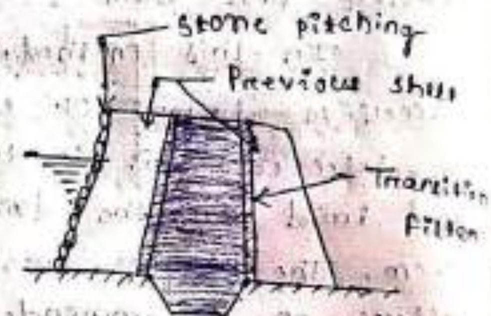
This type of dam is constructed purely with earth in trapezoidal section having the side slopes according to the angle of repose of the soil. The top width and height depends on the depth of water to be retained and the gradient of the seepage line.

Zoned type Dam :—

This type of dam consists of several materials the impervious core is made of puddle clay and the other previous shell is constructed with the mixture of earth, sand, gravel, etc. The core is trapezoidal in section and its width depends on the seepage characteristics of the soil mixture on the upstream side.



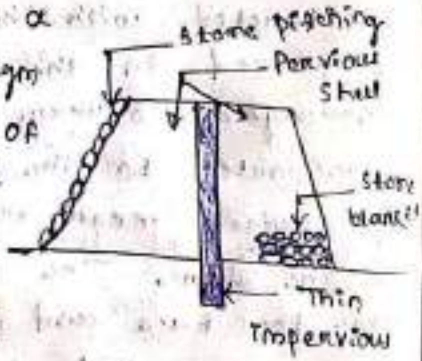
Homogeneous type dam



Zoned type dam

Diaphragm type dam :—

In this type of dam, a thin impervious core or diaphragm is provided which may consist of puddle clay or cement concrete or betuminous concrete. The upstream and downstream body of the dam is constructed with pervious shell which consists of the mixture of soil, sand, gravel, etc. The thickness of the core is generally less than 3m.



Causes of failure of earthen dam :—

(I) Hydraulic failure :—

This type of failure caused by :

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(a) Overtopping :—

If the actual flood discharge is much more than the estimated flood discharge or the free board is kept insufficient, then it results in the overtopping of the dam.

(b) Erosion :—

If the stone protection of the upstream side is insufficient, then the upstream face may be damaged by erosion due to wave action.

(2) Seepage Failure :—

This type of failure may be caused by:

(a) Piping or undermining :—

Due to the continuous seepage flow through the body of the dam and through the sub-soil below the dam, the downstream side gets eroded or washed out and a hollow pipe like groove is formed which extends gradually towards the upstream through the base of the dam.

(b) Sloughing :—

The crumbling of the toe of the dam is known as sloughing.

(3) Structural failure :—

This type of failure may be caused by

(a) Sliding of the side slopes :—

Sometimes, it is found that the side slope of the dam slides down to form some steeper slope.

(b) Damage by burrowing animals :—

Some burrowing animals like crawfish, snakes, squirrels, rats etc cause damage to the dam by digging holes through the foundation and body of the dam.

(c) Damage by earthquake :—

Due to earthquake cracks may develop on the body of the dam and the dam may eventually collapse.

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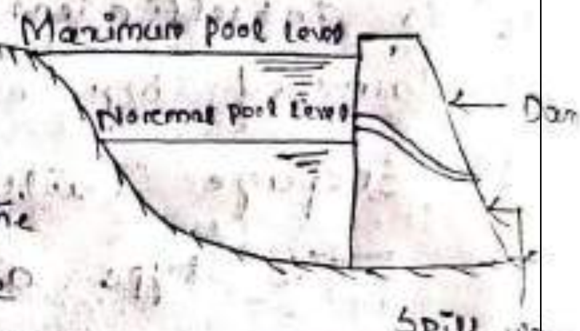
Spill ways :—

Necessity of spill ways :—

The spill ways are openings provided at the body of the dam to discharge safely the excess water or flood water level raises above the normal pool level.

The spill ways are provided on the dam for the following reasons,



(a) The height of the dam is always fixed according to the maximum reservoir capacity. The normal pool level indicates the maximum capacity of the reservoir.

(b) The top of the dam is generally utilised by making road. The surplus water is not to be allowed to over top the dam, so to stop the over over topping by the surplus water, the spill ways become extremely essential.

