Module - 1

Hydraulics

Hydrostatics (Chapter 1)

Properties of fluid :

1 Density :—

It is the mass of the matter occupied in unit volume at a standard temperature and pressure.

It is denoted by ρ.

$\rho = \frac{m}{v}$ kg/m^3

Matter	Mass density, ρ (kg/m³)
Air	1.2
Water	1000
Mercury	13600
Steel	7850
Wood	600

2. Specific gravity or relative density:—

→ It is the ratio of specific weight (or mass density) of a fluid to the specific weight (or mass density) of a standard fluid at a specified temperature.

→ Usually water at 4°C,

$$S = \frac{\rho}{\rho_{water}} = \frac{\gamma}{\gamma_{water}}$$

→ It has no units.

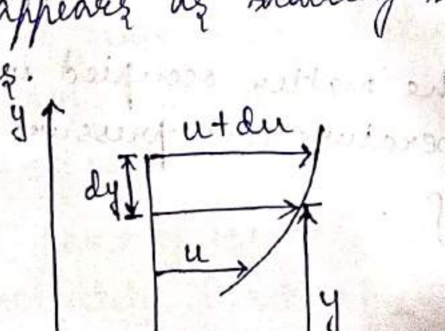
Matter	Specific gravity (S)
Air	0.0012
Water	1.0
Wood	0.6

→ $S < 1$ ⇒ fluid is lighter than water.

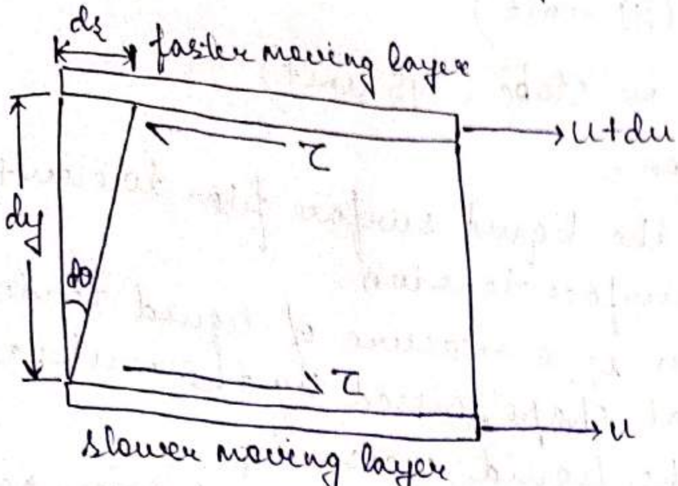
3. Viscosity:—

→ It is a measure of resistance of fluid to deformation.

→ It is due to cohesion and molecular momentum exchange between fluid layers and as flow occurs, these effects appears as shearing stresses between the moving layers.



upper layer which is moving faster tries to draw the lower slowly moving layer along with it.



In time dt, the top layer will move w.r.t. the bottom layer by a distance $dz = du \cdot dt$.

$$\Rightarrow \frac{dz}{dy} = d\theta = \text{shear strain}$$

$$\Rightarrow \frac{du \cdot dt}{dy} = d\theta$$

$$\Rightarrow \frac{d\theta}{dt} = \frac{du}{dy}$$

$\Rightarrow$ rate of change of shear strain = velocity gradient

For Newtonian fluid,

$$\tau \propto \frac{d\theta}{dt}$$

τ = shear stress opposing the movement of fluid

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

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

μ = absolute velocity or coefficient of viscosity or dynamic viscosity

$\mu = \frac{N \cdot sec}{m^2}$ or $\frac{kg}{m \cdot sec}$ (SI unit)

$\frac{dyne \cdot sec}{cm^2}$ (CGS unit)

→ Kinematic viscosity, $\nu = \frac{\text{dynamic viscosity}}{\text{mass density}} = \frac{\mu}{\rho}$

→ Unit = m^2/sec (SI unit)

cm^2/sec or stoke (CGS unit)

4. Surface tension :-

→ The property of the liquid surface film to exert tension is called the surface tension.

→ Surface tension is a measure of liquid tendency to take a spherical shape, caused by the mutual attraction of the liquid molecules.

→ Surface tension is due to cohesion between particles at the surface of liquid.

→ Surface tension is the force exerted by the free surface of the liquid per unit length.

→ Unit is N/m.

Dimension is MT^{-2}.

→ It is also expressed as work done per unit surface area.

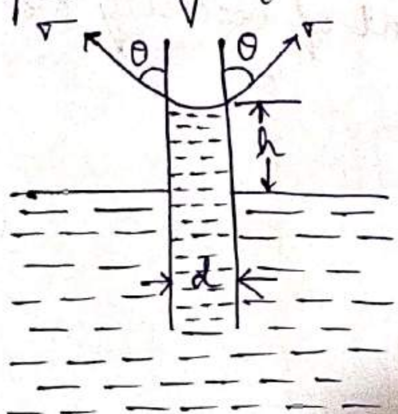
$$\sigma = \frac{W}{A} \ J/m^2$$

5. Capillary :-

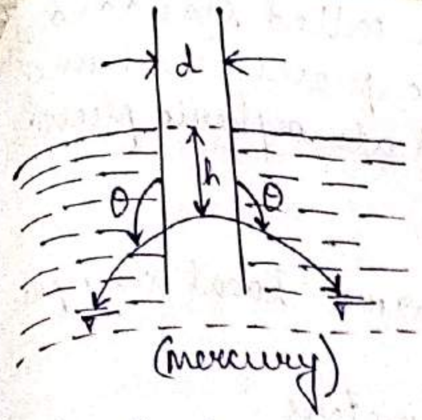
→ The phenomenon of rise or fall of a liquid surface relative to the adjacent general level of liquid in small diameter tubes.

→ The rise of liquid surface is designated as capillary rise and lowering is called capillary fall.

→ Capillarity is both due to cohesion and adhesion



(capillary rise)



$$h = \frac{4\sigma \cos\theta}{\gamma \cdot d}$$

h = capillary height (rise/fall)
σ = surface tension (N/m)
d = diameter of tube (m)
γ = specific weight of the liquid (N/m^3)
θ = angle of contact between liquid and boundary.
θ = 0° (water and glass) = 130° (mercury and glass)

<u>Intensity of pressure:</u>
Pressure is defined as normal force exerted by fluid per unit area and is denoted by 'P'

$$P = \frac{F}{A} = \frac{\text{force}}{\text{area}} = N/m^2 = \text{pascal}$$

→ The pressure of a fluid on a surface will always act normal to the surface.
→ Pressure is a scalar quantity which has magnitude but doesn't have a definite direction.

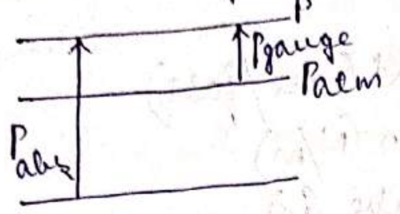
<u>Atmospheric pressure:</u>
→ It is the pressure exerted by atmosphere.
→ Its value is taken as 1.013 bar at mean sea level.
→ It is measured by barometer.
→ At MSL it is equal to 10.3m head of water or 76cm head of mercury.

→ Atmospheric pressure at MSL is called standard atmospheric pressure and atmospheric pressure at any other location is called local atmospheric pressure.

Gauge pressure:

→ It is the pressure measure w.r.t. local atmospheric pressure as datum.

→ It is measured using manometers.



Absolute pressure:

→ Pressure measured w.r.t. absolute zero or complete vacuum is called absolute pressure.

→ It is also called the actual pressure at a given position.

→ It is measured using aneroid barometer.

Vacuum pressure:

→ It is the amount of pressure in which inside pressure in a container is less than outside pressure.

→ It is often measured in torrs

Relationship between P_{atm}, P_{gauge} and P_{abs}:

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

$$\Rightarrow P_{abs} = P_{atm} - P_{vacuum}$$

Pressure head:

→ It is the height of a liquid column that corresponds to a particular pressure exerted by the liquid column on the base of its container.

→ It is also called as static pressure head or static head.

→ Pressure head $= P/\gamma$

Pressure gauges:

Instruments used to measure and display pressure in an integral unit are called pressure meter or pressure gauges or vacuum gauges.

Total pressure:

When a static fluid comes in contact with any surface, either plane or curved, a force is exerted by the fluid on that surface. This force is known as total pressure or hydrostatic force or thrust.

Resultant pressure:

At every point the direction of force is different. Hence, we calculate component of forces in various coordinate direction and add them to obtain resultant force in the coordinate direction.

Total pressure exerted on horizontal surface:

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

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

$$F = P \cdot A = (\gamma h) A = \gamma A h$$

Total pressure exerted on vertical 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 '$\bar{h}$' below the free surface of liquid.

