GOVT. POLYTECHNIC KANDHAMAL , PHULBANI

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Th-1 Hydraulic and Irrigation Engineering

4th Semester , Diploma

Lecture Notes

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Hydraulics & Irrigation Engineering

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		Hydrostatics
1.		properties of fluid.
2.		pressure & it's measurements
3.		Pressure exerted on an immersed surface.
II		Kinematics of fluid flow
1.		Basic eqn of fluid flow & their Applicatn
2.		Flow over Notches & weirs
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5.		flow through the open Channels.
III		Pumps.
1.		Types of pumps
2.		Centrifugal pump
3.		Reciprocating pumps.

Hydrostatics

Properties of fluid:

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Density, specific gravity, surface tension capillarity, viscosity & their uses.

Fluid: Fluid can flow. Then question arises what is flow? flow is contineous plastic deformatn

Fluid is a substance that can flow (i.e can deform continuously) under the action of shear stress (Tangential force). no matter how small the shear stress.

→ study movement

Matter —
- Solid
- Liquid] → Fluid — motion, molecules spaced Apart.
- Gas]

Mechanics → study of motion.

Solid Mechanics → system approach
⇓
matter → fixed.
"
same → boundary condn → change.

Fluid Mechanics → Matter → not constant
⇓
Control volm approach. Boundary condn are same.

motion
→ system → solid mech (matter fixed)
→ control volm → Fluid mec. (Boundary fixed)

Fluid → molecules → spacing
⇓
Relative motion w.r.t. each other.

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Properties of fluid

1. Density (ρ) ⇒ Density is mass per unit Volume.

$$\rho = \frac{Mass}{Volume} = \frac{M}{\forall} \; (kg/m^3)$$

c.g.s ⇒ g/cc   M.K.S ⇒ kg/m3

$1 g/cc = 10^3 kg/m^3$ P↑ ρ↑   T↑ ρ↓

⇒ Density depends on T & types of material.

2. Specific volume ($\forall$) ⇒ The specific volm of fluid is the volm occupied by unit mass of fluid.

$$\forall = \frac{V}{M} = \frac{1}{\rho} \; (m^3/kg)$$

3. Specific weight (γ) ⇒ The specific weight is the weight of fluid per unit volm.

$$\gamma = \frac{W}{\forall} = \frac{mg}{\forall} = \rho g \; (N/m^3)$$

4. Specific Gravity

$$s.g = \frac{\text{Density of fluid}}{\text{Density of standard fluid}}$$

⇒ In case of liquid, standard fluid is water.
⇒ In case of gases, standard fluid is air.

5. Compressibility (β) → compressibility of any substance is the measure of its change in volm under the action of external compressive force namely pressure.

$$\beta = -\frac{\text{Volumetric strain}}{\text{Change in pressure}} = \frac{-(dV/V)}{dp} = -\frac{1}{V}\frac{dV}{dp}$$

unit → Pa^{-1}

6. Bulk modulus (K) unit : Pa.

$$K = \frac{1}{\beta} = -V\frac{dp}{dV} = \rho\frac{dp}{d\rho} \; (Pa)$$

7 Viscosity (μ) ⇒

Q) Calculate the specific weight, specific volume, specific gravity & mass density of liquid having a volm of $6m^3$ & weigh of 44KN.

Given. $V = 6\,m^3$

$w = 44KN$

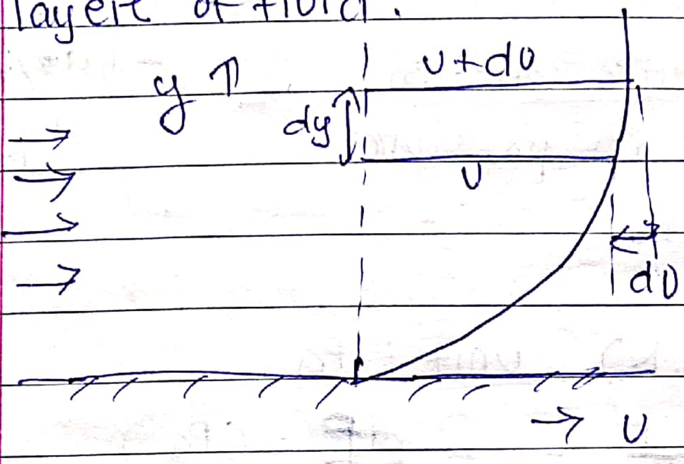
Weight = $W = \rho g \Rightarrow \rho = \frac{w}{g}$

$\rho = ?$

Reason's of Viscosity

1. Cohesive force (attraction, Inter mole)
2. Intermolecular momentum transfer

Viscosity (μ) => It is the property of fluid which offer resistance of moment of one layer of fluid over another adjacent layer of fluid.



(The shape is parabolic)

$$\tau \propto \frac{du}{dy}$$

Newton's Law of Viscosity.

→ According to Newton's law of viscosity shear stress is proportional to velocity gradient

$$\tau \propto \frac{du}{dy}$$

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

μ = dynamic viscosity or constant ($\frac{N sec}{m^2}$)

τ = shear stress b/w two adj layer of fluid (N/m^2)

$\frac{du}{dy}$ = velocity gradient.

Dimension of $\mu = ML^{-1}T^{-1}$

CGS unit of dynamic viscosity is Poise

CGS unit of Kinematic viscosity is Stoke

Note Hook's law = Shear stress ∝ shear strain

New' law = Shear stress ∝ Rate of shear strain.

Dynamic Viscosity (μ)

Dimension of μ = $[ML^{-1}T^{-1}]$

unit of μ = $N\text{-}s/m^2$ or Pa.S

In c.g.s units, μ is expressed as poise

1 poise = 0.1 $N\text{-}s/m^2$

$\mu_{water} \approx 10^{-3}$ $N\text{-}s/m^2$

$\mu_{Air} \approx 1.81 \times 10^{-5}$ $N\text{-}s/m^2$

(Both 20°c & at Standard Atm pressure)

Kinematic Viscosity (ν)

The Kinematic viscosity (ν) is defined as the ratio of dynamic viscosity to mass density of the fluid

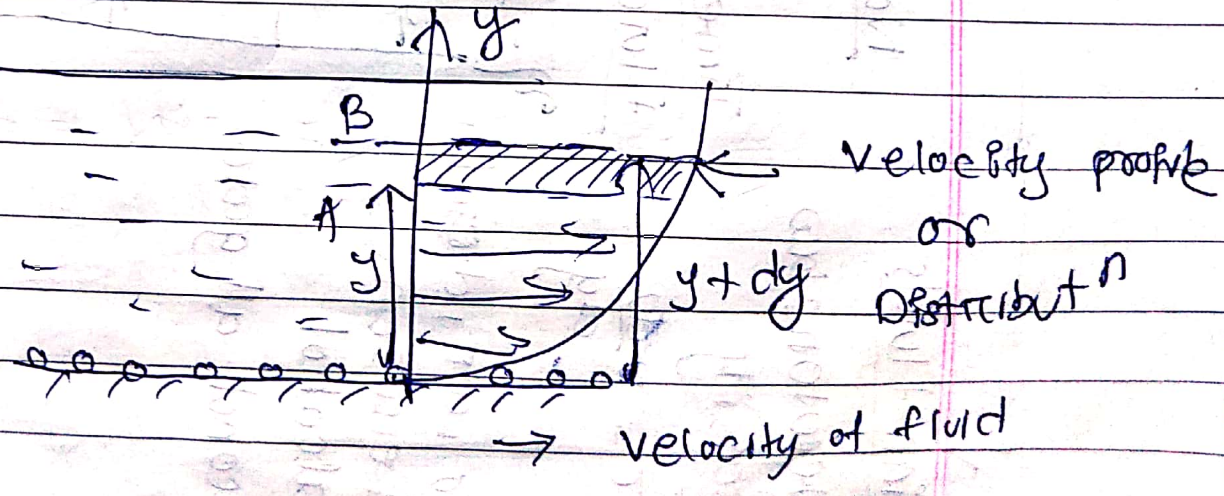
therefore $\nu = \mu/\rho$

Dimension of ν = $[L^2 T^{-1}]$

unit of ν = m^2/s or cm^2/s (stoke)

1 stoke = 10^{-4} m^2/s

$\nu_{water} = 1 \times 10^{-6} m^2/s$, $\nu_{air} = 15 \times 10^{-6} m^2/s$



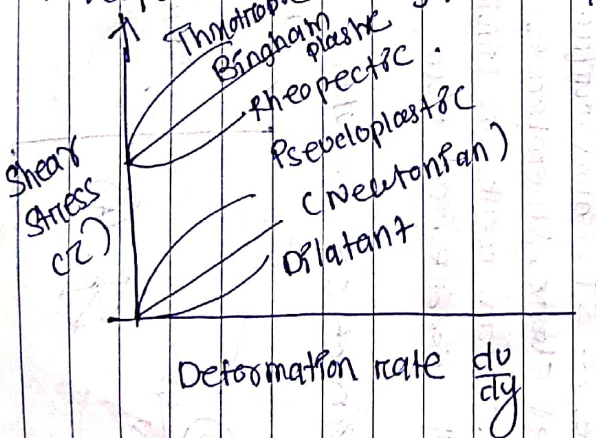
Rheology (Classification of fluids)

Fluids

- **Newtonian fluids**
  - Obeys Newton's law of viscosity
  - i.e. $\tau = \mu \frac{du}{dy}$
  - e.g.- water, air, diesel, petrol, kerosene, methyl alcohol, ethyl alcohol, all gases.
  - linear relationship
- **Non-Newtonian fluids**
  - **Time independent fluid**
    - $\eta = f\left(\text{Temp}, \frac{du}{dy}\right)$
    - → Dilatant fluid
    - → Psuedoplastic fluid.
    - → Bingham plastic fluid or Ideal plastic fluid.
  - **Time dependent fluid**
    - $\eta = f\left(\text{Temp}, \frac{du}{dy}, \text{time}\right)$
    - → Thixotropic fluid
    - → Reopectic fluid.
  - Does not obey Newton's law of viscosity
  - $\tau = A\left(\frac{du}{dy}\right)^n + B$
  - Non linear
  - A → Flow consistency index
  - n → Flow behaviour index
  - B → Yield stress.
- **Ideal Fluid**

Various types of non-Newtonian fluids are

1. Pseudoplastic : Polymer solⁿ, Milk, Blood ($B=0, n<1$)
2. Dilatant : suspensions of starch, saturated sugar solⁿ ($B=0, n>1$)
3. Bingham Plastic : clay suspensions, drilling muds, creams & toothpaste ($B\neq0, n\approx1$)
4. Thixotropic : Paint, printer inks
5. Rheopectic : Gypsum pastes.



Ideal Fluid

Ideal fluid is a hypothetical fluid with
a. zero viscosity
b. zero surface tension
c. Incompressible.

$\tau = 0$ since $\mu = 0$

All the fluid in reality has viscosity ($\mu > 0$) & hence they are termed as real fluid.

Surface tension.

The liquid molecules on the surface experience a net inward pull due to which there will be tension in the liquid surface. This tension is referred as surface tension.

Surface tension is due to cohesion betn the liquid particles & the surface.

Whenever a liquid is in contact with other liquids or gases or solid surface an interface develops that acts like a stretched elastic member, creating surface tension.

Because of ST liquid surface behave like stretched elastic membrane due to which
1. Insects can walk on liquid surface
2. Small needle can float.

Dimension of ST = N/m

~~Capillarity~~ Effect of temp & pressure on ST

surface tension generally decreases with increase in temp & becomes zero at the critical point

The effect of pressure on surface tension is usually negligible.

Curved liquid interface.

$$\Delta P = \sigma \left[\frac{1}{R_1} + \frac{1}{R_2} \right]$$

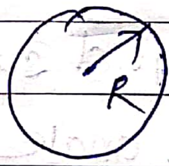
if there are two liquid interface

$$\Delta P = 2\sigma \left[\frac{1}{R_1} + \frac{1}{R_2} \right]$$

Special case:

1. Spherical liquid drop

$R_1 = R_2 = R$

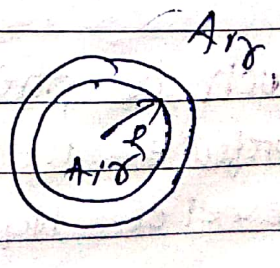


$\Delta P = \frac{2\sigma}{R}$ or $\Delta P = \frac{4\sigma}{D}$

2. Cylindrical liquid jet

$\Delta P = \frac{\sigma}{R}$ or $\Delta P = \frac{2\sigma}{D}$

3. Spherical Bubble



$\Delta P = \frac{4\sigma}{R}$ or $\Delta P = \frac{8\sigma}{D}$

$R_1 = R_2 = R$

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Capillarity: The interplay of forces of cohesion & adhesion explain the phenomenon of capillarity.

- For a liquid in contact with a surface, if adhesion predominates cohesion, then the liquid will wet the surface with which it is in contact & tends to rise at the point of contact.
- The free surface of the fluid will be concave upward & the contact angle (θ) will be less than 90°.

Example: Immersion of a glass tube in water.

- On the other hand, if for any liquid in contact with a surface, cohesion predominates, the liquid will not wet the surface & the liquid surface will be depressed at the point of contact.
- The liquid surface will be concave downward & the angle of contact θ will be greater than 90°.

Example: Immersion of the glass tube in mercury.

Such a phenomenon of rise or fall of liquid surface relative to the adjacent general level of liquid is known as capillarity.

Surface tension force = weight of the fluid.

$$\sigma (2\pi r) \cos\theta = \rho (\pi r^2 h) g$$

$$\boxed{h = \frac{2\sigma \cos\theta}{\rho r g}}$$

Chapter-2

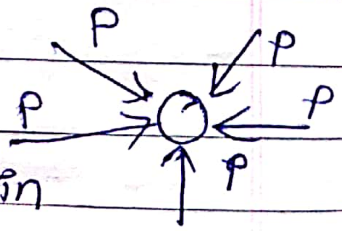
Fluid Pressure & It's Measurement

Pressure (P):

- Pressure is defined as a normal force exerted by a fluid per unit Area.
- Pressure is always defined at a point.
- Pressure is defined only for fluid. The counterpart of pressure in solids is normal stress
- Pressure is a scalar quantity.
- Pressure is always compressive in the nature & it always act ⊥r to the wall in contact.

Pascal's Law for Pressure at a Point

- According to Pascal's law, pressure at a point in a fluid system is equally distributed in all directions.
- It means that the pressure at a point in a fluid at rest, or in motion, is independent of direction as there are no shearing stresses present.



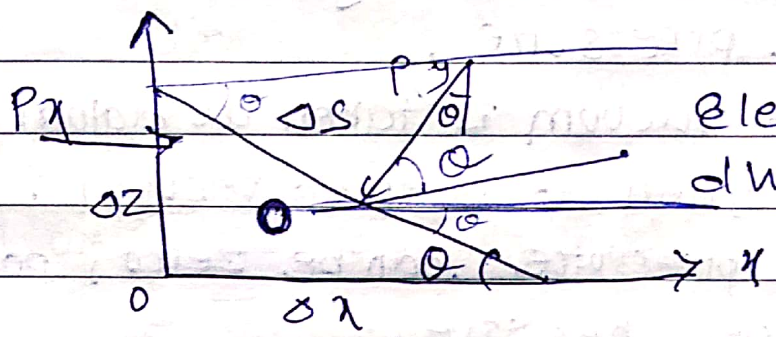
- Pressure in a fluid system has magnitude but not a specific direction & thus it is a scalar quantity.
- It applies to a fluid at rest.

considere a small wedge of fluid at rest of size Δx by Δz by Δs & depth b into the paper. Pressures P_x, P_z and P_n may be different on each face.

Summation of forces must equal zero (no acceleration) in both the x & z directions.

$\Sigma F_x = 0 = P_x b \Delta z - P_n b \Delta s \sin\theta$ —(1)

$\Sigma F_z = 0 = P_z b \Delta x - P_n b \Delta s \cos\theta - \frac{1}{2} \rho (b \Delta z \Delta x) g = 0$ —(2)



But the geometry of the wedge is such that $\Delta s \sin\theta = \Delta z$ & $\Delta s \cos\theta = \Delta x$

substitution and rearrangement of the eq^n (1) & eq (2) gives

$P_x = P_n$ & $P_z = P_n + \frac{1}{2} \rho \Delta z g$ --(3)

In the limit as the fluid wedge shrinks to a point $\Delta z \to 0$ & eq^n(3) becomes

$P_x = P_n = P_z = P$

since θ is arbitrary, we conclude that the pressure p at a pt in a static fluid is independent of orientat^n or pressure at a point is same in all direct^n hence it is scalar quantity.

Pressure measurement

Units of Pressure

1. 1 Pa = 1 N/m^2
2. 1 Bar = 10^5 N/m^2
3. 1 atm = 101325 N/m^2 = 1.01325 Bar
   = 760 mm of Hg = 760 Torr = 14.7 Psi
4. 1 kgf/cm^2 = 98100 Pa
5. 1 Psi = 1 $lbf/inch^2$ = 6888.105 Pa
6. 1 Torr = 1 mm of Hg = 133.416 Pa

Absolute pressure,

→ Perfect vacuum is taken as datum and zero value is given to perfect vacuum.
→ Absolute pressure can be zero, positive but cannot be negative.
→ Minimum possible value of pressure is absolute zero.

Gauge pressure

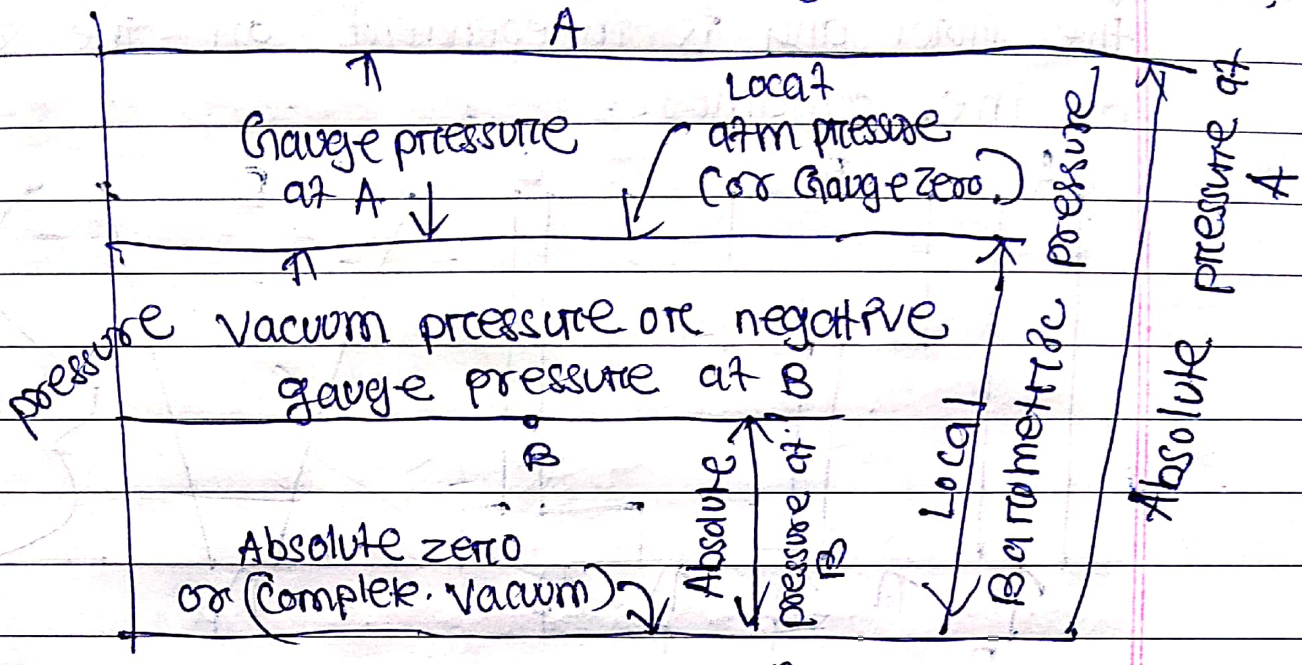
→ Atmospheric pressure is taken as datum and zero value is given to atmospheric pressure.
→ Generally defined when pressure is more than atmospheric pressure.
→ $P_{gauge} = P_{abs} - P_{atm}$
→ It can have positive, negative or zero value.

Vacuum pressure

→ Atmospheric pressure is taken as datum and zero value is given to atmospheric pressure.
→ Generally defined when pressure is less than

atmospheric pressure.

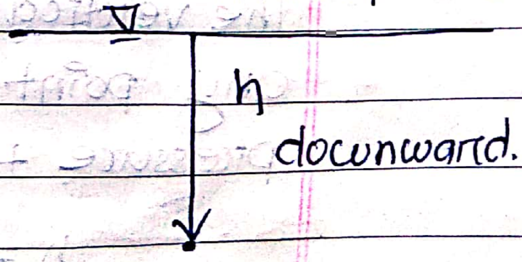
- $P_{vacuum} = P_{atm} - P_{abs}$
- Also known as negative gauge pressure.



Relationship betn Absolute Gauge or vacuum pressure.

Hydrostatic law

The rate of increase of pressure in vertical downward direction must be equal to the specific weight of the liquid at that point.



For downward 'h'

$$\frac{dp}{dh} = w$$

$$dp = w\,dh$$

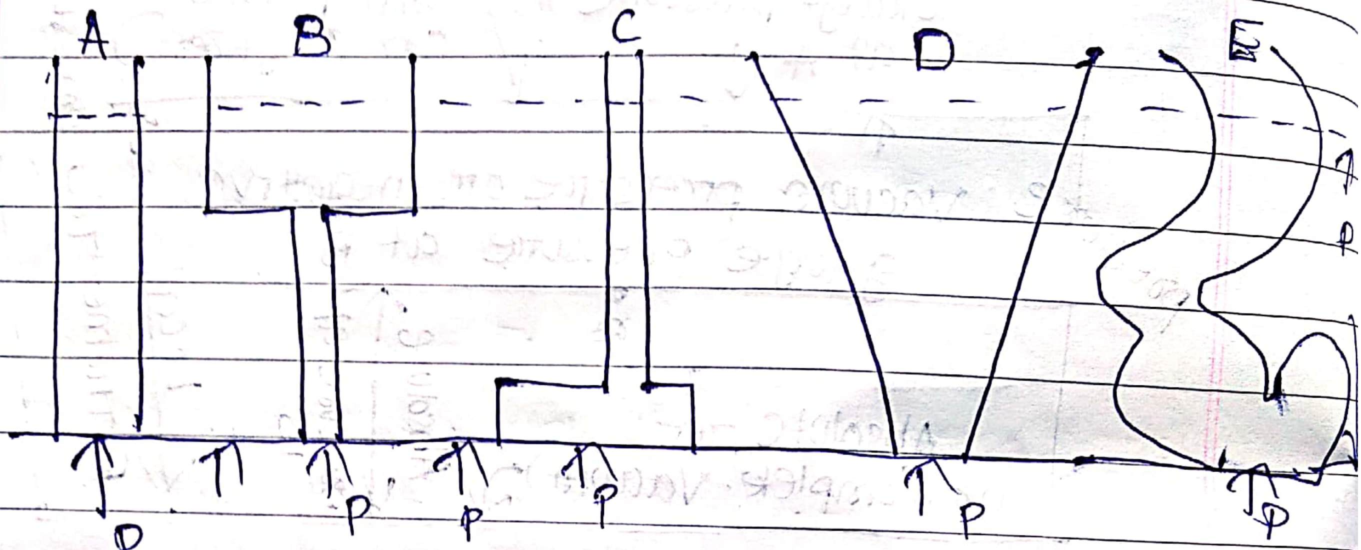
$$p = wh = \rho g h$$

For upward 'h'

$$\frac{dp}{dh} = -w$$

Hydrostatic Paradox :

Pressure at a point depends on its depth from free surface and specific weight of the fluid and is independent on the shape of the container.



The pressure is the same at all points on a horizontal plane in a given fluid regardless of geometry, provided that the points are interconnected by the same fluid.

Pressure Head

The vertical height of the free surface above any point in a liquid at rest is known as pressure head for that point.

$$h = \frac{P}{\rho g} \text{ or } \frac{P}{\gamma}$$

→ Relationship betn the heights of columns of different liquids which would develop the

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same pressure at any point.

$p = \gamma_1 h_1 = \gamma_2 h_2$. If S_1 and S_2 are specific gravities of the two liquids then,

$$p = S_1 \gamma_w h_1 = S_2 \gamma_w h_2$$

$$\boxed{S_1 h_1 = S_2 h_2}$$

Pressure Measurement Devices

Types of Devices

↓

- Barometer
- Manometers
  - Simple Manometers
    1. Piezometer
    2. U-tube manometer
    3. Single column Manometer.
  - Differential Mano
    1. Two Piezometer Manometer
    2. Inverted U-Tube Manometer
    3. U-Tube Differential Mano
    4. Micrometer.
- Mechanical Gauges

Barometer:

→ Atmospheric pressure is measured by a device called barometer, thus, the atmospheric pressure is often referred to as the barometric pressure.

→ The barometer consists of a inverted mercury filled tube into a mercury container that is open to the atmosphere as shown in fig.

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→ The pressure at point B is equal to the atmospheric pressure, and the pressure at C can be taken to be zero since there is only mercury vapour above point C and the pressure is very low relative to P_{atm} and can be neglected.

→ Writing a force balance in the vertical direction gives.

$$P_{atm} = \rho g h$$

→ In barometer, Hg is used because of its two important properties.

(i) Hg is a high density fluid.

(ii) Hg has very low vapour pressure.

Manometers

→ Manometers are those pressure measuring devices which are based on the principle of balancing the column of liquid by the same or another column of liquid.

→ Manometers are classified as

1. Simple: which measure pressure at a point
2. Differential: which measure pressure difference betn any two points.

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(1) <u>simple manometer</u>

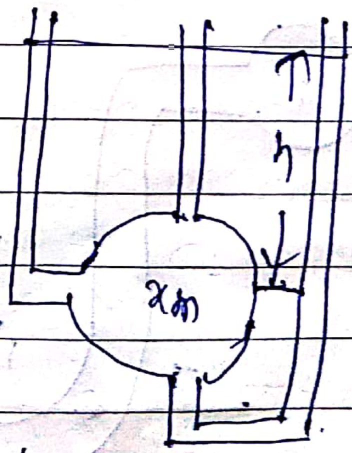
A simple manometer consists of a glass tube having one of its ends connected to the gauge pt where the pressure is to be measured & the other remains opens to atmosphere. following are the types of simple manometers.

(i) <u>Piezometers</u>

→ A piezometer is the simplest form of manometer which can be used for measuring moderate pressure of liquids.

→ It consists of a glass tube inserted in the wall of a pipe or a vessel, containing a liquid whose pressure is to be measured. The tube extends vertically upward to such a height that liquid can freely rise in it without overflowing.

→ The pressure at any point in the liquid is indicated by the height of the liquid in the tube above that point.

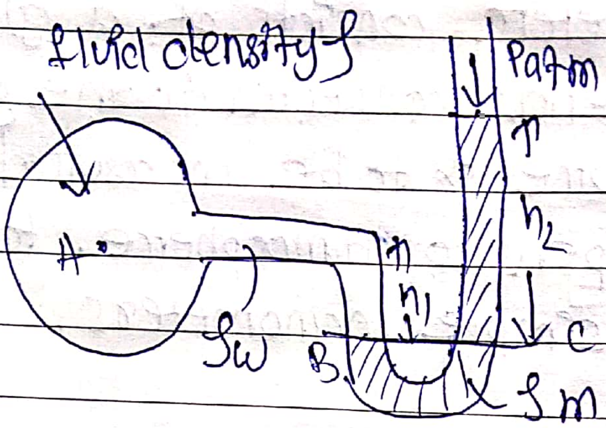


<u>Limitations</u>

→ cannot be used when large pressure in lighter liquids is to be measured.