(c) To protect the downstream base and floor of the dam from the effect of scouring and erosion, the spill ways are provided so that the excess water flows smoothly.

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Types of spill ways
The following are the common types of spill ways.

Drop spill way
In drop spill way, the over flowing water falls freely and almost vertically on the downstream side of the hydraulic structure. This type of spill way is suitable for weirs or low dams. The crest of the spill way is provided with nose so that the water jet may not strike the downstream base of the structure. To protect the structure from the effect of scouring horizontal impervious apron should be provided on the downstream side.

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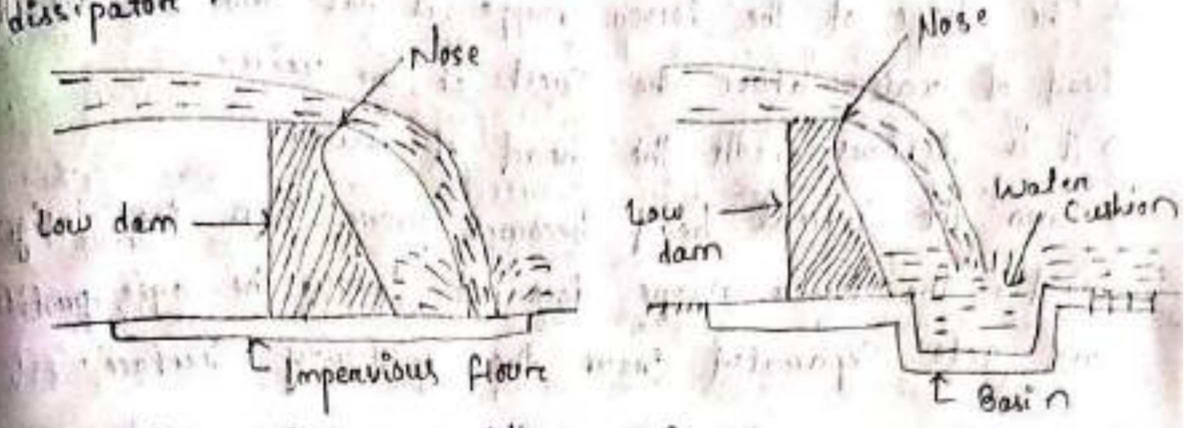
Sometimes a basin is Constructed on the downstream Side to form a Small artificial pool which is known as water Cushion. This Cushion Serves the purpose of energy dissipaton.



(a) Drop Spillway with impervious apron

(b) Drop Spillway with water Cushion

The drop spill ways is not Suitable for a high dam, because the downstream apron will be Subjected to high impact force for which massive protection works will be necessary.

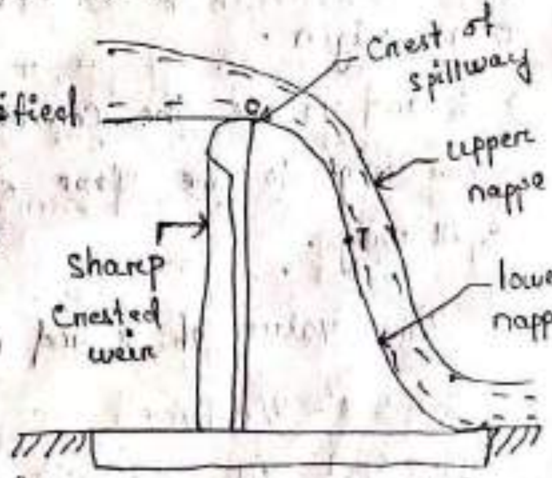
→ Again, high impact on the downstream apron may Cause vibration in the structure which may Create Cracks in the foundation.

→ Thus, the stability of the Structure will be in danger due to undermining.

Ogee Spill way :—

→ The ogee Spill way is a modified form of drop spill way.

→ Here, the down stream profile of the spill way is made to Coincide with the shape of the lower nappe of the free falling waterjet from a sharp Crested weir.



(Ogee Spillway)

→ In this Case, the shape of the lower nappe is similar to a projectile and hence downstream Surface of the ogee spill way will follow the parabolic path where 'o' is the origin of the parabola.