$P = \gamma \cdot y$

Total pressure $= dF = P \cdot dy$

$\Rightarrow dF = \gamma \cdot y \cdot b dy$

$\Rightarrow F = \gamma \int y \, (b dy)$

Since, summation of first moments of areas of the strips,

$\Rightarrow \int y \, (b dy) = A\bar{h}$

$\Rightarrow F = \gamma A \bar{h}$

$\Rightarrow \gamma \bar{h} A = F$

A = area of plate

$\gamma \bar{h}$ = pressure intensity of centroid of plate

Kinematics of fluid flow (Chapter 2)

Rate of discharge:

→ It is defined as the quantity of fluid flowing per second through a section of the conduit.

$Q = AV$

A = cross-sectional area

V = mean or average velocity

→ Unit → m^3/sec or cumec.

Continuity equation:

→ It is based on the principle of conservation of mass.

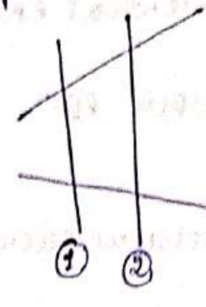
→ According to this mass inflow in a fixed region is equal to mass outflow from that fixed region in a particular time

→ For 1D flow, $\frac{\partial(\rho A)}{\partial t} + \frac{\partial(\rho A V)}{\partial s} = 0$

For 2D and 3D flow, $\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0$

For 1D steady flow, $\rho A V = \text{constant}$

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



For steady and incompressible flow,

$A_1 V_1 = A_2 V_2$

In 2D and 3D steady and incompressible flow,

$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \longrightarrow$ 2D flow

$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \longrightarrow$ 3D flow

(u, v, w) are the velocity components in (x, y, z) direction respectively

Bernoulli's equation:

Integration of euler's eqn of motion along a streamline under steady incompressible condition yields it.

$\int \frac{dP}{\rho} + \int g\,dz + \int v\,dv = \text{constant}$

$\Rightarrow \int \frac{dP}{\rho} + gz + \frac{v^2}{2g} = \text{constant} \longrightarrow (1)$

Above eqn is applicable for steady and compressible flow and the eqn of motion is known as bernoulli's eqn for compressible flow.

For incompressible flow, above eqn can be reduced to, $\frac{P}{\rho} + gz + \frac{v^2}{2} = \text{constant}_1 \longrightarrow (2)$

From above eqn,

$\frac{P}{\rho}$ = pressure energy per unit mass.

$\frac{v^2}{2}$ = kinetic energy per mass

gz = potential energy per mass

Also, above eq^n can be written as $\frac{p}{\gamma} + \frac{v^2}{2g} + z = c$

$\frac{p}{\gamma}$ = pressure energy per unit weight or pressure head

$\frac{v^2}{2g}$ = ~~velocity~~ kinetic energy per unit weight or kinetic head

z = potential energy per unit weight or elevation head

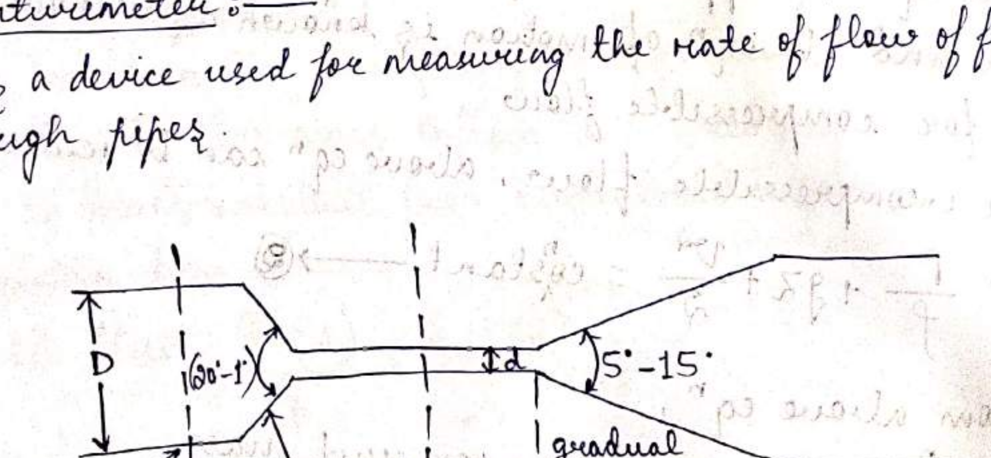
__Limitations of bernoulli's equation:__

1. Long narrow flow passage → friction is significant.
2. Wake region downstream of an object → losses in energy.
3. Near solid boundary → viscosity predominates.
4. Diverging flow section → chances of flow separation and wake formation.
5. For mach number ⩾ 0.3 → because compressibility becomes predominant.
6. Flow section that involves temperature changes, because as temperature changes density.

__Application of bernoulli equation:__

1. __Venturimeter:__—

→ It is a device used for measuring the rate of flow of fluid through pipes.



Area ratio = $\frac{a_2}{a_1}$

Diameter ratio = $\frac{d}{D}$

Applying bernoulli's eqn,

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

$$\Rightarrow \left(\frac{P_1}{\gamma} + z_1\right) - \left(\frac{P_2}{\gamma} + z_2\right) = \frac{V_2^2 - V_1^2}{2g} = h$$

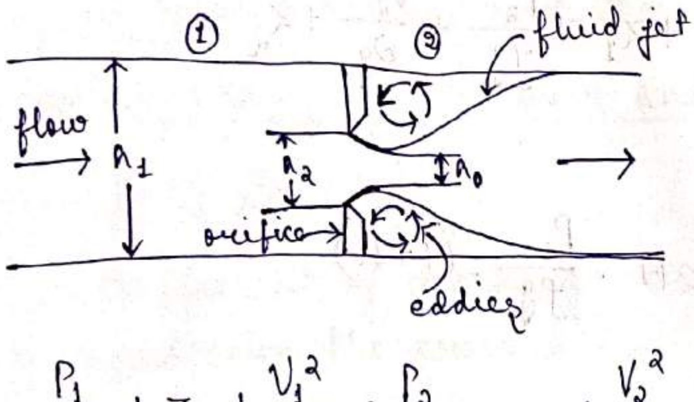
$$\therefore h = \frac{V_2^2 - V_1^2}{2g} = \text{piezometric head difference} = \frac{Q^2\left(\frac{1}{a_2^2} - \frac{1}{a_1^2}\right)}{2g}$$

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

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

__Orificemeter :—__

This device is used for measuring discharge through pipes.



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

$$\Rightarrow \left(\frac{P_1}{\gamma} + z_1\right) - \left(\frac{P_1}{\gamma} + z_2\right) = \frac{V_2^2 - V_1^2}{2g} = h$$

$$\therefore V_2 = \sqrt{V_1^2 + 2gh}$$

$$Q = a_1 V_1 = a_2 V_2$$

$C_c = \frac{a_2}{a_0}$ (C_c = coefficient of curvature)

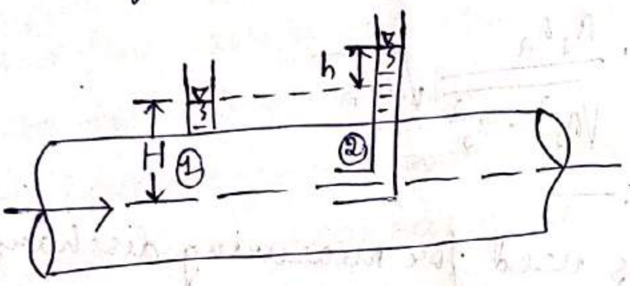
$\Rightarrow h = \frac{V_2^2 - V_1^2}{2g} = \frac{Q^2\left(\frac{1}{a_2^2} - \frac{1}{a_1^2}\right)}{2g}$

$\Rightarrow Q = \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}}\sqrt{2gh} = \frac{C_c \cdot a_1 a_0}{\sqrt{a_1^2 - a_0^2 \cdot C_c^2}}\sqrt{2gh}$

$\Rightarrow Q_{actual} = \frac{C_d \cdot a_1 a_0}{\sqrt{a_1^2 - a_0^2}}\sqrt{2gh}$

3. <u>Pitot tube</u> :—

→ It is a device for measuring the velocity of flow.



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

$z_1 = z_2$

$\therefore \frac{P_1}{\rho g} = H$, $\frac{P_2}{\rho g} = (H + h)$

$V_2 = 0$

$\Rightarrow H + \frac{V_1^2}{2g} = (H + h) + 0$

$\Rightarrow V_1 = \sqrt{2gh}$

$V_{actual} = C_v \cdot \sqrt{2gh}$

C_v = coefficient of velocity

4. Current meter :—

→ It measures point velocity of an open channel.

Notch :

→ It is a device used for measuring the rate of flow of a liquid through a small channel or a 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.

5. Weir :

→ A weir is a concrete or masonry structure placed in an open channel over which the flow occurs.

→ It is generally in the form of vertical wall, with a sharp edge at the top, running all the way across the open channel.