→ Gas pressure can not measured, because gas forms no free atmospheric surface.

3. Simple U-Tube manometer



$$P_B = P_C$$

$$P_A + \rho_w g h_1 = P_{atm} + \rho_m g h_2$$

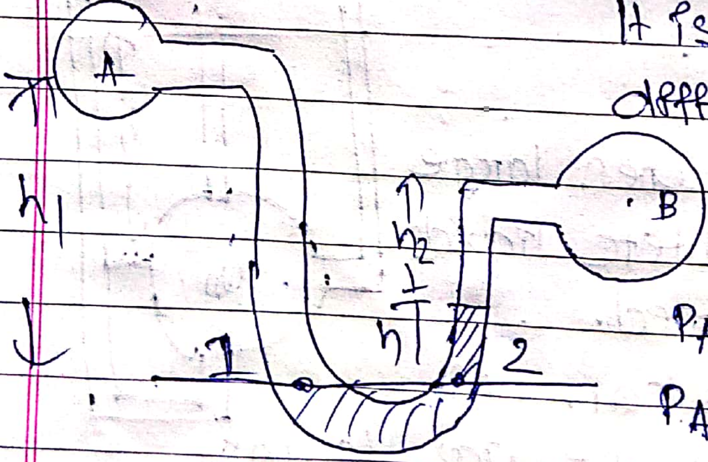
$$P_A - P_{atm} = \rho_m g h_2 - \rho_w g h_1$$

$$P_{Ag} = \rho_m g h_2 - \rho_w g h_1$$

→ Manometric fluid is used to reduce height reqd of the limb.

→ It can be used to measure low, moderate & high gauge and vacuum pressure of both liquids as well as gases.

4. Differential U-Tube manometer.



It is used to measure pressure difference betn two point $(P_A - P_B)$

$$P_1 = P_2$$

$$P_A + \rho_w g h_1 = P_B + \rho_w g h_2 + \rho_m g h$$

$$P_A - P_B = \rho_w g h_2 + \rho_m g h - \rho_w g h_1$$

Q) Find the kinematic viscosity of an oil having density 970 kg/m³. the shear stress at a point in oil is 0.3245 N/m² & velocity gradient at the point is 0.35 per sec.

Given data

Density, $\rho = 970\ kg/m^3$

viscosity gradient = $\frac{du}{dy} = 0.35/sec$

Shear stress = $0.3245\ N/m^2$

Velocity gradient, $\frac{du}{dy} = 0.35\ (1/sec)$

We know that

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

$$\mu = \frac{\tau}{\frac{du}{dy}} = \frac{0.3245}{0.35} = 0.92\ NS/m^2$$

$$\text{kinematic viscosity } (\nu) = \frac{\mu}{\rho} = \frac{0.92}{970} = 9.48 \times 10^{-4}\ m^2/s$$

Q) Find the surface tension in a soap bubble of 35.70 mm dia when the inside pressure is 2.75 N/m² above atm pressure.

$d = 35.70\ mm$, $P = 2.75\ N/m^2$

For Soap bubble

$$P = \frac{8\sigma}{d} \Rightarrow \sigma = \frac{Pd}{8} = \frac{2.75 \times 35.70 \times 10^{-3}}{8}$$

$$= 0.012\ N/m \text{ (Ans)}$$

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Q Calculate the specific weight, Density and specific gravity of 1lt of a liquid which weights 7N.

Soln Volume = 1lt $\quad 1lt = 10^{-3}\,m^3$

Weights = W = 7N

(1) Specific Weight = $\frac{\text{Weight}}{\text{Volume}}$

$(\gamma = \rho g)$

$= \frac{7}{1} = 7\,N/10^{-3}m^3 = 7\times10^{3}\,N$

(2) Mass density = $\frac{\text{specific wt of oil}}{\text{Accelearation due to}}$

$= \frac{7}{9.81} = 0.713\ N sec^2/m^2$

$= \frac{0.713}{9.81} = 0.072\ kg sec/m$

(3) Density = $\frac{\text{mass}}{\text{Vol m}} = \frac{0.072}{1\times10^{-3}} = 72\ kg/m^3$

slug / m^3

$4^\circ C = 101.945\ slug/m^3$

specific gravity = $\frac{72}{101.94} = 0.7$

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Q: If the velocity distribution of a plate is given by

$$U = \frac{2}{3}y - y^2$$

Where y is distance from solid Boundary in metere. V is velocity in m/s.
Determine sheare stress at
$y = 0$ & $y = 0.15$ m
Take Dynamic viscosity as $\mu = 8.63$ poise.

Soln Given

Dynamic viscosity

$\mu = 8.63$ poise $= 0.863 \frac{Ns}{m^2}$

Velocity distributn

$$U = \frac{2}{3}y - y^2$$

To find Sheare stress τ at $y = 0$ m, $y = 0.15$ m.

Newton's law of viscosity

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

$$= 0.863 \frac{d}{dy}\left(\frac{2}{3}y - y^2\right)$$

$$\tau = 0.863 \times \left(\frac{2}{3} - 2y\right)$$

Sheare stress at $y = 0$

$$\tau = 0.863 \times \frac{2}{3} = 0.5753 \text{ N/m}^2$$

Sheare stress at $y = 0.15$ m

$$\tau = 0.863 \times \left(\frac{2}{3} - 2 \times 0.15\right)$$

Pressure exerted on an immersed surface.

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Hydrostatic Forces on surface.

→ Fluid statics or hydrostatics is the branch of fluid mechanics in which stresses generated in fluid system & determined when it is at rest or static condition.

→ The velocity gradient is zero as the fluid is under static condition.

→ Shear stress betn two adjacent layers of fluid is zero.

→ only a force can be exerted by the fluid on its surrounding walls and base is called as hydrostatic force. $P = \rho g z$.

→ In hydrostatic force analysis one should have a knowledge.

① Total pressure

② center of pressure.

<u>Total pressure</u>

Force exerted by the fluid on the surface with which it is in contact is called Total Hydrostatic force.

<u>Center of Pressure</u>

The point of application of total hydrostatic force on the surface is known as centre of pressure.

3.2.1 Total Hydrostatic Force on a Horizontal Plane Surface

- Consider a plane surface immersed in a static mass of liquid of specific weight γ, such that it is held in a horizontal position at a depth h below the free surface of the liquid. (Figure 3.2)

  Since every point on the surface is at the same depth below the free surface of the liquid, the pressure intensity is constant over the entire surface.

  If, A is the total area of the surface, then the total hydrostatic force on the horizontal surface,

  $F = pA = (\gamma h)A = \gamma Ah$ ...(1)

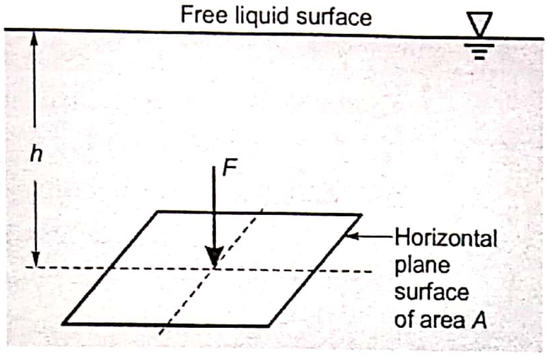


Figure 3.2 Total hydrostatic force on a horizontal plane surface

- The direction of this force will be vertically downward and normal to the surface and will act at the centroid of the surface.

3.2.2 Total Hydrostatic Force on a Vertical Plane Surface

- Consider a plane surface having area A is submerged in static mass of liquid having specific weight γ. The surface is in vertical position such that the centroid of surface is at a depth of $\bar{h}$ below the free surface of the liquid (Figure 3.3).
- Since the depth of the liquid varies from point to point on the surface, the pressure intensity is not the same all over the surface.
- Consider a horizontal strip of infinitesimal thickness dy and width b lying at a vertical depth y below the free surface of the liquid. It is assumed that the pressure intensity is constant over the area of the strip and having magnitude of $p = \gamma y$.

  Thus, total hydrostatic force acting on the strip,

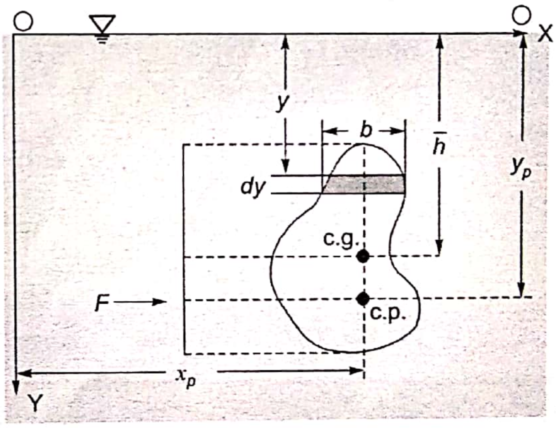


Figure 3.3 Total hydrostatic force on a vertical plane surface

$$dF = pdA$$

$\because$ $dA = bdy$

$\therefore$ $dF = \gamma y(bdy)$

Then, total hydrostatic force on the entire plane surface,

$$F = \int dF = \gamma \int y(bdy)$$

since, $\int y(bdy)$ = summation of first moments of the areas of the strips about an axis OO.

$\because$ $\int y(bdy) = A\bar{h}$

$\therefore$ $F = \gamma A\bar{h}$ ...(2)

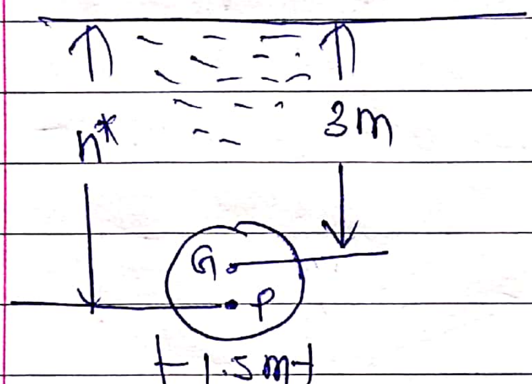
$\gamma \bar{h}$ is the pressure intensity at centroid of the surface. Therefore, it can be stated that the total hydrostatic force on a plane surface is equal to the product of the surface area and the intensity of pressure at the centroid of the area.

Centre of Pressure for Vertical Plane Surface

(a) Vertical Location

- In case of vertical plane surface, pressure intensity increases with depth. Thus, centroid of pressure intensity will always be below the centroid of the surface area.

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



$$\text{Area } (A) = \frac{\pi}{4} \times d^2$$

$$= \frac{\pi}{4} \times (1.5)^2$$

$$= 1.767 \text{ m}^2$$

$$\bar{y} = 3 \text{ m}$$

$$I_g = \frac{\pi d^4}{64} = \frac{\pi \times (1.5)^4}{64} = 0.248 \text{ m}$$

Total pressure $= P = wA\bar{y}$

$$= 1000 \times 1.767 \times 3$$

$$= 5301 \text{ kg}$$

position of centre of pressure.

$$\bar{h} = \bar{y} + \frac{I_g}{A\bar{y}}$$

$$= 3 + \frac{0.248}{1.767 \times 3}$$

$$= 3.046 \text{ m}$$

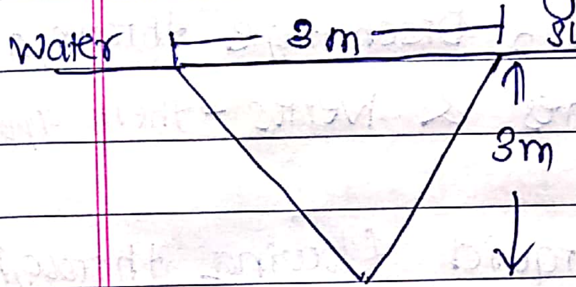
Q) A steel plate is immersed in an oil of s. weight 7.5 KN/m³ upto a depth of 2.5 m. What is the intensity of pressure on the plate due to oil.

$w = 7.5 KN/m^3$, $h = 2.5 m$

$p = wh$

$= 7.5 \times 2.5 = 18.75 KN/m^3$

Q) An isosceles triangular plate of base 3 m and altitude 3 m is immersed vertically in water as shown in fig below.



Given
Base of plate = 3m
Height of plate = 3m

$A = \frac{1}{2} bh = \frac{3 \times 3}{2} = \frac{9}{2} = 4.5 m^2$

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

Distance of C.G from the surface of oil

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

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

$= 1000 \times 9.81 \times 4.5 \times 1$

$= 44145 N$ Ans.

centre of pressure

$h^* = \frac{I_G}{A\bar{h}} + \bar{h} = \frac{\frac{bh^3}{36}}{4.5 \times 1} + 1$

$h^* = 1.5 m$

Kinematics of fluid flow

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1. Basic equation of fluid flow and their application.
Rate of discharge, eq^n of continuity of liquid flow, total energy of a liquid in motion - potential kinetics & pressure, Bernoulli's theorem and its limitations. Practical applications of Bernoulli's eq^n.

2. Flow over Notches & weirs: Notches, weirs types of notches & weirs, Discharge through different types of notches & weirs - their applicat

3. Losses of head of a liquid flowing through pipes.
Different types of major & minor losses, simple numerical problems on losses due to friction using Darcy's eq^n, Total energy lines & Hydraulic gradient lines.

4. Flow through open channels.

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The science which deals with the motion of fluids without reference to the forces causing the motion is known as ~~hydrostat~~ hydrokinematics or fluid kinematics. Thus fluid kinematics involves merely the description of motion of fluids in terms of space-time relationship.

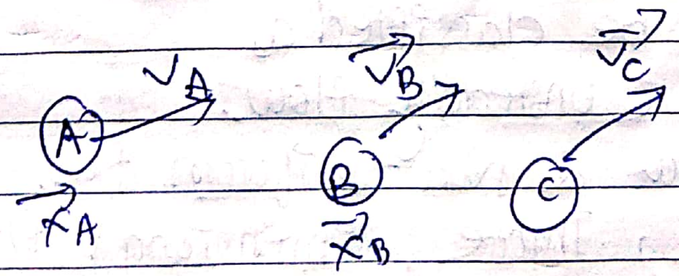
The fluid motion can be described by two methods.

1. Lagrangian Mtd 2. Eulerian Mtd.

1. Lagrangian Method

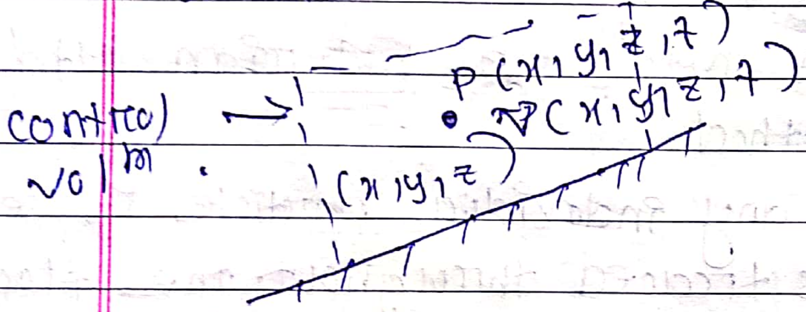
→ In this method any individual particle is selected whose motion is traced throughout the flow & its various properties such as velocity, acceleration etc are observed at different points.

→ Though the approach is very accurate, it is very difficult to keep track of even a single fluid particle, so Lagrangian approach to describe fluid flow is not generally used.



Lagrangian Description of Fluid Motion.

2. Eulerian Method · In this Eulerian description of fluid flow, a finite volm called a flow domain or control volume is defined, through which fluid flows in & out. We do not need to keep track of the position & velocity of fluid particle of fixed identity instead we define field variable, function of space & time with in the control volume.



Rate of Discharge

Quantity of a gas or liquid moving through a pipe or channel within a given or standard period (usually a minute or hour).

Type of fluid flow

Fluid flows may be classified as

1. Steady flow & Unsteady flow.
2. Uniform flow & Non-Uniform flow.
3. One, two, Three dimensional flow.
4. Rotational flow & Irrotational.
5. Laminar flow & Turbulent flow.
6. Compressible flow & Incompressible flow.

Steady flow

A steady flow is defined as a flow in which the flow velocities & fluid properties at any point do not change with time.

$$\frac{\partial v}{\partial t} = 0 \;,\; \frac{\partial p}{\partial t} = 0 \;,\; \frac{\partial \rho}{\partial t} = 0 \qquad \left(\left.\frac{\partial R}{\partial t}\right|_{space} = 0 \right)$$

Unsteady flow

An unsteady flow is defined as flow in which the fluid velocity and fluid properties change with time.

e.g. $\frac{\partial v}{\partial t} \neq 0$ or $\frac{\partial p}{\partial t} \neq 0$.

Uniform flow

When velocity & fluid properties at any instant of time do not change from point to point in flow field, the flow is said to be uniform.

Non-uniform flow :

In case of non-uniform flow velocity & other hydrodynamic parameter changes from point to point in flow field.

One, two and three Dimensional flow.

One dimensional flow (1-D flow)

1-D flow is that in which all the flow parameters may be expressed as function of time & one space co-ordinate only

$$u = v(x, t)$$

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For e.g → fully developed flow through a pipe of constant dia.

2-D flow ⇒ $v = v(x, y, t)$

e.g → flow over cylinder of very long length

3-D flow $v = v(x, y, z, t)$

e.g – All the real fluid flow problems are actually 3-D.

Compressible & Incompressible.

if $\frac{D\rho}{Dt} \neq 0$ → compressible flow

$\frac{D\rho}{Dt} = 0$ → incompressible flow

$$\frac{D\rho}{Dt} = u\frac{d\rho}{dx} + v\frac{d\rho}{dy} + w\frac{d\rho}{dz} + \frac{d\rho}{dt},$$

For incompressible flow $D\rho/Dt = 0$

$$\frac{D\rho}{Dt} = u\frac{d\rho}{dx} + v\frac{d\rho}{dy} + w\frac{d\rho}{\partial z} + \frac{\partial \rho}{dt} = 0$$

+ ~~Streamline~~

Flow visualization technique.

1. Streamline – A stream line at any instant can be defined as an imaginary curve in the flow field such that tangent to curve at any point represents the direction of the instantaneous velocity vector at that point.

Eqn of Streamline

$$\frac{dx}{u} = \frac{dy}{v} = \frac{dz}{w}$$

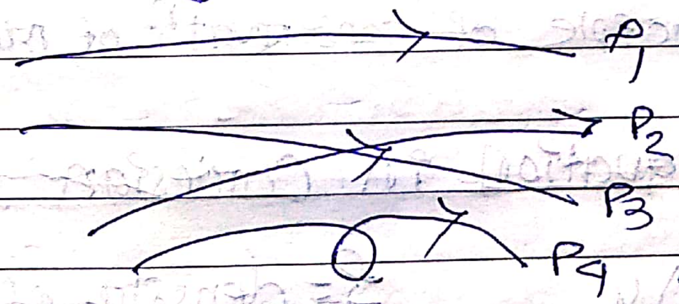
properties of stream line.

→ The stream-tube is bounded on all sides by stream lines,

→ fluid velocity does not exist across streamline fluid may enter or leave streamline tube only through ends.

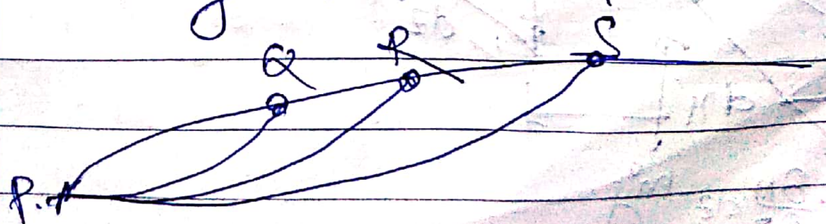
Pathline

It is actual path traced by a fluid particle over a given interval of time.



Steak line

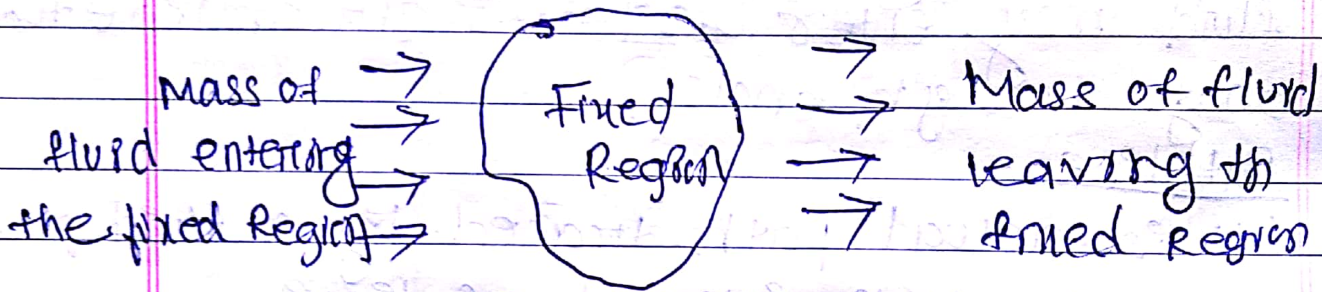
A streak line is the locus of the temporary locatn of all particles that have passed through a fixed point in the flow field at any instant of time



Eq^n of continuity of liquid flow.

→ The continuity eq^n is a mathematical statement of the principle of conservation of mass.

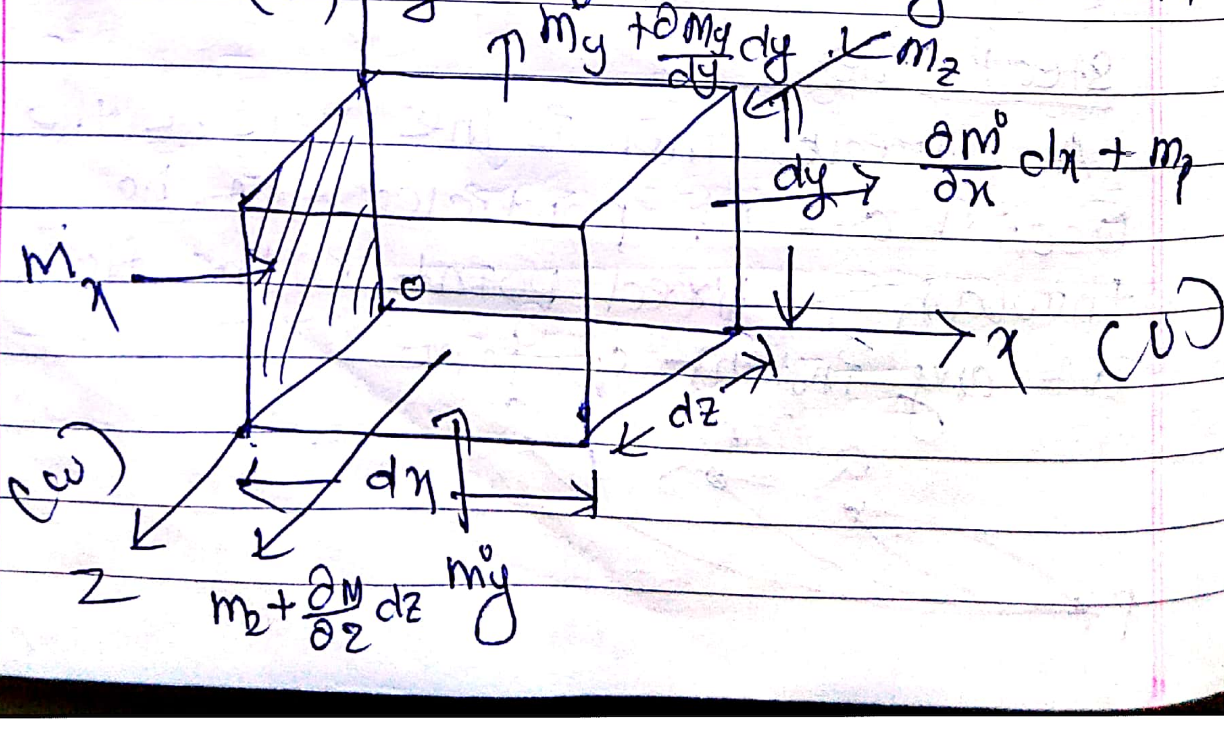
→ According to this, mass inflow in a fixed region or control volume should be equal to mass outflow from that fixed region in a particular time i.e fluid mass can neither be created nor be destroyed.



The principle of conservat^n of Mass.

Continuity Equation in Cartesian co-ordinate systems

ρ = density of fluid.



$$\dot{m}_{in} - \dot{m}_{out} = \dot{m}_{st}$$ conservat^n of mass

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x-direction

$$(\dot{m}_{in} - m_{out})_x : \dot{m}_x - \left(\dot{m}_x + \frac{\partial m_x}{\partial x} dx\right)$$

$$= -\frac{\partial m_x}{\partial x} . dx$$ { mass flow rate = Density x Area of cross s^n x velocity along direct^n of flow

$$= -\frac{\partial \rho\, dy dz\, u}{\partial x} . dx$$

$$= -\frac{\partial}{\partial x} \rho\, dx dy dz\, v$$ { $dV = dx dy dz$)

$$(m_{in} - m_{out})_x = -\frac{\partial}{\partial x} \rho\, dV\, v$$

Y-direction

$$(m_{in} - m_{out})_y = m_y - \left(m_y + \frac{\partial m_y}{\partial y} dy\right)$$

$$= -\frac{\partial}{\partial y} \rho\, dV\, v$$

z-dire $$(m_{in} - m_{out})_z = -\frac{\partial}{\partial z} \rho\, dV . w$$

V = constant

$$\dot{m}_{st} = \frac{\partial m_{st}}{\partial t} = \frac{\partial}{\partial t} \rho\, dV = \frac{\partial \rho}{dt} dV \quad \text{--- (1)}$$

$$(\dot{m}_{in} - \dot{m}_{out}) = (m_{in} - m_{out})_x + (m_{in} - m_{out})_y + (m_{in} - m_{out})_z$$

$$\dot{m}_{in} - \dot{m}_{out} = -\left(\frac{\partial}{\partial x} \rho u + \frac{\partial}{\partial y} \rho v + \frac{\partial}{\partial z} \rho w\right) dV \quad \text{--- (2)}$$

$$\frac{d\rho}{dt} d\cancel{V} = -\left(\frac{\partial}{\partial x} \rho u + \frac{\partial}{\partial y} \rho v + \frac{\partial}{\partial z} \rho w\right) d\cancel{V}$$

$$\boxed{\frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho w) + \frac{\partial \rho}{\partial t} = 0}$$

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(Gradient or del operator (∇)   div — divergence

$$\nabla = \hat{i}\,\partial/\partial x + \hat{j}\,\partial/\partial y + \hat{k}\,\partial/\partial z$$

$$\rho\vec{V} = \rho u\hat{i} + \rho v\hat{j} + \rho w\hat{k}$$

$$\text{div}(\rho\vec{V}) = \nabla\cdot(\rho\vec{V}) = \frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho w)$$

$$\boxed{\nabla(\rho\vec{V}) + \frac{\partial\rho}{\partial t} = 0}$$

1. Unsteady & compressible flow

$$\nabla\cdot(\rho\vec{V}) + \frac{\partial\rho}{\partial t} = 0$$

2. Steady & compressible flow.

$$\nabla\cdot(\rho\vec{V}) = 0$$

3. Unsteady & Incompressible flow

$$\nabla\cdot\vec{V} = 0$$

4. Steady & Incompressible flow

$$\nabla\cdot\vec{V} = 0.$$

Continuity eqn (in Polar co-ordinates)

x	y	z	dx	dy	dz	u	v	w
↓	↓	↓	↓	↓	⇓	⇓	‖	‖
r	θ	z	dr	$r\,d\theta$	dz	v_r	v_θ	v_z

$$\boxed{\frac{1}{r}\cdot\frac{\partial}{\partial r}(r\cdot\rho v_r) + \frac{\partial}{r\,d\theta}(\rho v_\theta) + \frac{\partial}{\partial z}(\rho v_z) + \frac{\partial\rho}{\partial t} = 0}$$

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One-Dimensional cross sectionaly avg form of continuity eqn.