→ The downstream face of the spill way forms a Concave Curve from a point 'T' and meets with the downstream floor.

→ This point 'T' is known as point of tangency. Thus the spill way takes the shape of the letter 'S' (i.e. elongated form). Hence, this spill way is termed as ogee spill way.

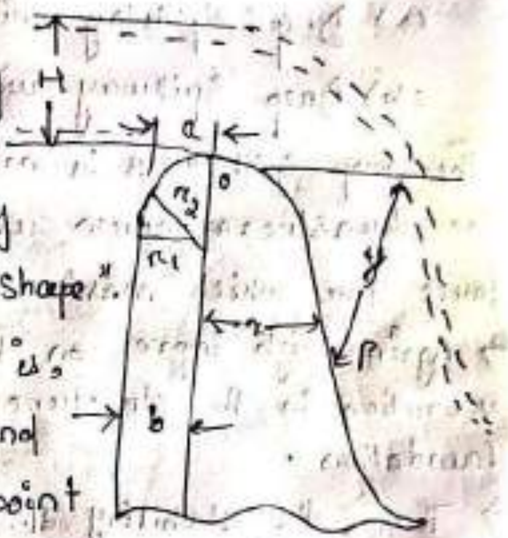
→ The shape of the lower nappe is not same for all the head of water above the crest of the weir.

→ It is differs with the head of water.

→ When the actual head becomes more than the designed head, the lower nappe does not follow the ogee profile and gets separated from the spill way surface.

The shape of the ogee spill way has been developed by U.S. Army Corps Engineers which is known as "Water way experimental station spill way shape".

→ The equation given by them is, $x^n = K \cdot H^{n-1} y$, where, x and y are the coordinates of a point P on the ogee profile taking O as origin.



$r_1 = 0.5H$ $a = 0.139H$

$r_2 = 0.21H$ $b = 0.237H$

(Shape of ogee spill way

→ K and n are the constants according to the slope of the upstream face of the spill way.

The value of K and n are given as follows :

Shape of U/s face of spill way	K	n
Vertical	2.0	1.85
1:3 (H:V)	1.936	1.836
1:1½ (H:V)	1.939	1.810
1:1 (H:V)	1.873	1.776

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Siphon Spill way :-

The spill way which acts on the principle of Siphon is known as Siphon Spillway.

→ The siphon spill way may be of 2 types.

(a) Saddle siphon spill way :-

It Consists of a reinforced Concrete hollow pipe in the shape of an inverted 'U'.

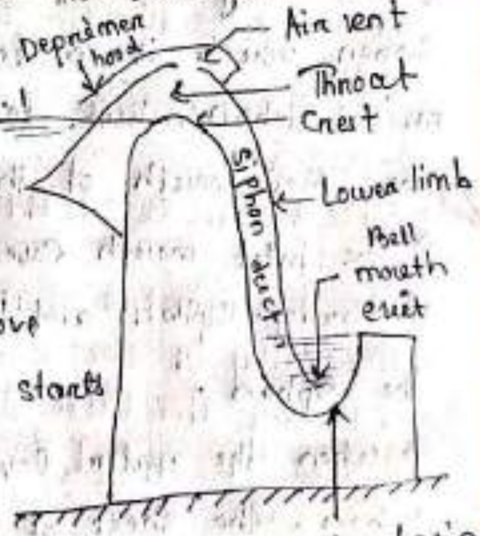
→ The upper limb is short and Consists of a bell mouth inlet.

→ The lower limb is longer and Consists of a bell mouth exit.

→ The inlet mouth is kept Submerged below the Full Supply level (F.S.L) to control the entry of floating debris into the siphon duct which may disturb the Siphonic action.

→ The exist mouth is also kept Submerged below the water level of the Sealing basin.

The functioning of the spill way. The description as follows.