Types of weir and notches and their discharge :

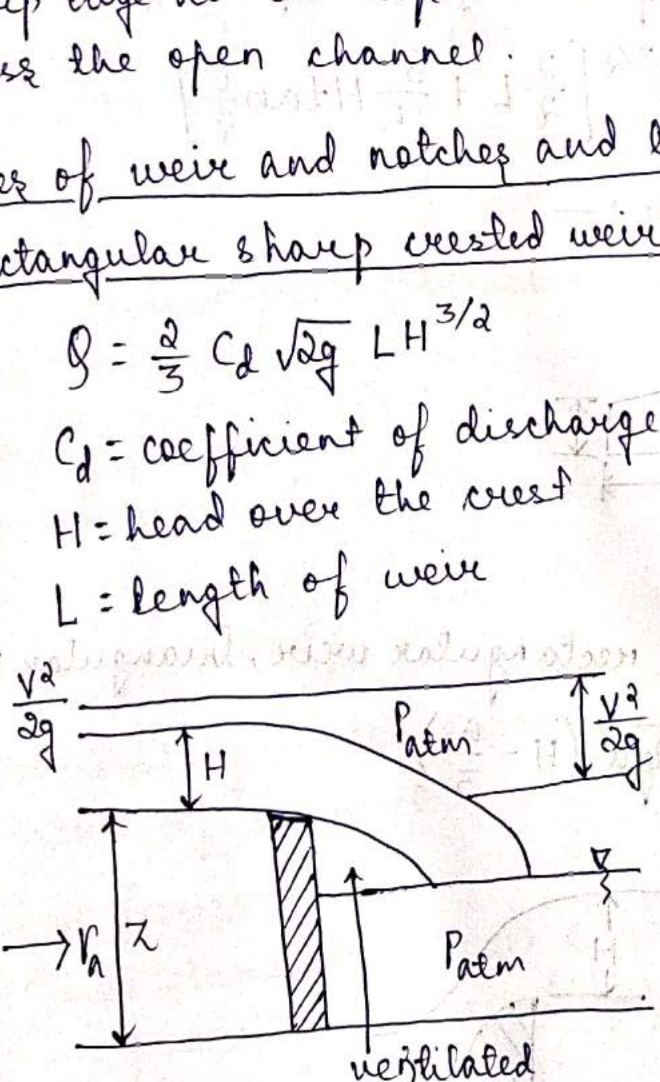
1. Rectangular sharp crested weir and notch :—

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

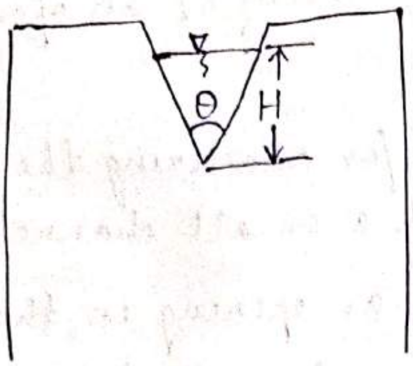
C_d = coefficient of discharge = 0.62

H = head over the crest

L = length of weir

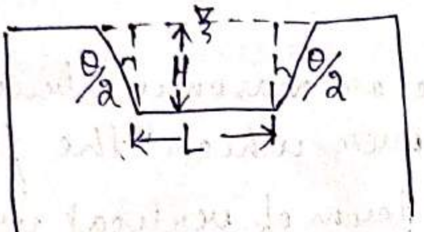


2. Flow over triangular weir and notch :—



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

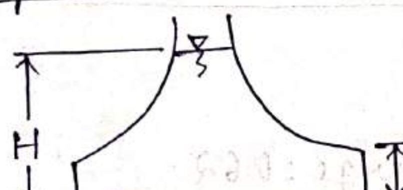
3. Trapezoidal weir and notch :—



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

$$\Rightarrow Q = C_d \sqrt{2g}\, H^{3/2} \left[\frac{2}{2} L + \frac{8}{15} H \tan\frac{\theta}{2}\right]$$

4. Proportional weir :—

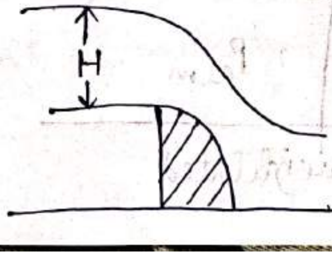


$Q \propto H^n$

$n = \frac{3}{2}$ for rectangular weir, triangular weir

$$Q = C_d \cdot L \sqrt{2ga} \left(H - \frac{a}{3}\right)$$

5. Spillway :—



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

Uniform flow:

→ When velocity of flow doesn't change at any given instant of time

$$\left(\frac{\partial V}{\partial s}\right)_t = 0$$

→ Eg → flow under pressure through long pipeline of constant diameter.

Non-uniform flow:

→ If the velocity of flow changes at any instant.

$$\left(\frac{\partial V}{\partial s}\right)_t \neq 0$$

→ Flow through a tapering pipe

Steady flow:

→ When the fluid properties such as velocity, density, acceleration, etc don't change with time at any particular location.

$$\frac{\partial V}{\partial t} = 0, \frac{\partial P}{\partial t} = 0, \frac{\partial \rho}{\partial t} = 0$$

→ Liquid efflux from a vessel in which constant level is maintained.

Unsteady flow:

→ If one or more fluid properties or anyone changes with time.

$$\frac{\partial V}{\partial t} \neq 0, \frac{\partial P}{\partial t} \neq 0$$

→ Liquid falling under gravity out an opening in the bottom of a vessel.

Laminar flow:

→ The fluid element move in a smooth path.

→ It occurs generally in smooth pipes when the velocity of flow is low.

Turbulent flow:

→ Fluid element move in erratic and unpredictable path.

→ Turbulent flow is an example of unsteady flow.

Reynold's number:

→ It is the ratio of inertial force to viscous force within a fluid which is subjected to relative internal movement due to different fluid velocities.

$$R_e = \frac{\text{inertial force}}{\text{viscous force}} = \frac{F_i}{F_v}$$

Application of Reynold's number:

→ It is used to predict the nature of flow.

→ It is used to study the rate of sedimentation in suspension.

→ It helps in calculation of friction factor in a few equation.

Losses in pipe flow:

1. Major losses (frictional loss)
   ((80-90%) of total head loss)
2. Minor losses (due to pipe fittings)
   (10-20% of total loss)

Major losses:

1. Darcy's Weisbatch eqⁿ:—

$$h_L = \frac{fLV^2}{2gD}$$

$$f = \text{friction factor} = \frac{64}{Re} \text{ (for laminar flow)}$$

$$f = (4000 < Re < 10^5) = \frac{0.316}{(Re)^{1/4}} \text{ (turbulent flow in smooth pipe)}$$

$$\frac{1}{\sqrt{f}} = 2\log_{10}\left(\frac{R}{k}\right) + 1.74 \text{ (for turbulent flow in rough pipe)}$$

7. Chezy's formula:—

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

V = average velocity

C = Chezy's constant

R = hydraulic radius $= \frac{A}{P} = \frac{\frac{\pi}{4}D^2}{\pi D} = \frac{D}{4}$

S = slope of energy line

$$V = C\cdot\sqrt{\frac{D}{4}\left(\frac{h_L}{L}\right)}$$

$$\Rightarrow V^2 = C^2\cdot\frac{D}{4}\cdot\frac{h_L}{L}$$

$$\Rightarrow h_L = \frac{4LV^2}{C^2\cdot D}$$

Minor losses:

1. Sudden expansion:—

$$h_L = \frac{(V_1 - V_2)^2}{2g} = \frac{V_1^2}{2g}\left(1 - \frac{A_1}{A_2}\right)^2$$

2. Sudden contraction:—

$$h_L = 0.5\frac{V_2^2}{2g}$$

3. At entrance:—

$$h_L = 0.5\frac{V^2}{2g}$$

4. At exit:—

$$h_L = \frac{V^2}{2g}$$

5. Bends in pipe fittings:—

$$h_L = \frac{KV^2}{2g}$$

K = bend constant

Q. Given $d_1 = 0.35m$ $d_2 = 0.7m$ $Q = 0.25 m^3/sec$

$$A_1 = \frac{\pi}{4}(0.35)^2 = 0.0962 m^2$$

$$A_2 = \frac{\pi}{4}(0.7)^2 = 0.385 m^2$$

$$V_1 = \frac{Q}{A_1} = \frac{0.25}{0.0962} = 2.6 m/sec$$

$$h_L = \frac{V_1^2}{2g}\left(1 - \frac{A_1}{A_2}\right)^2 = \frac{(2.6)^2}{2 \times 9.81}\left(1 - \frac{0.0962}{0.385}\right)^2 = 0.1938m$$

<u>Total energy line</u>:

→ It is defined as the line which gives the sum of pressure head, datum head and kinetic head of a flowing fluid in a pipe w.r.t. some reference line

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

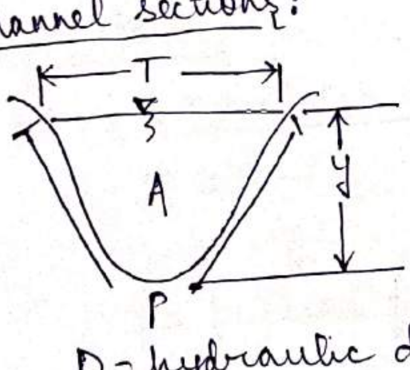
→ It is also known as energy grade line.