Consider steady flow through variable Area conduit.

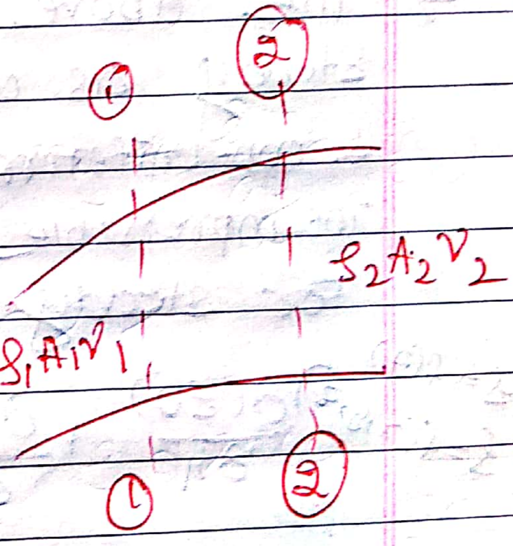
$$m_{in} - m_{out} = m_{st}$$

$$\rho_1 A_1 V_1 - \rho_2 A_2 V_2 = 0$$

$$\boxed{\rho_1 A_1 V_1 = \rho_2 A_2 V_2} \rightarrow \text{For compressible \& steady flow.}$$

For incompressible flow & steady flow

$$\boxed{A_1 V_1 = A_2 V_2}$$



Representatn of continuity eqn.

$$\frac{\partial(\rho A)}{\partial t} + \frac{\partial(\rho A V)}{\partial s} = 0$$

A = cross-sectional Area of flow

V = Velocity of flow,

s = co-ordinate in the flow direction.

For steady flow : ρ = constant with respect to time

$$\frac{\partial(\rho A V)}{\partial s} = 0$$

$$\rho A V = \text{constant}$$

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

For steady incompressible flow

$$A_1 V_1 = A_2 V_2$$

The general form of the continuity eq^n in cartesian co-ordinates system is

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0$$

ρ = density of fluid.

u, v, w are the components of velocity in x, y & z directions resply.

→ The above eq^n is applicable for steady as well as unsteady flow, uniform & non-uniform & compressible as well as incompressible flow.

For steady flow $\frac{\partial \rho}{\partial t} = 0$ then the above eq

$\rho \neq f(t)$

$\rho = f(x, y, z)$

$$\frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0$$

For incompressible flow ρ is constant

ρ = const

$\rho \neq f(x, y, z, t)$

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

For two-dimensional steady incompressible

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$$

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Bernoullis Equation.

It states that in a steady, ideal flow of an incompressible fluid, the total energy at any point of the fluid is constant. The total energy consists of pressure energy, kinetic energy and potential energy or datum energy.

i.e. $\frac{P}{\rho g} + \frac{v^2}{2g} + z = \text{constant}$.

Limitation of Bernoulli's Equation.

The Bernoulli's eqn has been derived from certain assumptions which are scarcely possible. Thus the Bernoulli's eqn has been derived under

→ The Bernoulli's eqn has been derived under the assumptions that the velocity of every liquid particle across any c/s of a pipe is uniform but in actual practice, it is not so. The velocity of liquid particle in the centre of a pipe is maximum & gradually decreases towards the walls of the pipe due to pipe friction. Thus while using the Bernoulli's eqn only the mean velocity of liquid should be taken into account.

→ The Bernoulli's eqn has been derived under the assumption that no external force except for Real fluid

① $E_2 < E_1$ ②

$E_1 \rightarrow E_1 \rightarrow E_2$

$E_1 = E_2 +$ Energy lost to overcome

Energy lost per unit wt = Head loss

$E_1/g = E_2/g + h_L$

$E_1 = E_2 + E_L$

$$\frac{P_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{v_2^2}{2g} + z_2 + h_L$$

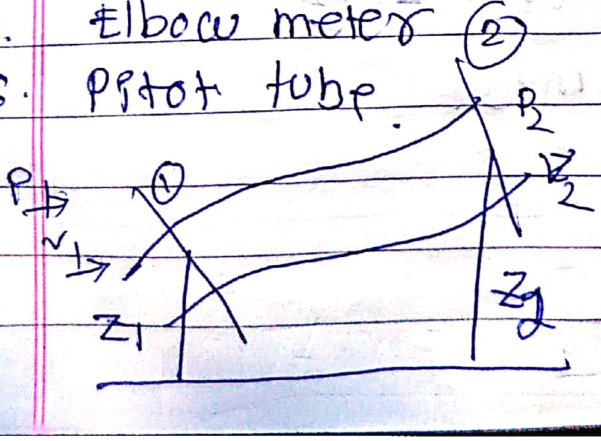
the gravity force is acting on the liquid. But in actual practice it is not so.

→ The Bernoulli's eq^n has been derived under the assumption that there is no loss of energy of the liquid while flowing. But in actual practice, it is rarely so. In a turbulent flow some K.E is converted into heat energy. & in a viscous flow, some energy is lost due to shear forces. Thus while using Bernoulli's eq^n all such losses should be neglected.

→ if the liquid is flowing in a curved path the energy due to centrifugal force should also be taken into account.

Application Bernoulli's eq^n

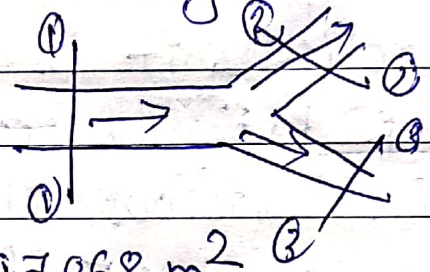
1. Venturimeter – used for measurement of flow fluid through a pipe.
2. Orifice meter
3. Nozzle meter
4. Rotameter
5. Elbow meter
6. Pitot tube



Assumptions of Bernoulli's eq^n

(i) The flow is steady
is Ideal
one dimensional
continuous
only pressure & gravitational force is considered.

Q) A 30 cm diameter pipe, conveying water, branches into two pipes of diameter 20 cm & 15 cm respectively. If the avg velocity in the 30 cm diameter pipe is 2.5 m/s. Find the discharge in this pipe. Also determine the velocity in 15 cm pipe, if the average velocity in 20 cm dia pipe is 2 m/s.



Given data

$d_1 = 30cm = 0.3 m$

$A_1 = \pi/4 \times d_1^2 = 0.07068 m^2$

$d_2 = 20cm = 0.2 m$

$A_2 = \pi/4 \times (0.2)^2 = 0.0314 m^2$

$d_3 = 15cm = 0.15 m$

$A_3 = 0.0176 m^2$

$v_1 = 2.5 m/s$

$v_2 = 2 m/s$, $v_3 = ?$

$Q_1 = Q_2 + Q_3$

$Q_1 = A_1 v_1 = 0.07068 \times 2.5 = 0.1768 m^3/s$

$Q_2 = A_2 v_2 = 0.0314 \times 2 = 0.0628 m^3/s$

$0.1768 = 0.0628 + A_3 v_3$

$v_3 = 6.417 m/s$

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Q4 Water is flowing through a pipe having diameter 600mm & 400mm at the bottom & upper end respectively. The intensity of pressure at the bottom end is 350 kN/m² and the pressure at the upper end is 100 kN/m². Determine the difference in datum head if the rate of flow through the pipe is 60lts/sec.

Given data:

$d_1 = 400mm = 0.4 m$, $P_1 = 100 \times 10^3 N/m^2$

$d_2 = 600 mm = 0.6 m$, $P_2 = 350 \times 10^3 N/m^2$

$$\text{Area } (A_1) = \frac{\pi}{4}(d_1)^2 = \frac{\pi}{4}(0.4)^2 = 0.125 m^2$$

$$\text{Area } (A_2) = \pi/4 (d_2)^2 = \pi/4 (0.6)^2 = 0.282 m^2$$

Discharge $Q_1 = a_1 v_1$

$$60 \times 10^{-3} = 0.125 v_1$$

$$v_1 = \frac{60}{1000 \times 0.125} = 0.48 m/s$$

Discharge $Q_2 = a_2 v_2$

$$60 \times 10^{-3} = 0.282 v_2$$

$$v_2 = \frac{60}{1000 \times 0.282} = 0.212 m/s$$

Applying Bernoulli's eqn

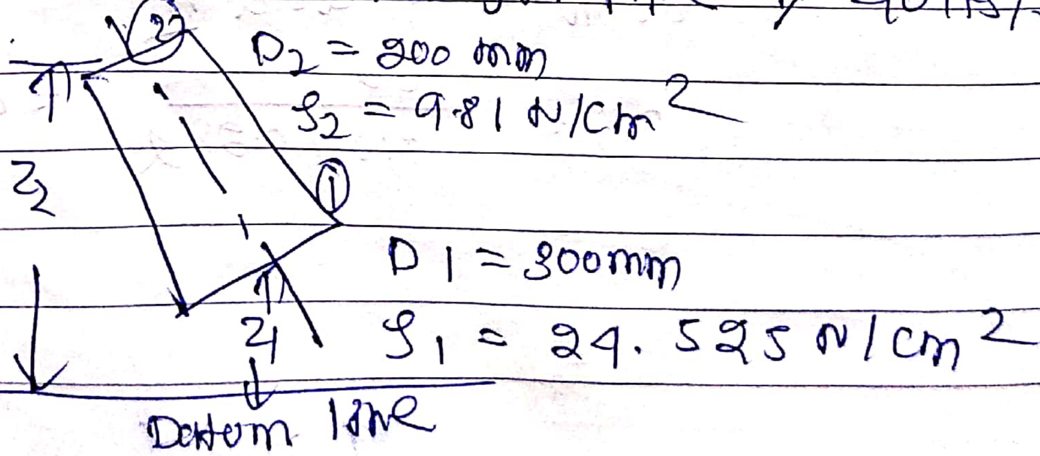
$$z_1 + \frac{P_1}{w} + \frac{v_1^2}{2g} = z_2 + \frac{P_2}{w} + \frac{v_2^2}{2g}$$

$$\Rightarrow z_1 + \frac{100\times10^3}{w} + \frac{0.48^2}{2\times9.81} = z_2 + \frac{350\times10^3}{w} + \frac{0.212^2}{2\times9.81}$$

$$\Rightarrow z_1 - z_2 = \frac{350\times10^3}{\rho g} + \frac{0.212^2}{2\times9.81} - \frac{100\times10^3}{w} + \frac{0.48^2}{2\times9.81}$$

$$= 25.468\ m$$

Q) Water is flowing through a pipe having diameter 300 mm & 200mm at the bottom & upper and respectively, the intensity of pressure at the bottom end is 24.525 N/cm² and the pressure at the upper end is 9.81 N/cm² Determine the differences in datum head of the rate of flow intensity of pressure at the bottom end is 24.525 N/cm², & the pressure at the upper end is 9.81 N/cm². Determine the differences in datum head of the rate of flow through pipe is 40 lts/s.



Notches and Weirs

1. Notch: It is a device used for measuring the flow rate of a liquid through a small channel or tank. It may be defined as an opening in the side of a tank or a small channel in such a way that the liquid surface in the tank or channel is below the top edge of the opening.

2. Weir: It is a concrete or masonary structure placed in a open channel over which the flow occurs. It generally in the form of vertical wall, with a sharp edge at the top running all the way across the open channel.

3. Nappe or vein: The sheet of water flowing through a notch or over a weir is called Nappe or vein.

4. Crest or sill: The bottom edge of a notch or a top of a weire over which the water flows is known as the sill or crest. It height above the bottom of the tank or channel is known as crest height.

Note: The notch is of small size while the weir is of a bigger size. The notch is generally made of metallic plate while weire is made of concrete or masonry structure.

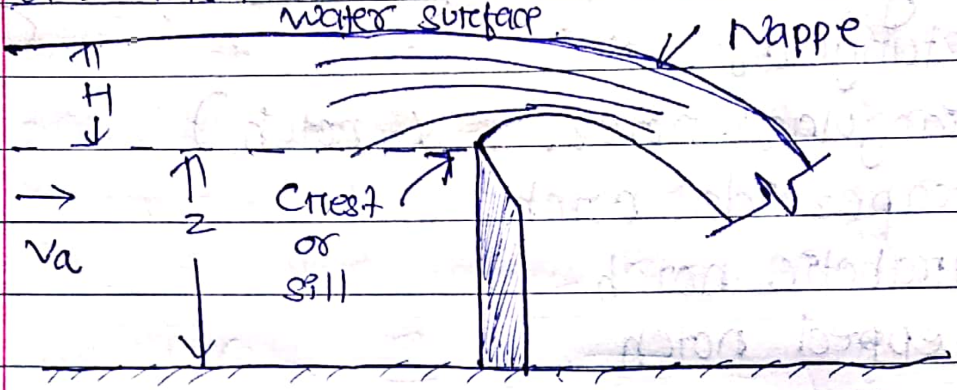
Classification of Notches

1. According to the shape of the opening
   (i) Rectangular notch
   (ii) Triangular notch (V-notch)
   (iii) Trapezoidal notch
   (iv) Parabolic notch
   (v) Stepped notch
2. According to the effect of sides on nappe emerging from a notch:
   (i) Notch with end contraction
   (ii) Notch without end contraction or suppressed notch.

Classification of Weirs

1. According to the shape of opening, weirs may be classified:
   (i) Rectangular weir (ii) Triangular weir
   (iii) Trapezoidal weir.
2. According to the shape of crest:
   (i) Thin plate or sharp-edged weir
   (ii) Narrow crested weir
   (iii) Broad crested weir
   (iv) Ogee shaped weir.
3. According to the effect of the sides on the issuing nappe.
   (i) Weir with end contration.
   (ii) Weir without end contraction.

Flow over a Rectangular Sharp-crested weir or Notch.



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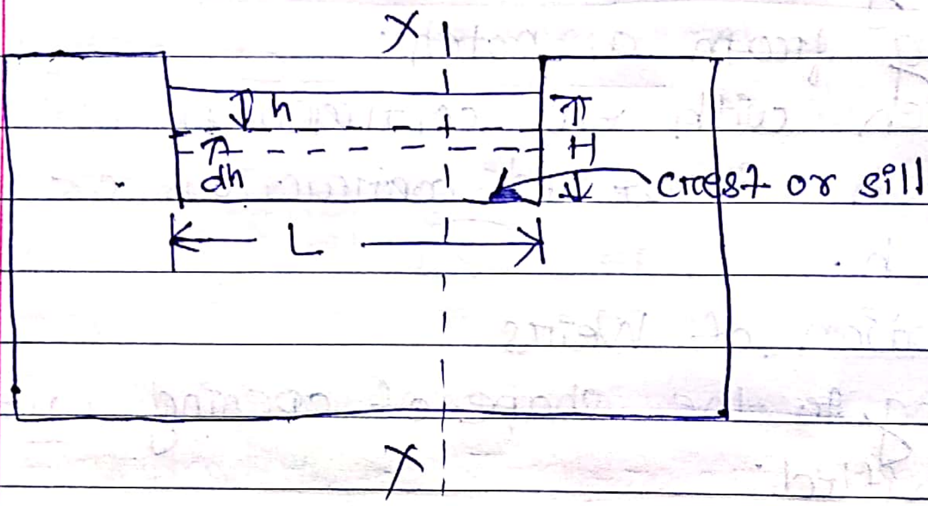


Flow over rectangular sharp crested weir or notch

→ Consider a rectangular sharp-crested weir or notch provided in a channel carrying water. Let L be the length of the crest of the weir or notch and H be the height of the water surface above its crest. which is known as the head causing the flow.

→ As water flows over weir or notch, the surface of water over the crest and immediately upstream of it becomes curved. The head H above the crest is therefore measured at a certain distance upstream of the weir or notch where the water surface may be assumed to be unaffected by the curvature effect.

→ consider an elementary horizontal strip of water of thickness dh and length L at depth h below the water surface.

Area of strip = L × (dh)

Theoretical Velocity (V_{th}) = $\sqrt{2gh}$.

Therefore, discharge passing through the strip

$$dQ = v \times dA$$

$$dQ = C_d \times L \times dh \times \sqrt{2gh}$$

C_d = co-efficient of discharge.

Applying integration in Eqn.

$$\int_0^Q dQ = L \int_0^H C_d \sqrt{2gh}\, dh$$

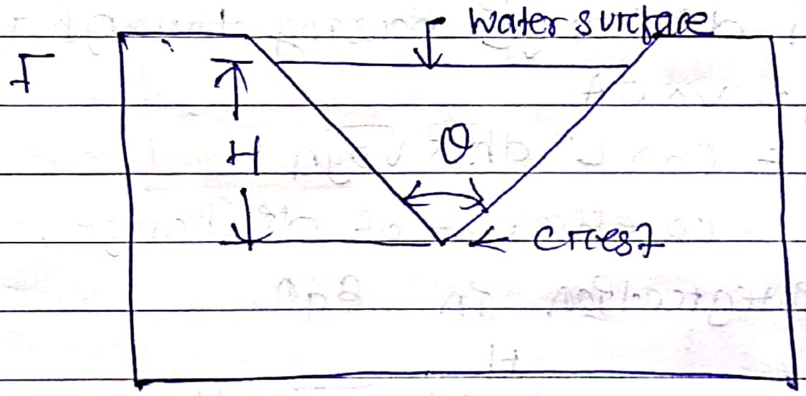
$$\boxed{Q = \frac{2}{3} C_d \sqrt{2g}\, L H^{3/2}}$$

Flow over a Triangular Weir (V-weir) or Triangular Notch (V-notch)

Generally, a triangular weir or notch is preferred over rectangular weir or notch for measuring the low discharges. This is so because in case of rectangular weir with low discharge the height of free water surface is very low which can not be measured.

accurately. But a triangular weir or notch may be used because the crest length for a triangular weir or notch is equal to zero and therefore even for a low discharge the head over the crest is fairly large which can be measured more accurately.

$$Q = \frac{8}{15} C_d \sqrt{2g} \cdot \tan\frac{\theta}{2} H^{5/2}$$



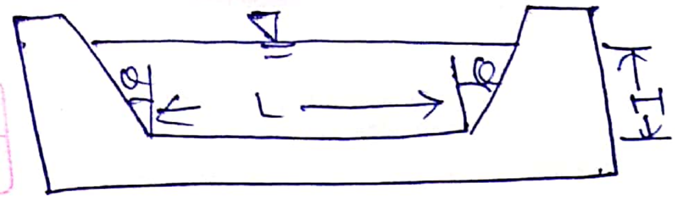
Flow over a Trapezoidal Weir or Notch

A trapezoidal weir or notch is the combination of a rectangular and a triangular weir or notch. The discharge over such a weir can be obtained by adding the discharge of the rectangular weir or notch and of the triangular weir or notch.

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

C_{d_1} = co-efficient of discharge for the rectangular portion.

C_{d_2} = " " " triangular portion.



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Discharge over a stepped Notch or weir

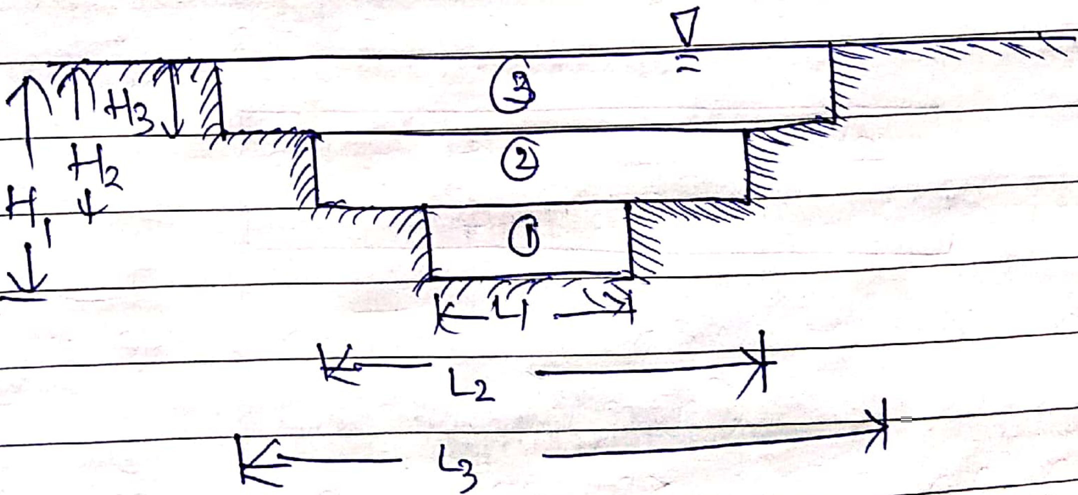
A stepped notch or weir is a combination of rectangular notches or weirs. Hence, the discharge through a stepped notch is equal to the sum of the discharges through the different rectangular notches.

Let $H_1; H_2, H_3$ be the height of water above the crest of notch (1), (2) and (3) respectively and L_1, L_2, L_3 are the respective crest lengths.

C_d = co-efficient of discharge for all notches.

Total discharge $Q = Q_1 + Q_2 + Q_3$

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



Stepped Notch or Weir.

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Reynold's Number

Reynolds discovered that the occurrence of a laminar and turbulent flow was governed by the relative magnitudes of the inertia and the viscous forces. Reynolds related the inertia to viscous forces and arrived at a dimensionless parameter.

$$Re = \frac{\text{Inertia force}}{\text{Viscous force}}$$

$$Re = \frac{\rho L^2 V^2}{\mu V L}$$

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

Where Re = Reynold's number
ρ = mass density of fluid
V = mean velocity
L = characteristic length = diameter of pipe for pipe flow (D)
μ = dynamic viscosity

For pipe flow

$$Re = \frac{\rho V L}{\mu} = \frac{VD}{\nu}$$

Where

ν = kinematic viscosity $= \frac{\mu}{\rho}$

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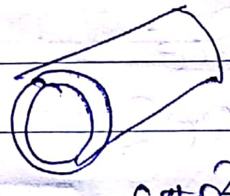
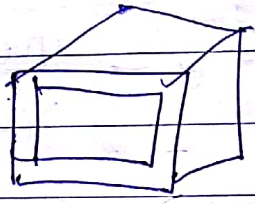
→ For flow through non circular pipes, the Reynolds number is based on the hydraulic diameter D_h defined as

$$D_h = \frac{4A_c}{P}$$

A_c = cross-sectional Area P = wetted perimeter





$$D_h = \frac{4\left(\frac{\pi D^2}{4}\right)}{\pi D} = D \qquad D_h = \frac{4a^2}{4a} = a$$

Flow condition	Reynolds No (Re)	Type of flow
flow in pipes	< 2000	Laminar
	2000 – 4000	Transition
		Turbulent
Flow betn parallel plates	< 1000	Laminar
	1000 – 2000	Transitional
	> 2000	Turbulent
Flow in a whole open Channel	< 500	Laminar
	500 – 1000	Transition
	> 1000	Turbulent

Losses of head of a liquid flowing through pipes.

When a fluid flows through a pipe, certain resistance is offered to the flowing fluid, which results in causing a loss of Energy.

Pipe losses

- **Major losses** (pipe, wall friction)

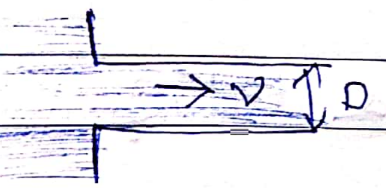
$$h_L = f\left(\frac{L}{D}\right)\left(\frac{v^2}{2g}\right)$$

↳ can be calculated using darcey weisbach eqn.

- **Minor losses** (Energy loss due to Eddy formation)

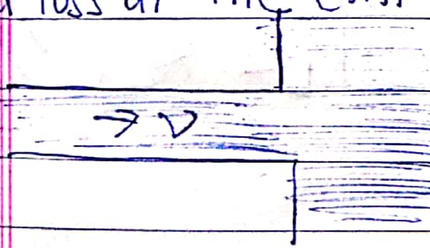
1. Head loss at the entrance of pipe.
2. Head loss at the exit of the pipe.
3. Head loss due to sudden contraction.
4. Head loss due to sudden expansion.
5. Head loss due to pipe bend.
6. Head loss due to valves and fittings.

① Head loss at the entrance of pipe



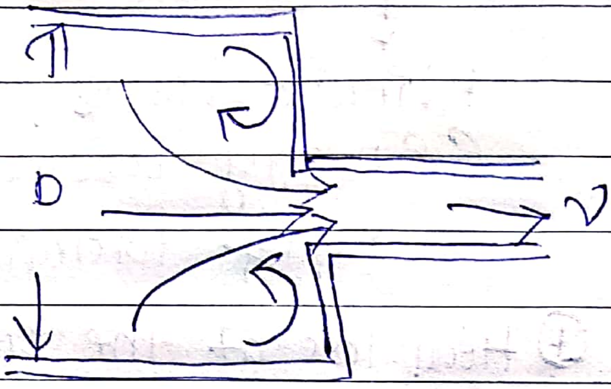
$$h_L = 0.5\left(v^2/2g\right)$$

② Head loss at the exit of the pipe.



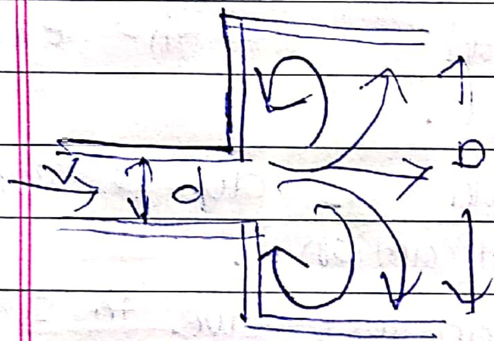
$$h_L = \left(v^2/2g\right)$$

3. Head loss due to Sudden contraction



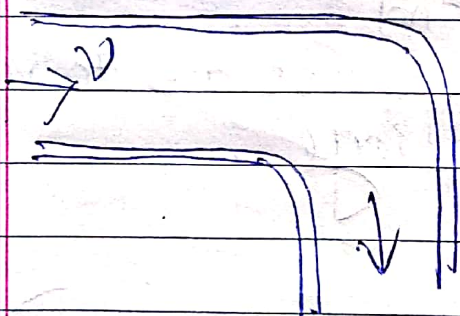
$$h_L = 0.5\left(v^2/2g\right)$$

4. Head loss due to sudden Expansion



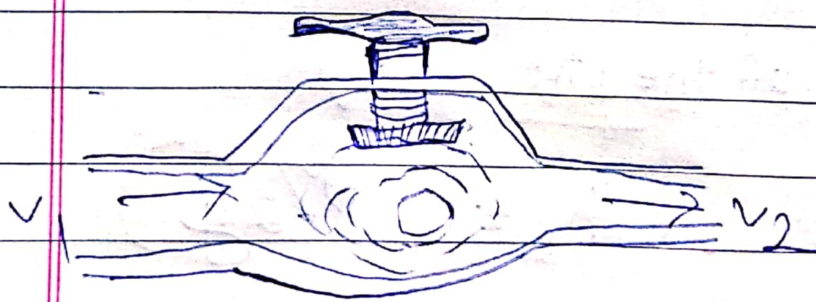
$$h_L = (v_1 - v_2)^2/2g$$

5 Head loss due to pipe Bend



$$h_L = K_L\left(v^2/2g\right)$$

(6) Head loss due to Valves & fittings



$$h_L = K_L\left(v^2/2g\right)$$

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Majore losses

The majore loss of energy, as a fluid flows through a pipe, is caused by friction. It may be computed by Darcy-weisbach eqn as indicated as earlier. The loss of energy due to friction is classified as a major loss because in the case of long pipelines it is usually much more than the loss of energy incurred by other causes.

Minor losses

The minor losses of energy are those which are caused on account of the change in the velocity of flowing fluid. In case of long pipes these losses are usually quite small as compared with the loss of energy due to friction and hence these are termed as minor losses.