(Saddle Siphon Spill way)

1. When the water is just on the full reservoir level (i.e. on the Crest of the spill way), there is no flow of water.

2. As the water starts rising above the F.R.L, the flow of water also starts over the Crest.

3. When the inlet of the deprimer gets Submerged, the entry of air to the Siphon duct through the air vent is stopped.

4. The entrapped air in the top portion of the siphon duct is then sucked by the flowing water. Thus the inside pressure is dropped below the outside atmospheric Pressure. Due to this pressure difference a Suction pressure is Created which draws more and more water over the

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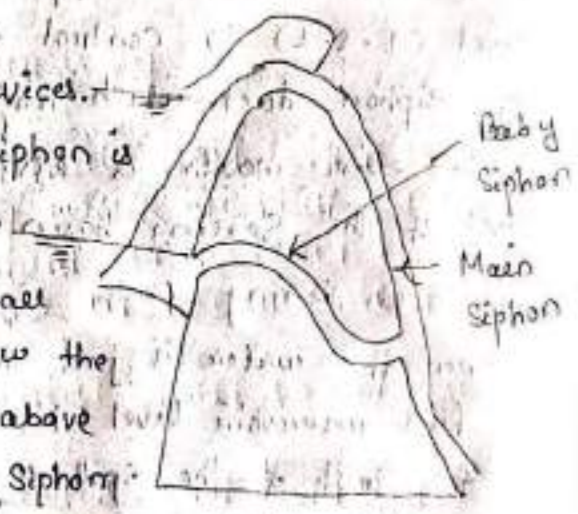
Crest of the siphon. This suction pull goes on increasing gradually.

5. Due to the gradual increase of suction pull, a time comes when the siphonic action starts and the siphon duct goes on running full. This phenomenon is known as priming. until the entrapped air is forced out completely through the sealing basin, the condition of priming does not arise. However, this condition arises when the water level rises to a considerable height but it takes too much time. So, to expedite the priming of siphon at times some priming devices are used.

Priming Devices :-

There are several priming devices. But the priming by baby siphon is generally adopted.



→ The baby siphon is a small siphon which is located below the main siphon, but slightly above the inlet mouth of the main siphon.

→ The inlet mouth covers the passage (Baby siphon) of baby siphon and hence the floating debris cannot enter the siphon.

→ when the water level rises above the crest of the baby siphon, the sheet of water starts flowing and the sheet of water starts flowing and the lower limb of the main siphon is sealed.

→ Thus, when the water rises above the full reservior level, the main siphon gets primed very quickly.

(b) Volute siphon spill way :-

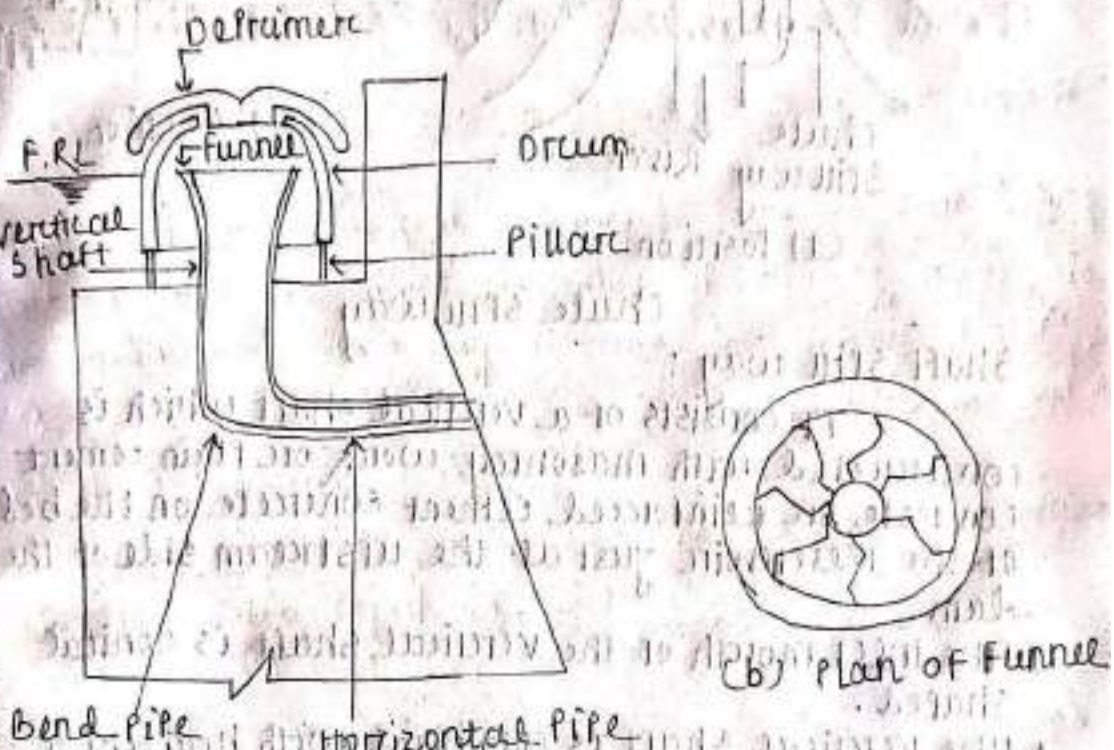
It consists of a vertical shaft having a funnel at the top end and the bottom end is connected to a bend pipe. The bend pipe again is connected to a horizontal pipe which carries the flowing water away from the base of the dam.