<u>Hydraulic gradient line</u>:

→ It is defined as the line which gives the sum of pressure head $\left(\frac{P}{\gamma}\right)$ and datum head (z) of a flowing fluid in a pipe w.r.t. some reference line.

→ It is also known as piezometric head $\left(\frac{P}{\gamma} + z\right)$ line.

<u>Channel sections</u>:



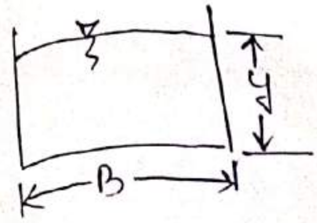
T = top width of water surface
y = depth of flow
P = wetted perimeter
A = wetted area

$$D = \text{hydraulic depth} = \frac{\text{wetted area}}{\text{top width}} = \frac{A}{T}$$

R = hydraulic radius or hydraulic mean depth

$$\Rightarrow R = \frac{\text{wetted area}}{\text{wetted perimeter}} = \frac{A}{P}$$

1. Rectangular channel:—



Top width (T) = B

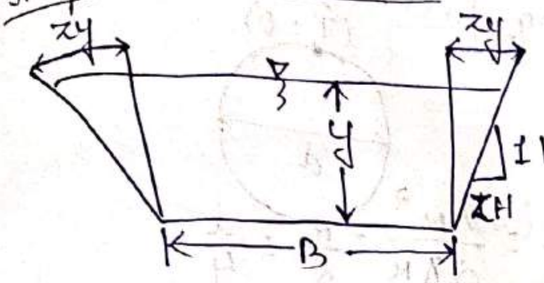
Depth = y

Area (A) = By

Hydraulic depth (D) = $\frac{A}{T} = \frac{By}{B} = y$

Hydraulic radius (R) = $\frac{A}{P} = \frac{By}{B+2y}$

2. Trapezoidal channel:—



Depth of flow = y

Top width (T) = B + 2zy

Area (A) = $\frac{1}{2}[(B+2zy)+B] \times y$

$= (B+zy) \cdot y$

Wetted perimeter (P) = $B + 2y\sqrt{1+z^2}$

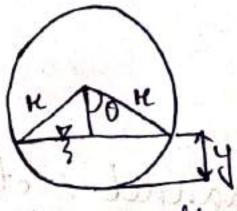
Hydraulic depth (D) = $\frac{A}{T} = \frac{(B+zy) \cdot y}{(B+2zy)}$

Hydraulic radius (R) = $\frac{A}{P} = \frac{(B+zy) \cdot y}{B+2y\sqrt{1+z^2}}$

3. Circular channel:—

1) running partially →

Top width (T) = $2r\sin\theta$



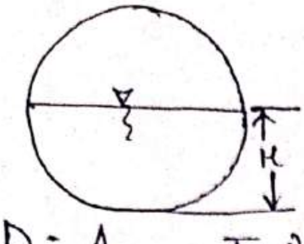
Area of flow (A) = $r^2\left(\theta - \frac{\sin 2\theta}{2}\right)$

Wetted perimeter (P) = $2r\theta$

Hydraulic radius (R) = $\frac{A}{P} = \frac{r^2\left(\theta - \frac{\sin 2\theta}{2}\right)}{2r\theta}$

Hydraulic depth (D) = $\frac{A}{T} = \frac{r^2\left(\theta - \frac{\sin 2\theta}{2}\right)}{2r\sin\theta}$

b) Circular channel running half full →



$A = \frac{\pi r^2}{2}$

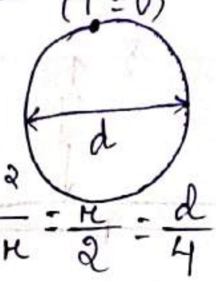
$T = 2r$

$P = \pi r$

$D = \frac{A}{T} = \frac{\pi r^2/2}{2r} = \frac{\pi r}{4} = \frac{\pi d}{8}$

$R = \frac{A}{P} = \frac{\pi r^2/2}{\pi r} = \frac{r}{2} = \frac{d}{4}$

c) Circular channel running full → (T = 0)



$A = \pi r^2$

$P = 2\pi r$

Hydraulic radius $(R) = \frac{A}{P} = \frac{\pi r^2}{2\pi r} = \frac{r}{2} = \frac{d}{4}$

Chezy's formula:

$V = C\sqrt{RS}$

$Q = AV$

$\Rightarrow Q = AC\sqrt{SR} = K\sqrt{S}$

$\because K = AC\sqrt{R}$ conveyance of channel section.

Manning's formula:

$V = \frac{1}{n} R^{2/3} S^{1/2}$ $\left[R = \frac{A}{P}\right]$

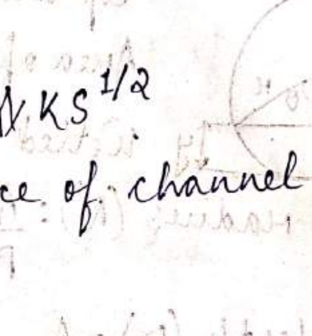
$Q = AV$

$\Rightarrow Q = A \times \frac{1}{n} R^{2/3} S^{1/2} = KS^{1/2}$

$\because K = \frac{1}{n} AR^{2/3}$ conveyance of channel section.

Best economical section:

1. Rectangular section :—



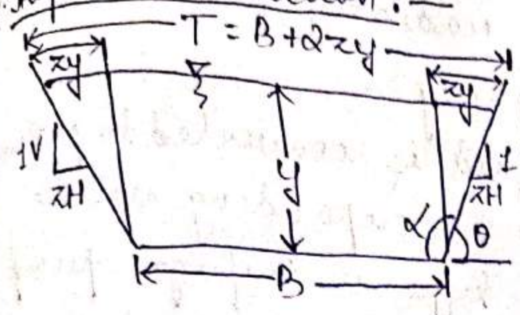
$A = 2y^2$

$P = 4y$

$y = \frac{B}{2}$

$R = \frac{y}{2} = \frac{B}{4}$

2. Trapezoidal section:—



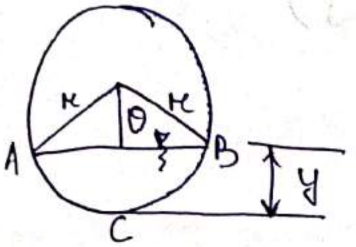
$\frac{T}{2}$ = length of one side slope

$R = \frac{y}{2}$

A circle of radius (y) should be inscribed in trapezoidal channel section

$\theta = 60°$

3. Circular section:—



Condition for maximum discharge,

$r = 0.29d$

$y = 0.93d$

Condition for maximum mean velocity of flow,

$r = 0.3d$

$y = 0.81d$

Pump:

→ It is a device that moves fluids (liquid or gases) by mechanical action.

Types of pump:

1. Centrifugal pump
2. Reciprocating pump

Centrifugal pump:

Principle:—

It involves imparting energy to the liquid by means of a centrifugal force developed by the rotation of an impeller that has several blades or vanes.

Operation:—

→ Liquid enters the pump casing at the impeller eye.

→ Velocity energy is imparted to the liquid by means of the centrifugal force produced by rotation of the impeller and the liquid is radially pushed out towards the impeller periphery.

→ The velocity energy of liquid is converted to pressure energy by directing it to an expanding volute design casing in a volute type centrifugal pump or diffusers in a turbine pump.

Discharge:—

$Q = \text{head}(H) \times \text{density of fluid}(\rho)$

$\Rightarrow Q = kg/cm^2$

$$H = \frac{\text{flow rate} \times \rho \times g}{\eta \times P}$$

flow rate $= m^3/sec$

$\rho = kg/m^3$

$g = m/sec^2$

$P = kW$

Efficiency:— (for both pumps)

1. Hydraulic efficiency →

$$\eta_h = \frac{\text{pump total head } (H)}{\text{euler head } (He)} = \frac{gH}{V_2 U_2}$$

2. Manometric efficiency →

$$\eta_m = \frac{\text{pump manometric head } (H_m)}{\text{Euler head } (H_e)} = \frac{gH_m}{V_2 U_2}$$

3. Volumetric efficiency →

$$\eta_v = \frac{Q}{Q + \Delta Q}$$

4. Mechanical efficiency →

$$\eta = \frac{\text{power into the impeller}}{\text{power at the shaft}} = \frac{\rho(Q+\Delta Q)V_2 U_2}{\text{power shaft}}$$

5. Overall efficiency →

$$\eta_0 = \frac{P_{out}}{P_{in}} = \frac{\rho Q H}{T \cdot w}$$

$$\Rightarrow \eta_0 = \frac{P_{out}}{P_t} \times \frac{P_t}{P_{in}} = \frac{P_t}{P_{in}} \times \frac{\rho Q H}{\rho(Q+Q_i)h'}$$

$$\Rightarrow \eta_0 = \eta_m \times \eta \times \eta_h$$

Reciprocating pump:

Principle ~~and~~ operation:—

→It is a positive displacement pump as it sucks and raises the liquid by actually displacing it with a piston/plunger that executes a reciprocating motion in a closely fitting cylinder.