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* Hydraulic Gradient Line. (HGL)

It is defined as the line which gives the sum of pressure head (P/γ) and datum head (z) of a flowing fluid in a pipe w.r.t some reference line.

It is also known as piezometric head ($P/\gamma + z$) line.

* Total Energy line (TEL)

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

$$TEL = \frac{P}{\rho g} + \frac{V^2}{2g} + z$$

→ It is also known as Energy line

Note.

→ Total energy line always goes down in the direction of flow untill or unless an external energy is supplied during the flow.

→ Hydraulic gradient line may rise or fall in the direction of flow.

→ for a pipe of uniform dia HGL & TEL will always be parallel to each other.

Flow through the Open Channels

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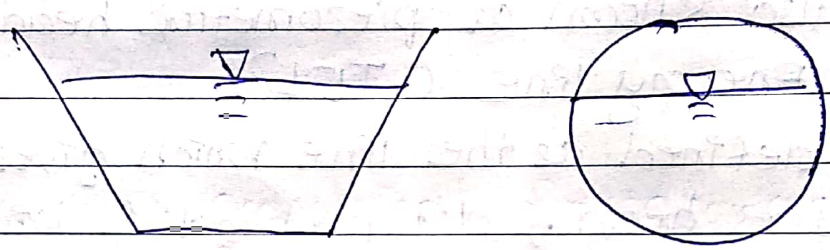
Flow in open channel (i.e. open to atmosphere) or in a closed conduit (Ex pipe) in which liquid does not fill the conduit completely is called open channel flow.



Most Economical or Most Efficient section of Channel.

→ A section is said to be economical when its construction cost is minimum for a given discharge.

→ A channel section is considered to be the most economical or most efficient when it can pass maximum discharge for given cross-sectional area, resistance co-efficient & bottom slope.

$$Q = AV = A \cdot \frac{1}{n} R^{2/3} S_0^{1/2}$$

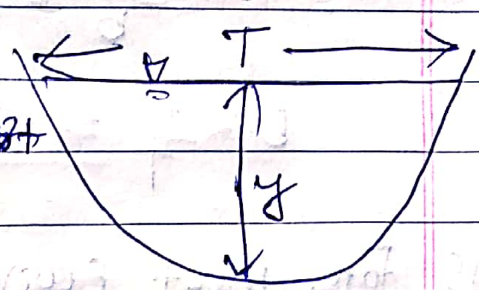
Discharge is max^m when R becomes max^m

since $R = \frac{A}{P}$

Therefore R is maximum when P is minimum

→ As we know that the highest component of total construction cost is a channel sectⁿ is cost of lining & if the perimeter is kept minimum the cost of lining will be minimum, hence it will be most economical sectn.

Channel Geometry



y = depth of flow
= free surface to deepest point.

T = Top width of flow
= width of free surface.

P = wetted perimeter
= solid boundary in contact with fluid.

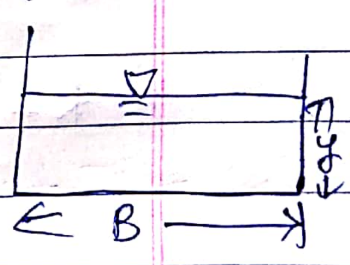
A = Wetted Area.
= c/s Area of flow.

R = hydraulic radius = hydraulic mean depth
$= \frac{\text{wetted Area}}{\text{wetted perimeter}} = \frac{A}{P}$

D = hydraulic depth $= \frac{A}{T}$

1. **Rectangulare Channels section.**

consider a Rectangular channel section of width (B) & depth of flow (Y)



Area of the flow $A = By$

Wetted perimeter $P = B + 2y$

R (Hydraulic Radius) $= \frac{A}{P} = \frac{by}{b+2y}$

In case of wide Rectangular channel
$y <<< b$ (e.g. Rivers)

$$R = \frac{by}{b} = y$$

2 mark
IMP

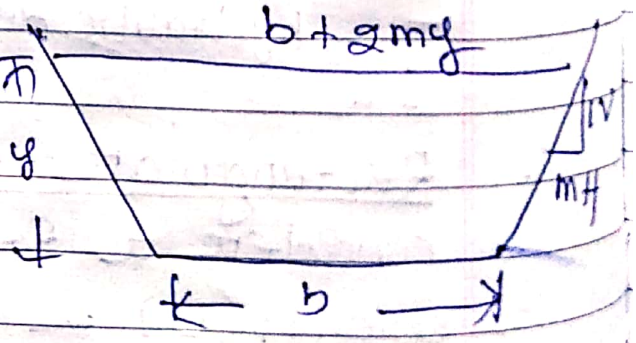
$$D = \frac{A}{T} = \frac{by}{b} = y$$

Conditions for most economical Rectangular section

1. $A = 2y^2$
2. $T = 2y$
3. $P = 4y$
4. $R = y/2$
5. $D = y$

Trapezoidal channel section.
consider a channel section of bottom width (B) depth of flow (y) side slope = 1 : m

$T = b + 2my$
$A = by + my^2$
$A = (b + my)y$
$P = b + 2y\sqrt{1+m^2}$



$$R = \frac{A}{P} = \frac{(b+my)y}{b + 2y\sqrt{1+m^2}}$$

$$D = \frac{A}{T} = \frac{(b+my)y}{b + 2my}$$

→ Thus, the most Economical Trapezoidal channel secⁿ is half of the regular hexagon

Imp 2 mark) condition

For most economical trapezoidal channel

1. $B = \frac{2y}{\sqrt{3}}$

2. $T = \frac{4y}{\sqrt{3}}$

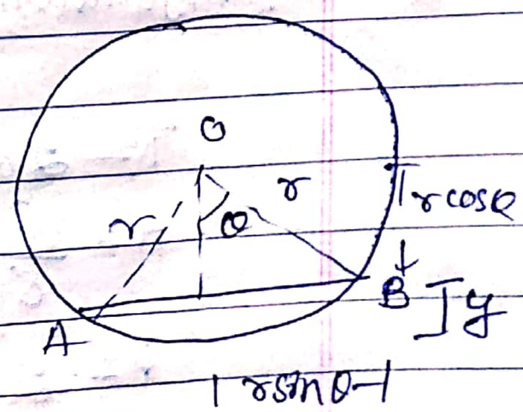
3. $A = \sqrt{3}y^2$

4. $P = \frac{6y}{\sqrt{3}}$

5. $R = y/2$

6. $D = A/T = \frac{3y}{4}$

<u>Circular Channels</u>



$T = 2r\sin\theta$

A = Sector Area OACB − Area of △le OAB

For $2\pi \rightarrow \pi r^2$

$2\theta \rightarrow r^2\theta$

$A = r^2\theta - \frac{1}{2} \times 2r\sin\theta \times r\cos\theta$

$= r^2\left(\theta - \frac{\sin 2\theta}{2}\right) = r^2\left(\frac{2\theta - \sin 2\theta}{2}\right)$

$= \frac{d^2}{8}(2\theta - \sin 2\theta)$

$P = 2r\theta = d\theta$

$$R = \frac{A}{P} = \frac{d^2(2\theta - \sin 2\theta)}{8 \cdot d\theta}$$

$$R = \frac{d(2\theta - \sin 2\theta)}{8\theta}$$

$$D = \frac{A}{T} = \frac{d(2\theta - \sin 2\theta)}{8 \cdot \sin\theta}$$

2marks
IMP

If the circle is half full ($2\theta = \pi$)

Wetted Area $= \frac{\pi r^2}{2}$

Wetted perimeter $= P = \pi r$

Hydraulic Radius $R = \frac{A}{P} = \frac{r}{2} = d/4$

$T = 2r\sin\theta$

$A = \frac{d^2}{8}(2\theta - \sin 2\theta)$

$P = 2r\theta = d\theta$

$$R = \frac{d(2\theta - \sin 2\theta)}{8m}$$

$$D = \frac{d(2\theta - \sin 2\theta)}{8\sin\theta}$$

IMP 2 marks.

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Chezy's Formula.

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

C = Chezy's constant

m = hydraulic Radius = $\frac{A \text{ (Area)}}{P \text{ (wetted perimeter)}}$

i = slope of the bed.

Empirical relations for the chezy's constant C

1. Bazin's Formula

$$C = \frac{157.6}{1.81 + \frac{K}{\sqrt{m}}}$$

where K = Bazin's constant

2. Kutter's formula

$$C = \frac{23 + \frac{0.00155}{S} + \frac{1}{N}}{1 + \left(23 + \frac{0.00155}{S}\right)\frac{N}{\sqrt{m}}}$$

N = Kutter's constant & S = bed slope.

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Manning's formula.

Manning gave an empirical formula according to which the mean velocity V of uniform flow in a channel is expressed in terms of a co-efficient of roughness, called Manning's n, hydraulic radius & slope of channel bottom, so as.

$$V = \frac{1}{n} R^{2/3} S_0^{1/2}$$

Merits of Manning's formula:

1. It is a simple formula.
2. As most of the channels are turbulent it has experimental report compared to other formula. It is more accurate.

* Relatⁿ betⁿ Chezy 'C' & Manning 'n'

$$V = C\sqrt{RS} = \frac{1}{n} R^{2/3} S^{1/2}$$

$$\boxed{C = \frac{1}{n} R^{1/6}}$$

Part : B (Irrigation Engineering)

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Hydrology

1. Hydrology cycle.
2. Rainfall types, intensity, hyetograph.
3. Estimation of rainfall, rain gauges, its types
4. Catchment Area, types, run-off Estimation of flood discharge by Dicken's & Ryve's formulae.

Hydrology - Hydrology is a science which deals with the occurrence, circulation and distribution of water on the earth and earth's atmosphere.

The Hydrologic cycle.

→ It is also known as water cycle.

→ water occur on the eath & atmosphere in all three states (liquid, gas, solid). There is endless circulation of water betn the earth and atm.

→ This circulation is called hydrologic cycle.

→ The hydrologic cycle is a continuous process in which water is evaporated from water surface and oceans, moves inland as moist air masses and produce presipitation. if the correct vertical lifting conditions exist.

→ sun imparts energy movement of the cycle.

→ Extent of Hydrologic Cycle: 1km below earth surface to 15 km above earth surface.

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Components of Hydrologic cycle.

(I) Evaporation: When the water come into contact with heat radiation, it turns into vapour. It is called evaporation.

→ In hydrologic cycle, evaporation mainly occur from ocean. ocean contributes large part and the real evaporation occur from land mass and raindrop evaporation.

(II) Precipitation: As evaporation continues, the amount of vapour in atmosphere goes on increasing, after reaching a certain amount, the vapour condense and come to earth's surface in solid or liquid form, this is called precipitation.

(III) Interception: Some amount of precipitation is evaporated back to the atmosphere and another parts of precipitation is intercepted by vegetation, structure etc. from where it may be either evaporated back to atmosphere or move down to ground surface.

(IV) Infiltration: When water comes into the earth surface. some portion of it penetrate the ground and increases the moisture capacity of soil beneath the surface.

→ This water is called infiltrated water & this process is called infiltration.

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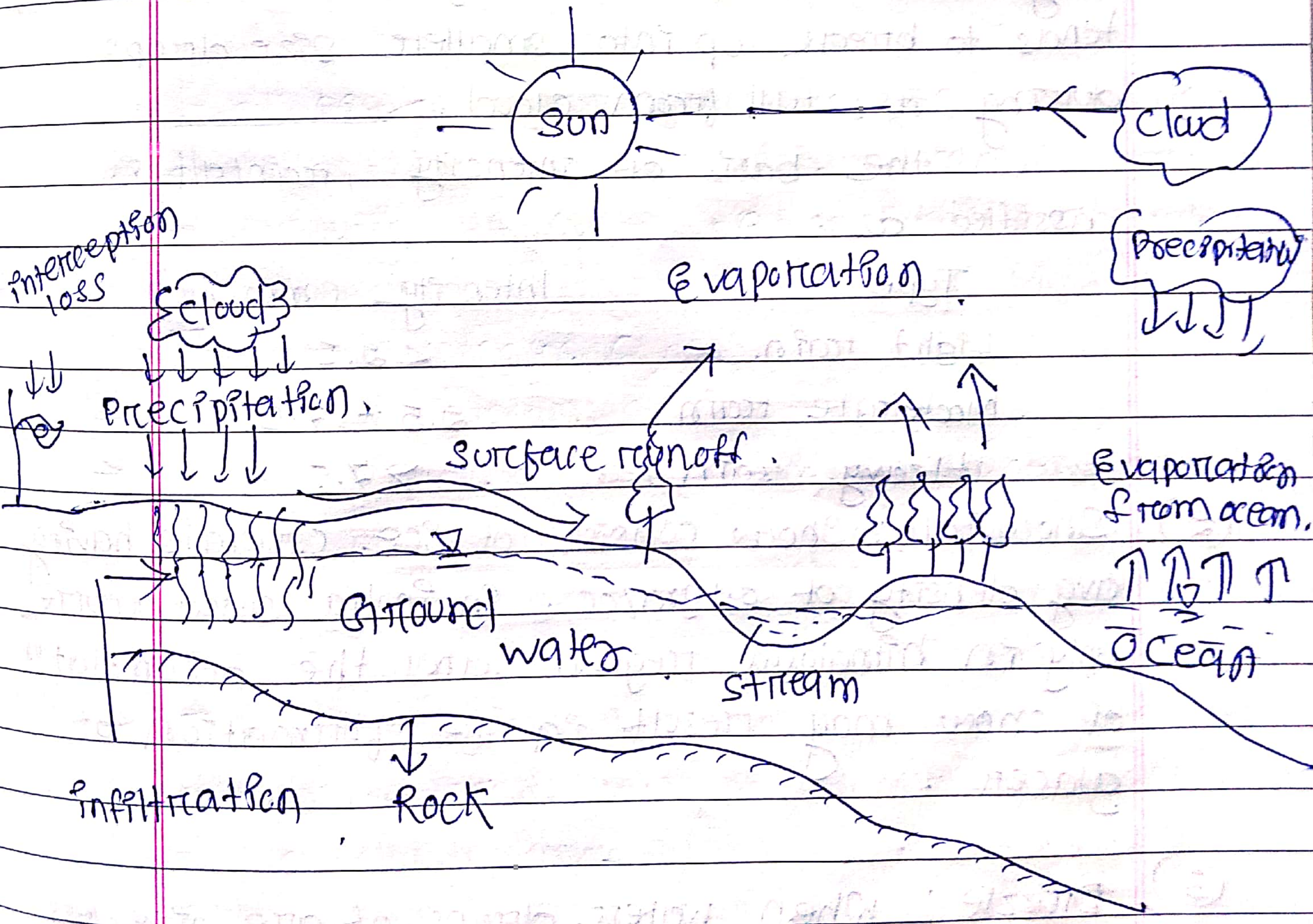
(v) Transpiration: Vegetation use the ground water or soil moisture for their growth. This moisture again convert in evapaporation through vegetation. This is called transpiration.

(vi) Runoff: The portion of precipitation which come on the surface & reach the stream channel by above & below the surface of earth is called runoff.



The global hydrologic cycle.

Precipitation : The term precipitation denotes all forms of water that reaches on the earth from atmosphere.

Forms of Precipitation

(1) Rain. It is the most common form of precipitation. In this the water droplet size are larger than 0.5mm and smaller than 6mm.

→ Any drops of water larger then size 6mm tends to break up into smaller size drops during its fall from cloud.

On the basis of intensity, rainfall is classified as :

Type	Intensity (mm/hr)
Light rain	< 2.5
Moderate rain	2.5 - 7.5
Heavy rain	> 7.5

(2) Snow Fall : Snow consist of ice cristals having avg density of 0.1gm/cc. In India snow occure only in himalaya region and the accumulation of snow may result in the formation of glacer.

(3) Drizzle : When water drops of are size less than 0.5mm & the intensity of water flow less than 1mm/h then it called drizzle.

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(4) glaze : When the water droplet (rain & drizzle) come in contact with ground which have the temperature near about 0°C or less than it.

(5) Sleet : It is a frozen rain drops if falling rains convert into ice crystal at some freezing temp then it is called sleet.

(6) Hail : if ice crystal convert into lumps of size more than 8mm then it is called Hails.

Hails are formed due to violent thunder strom in which vertical currents are very strong (i.e movement of water in vertical direction is very high).

Index of Wetness :

$$\text{index of Wetness} = \frac{\text{Rainfall in any year}}{\text{Avg rainfall of all the years (min}^m\text{ 30 years)}}$$

Presentation of Rainfall data

Methods (I) Mass curve of rainfall
(II) Hyetograph
(III) Point Rainfall
(IV) moving average Method.

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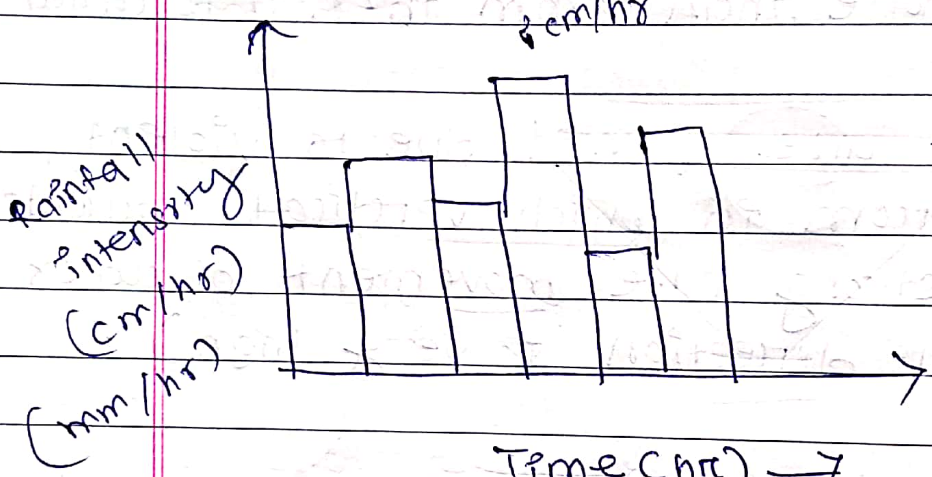
Hyetograph

A hyetograph is a plot of intensity of rainfall against time interval. the hyteograph is derived from the mass curve of rainfall & it is represented on the form of bar chart

Area of Hyetograph will be total rainfall.



Measurement of Rainfall

Rainfall is measuring cm/mm. Which is Volom / unit Area. It is measured by a instrument which is called rain gauge.

For setting of rain gauge following consideration are reqd.

A rain gauge must be surrounded by an open phase area of at least 5.5m x 5.5m. no object should be near to the instrument than 30m or twice the height of obstruction

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which ever is more.

→ The ground must be leveled & must represented a horizontal surface.

→ ~~Raingauge must be set as near the ground as possible to reduce the buid effect b.~~

Types of Rain gauges:

(1) Non recording Raingauge.
e.g - Symon's Raingauge.

(2) Recording Raingauge:
(i) Tipping Bucket type raingauge.
(ii) Weighing Bucket type raingauge.
(iii) Natural Syphon type raingauge.
or Float type Raingauge.

(3) Radar Measurement of Raingauge.

Non Recording Raingauge.

Symon's Raingauge

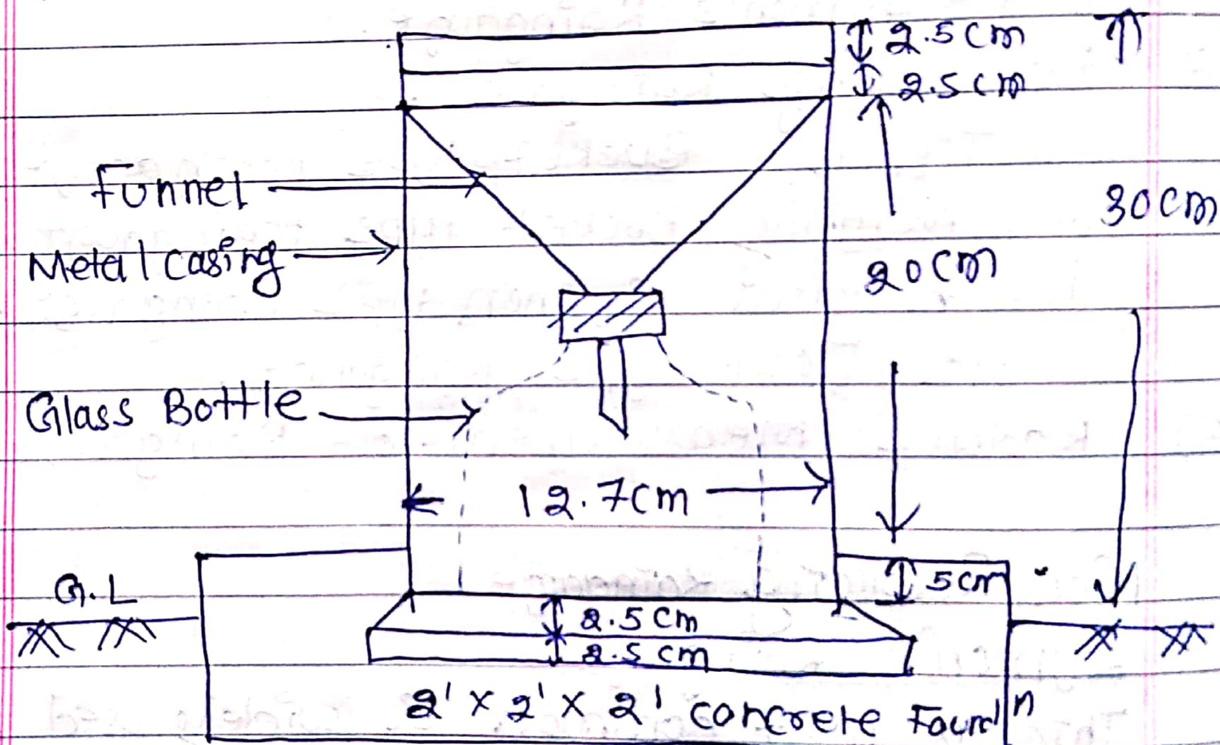
This is most common & widely used non-record rain gauge in India. It consist a circular vessel of 12.7 cm dia (5") 30.5cm height above ground level. It also called 5 inch rain gauge.

~~The rain water is discharge from funnel into the receving vessel of 12.7cm dia (5") 30.5cm height above ground level~~

It also called 5 inch rain gauge.

The rain water discharges from funnel into the receiving vessel. the funnel & Receiving vessel are inside metalic container. water receive in receiving vessel is measured in cm or mm.

Recently IMD has invented fiber glass polistere



Symon's non-recording raingauge

Disadvantages:

The receiving bottle normally does not hold more than 10cm of rain. if rain fall is more than 10cm i.e heavy rainfall the bottle may be overflow & hence it will

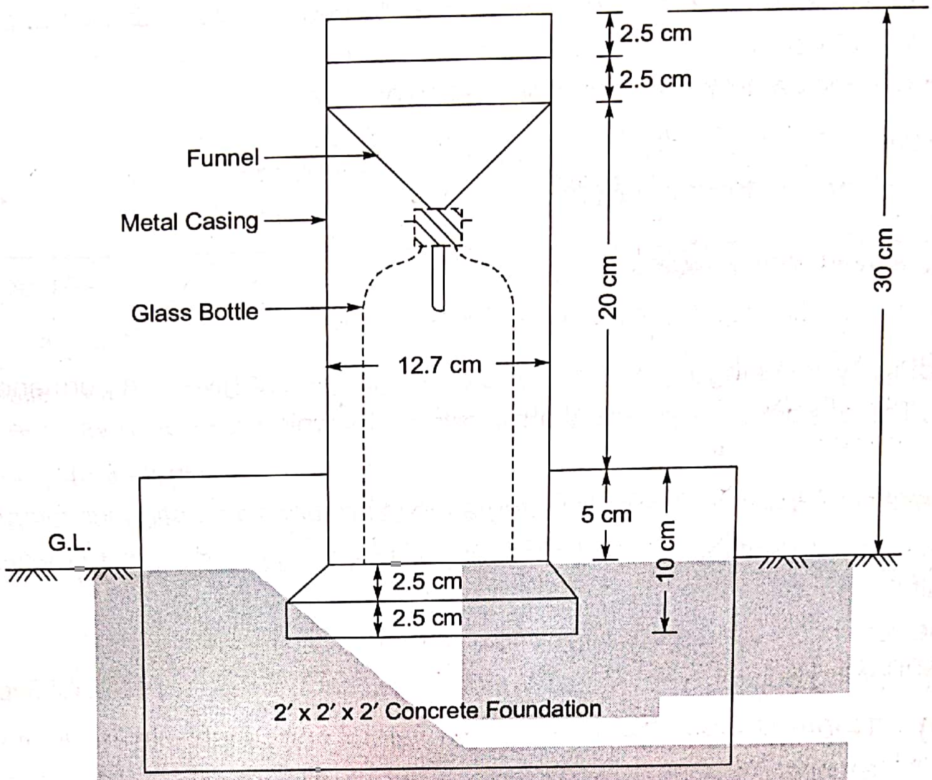


Fig.2.8 *Symon's non-recording rainguage*

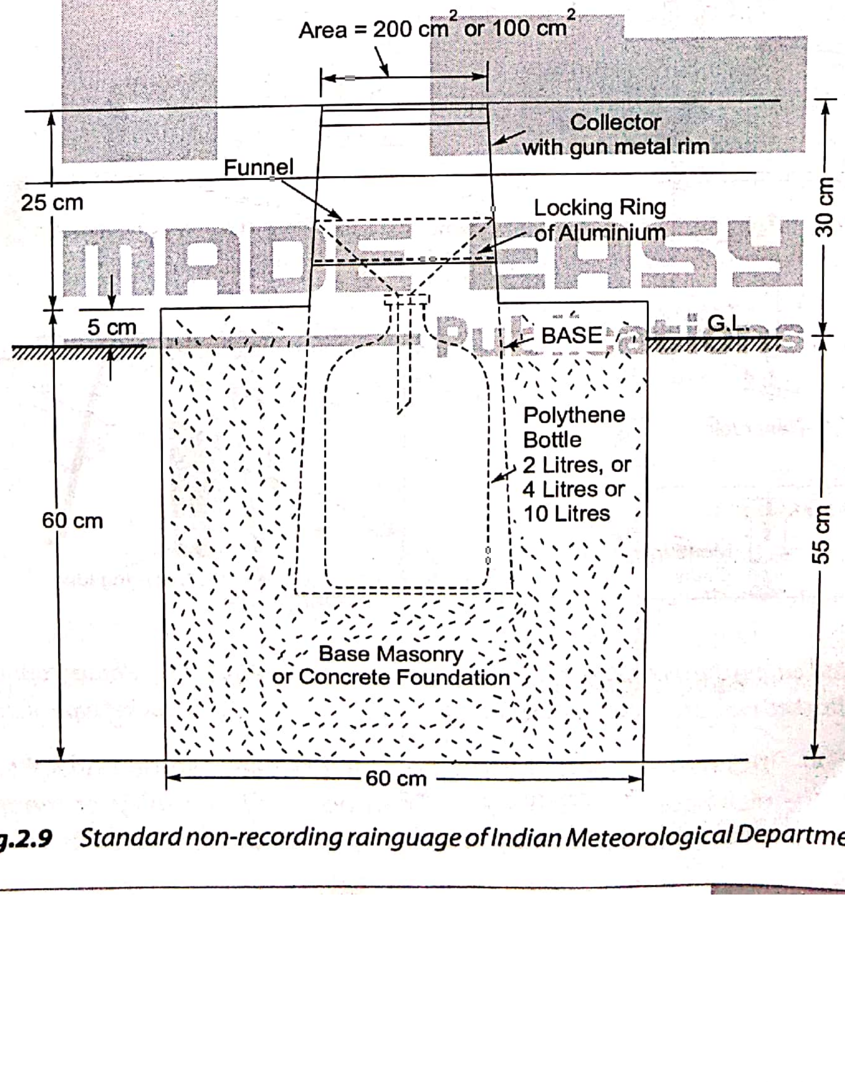


Fig.2.9 *Standard non-recording rainguage of Indian Meteorological Department*

- These raingauge can also be used to measure snowfall, when snow is expected. In the case of snow, the funnel and bottle is removed and snow is allowed to collect in the outer metal container. When the snow is melted, the depth of resulting water is measured.