→ The top level of the funnel is a kept just at the full reservoir level.

→ The funnel consists of several volutes (curved vanes or blades).

→ Thus the water has a spiral motion while passing through the funnel.

→ A circular drum is placed over the funnel. The drum is supported on pillars.



(a) Section of siphon

Volute siphon spill way

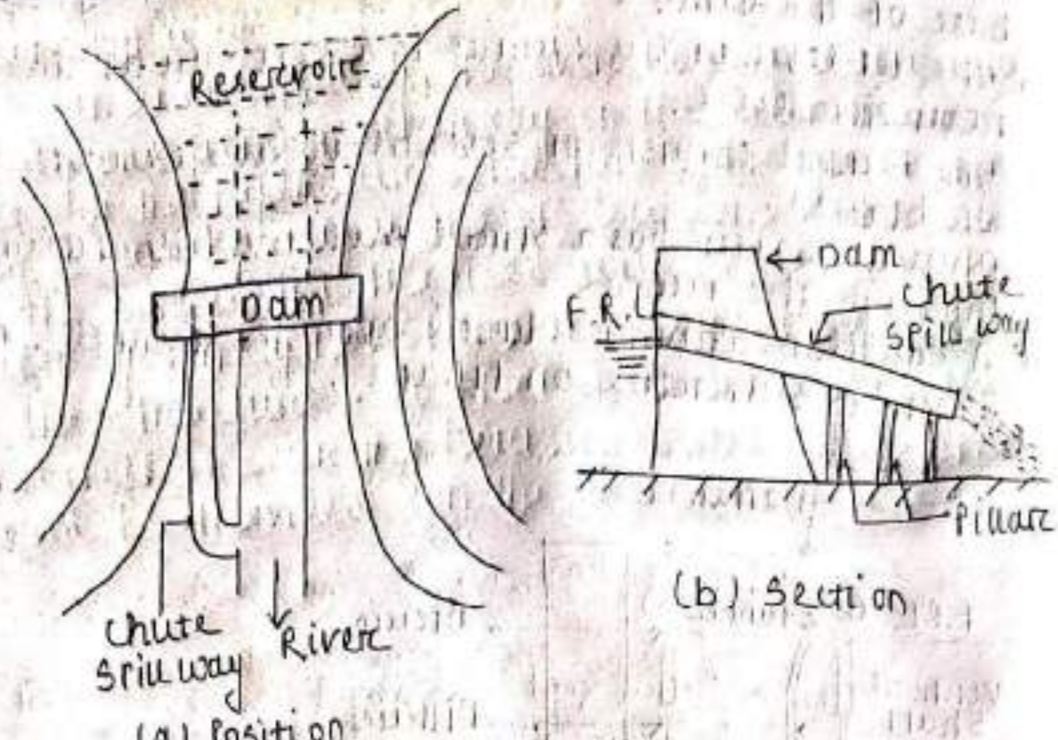
Chute or Trough spill way :-

This spill way is simply a rectangular open channel or trough (known as chute) provided on the dam to discharge the surplus water from the reservoir to the same river on the downstream side.

→ The spill way may be provided along the abutment of the dam or along the edge of the reservoir at the full supply level.

→ The chute is constructed by joining pre-cast R.C.C.

→ Channels in a longitudinal slope of 1 in 4 or 1 in 6.
→ The channels are supported on pillars.