→The amount of liquid pumped is equal to the volume displaced by the pistons.

→The pumps designed with disk pistons create pressures upto 25bar and the plunger pumps built up still higher pressures.

→Discharge from these pumps is almost wholly dependent on the pump speed.

Discharge:—

$$Q = A \times L \times \frac{N}{60}$$

$\Rightarrow Q$ = area × stroke length × $\frac{rpm}{60}$ = m^3/sec

A = cross-sectional area of cylinder

r = crank radius

N = rpm of crank

L = stroke length = 2r

Types:—

1. Piston pump →
In this pump piston is a reciprocating member.

2. Plunger pump →
In this pump plunger is a reciprocating pump.

3. Bucket pump →
When non return valve is fitted on the piston, the piston is called bucket and the pump is called bucket pump.

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Module-2

Hydrology

Defination:

→ Hydrology means the science of water.
→ It deals with the occurrence, circulation and distribution of water on the earth and atmosphere.
→ It may be also defined as the science that deals with the charging and discharging of water resource.
→ Practical application of hydrology is required in the design and operation of hydraulic structure, water supply, irrigation, hydro power generation, flood control etc.

Hydrology cycle:

→ Water occur on the earth and atmosphere in all three states (liquid, gas, solid). There is endless circulation of water between the earth and atmosphere. This circulation is called hydrology cycle.
→ Hydrology cycle has no beginning or end and its many process occurs simultaneously.

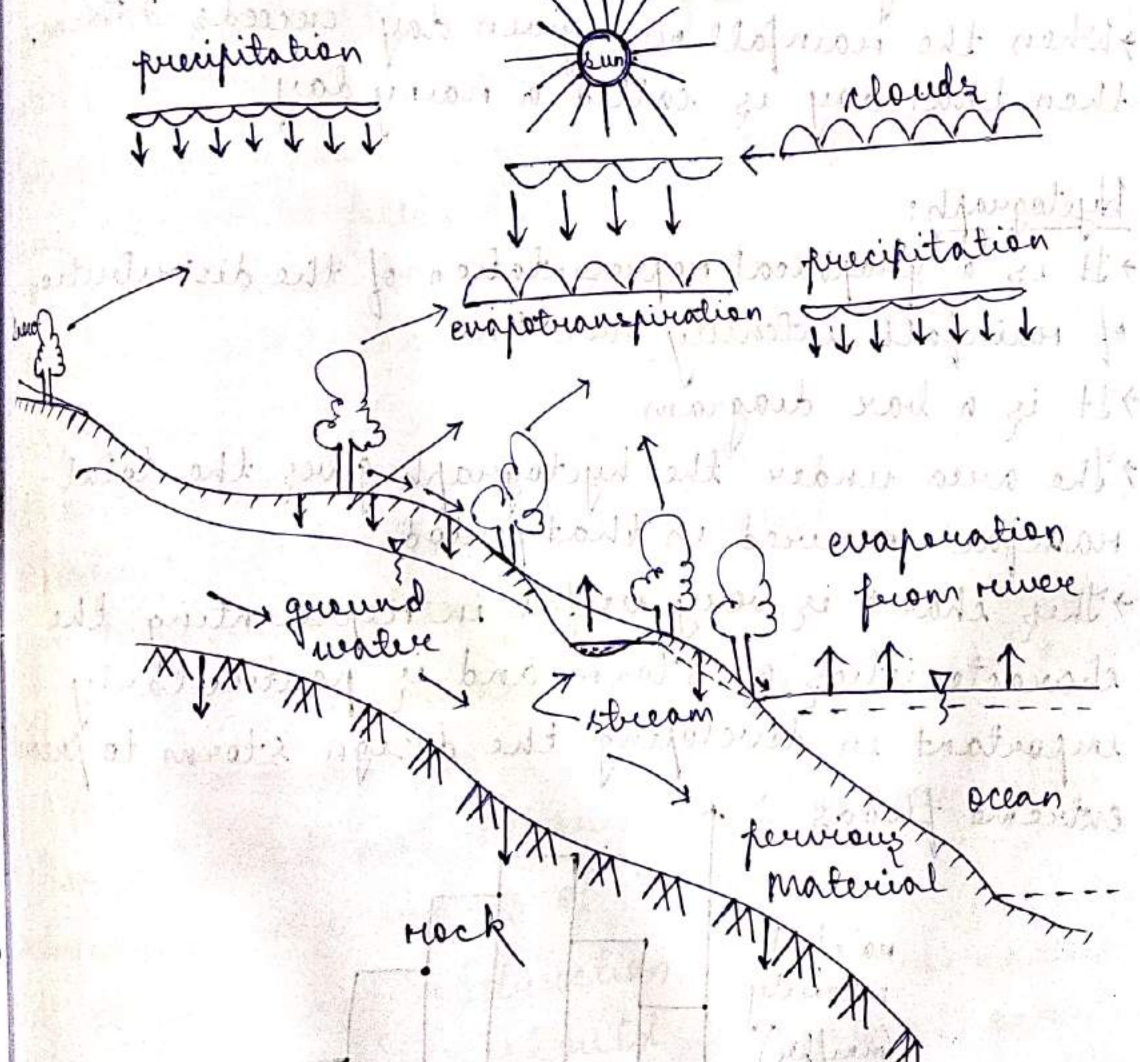
→ Evapouration: when the water come into contact with head radiation, it turns into vapour, it is called evaporation.
→ Precipitation: as the evapouration continues, the amount of vapour in atmosphere goes on increasing, after reaching a certain amount, the vapour condense and come to earth's surface in solid or liquid form, this is called precipitation.
→ Interception: some amount of precipitation is evaporated back to the atmosphere and another part of precipitation is intercepted by vegetation, structure, etc from

where it may be either evaporated back to atmosphere or move down to ground surface

Infiltration: when the water come into the earth surface, some portion of it penetrate the ground and increase the moisture capacity of soil beneath the surface, this water is called infiltrated water and this process is called infiltration

Transpiration: vegetation use the ground water or soil moisture for their growth, this moisture again convert in evaporation through vegetation, this is called transpiration.

Runoff: the portion of precipitation which come on the surface and reach the stream channel by above and below the surface of earth is called runoff.



Rainfall:

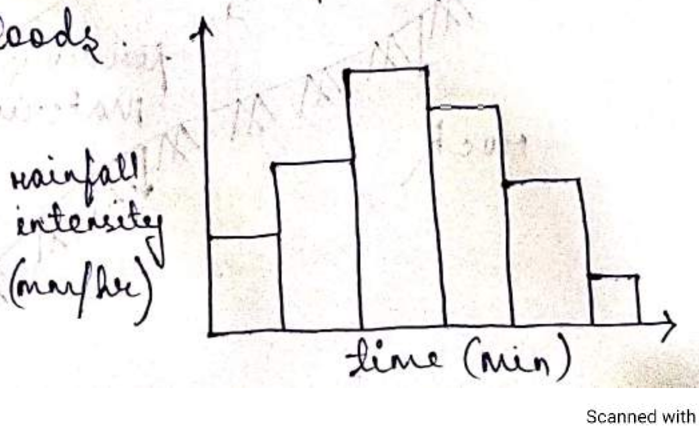
→ It is the principal form of precipitation in India.
→ The term rainfall is used to describe precipitations in the form of water drops of sizes larger than 0.5mm.
→ The maximum size of a raindrop is about 6mm.
→ This term is used when water drops are of sizes between 0.5mm to 6mm.

Types	Intensity
1. Light rain	→ trace to 2.5mm/hr
2. Moderate rain	→ 2.5mm/hr to 7.5mm/hr
3. Heavy rain	→ >7.5mm/hr

→ Rainfall is measured at 8:00am and recording the rainfall of the past 24hrs is common throughout the country.
→ When the rainfall on a given day exceeds 2.5mm, then that day is called a rainy day.

Hyetograph:

→ It is a graphical representation of the distribution of rainfall intensity over time.
→ It is a bar diagram.
→ The area under the hyetograph gives the total rainfall occurred in that period.
→ This chart is very useful in representing the characteristics of storm and is particularly important in developing the design storm to predict extreme floods.



Estimation of rainfall:

If 1cm rainfall occur over a area of $1 km^2$, then it represents that the total volume of water over that area is $10^4 m^3$.

⇒ volume of water = rainfall depth × area

As it is not possible to collect all the rainfall which comes down on an area, we use an instrument for measurement of rainfall called a rain gauge. They should be placed in place so that it clearly represent the rainfall of that area.

Rain gauge:

It is an instrument used for measurement of rainfall.

These rain gauge are also called as pluviometer, ombrometer, hyetometer and udometer.