- $$\frac{\text{Volume of water collected in bottle (cm}^3\text{)}}{\text{Area of the gauge (cm}^2\text{)}} = \text{Depth of rainfall(cm)}$$

Do you know? The rainfall in raingauge is measured everyday at 8:30 AM (*IST*) and is recorded as the rainfall of that day.

(ii) **Recording Type Raingauges:** This type of raingauge can give us a permanent automatic rainfall record. There is some mechanical arrangement by which *rain fallen vs. time plot* come on graph paper.

- These are sometimes called as *Integrating raingauges* or *continuous raingauges.*
- They are of great use in hills and for opposite areas, where it is not practically feasible to daily visit the gauge station.

The commonly used *recording raingauges* are:

(a) Tipping Bucket Type (b) Weighing Bucket Type (c) Natural Syphon Type

(a) **Tipping Bucket Type:** In this, rain water is first caught in a collector and passed through a funnel. The funnel discharge the water into a two bucket compartment when some amount of rain (0.10 - 0.25 mm) gets filled up in one compartment the bucket tips, emptying into a reservoir and moving the second compartment into place beneath the funnel.

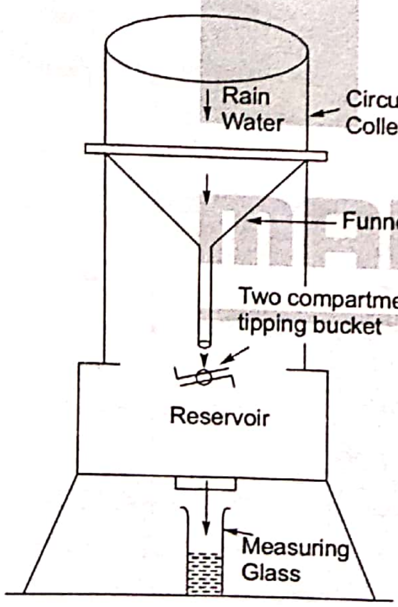


Fig.2.10 Indicating the recording mechanism of a 'Tipping Bucket' type of a recording rainguage

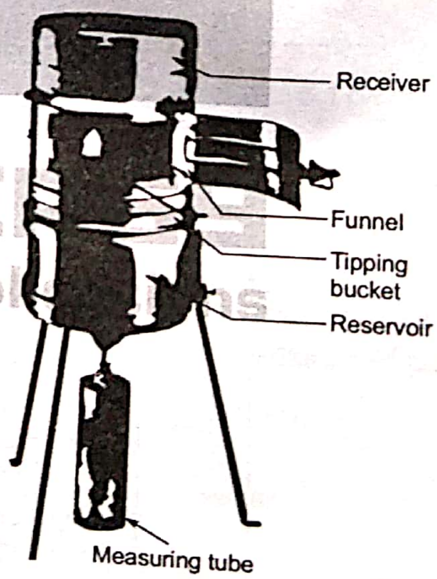


Fig.2.11 Photographic view of a Tipping Bucket type of a rainguage

- The movement of the tipping of the bucket can be transmitted electronically over distances. So such gauges can be installed in ***hilly or inaccessible areas***, from where they can supply measurements directly in the control room.

- The record from the tipping bucket type of raingauge gives the data of the ***intensity of rainfall.***

(b) **Weighing-Bucket Type Gauges:** In this type of raingauge, the weight of rain which falls into a bucket placed on the platform of a spacing on other weighing mechanism. The increasing weight of bucket helps in recording the increasing quantity of collected rain with time, by moving a pen on recording drum.

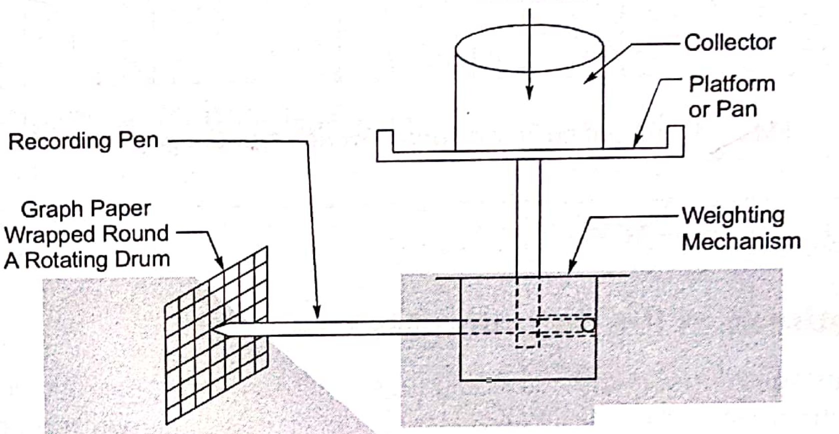


Fig.2.12 *Recording mechanism of a 'Weighing' type of a recording rainguage*

NOTE: This instrument gives a plot of *accumulated rainfall against the elapsed time*, means it provides mass curve of rainfall.

(c) **Natural-Syphon Type:** In this raingauge, the rainfall collected by a funnel-shaped collector and lead into a float chamber due to this float which rise. As the float rises, a pen attached to the float through a lever system records the elevation of the float on a rotating drum.

- A syphon arrangement empties the float chamber as the float has reached a pre-set maximum level and again the reading starts from initial point.

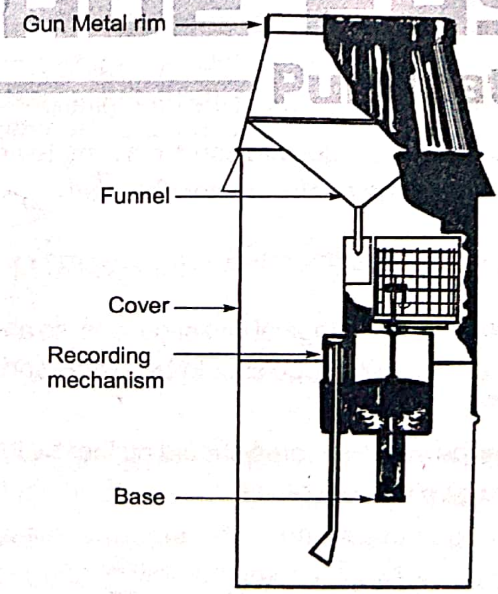


Fig.2.13 *Section through an automatic rainguage (Floating type)*

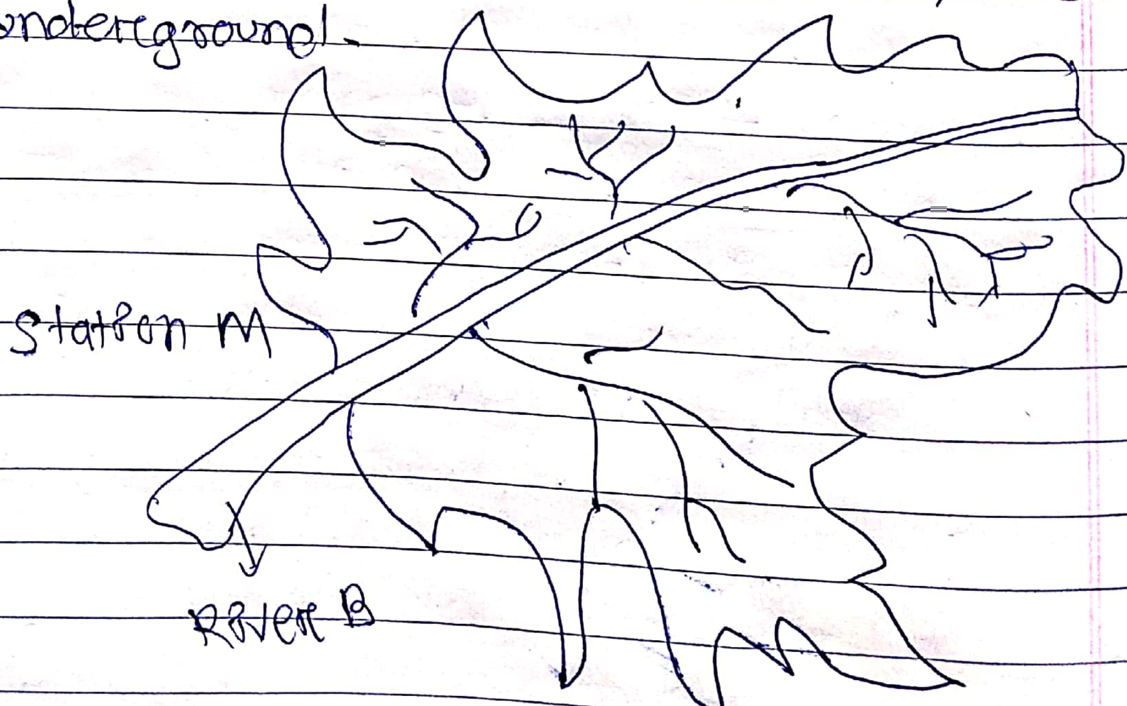
Catchment Area

→ The area of land from which the runoff comes into a stream is called the catchment Area of that stream.

→ It is also called as drainage basin or drainage area or water shed.

→ The Area of land draining into a stream or water course at a given location is known as catchment Area.

→ If the catchment has no outlet point than it is called a closed catchment. In closed Catchment water converges to a single point inside the basin known as sink, which may be a permanent lake, or a point where surface water is lost underground.



Sckematic Sketch of Catchment of River B at Station M

Estimation of Rainfall

Estimation of Missing Data

(1) Arithmetic Mean Method: If the normal annual precipitation of the nearby stations is 10% of within the normal annual precipitation at station X, then we use this method.

$$P_x = \frac{P_1 + P_2 + P_3 + \cdots P_n}{n}$$

Here $P_1, P_2, P_3 \cdots P_n$ are respective annual precipitation at station 1, 2, 3 ... n.

(2) Normal Ratio Method

If normal precipitation at any of these selected stations differe by more than 10% selected station then we use normal ratio method.

$$P_x = \frac{N_x}{n}\left[\frac{P_1}{N_1} + \frac{P_2}{N_2} + \frac{P_3}{N_3} \cdots \frac{P_n}{N_n}\right]$$

Q/ A raingauge was inoperative for sometimes during which storm occur at three station A, B, C surrounding. Area the total precipitation recorded during the storm was 75, 58, 47 mm. respectively. The normal precipitation was 826, 618 and 482 mm respectively. And the station where rainfall data missing, the normal precipitation was 752 mm. Estimate the missing rainfall data.

Page No.
Date

$N_x = 757$ mm $P_x = ?$

$N_A = 826$ mm $P_A = 75$ m

$N_B = 618$ mm $P_B = 58$ mm

$N_C = 482$ mm $P_C = 47$ mm

$N_x + 10\%$ of $N_x = 757 \times 1.1 = 832.7$ mm

$N_x - 10\%$ of $N_x = 757 \times 0.9 = 681.3$ mm.

$$P_x = \frac{N_x}{n}\left[\frac{P_A}{N_A} + \frac{P_B}{N_B} + \frac{P_C}{N_C}\right]$$

$$= \frac{757}{3}\left[\frac{75}{826} + \frac{58}{618} + \frac{47}{482}\right] = 71.198 \text{ mm}$$

Mean Precipitation over an Area.

In an Area, there are so many raingauge which show the rainfall data. As the data given by rainguge is point sample, but we need to find out the rainfall over the complete Area, so we use some methods.

(i) Arithmetic mean method.
(ii) Thiessen polygon method.
(iii) Isohyetal method.

(1) **Arithmetic Mean Method**

This method is used, when the rainfall measure at various stations in a catchment area show little variations or we can say the rain is uniformly distributed.

- This is a very simple method
- under normal condition, the result comes out from this is least accurate in comparision to other method.

If in a catchment, raingauges shows the rainfall $P_1, P_2, P_3 \cdots P_n$ in a given period then the average precipitation over the catchment is

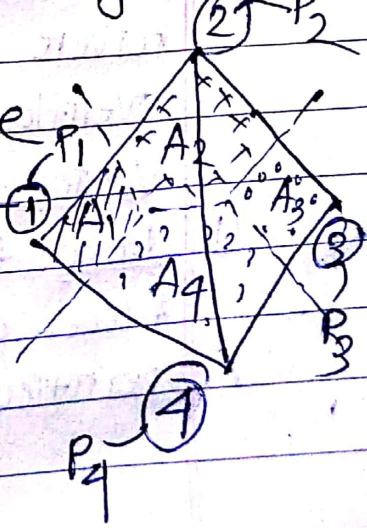
$$P_m = \frac{P_1 + P_2 + \cdots + P_n}{n}$$

Thiessen Polygon Method

In this method adjacent stations are joined by straight line thus forming a series of triangles & cut the entire straight line by perpendicular bisect thus forming a series on polygon.

- Each polygon containing one & only one raingauge station.

Let we have four raingauge 1, 2, 3, 4 for ppt^n values are P_1, P_2, P_3, P_4 cm respectively



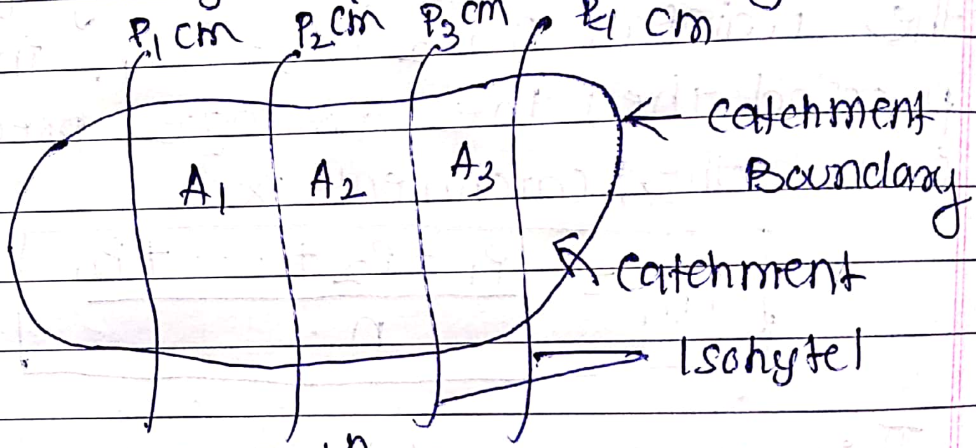
Mean Rain fall

$$\bar{P} = \frac{P_1A_1 + P_2A_2 + P_3A_3 + P_4A_4}{A_1 + A_2 + A_3 + A_4}$$

Isohytel Mtd

An Isohytel is a line ~~joing~~ joining the places of equal rainfall magnitude.

An isohydral map representing contours of equal interval and area enclosed betn two adjacent isohytel is measured by planimeter.



Mean precipitatn

$$\bar{P} = \frac{\left(\frac{P_1+P_2}{2}\right)A_1 + \left(\frac{P_2+P_3}{2}\right)A_2 + \left(\frac{P_3+P_4}{2}\right)A_3}{A_1+A_2+A_3}$$

* Flood

A flood is unusually a high stage in a river normally the level at which water overflow on its banks.

Various types of flood

(1) Design flood

flood adopted for design of a structure for a particular recurrence interval.

Date / /

2. Standard project flood

flood that could result from a sevior result from a seviour combination of metrological & hydrological factor that are applicable of any region is called standar project flood.

3. Probable Maximum flood

The extreem flood i.e physically possible in a region and a result of seviere most combination including rare combination of hydrological & metrological factor.

9 Marks IMP

Estimation of flood Peak

Empirical Method

① Dicken's Formula

Dicken gave the formula

$$Q_p = C_D A^{3/4}$$

Q_p = Maximum flood discharge (m^3/s)

A = Catchment Area (km^2)

C_D = Dicken constant ($6 < C_D < 30$)

Dicken's formula is given for the central & northern parts of country.

Ryve's Formula

This formula is originally developed for Tamil Nadu region. parts of Karnataka & AndraPradesh.

$$Q_p = C_R A^{2/3}$$

Q_p = Max^m flood discharge (m^3/s)

C_R = Ryve's co-efficient

A = Catchment Area (km^2)

CHAPTER 01

Irrigation Principles, Practices and Project

1.1 Definition of Irrigation

Irrigation may be defined as the process of artificial application of water to the soil or land for the growth of agricultural crops

In other words, it is a science of planning and designing a water supply system for the agricultural land to protect the crops from adverse effects of weather.

1.2 Main Concerns in Irrigation

Main concerns in irrigation are as follows:

(i) What should be the methods of irrigation?

(ii) How much moisture could be retained by the soil in their pores?

(iii) What should be the adequate time to irrigate the soil (i.e. optimum frequency of irrigation)?

In other words, after how much depletion of moisture level we should apply the next watering?

1.3 Advantages of Irrigation

(i) **Increase in crop yield**: Increase in crop yields occur on account of good irrigation systems leading to increase in food production

(ii) **Protection against famines:** Food production of a country can be increased by availing irrigation facilities. This helps preventing famine situations

(iii) **Revenue Generation:** Assumed supply of irrigation water leads to growing of superior crops by the farmers. Farmers become prosperous by selling the crops while governments revenue is generated by imposing taxes on irrigation water

(iv) **Avoidance of mixed cropping:** Mixed cropping means sowing of two or more crops together in the same field when weather conditions are not favorable for a particular type of crop. The need of mixed cropping is eliminated if we have good irrigation facility

(v) **Navigation:** Irrigation canals may be used for inland navigation. Inland navigation is useful for communication and transportation.

(vi) **Hydroelectric Power Generation:** Major river valley projects are planned to provide hydroelectric power together with irrigation. Thus, at the same time dual purpose is served

(vii) **Generation of employment opportunities:** During construction of irrigation works like canal headworks, weir/barrage, overhead irrigation works, employment opportunities are generated.

1.4 Disadvantages of Irrigation

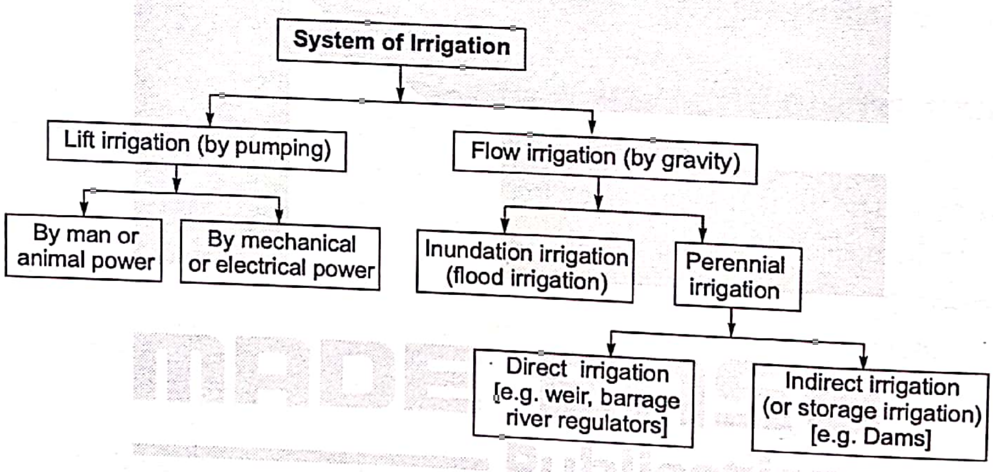
(i) **Wastage of irrigation water:** Abundant supply of irrigation water tempts the cultivators to use more than the required amount of water.

(ii) **Formation of marshy land:** Excessive seepage of water from irrigation canals may lead to formation of marshy lands along the course of the canals.

(iii) **Dampness in weather:** Temperature of the commanded area of irrigation project gets lowered considerably and the area may become damp. Dampness in the area lead to occurrence of diseases originating from dampness.

(iv) **Loss in valuable lands:** In various cases, valuable lands get submerged when storage reservoirs are formed on account of construction of weirs, barrages or dams.

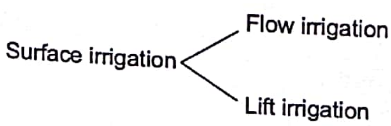
1.5 Systems of Irrigation



1.6 Surface and Sub Surface Irrigation

1.6.1 Surface Irrigation

- In this method, irrigation water is distributed to the agricultural land through small channels which flood the area upto a required depth.
- Water is applied and distributed either by gravity or pumping.
- This method is good for soils with low to moderate infiltration capacities and lands with uniform terrain.



(i) **Flow irrigation**

- Water available at higher level is supplied to a lower level by the action of gravity.

(ii) **Lift irrigation**

- Water available at lower level is lifted to a higher level by mechanical or manual means and then supplied for irrigation. (e.g. pumps etc.)
- Mostly tubewells are used for this purpose.

Flow irrigation can be further subdivided into:

(a) Perennial irrigation

(b) Flood irrigation

1.6.2 Subsurface Irrigation

- In this method, water flows underground and nourishes plant roots by capillarity.
- Water is applied to the root zones of crops by underground network of pipes.
- The network consists of main pipe, sub main pipes and lateral perforated pipes.
- This method is suitable for soils which are highly permeable.

It may be divided into following two types.

(i) **Natural Sub-irrigation**

- Leakage water from channels during its passage through sub soil irrigates crops sown on lower lands.

(ii) **Artificial Sub-irrigation**

- In this method, a system of open jointed drain is artificially laid below the soil.
- This is costly process, so recommended in areas where crops provide high returns.

1.7 Methods of Irrigation

Irrigation water can be applied to crop lands using one of the following irrigation methods :

(i) **Surface irrigation**

(a) Uncontrolled (or wild or free) flooding method,

(b) Border strip method,

(c) Check method,

(d) Basin method, and

(e) Furrow method.

(ii) **Subsurface irrigation**

(iii) **Sprinkler irrigation**

(iv) **Trickle (Drip) irrigation**

Each of the above methods have some advantages and disadvantages, and the choice of the method depends on the following factors:

(i) Size, shape, and slope of the field,

(ii) Soil characteristics,

(iii) Nature and availability of the water supply subsystem,

(iv) Types of crops being grown,

(v) Initial development costs and availability of funds, and

(vi) Preferences and past experience of the farmer

1.7.1 Uncontrolled Flooding

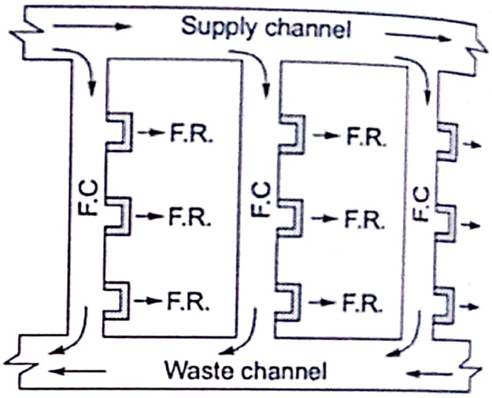


Fig. 1.1

- Ditches are excavated in the field.
- Water from these ditches are allowed to flow across the field without any restriction by opening the field regulators.
- In case of controlled free flooding, surplus water flows through the waste water channel and is discharged into the river or drainage.
- In this method, cost of land preparation is low and cost of labour is high.
- The main disadvantage is that the water application efficiency is low (especially when flooding is not controlled).
- In this case, we have series of field channels connected to the main supply channel.

1.7.2 Border Flooding

- In this method, land is divided into a series of long, uniformly graded, narrow strips separated by low levees (i.e. small bunds).
- Here, levees guide the flow of water down the field.
- Usually, length of strips is in the range 100 to 400 m whereas width of strips is in the range 10 to 20 m
- This method is suitable when the area is levelled in direction perpendicular to the flow in order to prevent water from concentrating on either side of the border.
- Water is allowed to flow from supply ditch into each strip and during its travel water gets infiltrated into the soil.
- As soon as the water reaches the lower end of the strip, water supply to that strip is turned off.
- This is the most popular method of flooding.

1.7.4 Basin Flooding

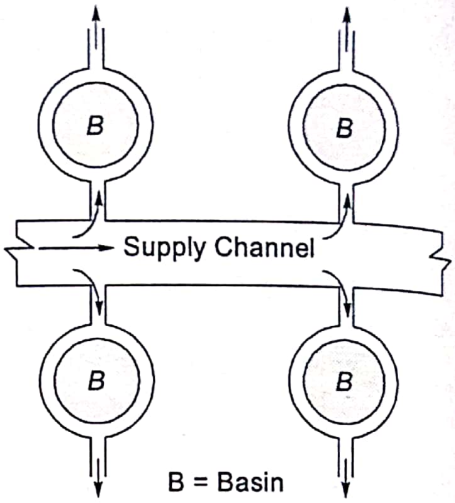


Fig. 1.4

- This method is mainly employed for watering orchards.
- In this method, one or more trees are generally enclosed by circular channel through which water flows.
- This circular channel acts as a basin.
- Each basin is connected to the field channel while field channel is connected to the supply channel.
- This method is most suitable for crops that are unaffected by standing water present over long period of time.

1.7.5 Furrow Method

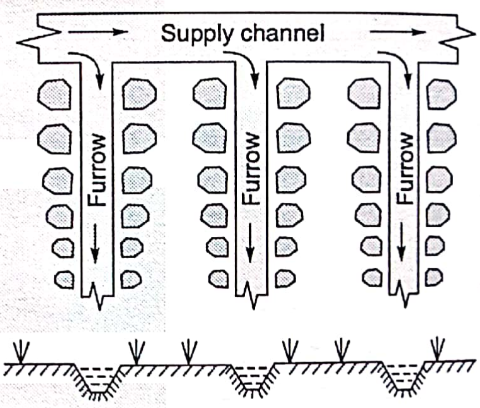


Fig. 1.5

- In this method, water is supplied to the land by digging narrow channels at regular interval.
- These narrow channels are called furrow.
- Water infiltrates through the wetted perimeter of the furrows and moves vertically and then laterally to saturate the soil.
- Usually, crops are grown on the ridges between the furrows.
- Depth of the furrows varies from 8 to 30 cm while length of furrows are around 400 m.
- This method is suitable for row crops like sugarcane, groundnut, potato, tobacco etc.
- Preferred on flat area or gentle slopes.

1.7.6 Subsurface Irrigation

Subsurface irrigation (or simply sub irrigation) is the practice of applying water to soils directly under the surface. Moisture reaches the plant roots through capillary action. The conditions which favor sub irrigation are as follows:

(i) Impervious subsoil at a depth of 2 meters or more,

(ii) A very permeable subsoil,

(iii) A permeable loam or sandy loam surface soil,

(iv) Uniform topographic conditions, and

(v) Moderate ground slopes.

In natural sub irrigation, water is distributed in a series of ditches about 0.6 to 0.9 meter deep and 0.3 meter wide having vertical sides. These ditches are spaced 45 to 90 meters apart. Sometimes, when soil conditions are favorable for the production of cash crops (i.e., high-priced crops) on small areas, a pipe distribution system is placed in the soil well below the surface. This method of applying water is known as artificial sub-irrigation. Soils which permit free lateral movement of water, rapid capillary movement in the root-zone soil, and very slow downward movement of water in the subsoil are very suitable for artificial sub-irrigation. The cost of such methods is very high. However, the water consumption is as low as one-third of the surface irrigation methods. The yield also improves.

1.7.7 Sprinkler Irrigation Method

- In this method, irrigation water is applied to the land in the form of a spray.
- Water is sprayed by employing the network of main pipe, sub main pipes and lateral pipes.
- Lateral pipes may be perforated at the top and sides or it may contain series of nozzles through which water comes out as a fountain.
- In present scenario, we are using mainly rotating sprinkles.