Chute spill way

Shaft spill way :-

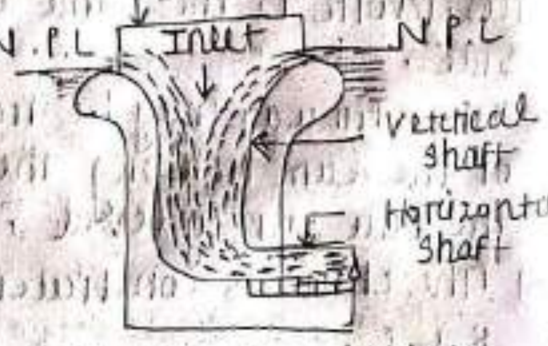
It consists of a vertical shaft which is constructed with masonry work or plain cement concrete or reinforced cement concrete on the bed of the reservoir just at the upstream side of the dam.

→ The inlet mouth of the vertical shaft is conical shaped.

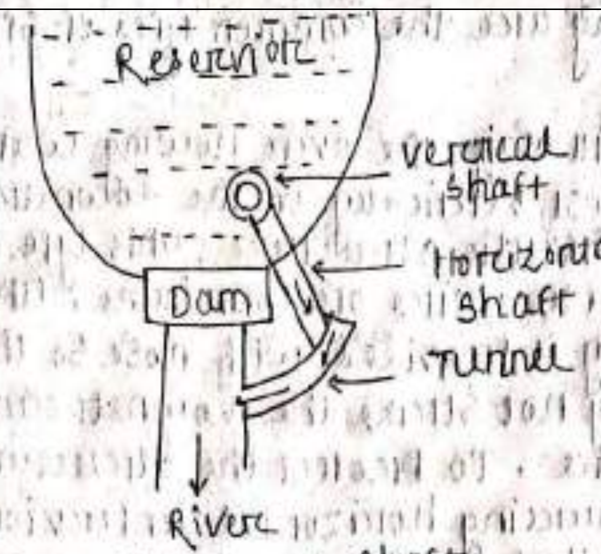
→ The vertical shaft is connected with horizontal shaft.

→ The horizontal shaft again may be taken through the body of the dam (in case of gravity dam) or through the base of the dam (in case of earthen dam) or may be connected to a tunnel outside the dam.

→ The inlet mouth is kept at the normal pool level of the reservoir.

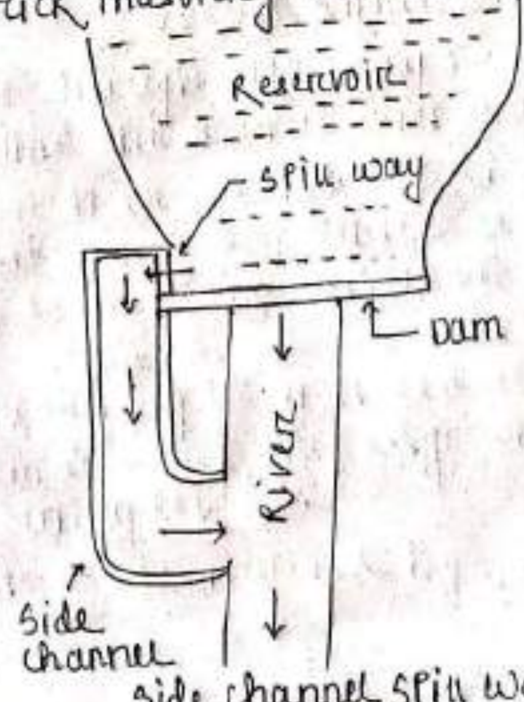


(b) Section of shaft



(a) Position of shaft

Side channel spill way :-
The side channel spill way is completely separate from the main body of the dam.
→ The spill way is constructed at right angle to the dam and at any side according to the site condition.
→ The crest of the spill way is kept at the normal pool level of the reservoir. When the water rises above the N.P.L. it spills over the crest of the spill way and flows through the side channel and ultimately meets the same river on the downstream side.
→ This type of spill way is recommended for the sites where other types of spill ways are found unsuitable.
→ The side walls of the channel may be constructed with brick masonry or stone masonry.



Side channel spill way

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