For placing a rain gauge in an area, following guidelines should be followed:—

1) The ground must be in the open, levelled and the instrument must present a horizontal catch surface.

2) It must be set as near the ground as possible to reduce wind effect but it must be sufficiently high to prevent from flooding.

3) It must be surrounded by an open fenced area of atleast 5.5m × 5.5m.

4) There should not be any object nearer to the instrument in a radius of 30m.

5) If there is any obstruction within 30m radius than the rain gauge should be kept at same

distance from the obstruction and that distance should be more than twice the height of obstruction

Types of rain gauges:

→ Rain gauges may be classified in the two categories as.

1. Non-recording gauges:—

• Extensively used in India of this type is Symon's gauge.

• It has the standard area such that diameter is 12.7cm (5-0 inches).

• This rain gauge can also be used to measure snowfall.

2. Recording gauges:—

• They produce continuous plot of rainfall against time and provide valuable data of intensity and duration of rainfall.

• Examples of this type are

a) Tipping-bucket types →

• This gives data on the intensity of rainfall and not on accumulated rainfall against time.

b) Weight-bucket types →

• This gives graph of accumulated rainfall vs. time i.e. curve curve.

c) Natural-syphon type or float-type gauge →

• This is generally adopted in India as the standard recording type rain-gauge.

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.

→A catchment area is separated from its neighbouring areas by a ridge called divide or watershed.

→The catchment area of tributary river A is α and $(\alpha+\beta)$ is the catchment area of river B.

→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.

Runoff:

→Runoff means the draining-off of precipitation from a catchment area through the surface channels.

→It is normally expressed as volume per unit time for a given ~~area~~ area, represents the output from the catchment in a given unit of time.

Types of runoff:

→ The total runoff from a typical catchment area may be divided into four parts for understanding.

i) Direct precipitation:—

• The precipitation on the water surface and into the stream channels will normally represent only a small percentage of total volume of water flowing in the stream.

ii) Surface runoff:—

• The precipitation over the land surface move as sheet flow, this portion of runoff is called overland flow and involves building up of a storage over the ground and finally its draining off from the basin.

iii) Interflow:—

• Part of precipitation that infiltrate into the soil moves laterally and returns to the surface at some location away from the point of entry to the soil is called interflow.

iv) Ground water flow:—

• Sometime infiltrated water is to undergo deep percolation and reach the ground water storage in the soil.

→ Based on the time delay between the precipitation and the runoff, the runoff is classified as

i) Direct runoff:—

• It is that part of runoff which enters the stream immediately just after the rainfall.

ii) Base flow :—

The delayed flow that reaches a stream generally as ground water.

Estimation of flood discharge:

1. Dicken's formula :—

→ It is suitable for north India and also central India.

→ $Q_p = C_D \cdot A^{3/4}$

Q_p = Flood peak discharge in m^3/sec

C_D = constant varies between 6 – 30 for India

A = catchment area in km^2

2. Ryve's formula :—

→ It is suitable for coastal region.

→ $Q_p = C_R A^{2/3}$

C_R = 6.8 for areas within 80km from east coast

= 8.5 for areas which are 80-160km from the east coast

= 10.2 for limited areas near hills

Module - 3

Water requirement of crop (Chapter 1)

Defination 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.

→ It is also a science of planning and designing a water supply system for the agricultural land to protect the crops from adverse effects of weather.

Necessity of irrigation:

→ Insufficient rainfall.

→ Uneven distribution of rainfall.

→ Improvement of perennial crop.

→ Development of agriculture in desert area.

Benefits of irrigation:

1. Increase in crop yield:—

→ Increase in crop yields occur on account of good irrigation systems leading to increase in food production.

2. Protection against famines:—

→ Food production of a country can be increased by availing irrigation families. This helps preventing famine situations.

3. Revenue generation:—

→ Assume supply of irrigation water leads to growing of superior crops by the farmers.

Farmers become prosperous by selling the crop while governments revenue is generated by imposing taxes on irrigation water.

4. <u>Avoidance of mixed cropping</u>:—

→ Mixed cropping means sowing of two or more crops together in the same field when weather conditions are not favourable for a particular type of crop. The need of mixed croping is eliminated if we have good irrigation facility.

5. <u>Navigation</u>:—

→ Irrigation canals may be used for inland navigation. Inland navigation is useful for communication and transportation.

6. <u>Hydroelectric power generation</u>:—

→ Major river valley projects are planned to provide hydroelectric power together with irrigation. Thus at the same time dual purpose is served.

7. <u>Generation of employment opportunities</u>:—

→ During construction of irrigation works like canal headworks, weir/barrage, overhead irrigation works, employment opportunities are generated.

<u>Types of irrigation</u>: ***

Irrigation may be broadly classified into.

1. <u>Surface irrigation</u>:—

→ 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.

→ Surface irrigation → flow irrigation
→ lift irrigation

→ a) Flow irrigation →

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

→ b) Lift irrigation →

- Water available at lower level is lifted to a higher level by mechanical or manual means and then supplied for irrigations.
- Mostly tubewells are used for this purpose.

→ Flow irrigation can be further sub divided into perennial irrigation and flood irrigation.

2. Sub-surface 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 pipe and laterated perforated pipes.

→ This method is suitable for soils which are highly permeable.

→ a) Natural sub-irrigation →

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

→ b) 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.

Crop season:

→ There are mainly 2 crop seasons in India.

a) Rabi (winter crops) → from october to march.

• It 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.

b) Kharif (monsoon crops) → from april to september.

• 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

→ But there is also a crop season called zaid in addition to rabi and kharif.

Duty:

→ The duty of water is the relationship between the volume of water and the area of the crop it matures.

→ It is defined as the area irrigated per cumec of

discharge running for base period B.
→ It is generally represented by D

Delta:
→ It is the total depth of water required by a crop during the entire period and is represented by Δ.

Base period:
→ Base period for a crop refers to the whole period of cultivation from the time when irrigation water is first issued for preparation of the ground for planting the crop to its last watering before harvesting.
→ It is represented by B.

Relation between D, Δ, B:

$$\Delta = 8.64\frac{B}{D} \text{ in 'm'} \quad \text{(SI unit)}$$

B = base period in days
D = duty in hectare/cumec
Δ = delta in metre (total depth of water)

$$\Delta = \frac{2B}{D} \text{ feet} \quad \text{(FPS unit)}$$

D is in acre/cumec
B is in days
Δ is in feet

$$\Delta = 864\frac{B}{D} \text{ in 'cm'} \quad \text{(CGS unit)}$$

Δ is in cm

Rabi crops:

→ These are winter crops grown in between october and march.

→ These 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, etc.

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 watershed between two drainage valleys.

→ GCA is the total area lying between the drainage boundaries which can be irrigated by a canal system.

Culturable command area (CCA):

→ It is that portion of GCA that is culturable or cultivable.

→ CCA = GCA − unculturable area

→ CCA can be divided into a) culturable cultivated area.
b) culturable uncultivated area

Irrigable area:

→ It is also known as command area (CA).

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

Intensity of irrigation:

→ It 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 irrigation.

→ No irrigation system is designed to irrigate all of its cultivable area every year.

Time factor:

→ The time factor of a canal is the ratio of the number of days the canal has actually run to the number of days of irrigation period.

→ For example, if the number of days of irrigation period = 12, and the canal has actually run for 5 days, then the time factor will be 5/12.

Crop ratio:

Crop ratio is the ratio of area irrigated in kharif season to rabi season.

Flow Irrigation (Chapter 2)

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.

→ Canals and channels 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.

→ Irrigation canals can also be utilized for transportation of goods as well as inland navigation.

Types of canal:

→ 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 (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 canal

b) Non-alluvial canal

vi) Based on the lining →

a) Lined canals

b) Unlined canals

Loss of water in canals:

→ Losses are sometimes very high i.e. 20–50% of discharge carried by the canals.

→ It may be of

1. Evaporation :—

→ The water lost by evaporation is generally very small, as compared to the water lost by seepage in certain channels.

→ These losses are generally of the order 2-3% of the total losses.

2. Seepage :—

→ They can be of 2 types.

a) Percolation :—

→ In this, the loss of water depends upon the difference of the top water surface level of the channel and the level of WT.

b) Absorption :—

→ In this case, the rate of loss is independent of seepage head but depends only upon water head plus the capillary head.