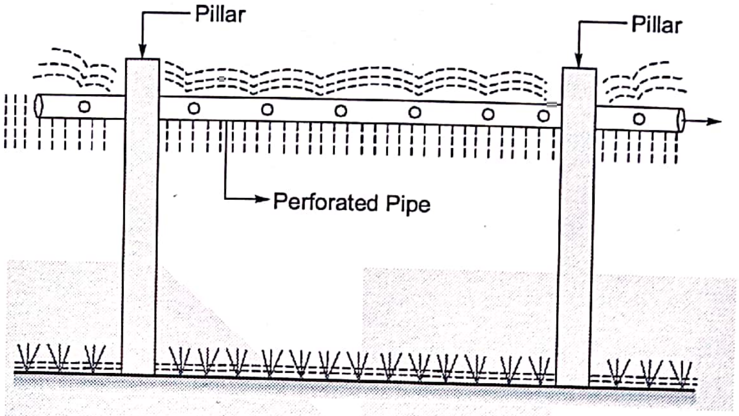


Fig. 1.6 *Perforated lateral pipes*

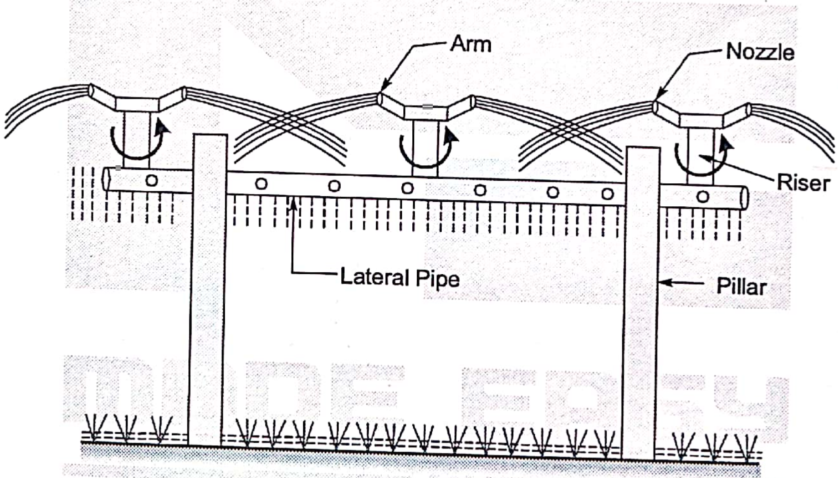


Fig. 1.7 *Rotary sprinklers*

1.7.7.1 Advantages of Sprinkler irrigation method

- Can be efficiently used for wide range of topography, soils and crops.
- Erosion of soil can be controlled
- Water is uniformly applied
- 80% of water application efficiency achieved
- Labour cost is reduced as no land preparation is required.
- No land levelling is required.

1.7.7.2 Disadvantages of Sprinkler irrigation method

- System is a bit costly to install, operate and maintain
- Continuous supply of power is required

- Corners remain unirrigated
- Under high wind condition and high temperature, application efficiency becomes poor
- High saline water at higher temperature causes leaf burning.

1.7.8 Drip Irrigation Method (Trickle irrigation)

- It is the latest method of irrigation
- In this method, water and fertilizer are slowly and directly applied to the root zone of the plant in order to minimize the evaporation and seepage losses
- Specially designed emitters and drippers are used for this purpose.
- This method is best suited for row crops and orchards (eg. tomatoes, grapes, corn, cauliflowers, cabbage etc.)

1.7.8.1 Advantages of drip irrigation

- Water requirement is minimal
- Evaporation losses are close to negligible
- Highest rate of vegetative growth is achieved in this method.
- Soil surface is least wetted and hence occurrence of diseases due to dampness decreases
- No land levelling is required
- No soil erosion takes place
- Less labour is required

1.7.8.2 Disadvantages of drip irrigation

- Plastic pipes or drippers may get attacked by the rodents
- Does not offer frost protection
- Needs regular flushing and supervision
- High skill is required in the design, installation, operation and maintenance

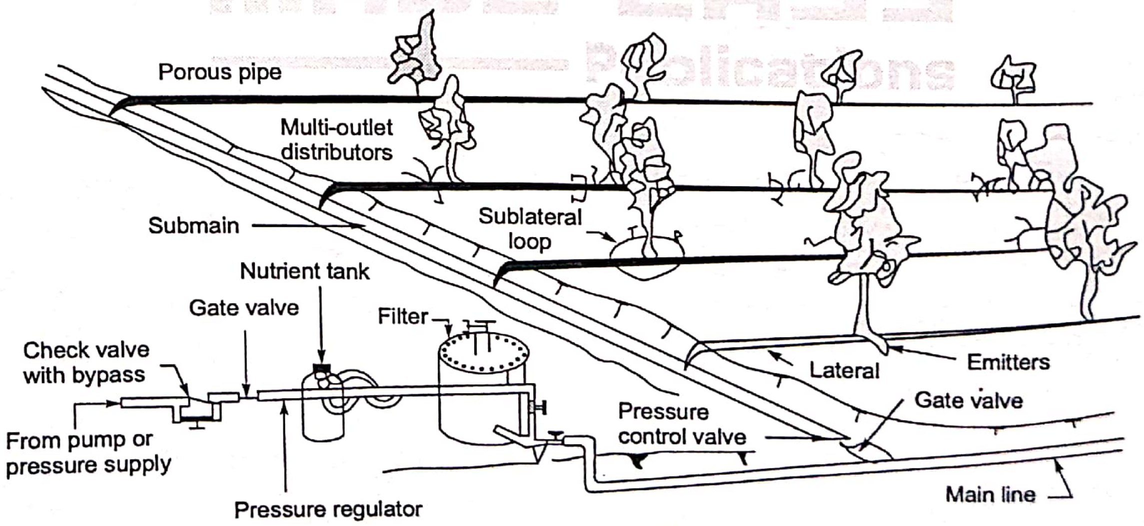


Fig. 1.8 *Line sketch of a typical drip irrigation system*

Water Requirements of Crops

3.1 Introduction

- The term water requirements of crop means the total quantity of water required by a crop from the time it is sown to the time it is harvested.
- Water requirement varies with both type of crop as well as place.
- For successful growth of crop, proper warmth, proper moisture, proper aeration, proper method of cultivation and proper agricultural soil are the main requirements.

3.2 Cropping Seasons in India

- There are mainly two crop seasons in India
  - (i) Rabi (Winter crops) ⇒ From October till March
  - (ii) Kharif (Monsoon Crops) ⇒ From April till September
- But there is also a crop season called Zaid in addition to Rabi and Kharif
- Sometimes in between Rabi and Kharif, Intermediate crops are also grown.

3.2.1 Rabi

- Rabi crops need relatively cool climate during the period of growth but warm climate during the germination of their seed and maturation
- Important crops are wheat, barley, gram, pea, mustard.

3.2.2 Kharif

- Crops are sown at the beginning of the south west monsoon and harvested at the end of the south west monsoon.
- Important crops are Rice, Jowar, Bajra, Groundnut, Jute

3.2.3 Zaid

- There are certain crops besides Rabi and Kharif which are being raised throughout the year with the help of artificial irrigation.
- Zaid Crops are divided into
  - → Zaid Kharif Crops
  - → Zaid Rabi Crops

NOTE: Irrigation crops of Rabi seasons are mostly crops with seeds

3.3 Duty and Delta

3.3.1 Duty

- Duty is defined as the area of the land irrigated by a unit discharge of water flowing continuously for the duration of the base period of the crop.
- It is denoted by *D*.
- Duty is mainly measured in hectares/m^3/s.
- Duty is essential for designing the physical structure of water storage and conveyance system.

NOTE: By comparing duty of an irrigation system with that of another irrigation system one can have an idea about the performance of the system.

3.3.1.1 Factors Affecting Duty of Water

(i) Type of crop
(ii) Climatic conditions
(iii) Method of irrigation
(iv) Type of soil
(v) Canal conditions
(vi) Time of irrigation and frequency of cultivation.

3.3.1.2 Types of duty

Duty is mainly of two types:

(i) Flow Duty of water

- Flow duty of water is the duty of water in case of direct flow irrigation.
- It is usually expressed in hectares per cumecs.

(ii) Storage (or Quantity) duty of water

- Storage duty of water is the duty of water in case of tank irrigation (or reservoir irrigation)
- It is usually expressed in hectare/one million cubic metre of water.

3.3.2 Delta

- Delta is the total depth of water in centimeters required by a crop to come to maturity
- It is denoted by symbol Δ

Example : If 5 cumecs of water is required for a crop sown in an area of 5000 hectares.

The duty will be $\frac{5000 \text{ ha}}{5 \text{cumec}}$ = (1000 ha/cumecs)

3.4 Crop Period and Base Period

3.4.1 Crop Period

- Crop period is the total time period from the instant of sowing of the crop to the instant of harvesting of the crop.

3.4.2 Base Period

- Base Period is the total time period from the first watering done for the preparation of land to the last watering done before its harvesting.

NOTE: (i) Crop period is greater than base period
(ii) Crop period and base period are expressed in days

3.5 Relation between Duty and Delta

Duty, $$D = \frac{8.64 \times B}{\Delta}$$

Where, D = Duty of water on the field (in ha/cumecs)
Δ = total depth of water supplied to a crop growing on the field during entire base period (in meter)
B = Base period of crop (in days)

3.5.1 Derivation

Let there be a crop of base period 'B' days. To this crop, 1 cumec of water is applied for 'B' days

Then,

Volume of water, $$V = 1 \times (B \times 24 \times 60 \times 60) = 86400\,B \text{ cubic meters}$$

Let V cubic meters of water mature D Ha of land

D Ha of land = $D \times 10^4$ square meters

$$\therefore \quad \Delta = \frac{V}{A} = \frac{86400\,B}{D \times 10^4} = \frac{8.64\,B}{D} \text{(in meters)} = \frac{864\,B}{D} \text{ (in centimeters)}$$

3.6 Important Definition Linked with Water Requirements of Crops

(i) Command Area (CA)

- It is that area which can be irrigated by a canal system.

(ii) Gross Command Area (GCA)

- It is the total area which can be irrigated by a canal so that unlimited quantity of water is available
- A canal is usually aligned along the water shed between two drainage valleys
- In other words, GCA is the total area lying between the drainage boundaries which can be irrigated by a canal system

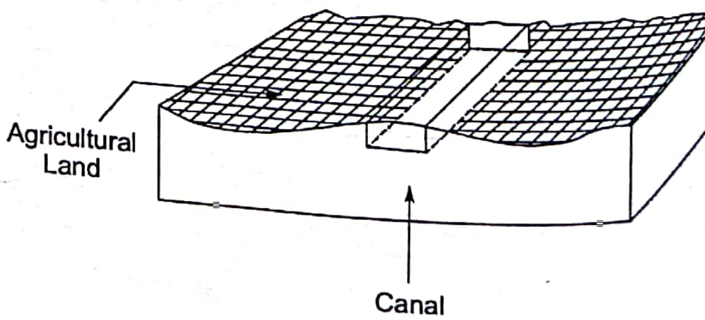


Fig. 3.1

(iii) Culturable command area (CCA)

- It is that portion of GCA that is culturable or cultivable
- CCA = GCA – unculturable areas

- Culturable commanded area can be divided into
  - (a) Culturable Cultivated area
  - (b) Culturable uncultivated area (or to be cultivated)

(iv) Intensity of Irrigation

- Intensity of irrigation is the percentage of CCA proposed to be irrigated annually.
- By adding intensities of irrigation for all the crop seasons we obtain the yearly intensity of irrigations.
- No irrigation system is designed to irrigate all of its, culturable area every year.

(v) Paleo Irrigation

- Watering done prior to the sowing of crops is called paleo irrigation.
- Paleo irrigation is required for the initial growth of the crop

(vi) Kor Watering

- First watering done after the plants have grown a few centimeters high is known as kor watering
- Kor depth and kor period are the terms used for depth of water applied and time period during this watering.

(vii) Capacity Factor

$$\text{Capacity Factor} = \frac{\text{Average supply discharge of a canal for a certain duration}}{\text{Maximum discharge capacity of a canal}}$$

NOTE: Canal is always designed for a certain maximum discharge. But usually this does not happen.

(viii) Time Factor

$$\text{Time factor} = \frac{\text{Number of days canal has actually run during a watering period}}{\text{Number of days of watering period}}$$

NOTE: Canal usually does not run on all the days during each watering period due to some unavoidable circumstances

(ix) Crop Ratio

- Crop ratio is the ratio of the area of land irrigated during the two main crop seasons (i.e. Rabi and Kharif).
- It is also called Rabi-Kharif ratio.

(x) Outlet Factors

- Duty of water at the outlet
- In other words, it is the duty of water at the head of a field channel

NOTE: Irrigation water is supplied to the land or fields by field channels (or water courses). Water is supplied from the canals through canal outlets to the field channels

(ix) Crop Calendar

- Crop calendar is a tool that provides timely information about seeds to promote local crop production.

- It contains information on planting, sowing and harvesting periods of locally adopted crops in specific agro-ecological zones.
- It provides a solid base for emergency planning of the rehabilitation of the farming systems after disasters.
- Information contained in the calendar is very useful to the planners, agricultural administrators, plant breeders, and farmers in formulating policy matters regarding plant breeding, crop adoption, supplemental irrigation, maximizing the yield etc.

3.7 Irrigation Efficiencies

In general,

$$\text{Irrigation efficiency} = \frac{\text{Water available for use}}{\text{Water applied during irrigation}}$$

3.7.1 Various Types of Irrigation Efficiencies

(i) Water Conveyance Efficiency (η_c)

$$\eta_c = \frac{\text{Quantity of water delivered to the fields } (W_f)}{\text{Quantity of water diverted into the canal system from the irrigation } (W_r)}$$

It includes losses which occurs in conveyance from point of diversion into canal system to the fields.

(ii) Water Application Efficiency (η_a)

$$\eta_a = \frac{\text{Quantity of water stored in the root zone of the plants } (W_s)}{\text{Quantity of water diverted to the fields } (W_f)}$$

It includes losses such as runoff from the field and deep percolation.

(iii) Water Use Efficiency (η_u)

$$\eta_u = \frac{\text{Quantity of water used beneficially } (W_u)}{\text{Quantity of water delivered to the fields } (W_f)}$$

It includes water required for leaching.

(iv) Water Distribution Efficiency (η_d)

$$\eta_d = \left(1 - \frac{y}{d}\right) \times 100$$

Where, y = average numerical deviation in depth of water stored
d = average depth of water stored in the root zone during irrigation.

- η_d evaluates the degree to which water is uniformly distributed throughout the root zone during irrigation.
- Hence, it is also called 'Uniformity coefficient'
- Higher is the value of η_d, better is the crop response.

(v) Water Storage Efficiency (η_s)

$$\eta_s = \frac{\text{Quantity of water stored in the root zone during irrigation } (W_s)}{\text{Quantity of water needed to bring the moisture content of the soil to the field capacity } (W_n)}$$

W_n = F.C. — Available moisture in the soil prior to irrigation.

It includes water required for leaching.

Example 3.1 A discharge of 150 litre/second was delivered from a canal and 110 litre/second reached the field. In eight hours, 2.2 Ha of area was irrigated

Following were the other dates:

(a) Run off loss in the field = 445 m^3

(b) Depth of water penetration varies linearly from 1.5 m at the head end of the field to 1.1 m at the tail end

(c) Effective depth of root zone = 1.5 m

(d) Available moisture holding capacity of the soil is 200 mm per meter depth of soil.

Find (i) Water conveyance efficiency (η_c)

(ii) Water application efficiency (η_a)

(iii) Water storage efficiency (η_s)

(iv) Water distribution efficiency (η_d)

Note that irrigation was started at a moisture extraction level of 50%

Solution:

$$\eta_c = \frac{W_f}{W_r} \times 100 = \frac{110}{150} \times 100 = 73.33\%$$

$$\eta_a = \frac{W_s}{W_f} \times 100 = \frac{2723}{3168} \times 100 = 86\%$$

W_f = Water delivered to the field

$= (110 \times 10^{-3}) \times (8 \times 3600) = 3168 \text{ m}^3$

W_s = Water stored in the root zone of the plant by supplied water

$= 3168 - 445 = 2723 \text{ m}^3$

Water storage efficiency

$$\eta_s = \frac{W_s}{W_n} \times 100 = \frac{2723}{3300} = 82.52\%$$

[Moisture holding capacity of soil in root zone

$= 200 \times 1.5 = 300$ mm

W_n = Moisture required in root zone

$$= \frac{50}{100} \times \left(\frac{300}{1000} \times 2.2 \times 10^4\right) = 3300 \text{ m}^3 \;]$$

Water distribution efficiency,

$$\eta_d = \left(1 - \frac{y}{d}\right) \times 100 = \left(1 - \frac{0.2}{1.3}\right) \times 100 = 84.62\%$$

Water Logging and Lining of Canal

4.1 Water Logging

- It is a phenomena in which productivity of land gets affected due to rise in water table, thus leading to the flooding of root zone of the plants
- In this process, the productivity of land is affected by rise in water table.

4.2 Causes of Water Logging

Main factors causing water logging are as follows:

(i) Inadequate surface drainage
(ii) Seepage from canal system
(iii) Over irrigation of fields
(iv) Obstruction of a natural drainage
(v) Destruction of a natural drainage
(vi) Inadequate capacity for arterial drainage

4.3 Effects of Water Logging

(i) Inhibiting activity of soil bacteria
(ii) Decrease in available capillary water
(iii) Fall in soil temperature
(iv) Rise in level of salts in the surface soil
(v) Delay in cultivation operations
(vi) Growth of wild flora (leading to decrease in crop yield)
(vii) Adverse effect on community health.

4.4 Remedial Measures Adopted for Controlling Water Logging

(i) Lining of canal and water courses
(ii) Reducing the intensity of irrigation
(iii) Optimum use of water
(iv) Provision of intercepting drains along the canal
(v) Provision of an efficient drainage system
(vi) By applying the crop rotation method in the best way
(vii) Depleting ground water storage by pumping

4.5 Losses in Canal

- Losses in Canal comprises of evaporation from water surface and seepage through bed and sides of the drain.
- Loss due to evaporation from a canal system depends on climatic condition of the region
- Loss due to evaporation is not preventable
- However, loss due to evaporation is considered insignificant in most of the cases (it is around 1 to 50%)
- Loss due to seepage depends upon various factors

  Few of the factors are:

  (i) Position of sub soil water table

  (ii) Extent of absorbing medium

  (iii) Design of canal cross section (i.e. depth of water and velocity of water in the canal)

  (iv) Conditions of canal system
- Losses in canal are measured by "inflow and outflow method"

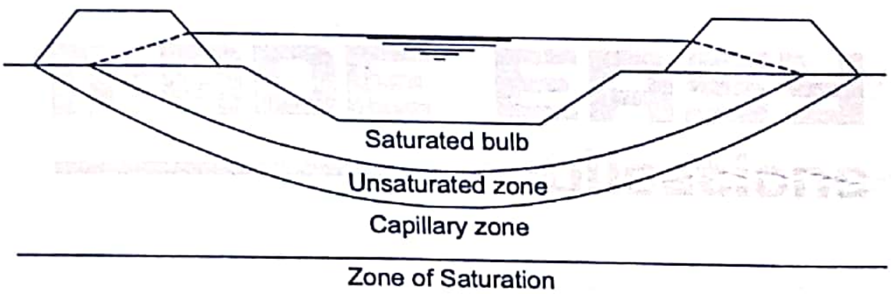
  {This method has been explained in article 3.9.7.3}
- Discharge measurement is done at the beginning and end of a long reach of canal for several days continuously

  (Outlets should be completely closed during observation period.)
- Seepage loss from canal occurs in two ways:

  (i) Absorption

  (ii) Percolation

Absorption: When water table is considerably below the ground level, seeping water is unable to join the water table and wets the subsoil locally forming a saturated bulb. Hence, an unsaturation zone lies between this saturated zone and zone of capillary moisture.



Percolation: When water table is close to the ground level, the seeping water may establish a direct and continuous flow between canal section and water. The zone between the water table and the canal bed remains completely saturated. As there is a continuous flow, so seepage loss will depend upon the head difference between the full supply level of canal and water table.

4.6 Leaching

- Leaching is the process of removal of alkali salts dissolved in irrigation water by flooding the land with adequate amount of water.
- This is mainly done to remove the alkali salts in the top layer of land for allowing the crops to be grown on the land.

Canal Irrigation, Sediment Transport and Canal Design

5.1 Canal Irrigation

- A canal is an artificial channel constructed on ground to carry water from a river or tank or reservoir for purposes like irrigation, power generation, navigation etc.
- Canal and channel means the same thing.
- Canals are usually having a trapezoidal cross section.
- Canals for the purpose of irrigation are usually open channels through earth or rock formation.

NOTE: Irrigation Canals can also be utilized for transportation of goods as well as inland navigation

5.2 Classification of Irrigation Canals

Irrigation canals can be classified in different ways on the following basis.

(i) Based on nature of source of supply

(a) Permanent Canals → Perennial Canals / Non Perennial Canals

(b) Inundation Canals (or Flood Canals)

(ii) Based on function of canals

(a) Feeder Canals (b) Carrier Canals

(iii) Based on discharge and relative importance in a given network of canals

(a) Main Canals (b) Branch Canals

(c) Major distributary (d) Minor distributary

(e) Water courses or Field channels

(iv) Based on Canal alignment

(a) Ridge Canal (b) Side Slope Canal

(c) Contour Canal

(v) Based on soil through which it is constructed

(a) Alluvial Canals (b) Non Alluvial Canals

(vi) Based on the lining
  (a) Lined Canals
  (b) Unlined Canals

5.3 Canal Alignment

- A canal should be aligned in such a way that it covers the entire area proposed to be irrigated, with shortest possible length and minimum cost of cross drainage works.
- Main canal while taking off from the river should mount the watershed or the ridge in the area at some point in shortest possible distance.
- Alignment of canal should be such that as far as possible a balanced depth of cutting and filling is achieved.

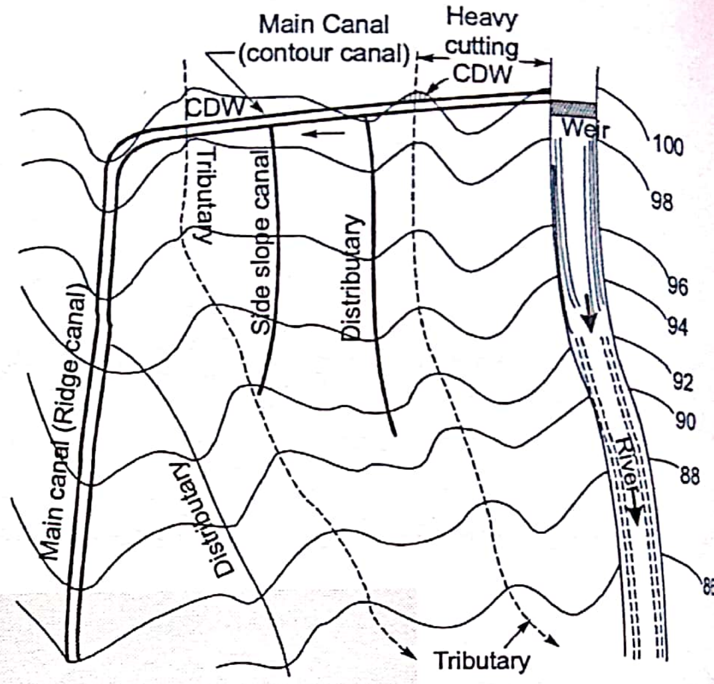


Fig. 5.1

5.3.1 Ridge Canal

- It is also called watershed canal
- Aligned along the ridge or natural watershed line.
- Can irrigate areas on both sides of the ridge and hence a large area can be brought under cultivation
- Cross drainage works are not required.
- They are economical

5.3.2 Contour Canal

- Aligned nearly parallel to the contours of the country.
- Can irrigate areas only on one side.
- Ground level on other side in this type of canal is higher, so it is not necessary to construct a bank on that side.
- Cross drainage works are required.

5.3.3 Side Slope Canals

- It is aligned roughly at right angles to the contour of the country.
- It is neither on the watershed nor in the valley.
- It is roughly parallel to the drainage of the country, so cross drainage works are not required.
- It can irrigate areas only on one side.
- It has a very steep bed slope. (Since the direction of the steepest slope of the ground is at right angles to the contours of the country)

5.4 Warabandhi Method

- Warabandhi is an integrated management system from a source (river or reservoir) down to the farm gate.

Canal Headworks and Seepage Theory

7.1 Introduction

Any hydraulic structure which supplies water to the off taking canal is termed as canal headworks. Canal headworks may be classified as:

(i) Storage headworks

(ii) Diversion headworks

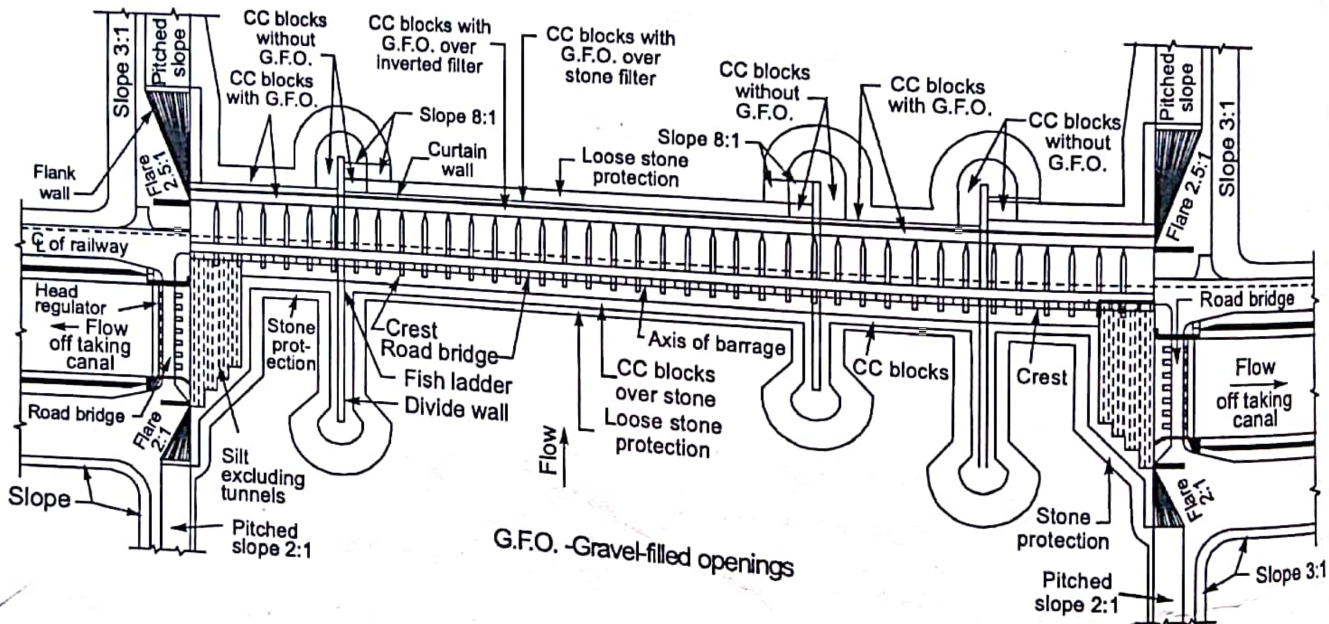


Fig. 7.1 *Typical layout of headworks*

7.1.1 Storage Headworks

- Dam is constructed across a river valley to form storage reservoir.
- Water is supplied to the canal from this reservoir through canal regulation.
- Storage reservoir stores water during the period of excess supplies in the river and releases it when demand exceeds available supplies.
- Storage headworks serves multipurpose functions like hydroelectric power generation, flood control etc.