3. Misuse by farmers.

Perennial irrigation:

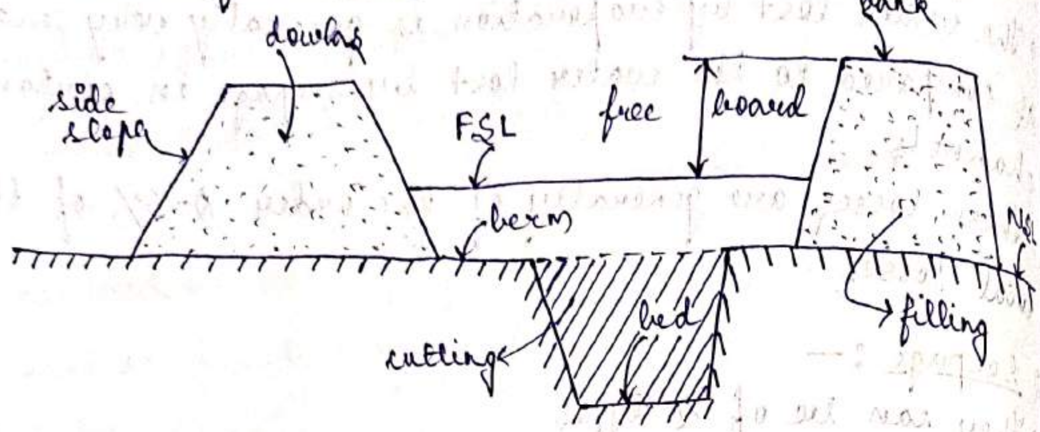
→ In this type of irrigation, source of water is from a river which is perennial.

→ A weir or barrage is constructed across this river.

→ Sometimes a dam may be constructed to form a reservoir upstream.

→ Main canal with a regulator is constructed where one or both banks supply water to the crop field.
→ This type is reliable as water is available during the whole period of the year.

Cross-section of a canal:



1. Side slope :—
→ It should be such that they are stable, depending upon the type of the soil.
→ A comparatively steeper slope can be provided in cutting rather than in filling, as the soil in the former case shall be more stable.
→ 1H:1V to $1\frac{1}{2}$ H:1V slope in cutting and $1\frac{1}{2}$ H:1V to 2H:1V in filling is generally adopted.

2. Berms :—
→ It is the horizontal distance left on the ground between toe of the bank and top edge of cutting.
→ It is provided in such a way that the bed line and the bank line remains parallel.
→ The silt deposited on sides is fine and impervious. It therefore serves as a good lining for reducing losses, leakage and consequent breaches, etc.

3. Free board:—

→ The margin between FSL and bank level is known as free board.

→ The amount of free board depends upon the size of the channel.

→ It gives safety against canal overtopping because of waves in canals or accidental raising of the water level.

4. Banks:—

→ The primary purpose of banks is to retain water.

→ They can be used as means of communication and as inspection paths.

→ They should be wide enough so that a minimum cover of 0.5m is available above the saturation line.

5. Dowlas:—

→ It's a measure of safety in driving, dowlas of 0.3m high and 0.3–0.6m wide at top with side slopes of $1\frac{1}{2}$H:1V to 2H:1V are provided along the banks.

→ They also help in preventing slope erosion due to rains, etc. (contd.)......

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(Contd)........ Chapter 2

Classification of canal acc. to alignment:

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.
→ CD works are not required.
→ They are economical.

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.
→ CD works are required.

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 CD works are not required.
→ It can irrigate area only on one side.
→ It has a very steep bed slope.

Lining of canals:

→ Water is very costly if used for irrigation and it should not be wasted while conveying it from source to the fields.

→ Most of canals in India are unlined and large part of costly irrigation water lost in percolation and absorption as seepage loss.

→ Seepage loss of the irrigation water must be minimised by lining of canals.

→ Lining of canal is the process of covering of earthen surface of the canal with a stable lining material such as concrete, tiles, etc.

Advantages:

→ Seepage control.

→ Prevention of water logging.

→ Increase in channel capacity.

→ Increased in commanded area.

→ Reduction in maintenance cost.

→ Elimination of flood dangers.

Disadvantages:

→ It requires heavy initial investment.

→ It is difficult to repair damaged lining.

→ It is difficult to shift the outlets very

→ It is very difficult to shift the outlets very often as linings are permanent.

Types of lining of canal:

1. Hard surface lining:—

a) Cement concrete lining.

b) Shotcrete or plaster lining.

c) Cement concrete tile lining or brick lining.

d) Asphaltic concrete lining.

e) Stone blocks lining.

2. Earth type lining:—

a) Soil cement lining.

b) Sodium carbonate lining.

c) Clay puddle lining.

3. Buried and protected membrane type lining:—

a) Prefabricated light membrane lining.

b) Bentonite soil and clay membrane lining.

Water Logging and Drainage (Chapter 3)

Defination:

→It is a phenomenon 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, productivity of land is affected by rise in water table.

Causes of water logging:

- Over and intensive irrigation.
- Seepage of water from the adjoining high lands.
- Seepage of water through the canals.
- Impervious obstruction.
- Inadequate natural drainage.
- Inadequate surface drainage.
- Excessive rains.
- Submergence due to floods.
- Irregular or flat topography.

Effects of water logging:

- Inhibiting activity of soil bacteria.
- Decrease in available capillary water.
- Fall in soil temperature.
- Rise in level of salts in the surface soil.
- Delay in cultivation operation.
- Growth of wild flora (leading to decrease in crop yield).
- Adverse effect of community health.

Prevention of water logging:

- Lining of canals and water course.
- Reducing the intensity of the irrigation.
- Crop rotation.
- Optimum use of water.
- Providing intercepting drains.
- Efficient drainage system.
- Improving natural drainage of the area.
- Introduction of lift irrigation.

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Remedies of water logging:

→Installation of lift irrigation system:—

→When a lift irrigation project in the form of a tube well irrigation system is introduced in the water logged area, the water table gets lowered sufficiently.

It is found to be very successful method of reclaiming water logged land.

→Implementation of drainage scheme:—

→The water logged area may be reclaimed by introducing overland and underground drainage schemes.

Detection of water logging:

→Main and important one is remote sensing which helps in detecting water logging.

Diversion Headworks and Regulatory Structures (Chapter 4)

Necessity and objective:

→The works which are constructed at the head of the canal inorder to divert the river water towards the canal so as to ensure a regulated continuous supply of silt free water with a certain minimum head into the canal.

→It consist of construction such as:—

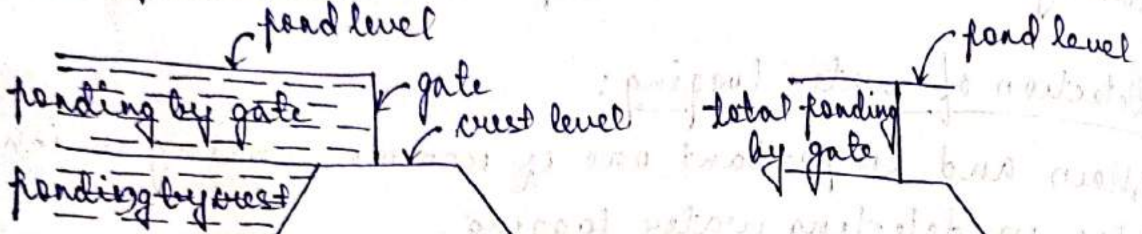
a) weir proper
b) under sluices
c) divide wall
d) river training work
e) fish ladder
f) canal head regulator
g) shutter, gates over weir, etc
h) silt regulation works

Weir and barrage:

→ If major part of the entire ponding of water is achieved by a raised crest and a smaller part or small part by the shutter, then this barrier is known as a weir.

→ If most of the ponding is done by gates and a smaller or part of it is done by raised crest then the barrier is known as barrage.

Barrage outlay:



(a) barrage with a small raised crest.

(b) barrage without any raised crest

→ If most of ponding or entire ponding is done by permanent raised crest, then afflux caused during high floods is very high.

→ If most of ponding is done by gates, which can be opened during high floods and afflux (i.e. rise in HFL near the site) will be minimum.

→ The rise in maximum flood level (HFL) in u/s of weir, caused due to construction of weir across the river is called afflux.

→ The water level required in under sluice pocket u/s of the canal head regulator so as to feed the canal with its full capacity is known as pond level.

→ The crest level is the highest level above a certain point (datum point) that a river will reach in a certain amount of time.

Silting:

→ The process of becoming filled or blocked with silt.

→ Silting is most often caused by soil erosion or sediment spill.

→ Sometimes silting is called sediment pollution, but that is an undesirable term since it is ambiguous and also refer to a chemical contamination of sediments accumulated on the bottom or to pollutants bound to sediment particles.

Scouring:

→ Scouring can be defined as a process due to which the particles of the soil or rock around the periphery of the abutment or pier of the highway, bridge spanning over a water body, gets eroded and removed over a certain depth called scour depth.

→ Scour in simple language is the erosion of soil surrounding a bridge foundation.

→ Bridge scour occurs when fast moving water around a bridge removes sediment from around the bridge foundation, leaving behind scour holes.

Regulatory structure:

→ The crest of the under-sluices portion of the weir is kept at a lower level than the crest of the normal portion of the weir.

→ The divide wall is a masonry or a concrete wall constructed at right angle to the axis of the weir and separates the weir proper from the under sluices.