7.1.2 Diversion Headworks

- Weir or barrage is constructed across a perennial river to raise water level and to divert the water to a canal.

7.1.2.1 Objective of Diversion Headworks

- Raises the water level on the upstream side.
- Regulates the supply of water into canals.
- Controls the entry of silt into the canals.
- Helps in controlling the fluctuation in the level of supply in the river during different seasons.

7.1.2.2 Types of Diversion Headworks

(i) Temporary diversion headworks
  - they are constructed every year after floods
  - these are mainly the spurs or bunds

(ii) Permanent diversion headworks
  - these are mainly the weir or barrages
  - if designed properly, they act as permanent structure

7.2 Location of Headworks

- Location of canal headworks depends on the stages of flow of river.
- A river is divided into four distinct stages

(i) Mountainous stage or torrential stage
  - River in this stage has very steep bed slope and high velocity
  - In this stage, river is in the hills

(ii) Sub mountainous or boulder stage
  - The sides and bed of the river are composed of boulder and gravel.
  - There is strong subsoil flow in the region.

(iii) Trough stage or alluvial stage
  - The cross section of the river is made of sand and silt.
  - The bed slopes are small and velocities are gentle.

(iv) Delta stage
  - In this stage, the bed slope and velocity are reduced so much that river is unable to carry its sediment load.
  - From trough stage, the river passes on to the delta stage as it approaches the ocean.
  - It drops down the sediment and gets divided into channel on either side of the deposit resulting in the formation of a delta.

NOTE: For the construction of canal headworks, boulder and the trough stage of the river is suitable

7.3 Components Parts of a Diversion Headworks

(i) Weir or barrage
(ii) Divide wall
(iii) Fish ladder
(iv) Under sluices
(v) Canal head regulation
(vi) Silt excluder/Silt ejectors
(vii) River training works (Marginal bunds and guide banks)

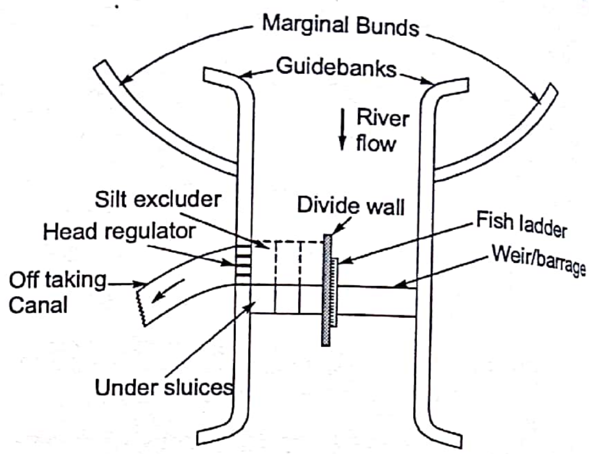


Fig.7.2 *Plan view of river-diversion headwork system*

7.3.1 Weir

- The weir is a solid obstruction constructed across the river to raise its water level and divert the water into the canal.
- Normally, the water level of any perennial river is such that it cannot be diverted to the irrigation canal. The bed level of the canal may be higher than the water level existing in the river.
- Adjustable shutters are usually provided on the crest but only small part of ponding is carried out by shutter.
- Main part of ponding of water is achieved through raised crest.
- Weirs are usually aligned at right angles to the flow direction of river.

7.3.2 Classification of Weir

7.3.2.1 Based on the criteria of the design of their floors

(a) Gravity weir (b) Non gravity weir

(a) Gravity weir: Weir in which uplift pressure due to the seepage of water below the floor is entirely resisted by the weight of the floor.

(b) Non gravity weir: Weir in which floor thickness is kept relatively less and the uplift pressure is largely resisted by the bending action of the reinforced concrete floor.

7.3.2.2 Based on the material and design features, gravity weir can further be subdivided into the following.

(a) Vertical drop weir, (b) Sloping weir of concrete or masonry, (c) Parabolic weir

(a) Vertical drop weir

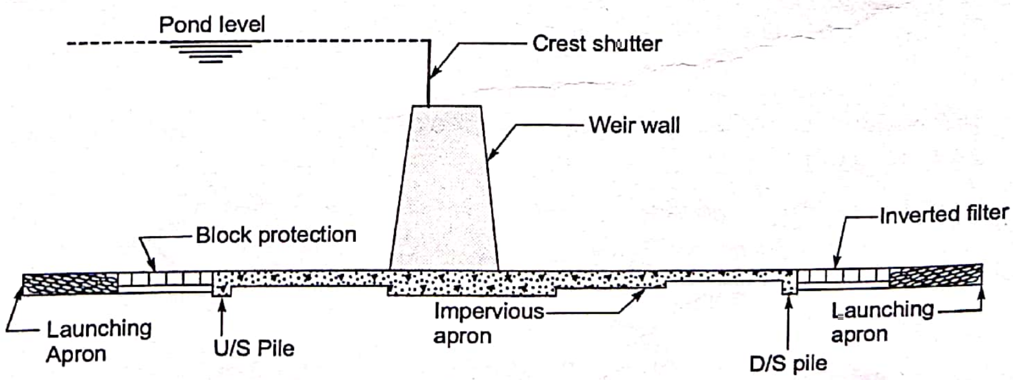


Fig. 7.3 *Vertical Drop Weir*

7.3.3 Barrage

- When the water level on the upstream side of the weir is required to be raised to different levels at different times, barrage is constructed.
- A barrage provides better control on the water level in the river but it is quite costly.
- In a barrage, a larger part of ponding is provided by the adjustable gates.

7.3.4 Undersluices

- Undersluices are the openings provided at the base of the weir or barrage. These opening are provided with adjustable gates. Normally the gates are closed.

Working of the undersluices:

- The suspended silt goes on depositing in the front of the canal head regulator (as the gates are closed).
- When the silt deposition becomes appreciable, the gates are opened and the deposited silt is loosened with an agitator mounting on a boat.
- Muddy water flows towards the downstream through the scouring sluices.
- The gates are then closed. But at the period of floods the gates are kept opened.

Function of the undersluices:

(i) They preserve a clear and well defined river channel towards the canal head regulator.

(ii) They scour the silt deposited on the river bed in the pocket upstream of the canal head regulator.

(iii) They pass low floods without the necessity of dropping shutters of the weir.

7.3.5 Divide Wall

- Divide wall is a long masonry or concrete wall constructed at right angles to the axis of the weir to separate the undersluices from the rest of the weir.
- On the upstream side, the wall is extended just to cover the canal head regulator and on the downstream side, it is extended upto the launching apron.
- The top width of the divide wall is about 1.5 to 2.5 m.

Function of Divide Wall:

(i) It controls the eddy current or cross current in front of the canal head.

(ii) It forms a still water pocket in front of the canal head so that the suspended silt can settle and scoured later through scouring sluices from time to time.

(iii) It provides a straight approach in front of the canal head.

(iv) It resists the overturning effect on the weir or barrage caused by the pressure of the impounding water.

7.3.6 Fish Ladder

- The fish ladder is provided just by the side of the divide wall for the free movement of fishes.
- Fish has a tendency to move from upstream part of the river to the downstream part in winters for search of warmth and from downstream part to upstream in monsoons for clearer water.

- This movement gets obstructed due to construction of weirs and barrages. So, this leads to a danger of survival for fishes.
- Fish Ladder is a device by which flow energy can be dissipated in such a manner so as to provide a smooth flow at a low velocity of around 3.0 to 3.5 m/s.
- Various types of fish ladders are:
  (i) Pool type
  (ii) Steep channel type
  (iii) Fish lock type
- To check the flow velocity, baffles and other staggering devices are provided.

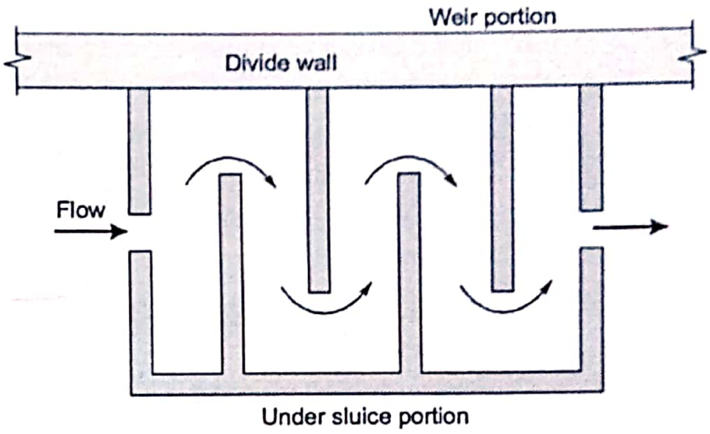


Fig.7.6 *Typical plan of a fish ladder*

7.3.7 Silt Regulation Works

- The entry of silt into a canal which takes off from headworks can be reduced by constructing certain special works (or devices) called silt control works.
- Silt control works are also called silt control devices.
- Silt regulation works may be classified into two types.
  (i) Silt Excluders
  (ii) Silt Ejectors (or silt extractors)

(i) Silt Excluders:

- Silt excluders are those works which are constructed on the bed of the river, upstream of the head regulator. The clearer water enters the head regulator and silted water enters the silt excluder.
- In this type of works, silt excluder consists of a number of rectangular tunnels resting on the floor of undersluice pocket.

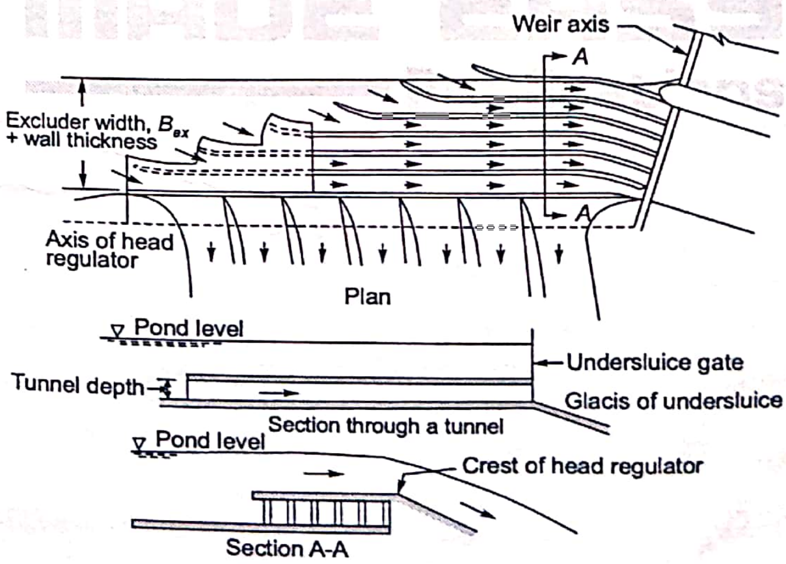


Fig.7.7 *Typical layout of a sediment excluder*

(ii) **Silt ejectors or extractors:**

- Silt ejectors are those devices which extract the silt from the canal water after the silted water has travelled a certain distance in the offtake canal.
- These works are constructed on the bed of the canal and a little distance downstream from the head regulator.
- Silt ejectors consists of horizontal diaphragm slab a little above the canal bed (which separates out the bottom layer)
- Under the diaphragm slab, there are tunnels to eject the heavily laden silt bottom water into an escape channel.
- The ejectors consists of a diaphragm, tunnels, control structure and an escape channel (or outfall channel)

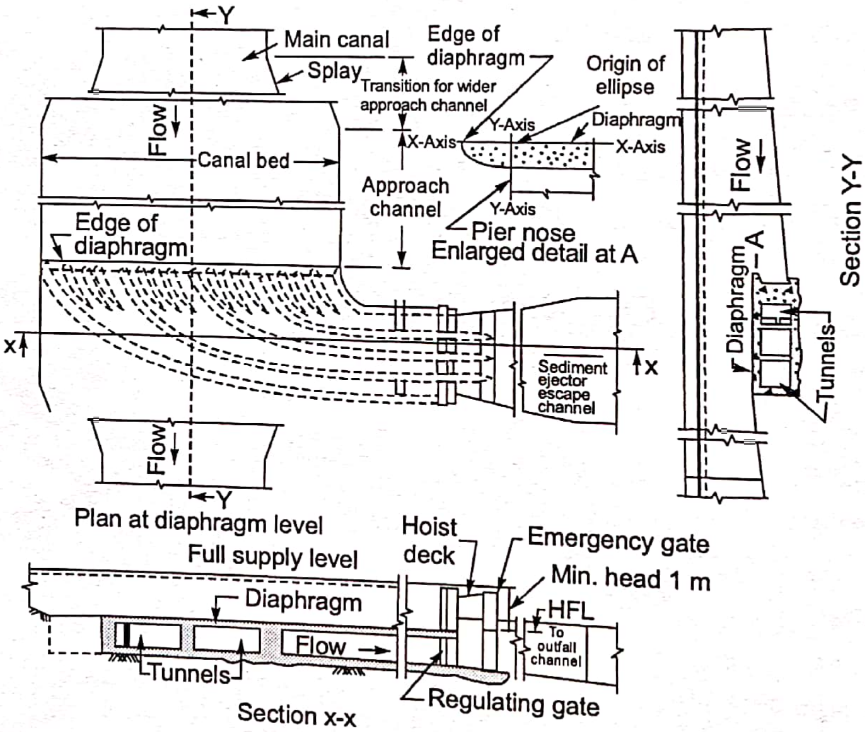


Fig.7.8 *Typical layout of a sediment ejector*

Efficiency of silt excluder and ejectors

Efficiency,

$$\eta = \frac{I_u - I_d}{I_u} \times 100$$

where, I_u = silt intensity in canal upstream of the ejector

I_d = silt intensity in canal downstream of the ejector

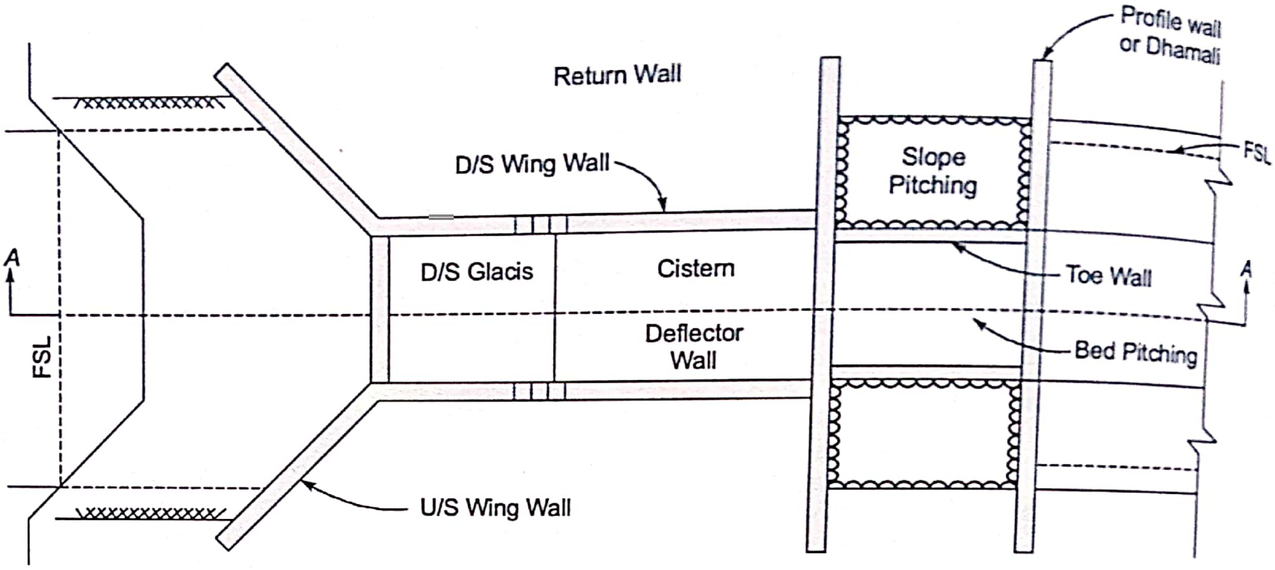


Fig. 6.7

- The glacis type of falls utilizes the standing wave phenomenon for dissipation of energy
- The glacis type of falls are mainly of two types
  - (i) Straight glacis type
  - (ii) Parabolic glacis type (Montague type falls)
- **Inglis fall:** A straight glacis fall when added with a baffle platform and a baffle wall. In this case formation of hydraulic jump takes place on the baffle platform.

6.4 Canal Regulators

- A canal obtain its share of water from the pool behind a barrage through a structure called the canal head regulator.
- A canal head regulator is located just upstream of barrage
- Canal regulators include the cross regulator and the distributary head regulator structures for controlling the flow through a parent canal and its off taking distributary
- Canal head regulator helps to maintain the water level in the canal on the upstream of the regulation.

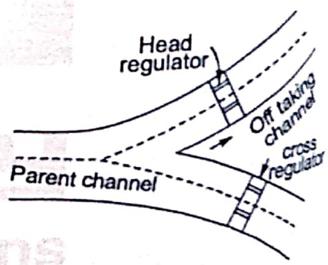


Fig. 6.8

6.4.1 Purpose of Providing a Canal Head Regulator

(i) to regulate the discharge flowing in the off taking channel.

(ii) to control the entry of sediment into the channel.

NOTE: The best alignment of off take is when the off take channel makes zero angle with the parent channel and then separates out along transition curves.

6.4.2 Cross Regulator and Distributary Head Regulators

- Cross regulator and distributary head regulator are provided to regulate the supplies of the parent channel and off taking channel respectively.
- A cross regulator is provided on the main canal (or the parent canal) at the downstream of the off take to head up the water level and enable the off taking channel to draw the required supply.
- A distributary head regulator is provided at the head of the off taking channel (or distributary) to control the supplies entering the off taking channel.

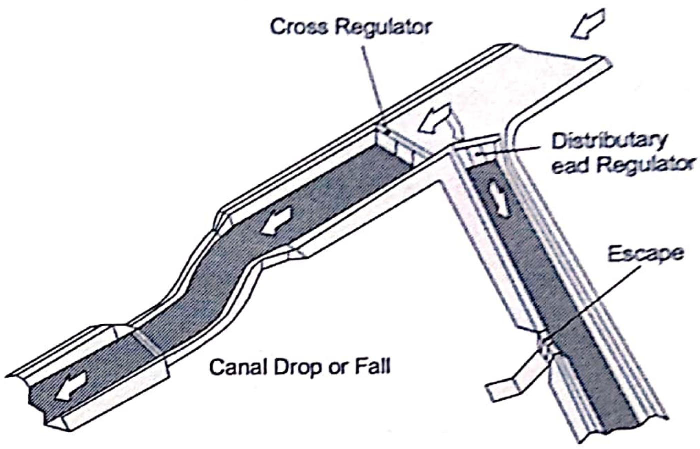


Fig. 6.9 *Canal structures for flow regulation and control*

Functions of Cross regulator:

(i) Effective regulation of the whole canal system.

(ii) Helps to feed the off taking channels by raising the water level of the upstream during the periods of low discharges in the parent channel.

(iii) Helps in closing the supply to the downstream of the parent channel for the purposes of repairs etc.

(iv) Helps in absorbing fluctuations in various section of the canal system and in preventing the possibilities of breaches in the tail reaches.

(v) Facilitates communication works (like bridges)

(vi) Help to control discharge at an outfall of canal into another canal or lake.

Functions of distributary head regulator:

(i) Regulates the supplies to the off taking channel from the parent channel.

(ii) Serve as a meter for measuring the discharge entering into the offtaking canal.

(iii) Regulates the entry of silt in the offtaking channel.

(iv) Shuts off the supply when it is not needed in the off taking channel or when the off taking channel is required to be closed for repairs.

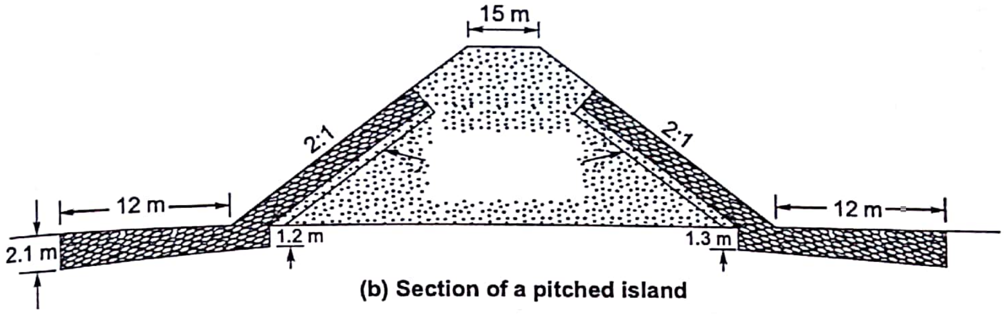
6.5 Canal Escapes

- Canal escapes are structure constructed on an irrigation canal for the purpose of releasing excess water from a canal

Functions of canal escapes:

(i) Provides protection to the canal against damage due to excess supplies

(ii) Emptying the canal for repairs and maintenance and removing a part of sediment deposited in the canal



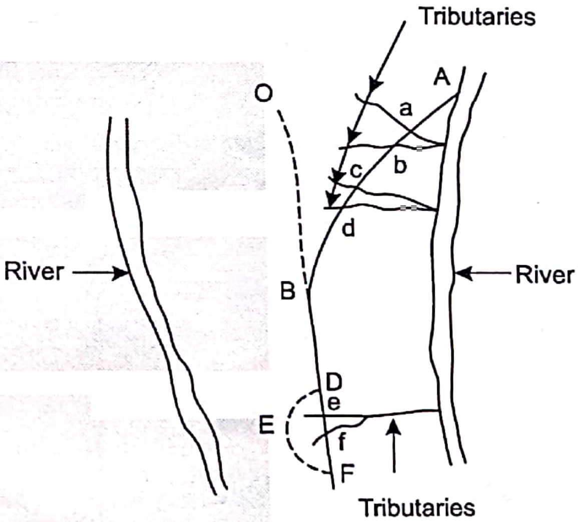
(b) Section of a pitched island

Fig. 8.14

- Pitched island gradually draw the main river current towards itself, thus, relieving attack on marginal bunds, guide banks, river bends etc.

8.6 Cross Drainage Works

- A cross drainage work is a structure carrying the discharge of a natural stream across a canal intercepting the stream.
- Aligning a canal on watershed is necessary so that water from canal can flow by gravity to fields on both sides of the canal.
- When a canal is to be taken to the watershed, it crosses a no. of natural streams in the distance between the reservoir to the watershed.
- A cross drainage work is a costly item so it should be avoided wherever possible by
  - (i) Diverting one stream into another
  - (ii) Changing the alignment of the canal so that it crosses below the junction of two stream



OBDEF — Watershed

ABDF — Canal alignment

Fig. 8.15

8.7 Types of CD Works

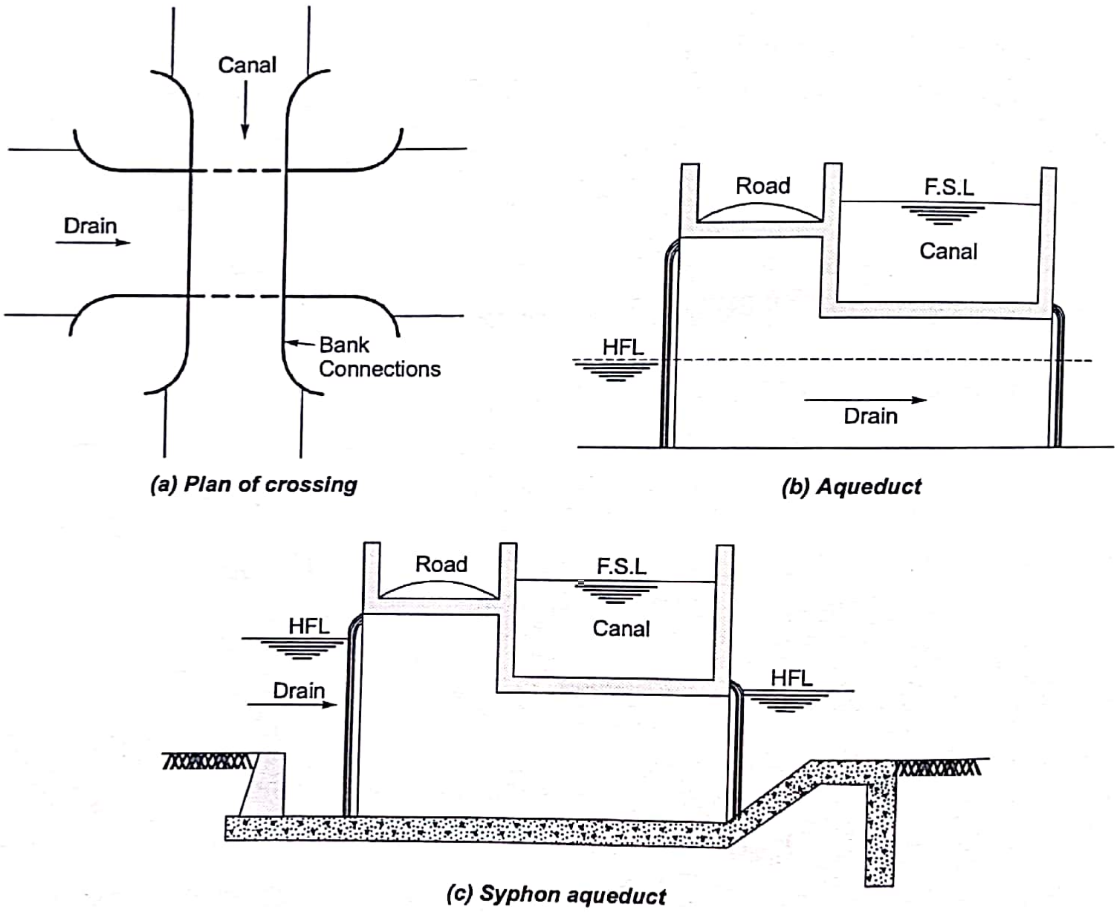
The CD works can be classified under three broad categories:

A. **CD works carrying canal over the drainage**

- In this type of arrangement, canal is carried over the natural drain.
- Canal is above the ground and hence is open to inspection.
- Damage done by floods is rare.
- Canal water is taken across the drain in a trough supported on rivers.
- This arrangement is constructed when the drain is very big in comparison to the section of the canal.
- Structure that fall under this category are:
  - (i) Aqueduct
  - (ii) Syphon aqueduct

(i) Aqueduct

- HFL of the drain is much below the bottom of the canal.
- So, the drainage water flows freely under gravity.



(a) Plan of crossing

(b) Aqueduct

(c) Syphon aqueduct

Fig. 8.16

(ii) Syphon Aqueduct

- HFL of the drain is much higher above the canal bed (on canal bottom)
- Water runs under syphonic action through the aqueduct barrels.
- Water surface level of the flood is depressed when it passes under the canal trough.
- Bed of the drain is also lowered.

B. CD works carrying drainage over the canal

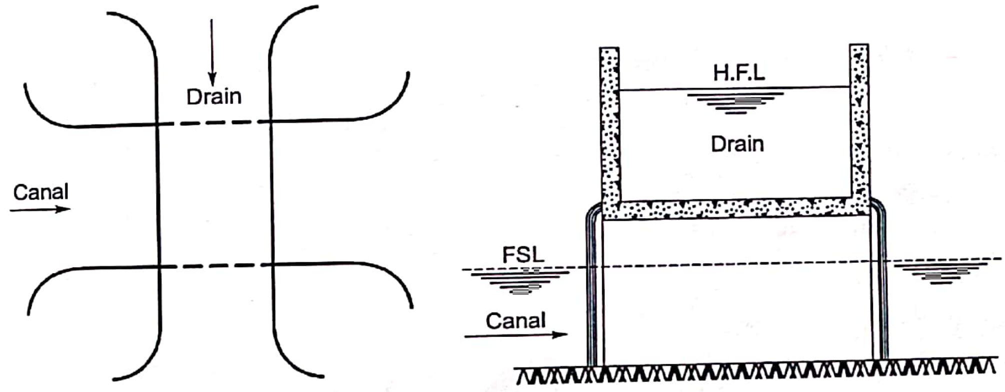
- In this type of arrangement, drainage is carried over the canal.
- Major advantage is that the CD works are less liable to damage than the earthwork of the canal.
- Major disadvantage is that the perennial canal is not open to inspection or maintenance as these are not easily accessible.
- Structure that falls under this category are:
  (i) Super passage
  (ii) Canal syphon

(i) Super passage

- FSL (full supply level) of canal is lower than the underside of the stream trough.
- Canal water runs under gravity.

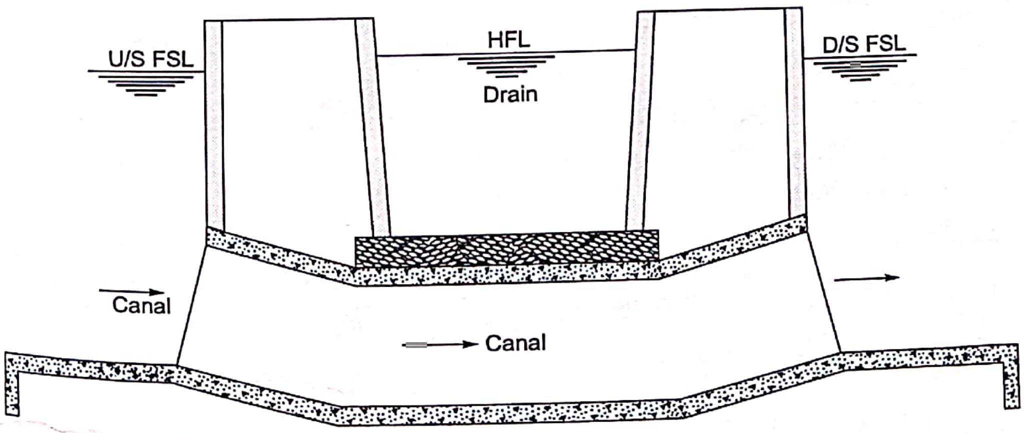
(ii) Canal syphon

- FSL of the canal is much above the bed level of the drainage trough.
- Canal runs under syphonic action under the stream trough.
- Canal bed is lowered and a ramp is provided at the exit to minimize trouble of silting.
- For siphoning small discharges, precast RCC pipes are adopted.
- For siphoning higher discharges, horse shoe shaped rectangular or circular barrels are adopted.



(a) Crossing (plan)

(b) Superpassage



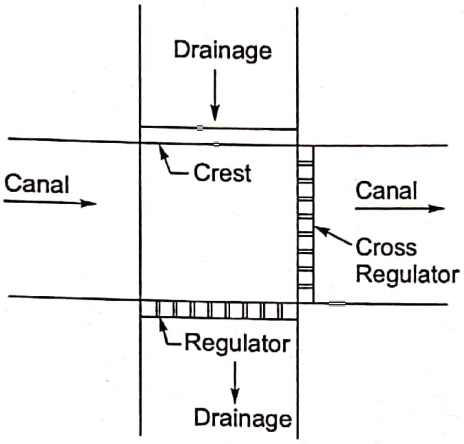
(c) Syphon

Fig. 8.17

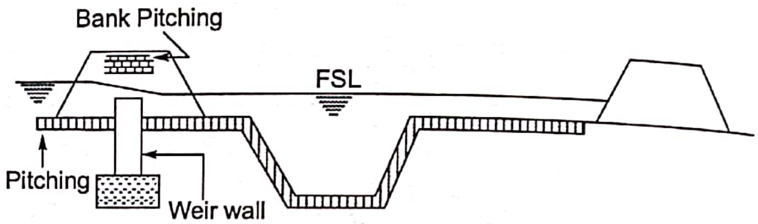
C. **CD Works admitting the drainage water into the canal**

- In this type of work, canal water and drainage water are permitted to intermingle with each other.
- This has a low initial cost.
- They are usually provided when a large sized canal crosses a large sized stream (carrying large discharge during high floods) and when siphoning of either of the two is prohibitory.

- Structures falling under this category are:
  (i) Level crossing, (ii) Inlets and outlets



(a) Level Crossing



(b) Inlet

Fig. 8.18

(i) Level crossing

- Canal and stream meet each other at practically the same level.
- Siphoning is prohibited mainly based on two considerations
  (a) economy
  (b) non permissibility of head loss through siphon barrels
- In this type of work, drainage water is passed into the canal and then taken out of the opposite bank.

(ii) Inlets and Outlets

- Canal inlet is constructed when drainage flow is small and its water may be absorbed into the canal without causing appreciable rise.
- In this case, it is made sure that river should be relatively silt free.
- Inlet is a structure consisting of an opening in canal bank, suitably protected to admit upland stream water into the canal.

NOTE

- Inlets do not have a regulator and hence the stream bed should be higher than canal FSL.
- If the stream taken into the canal by inlet is appreciable in quantity, it is allowed to flow out at a suitable site downstream of the inlet.

- Outlet are constructed, if the canal is small.
- Additional discharge entering into the canal is allowed to flow out through outlet.

NOTE: (i) Outlet is generally combined with other structures or are not provided.
(ii) In general, there may be one outlet for two to three inlets.

NOTE

Factors which affect the selection of the suitable type of cross drainage work are:
(i) Relative bed level and water levels of the canal and the drainage.
(ii) Size of the canal and the drainage.

Dams, Spillways, Energy Dissipation and Spillway Gates

9.1 Dams and its Classification

9.1.1 Dams

- Dam is a hydraulic structure constructed across a river in order to store water on its upstream side or divert water from river.
- Dam is an impervious or fairly impervious barrier put across a natural stream so that a reservoir is formed.
- This stored water is utilized when it is needed for various purposes.
- Due to construction of dam, a large area may get submerged on the upstream side.
- Dams are constructed mainly for irrigation or water power generation, diverting water into canals or other conveyances systems to the place of use, acting as a flood controlled reservoir.

Basis of Classification	Type	Common Examples
(a) Classification according to use	(i) Storage dam (ii) Diversion dam (iii) Detention dam	Gravity dam, Earth dam, Rockfill dam, Arch dam Weir, Barrage Dike, Debris dam
(b) Classification by hydraulic design	(i) Overflow dam (ii) Non overflow dam	Spillway Gravity dam, Earth dams, Rockfill dam
(c) Classification by materials	(i) Rigid dams (iii) Non rigid dams	Gravity dam, Arch dam, Buttress dam, Steel dam Earth dam, Rockfill dam

NOTE

(i) An overflow dam is commonly known as "Spillway"

(ii) In a river valley project, two types of dams are combined; the main dam is kept as non overflow dam while subsidiary dam is kept as overflow dam at some suitable location along the main dam.

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Necessity of Storage Reservoirs

Storage reservoirs are constructed to store the water in the rainy season and to release it later when the river flow is low flood control Reservoirs.

Storage Reservoir serve the following purpose.

→ Irrigation
→ Water supply
→ Hydroelectric power generation.
→ flood control
→ Navigation
→ Recreation
→ Development of fish & wild life.

Earthen Dams.

Earthen dams are made of soil that is pounded down solidly They are built in areas where the foundation is not strong enough to bear the weight of concrete dam and where the earth is more easily available as construction materials. They are flexible & non-rigid in nature.

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Types of Eartheren Dams

There are two types of Earthen dams

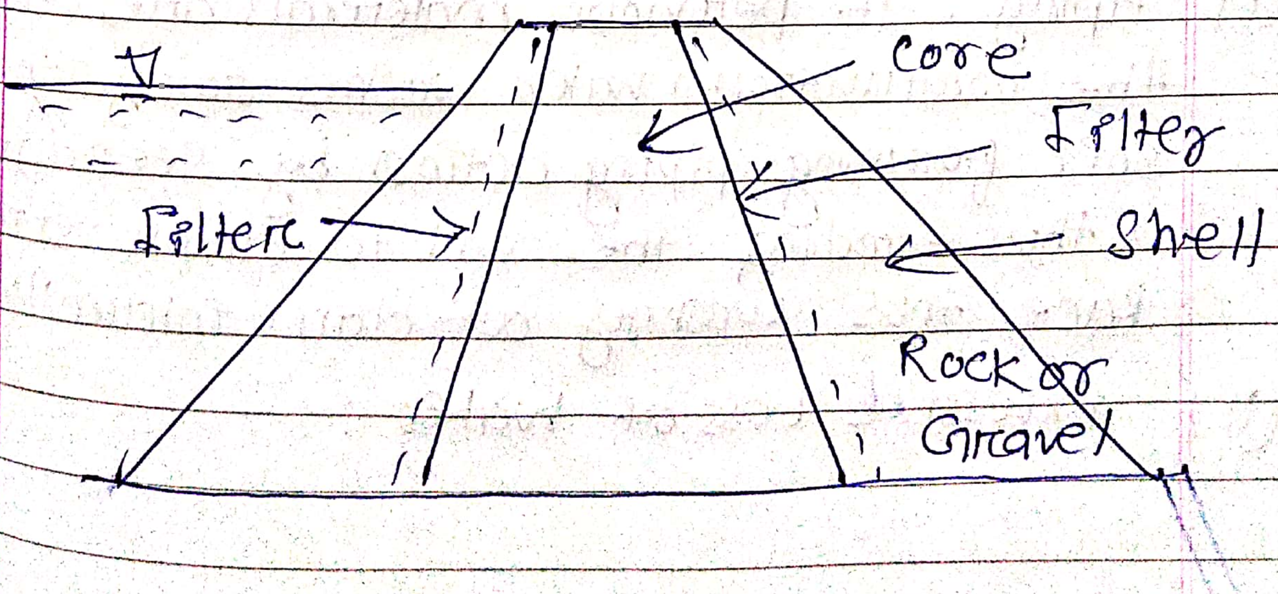
(1) Homogeneous Earthen Dam.

This is used for low to moderately high earth dams or levees & consists of single material. It faces the problems of seepage.

(2) Zoned Earthen Dams: In this the zoning of different materials is done with a central impervious core for obstructing the seepage. The outer zone gives stability to central impervious fill. These are mostly constructed.

Various parts of Earthen dams

(i) Core
(ii) Shell
(iii) cutoff
(iv) Transition Filter
(ix) key wall
(v) Rock Toe
(vi) Toe Drain
(vii) Rip Rap
(viii) pitching



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Causes of failure in Earthen Dams.

The Earthen dams may fail due to following

(i) Hydraulic failure

(ii) Seepage failure

(iii) Structural failure.

Hydraulic failure.

(i) Overtopping. It occurs when the reservoir water level rises above the top of dam due to insufficient provision of free board & thus washing away the dam.

(ii) Wave Erosion. It occurs when upstream face is not protected by rip-rap etc. & waves erode the dam.

(iii) Toe Erosion. When spillway is provided close to dam, the water flowing over causes the erosion of toe.

Seepage failure

(i) Piping: If pervious materials are used for the construction, water washes away the poor soil forming piping action by seepage water & thus eroding the soil to down-stream face thus washing out dam internally.

(ii) Excessive Loss of water:

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Q. 704. What are the structural failures in a earth dam ?

Ans. These failure are as under:

(*i*) Due to failure of upstream and downstream slopes.

(*ii*) Due to sliding of foundation.

(*iii*) Failure by spreading.

(*iv*) Failure due to flow slide : Due to presence of loose sand or silt in the dam it collapses.

(*v*) Due to uneven settlement of foundation.

(*vi*) Failure due to damage caused by burroughing animals.

(*vii*) Failures caused due to earthquakes.

(*viii*) Failure due to damage caused by water soluble materials in the water.

Q. 705. Describe methods of Improvements of a dam ?

Ans. Following are the methods of improvements of a dam:

(*i*) Embankment should be made safe against overtopping by providing sufficient spillway.

(*ii*) A sufficient free board should be provided.

(*iii*) Design of dam should be such that seepage flow is controlled.

(*iv*) Pervious materials may not be used in the construction.

(*v*) U/S and D/S slopes should be properly designed and protected.

(*vi*) D/S slope should be strong enough to resist gullying due to rains.

(*vii*) U/S slope should be protected against wave and toe erosions.

(*viii*) Proper blending of soil to be done to provide uniform bearing value.

(*ix*) Proper stabilising of the soil should be done.

(*x*) Compaction should be done properly.

(*xi*) By providing and improving the drainage facility.

(*xii*) By providing high bank and thus avoiding moisture variations.

Q. 706. What is a solid Gravity Dam ?

NOTE

(i) Earth dams are made of locally available soils and gravels and hence are most common types of dams used upto moderate heights.
(ii) A rockfill dam is an embankment which uses variable sizes of rock to provide stability and impervious membranes to provide water tightness.
(iii) Earth and rockfill dams cannot be used as overflow dams. So, separate spillways has to be provided.

9.2 Selection of Site for Dam

9.2.1 Factors governing selection of type of dam

(i) Topography
(ii) Geology and foundation conditions
(iii) Materials of construction
(iv) Spillway size and location
(v) Length and height of dam
(vi) Life of a dam

9.2.2 Requirement of good site for construction of dams

(i) Suitable foundation should be available at the dam site.
(ii) Length of dam should be as small as possible from economic point of view and for a given height it should store a large volume of water.
(iii) River cross-section at the dam site should preferably be narrow to reduce the length of the dam. However it should open out upstream to provide a large basin for reservoir.
(iv) Major portion of the dam should be on a high ground (reduces cost and facilitates drainage)
(v) A suitable site for spillway should be available in the vicinity of the dam.
(vi) Bulk of construction materials should be available at or near the dam site.
(vii) Value of property and land submerged in the reservoir created by the proposed dam should be low.
(viii) Reservoirs should not get frequently silted.
(ix) It is preferable to select a site which is connected by road or rail.

NOTE: (i) In case of earth or rockfill dam, spillway is located separately from the dam.
(ii) In case of gravity dam, spillway may be located at the middle of the dam.

9.3 Gravity Dams

- Gravity dam is a masonry structure which increases stability against all applied loads by its weight alone (without depending on arch or beam action)
- Gravity dam is a permanent type of dam.
- Gravity dam is mostly straight in plan and approximately triangular in cross-section.

Low dams: Dams upto 100 ft. (30.48 m) in height.
Moderate height dam: Dams of heights between 100 ft. (30.48 m) and 300 ft. (91.44 m)
High dams: Dams higher than 300 ft. (91.44 m)

Causes of failure of Gravity Dam.

(i) Overturning

- If resultant of all the force acting on a dam at any of its sections cuts the base of the dam downstream of the toe (i.e., outside the body of dam), the dam shall rotate and overturn @ the toe.
- On the other hand, if the resultant cuts the base within the body of the dam, there will be no overturning.
- For stability requirements, dam should be safe against overturning.

$$\text{FOS (against overturning)} = \frac{\Sigma \text{ restoring moment @ toe (anticlockwise)}}{\Sigma \text{ overturning moment @ toe (clockwise)}} = \frac{\Sigma M_R}{\Sigma M_o}$$

- FOS against overturning should not be less than 1.5.

(ii) Sliding

- A dam will fail in sliding at its base or at any other level, if the horizontal forces causing sliding are more than the resistance developed at that level.
- The resistance against sliding may be
  (a) due to friction alone
  (b) friction and shear strength of the joint
- FOS against sliding (shear strength not taken into account)

$$\text{FSS} = \frac{\mu \Sigma V}{\Sigma H}$$

where, μ = coefficient of friction (varies from 0.65 to 0.75)

ΣV = net vertical forces

ΣH = sum of horizontal forces causing sliding

FOS against sliding (shear strength taken into account)

$$\text{SFF} = \frac{\mu \Sigma V + bq}{\Sigma H} \quad \text{(for unit length of dam)}$$

where, q = average cohesion or shear strength of the joint

b = width of the joint

SFF = shear friction factor

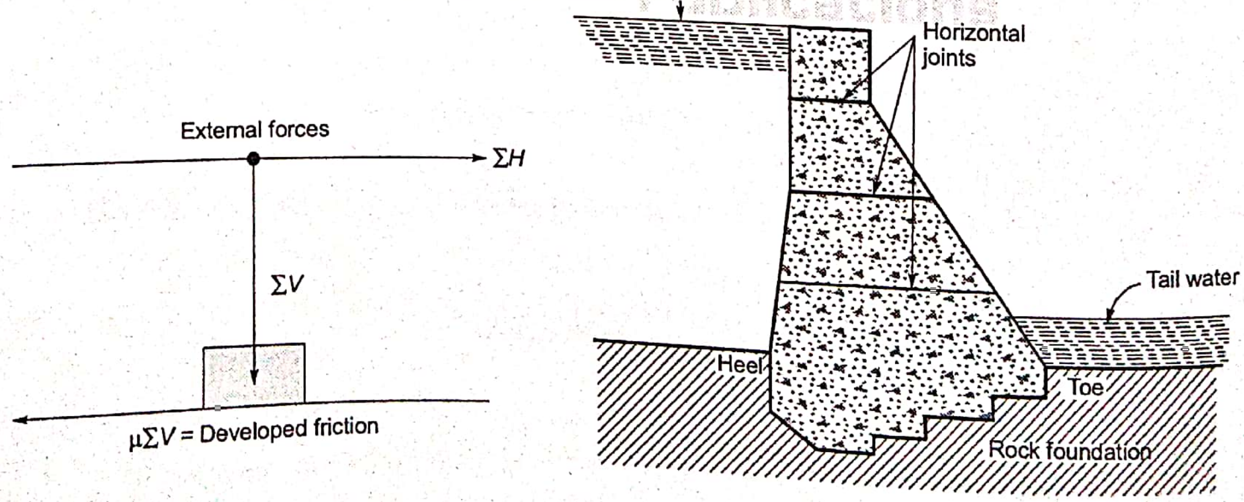


Fig. 9.3

NOTE: Shear st… between two interfaces or the joints in a structure. In case of masonry dams, it is due to interlocking of stones.

(iii) **Compression or crushing**

- A dam will fail in compression or crushing by the failure of its material i.e., maximum compressive stresses produced should exceed the permissible compressive stresses.
- Vertical direct stress distribution at the base is given by following equation

$$P_{max/min.} = \frac{\Sigma V}{B}\left(1 \pm \frac{6e}{B}\right)$$

where, e = eccentricity of the resultant force from the centre of the dam

ΣV = total vertical force

B = base width

- P = direct stress + bending stress

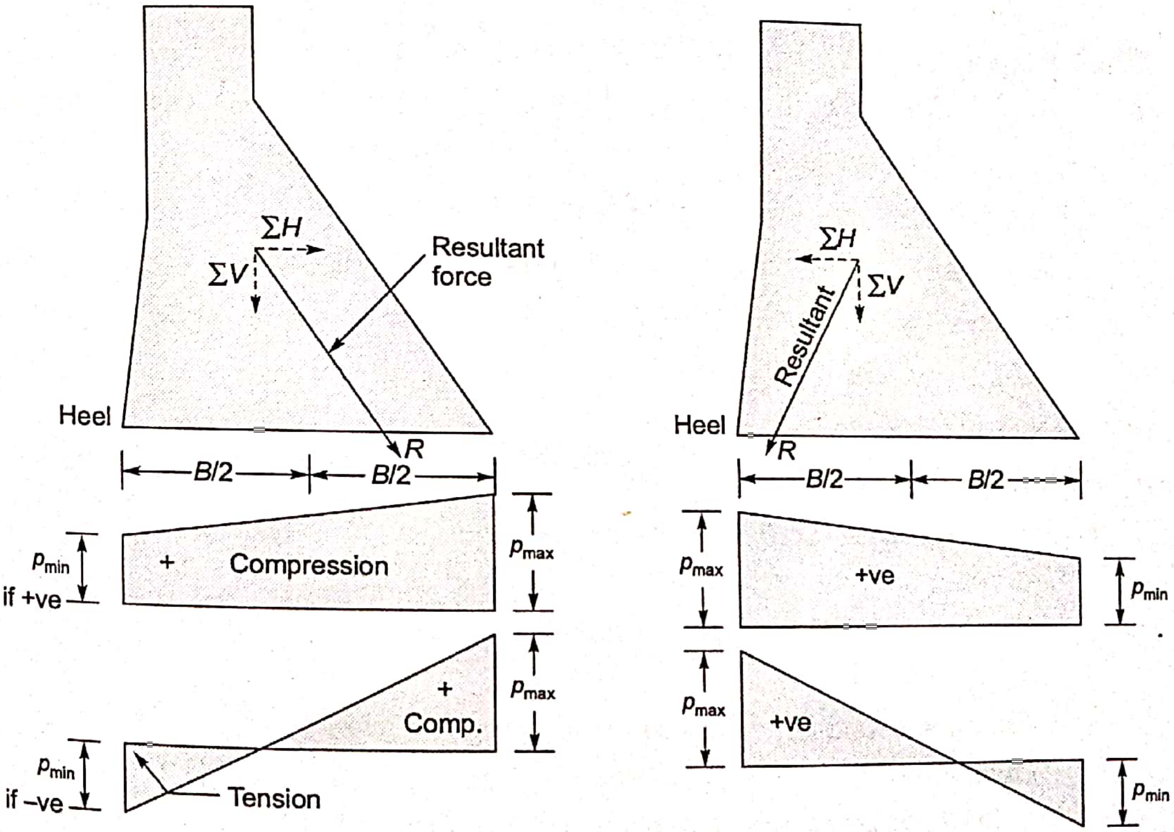


Fig. 9.4

- Maximum stress i.e., p_{max} will be provided at the end which is nearer to the resultant.

(iv) **Tension**

- Masonry and concrete gravity dam are not able to withstand tensile stresses. Hence, they are designed in a way to avoid tension anywhere in the structure.
- In order to avoid tension anywhere in the structure, p_{min} should be zero.

$$p_{min} = \frac{\Sigma V}{B}\left(1 - \frac{6e}{B}\right)$$

9.8 Spillways

- A spillway is a water way provided in a dam (either through the dam, above the dam or somewhere remote from the dam) for carrying the surplus flood water from a reservoir safely to a downstream river.

- Spillway acts as a safety valve of the dam (as many failures of dam have been caused by the improperly designed spillways or spillways of insufficient capacity)
- Spillway can be constructed either as part of the main dam such as in overflow section of a dam or as a separate structure altogether.
- Sufficient capacity of spillway is of paramount importance especially in earth and rockfill dams where overtopping may be very dangerous.
- A spillway must have the capacity to discharge major flood without damage to the dam or any appurtenant structures, at the same time keeping the reservoir below some predetermined maximum level.
- Design flood discharge required to be passed over the spillway can be determined by flood routing.

9.8.1 Essential requirement of spillway

(i) Must have sufficient capacity.
(ii) Must be hydraulically and structurally adequate.
(iii) Must be so located that it provides safe disposal of water.
(iv) Bonding surfaces of the spillway must be erosion resistant to avoid scouring actions.
(v) Energy dissipating devices are required on the downstream side.

9.8.2 Types of spillway

(I) Based on their utility, spillway can be of following types:

(i) Main spillway (ii) Emergency spillway

(i) Main spillway

- Main spillway is the first to come into operation.
- It is designed to pass entire design flood of a spillway.
- It is also known by another name "service spillway".

(ii) Emergency spillway

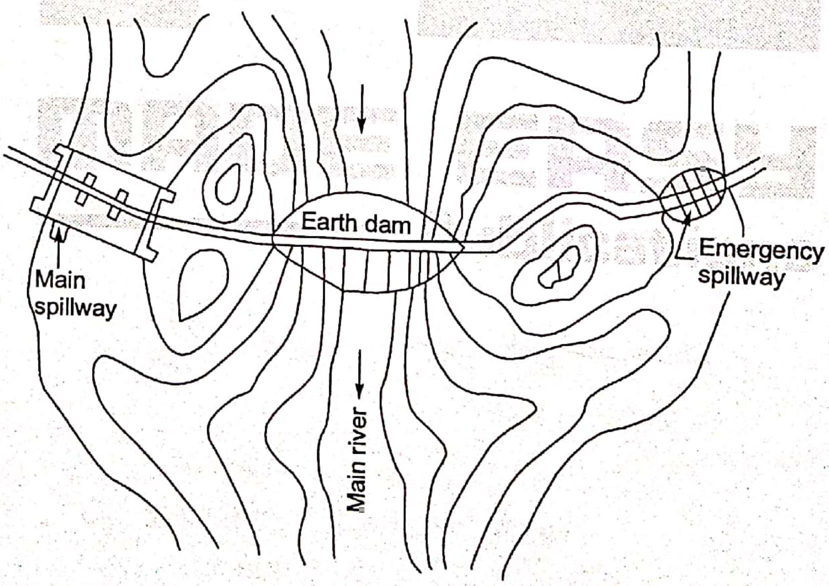


Fig. 9.8

- It is provided in addition to the main spillway and it comes into operation only during emergency.
- Some of the emergency situations may be
  (a) enforced shutdown of the outlet works

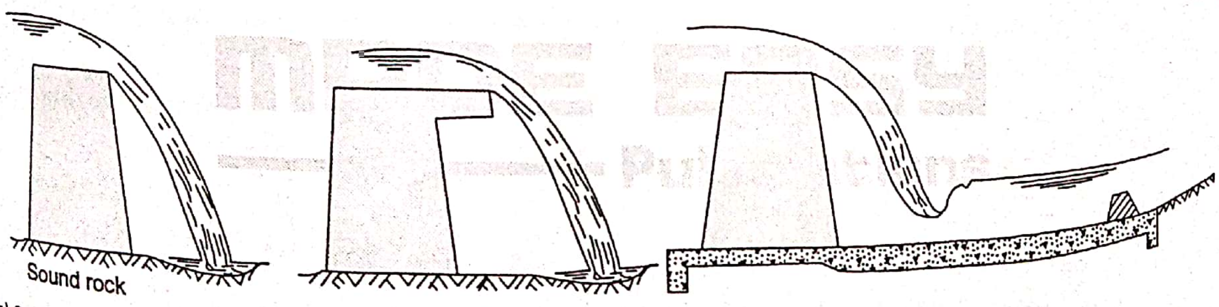
(b) malfunctioning of spillway gates
(c) occurrence of flood greater than design flood
(d) emergency spillway are provided for earth or rockfill dams only.

(II) **Based on the prominent features pertaining to various component of spillway, the spillway may be classified as follows:**

(i) straight drop spillway (free overfall spillway)
(ii) ogee spillway (overflow spillway)
(iii) side channel spillway
(iv) chute spillway (open channel or trough spillway)
(v) shaft spillway (morning glory spillway)
(vi) siphon spillway

(i) **Straight drop Spillway**

- It is the simplest type of spillway, constructed in the form of a low height weir having downstream face vertical or nearly vertical.
- Water flowing over the crest of this spillway drops as a free jet clearly away from the downstream face of the spillway.
- The underside of the falling nappe is ventilated sufficiently to prevent a pulsating, fluctuating jet.
- Occasionally, the crest is extended in the form of an overhanging lip to direct the small discharge away from the face of the overfall section.
- If artificial protection is not provided on the downstream side of the overfall section, the falling jet will cause the scouring of the stream bed and will form a deep plunge pool.
- This type of spillway is most commonly used for low earth dam (or earthen bunds)
- This type of spillway is not suitable for high drops on yielding foundations.
- It is used where hydraulic drops from head pool to tail water are not in excess of about 6 m.



(a) Spillway without D/S protection (b) Spillway with overhanging lip (c) Spillway with D/S protection work

Fig. 9.9

(ii) **Ogee Spillway**

- This is the most common type of spillway provided on gravity dam.
- The profile of the spillway is '*S*' shaped.
- Overflowing water is guided smoothly over the crest and profile of the spillway so that the overflowing water does not break contact with the spillway surface.
- If this is not assumed, a vacuum may form at the point of separation and cavitation may occur.