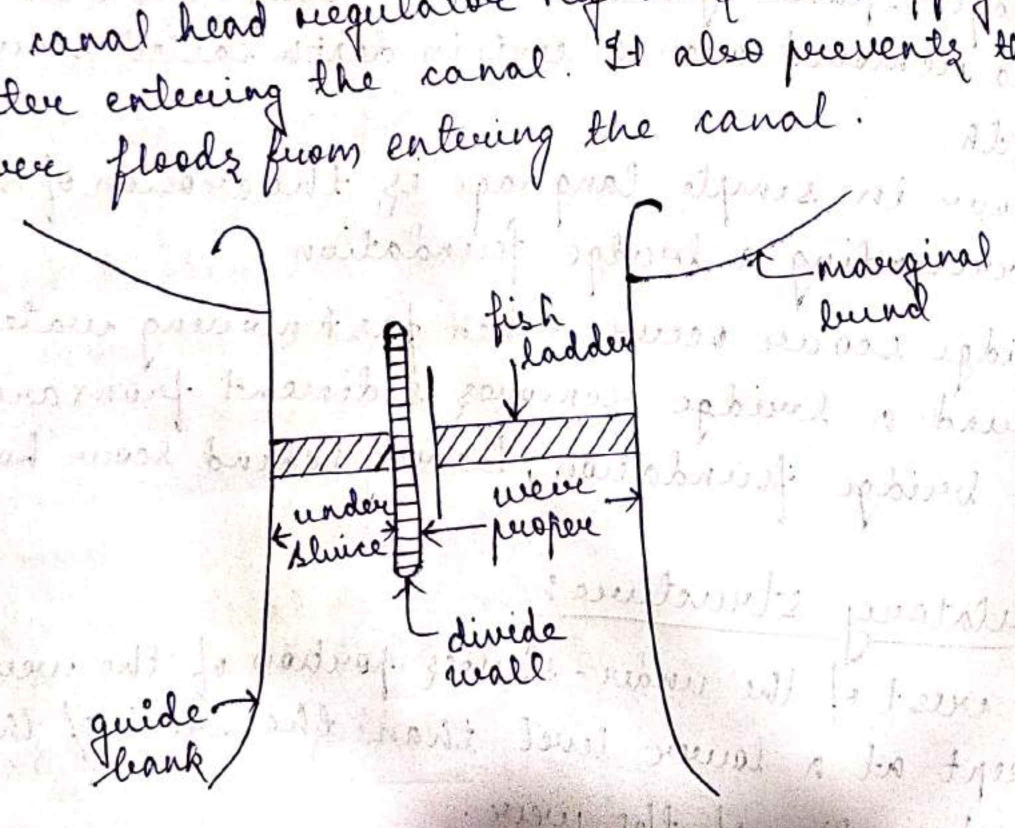
→ The guide banks force the river into a restricted channel, thus ensuring a smooth and an almost axial flow near the weir site.

→ Marginal bunds are provided on the u/s side of the works in order to protect the area from the submergence due to rise in HFL caused by the afflux.

→ Groynes are the embankment type structures, constructed transverse to the river flow, extending from the bank into the river.

→ Fish ladder is a structure which enables the fish to pass u/s.

→ A canal head regulator regulates the supply of water entering the canal. It also prevents the river floods from entering the canal.



Cross-drainage works (Chapter 5)

Function and necessity:

→ A CD work is a structure carrying the discharge of a natural stream across a canal intercepting the stream.

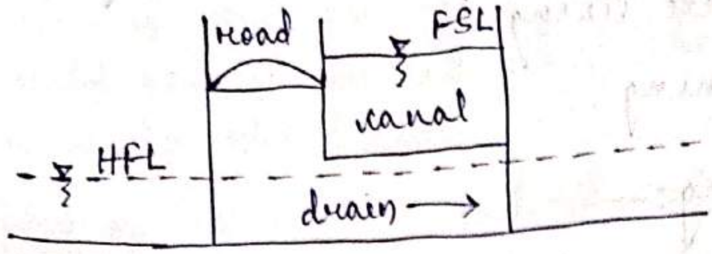
→ Aligning a canal on watershed is necessary so that water from canal can flow by gravity to fields on both sides of the canal.

→ 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 CD work is a costly item so it crosses below the junction of two stream.

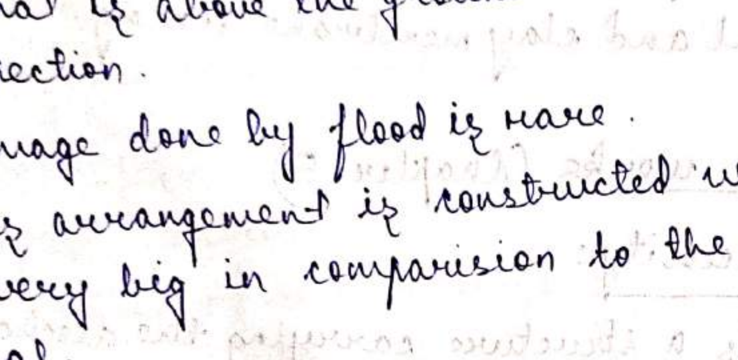
- diverting one stream into another.
- changing the alignment of the canal so that it crosses below the junction of two stream.

Aqueduct:



→ It is a CD work carrying canal over the drain.
→ HFL of the drain is much below the bottom of the canal.
→ Hence the drainage water flows freely under gravity.
→ Canal is above the ground and hence is open to inspection.
→ Damage done by flood is rare.
→ This arrangement is constructed when the drain is very big in comparision to the section of the canal.

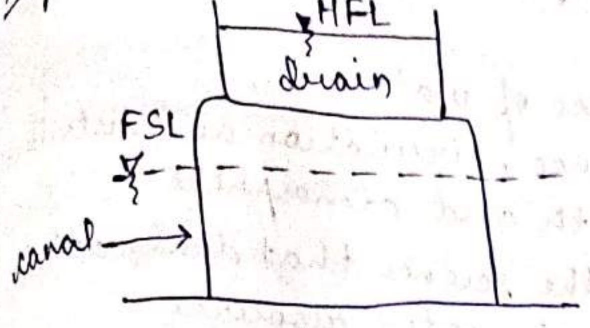
Syphon:



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

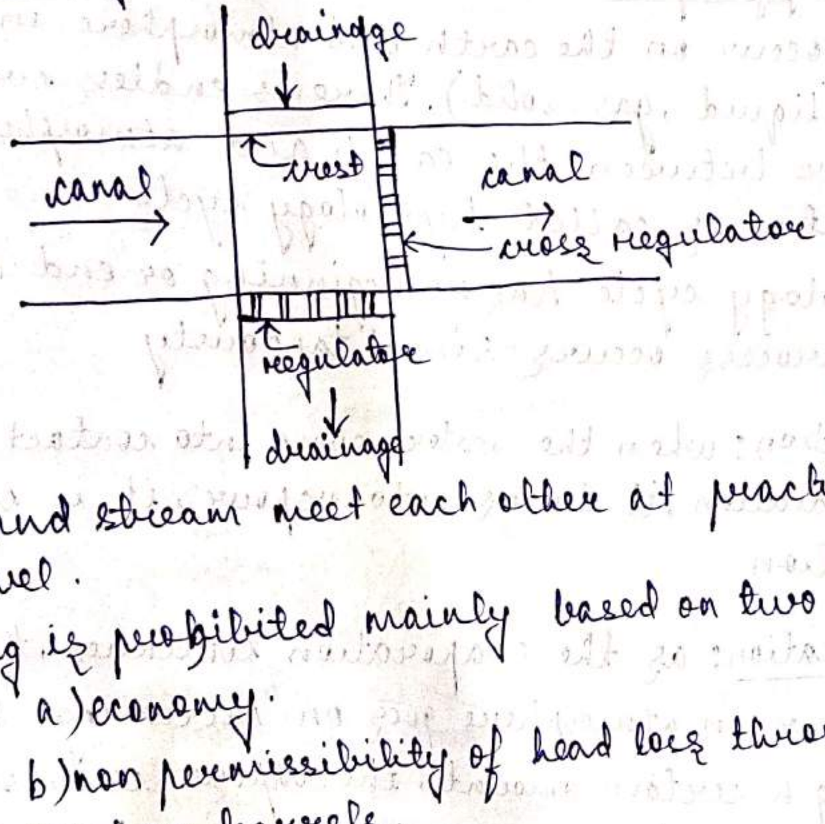
it circular barrels are adopted.

Super passage:



→FSL (full supply level) of canal is lower than the underside of the stream.
→Canal water runs under gravity.
→It is a CD work carrying drainage over the canal.

Level crossing:



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

Dam (Module 4)

Necessity of storage reservoir:

→ It is a hydraulic structure constructed across a river to store water on its u/s side or divert water from river.

→ The stored water is utilized when it is needed for different purposes.

→ It mainly provide water for irrigation or water power generation, diverting water into canals or other conveyances system to the place of use, acting as a flood controlled reservoir.

Types of dam:

Basis of classification	Type	Common examples
a) Classification according to use	a) Storage dam	Gravity dam, Earthen dam, Arch dam, Rockfill dam.
	b) Diversion dam	Weir, barrage.
	c) Detention dam	Dike, Debris dam.
b) Classification by hydraulic design	a) Overflow dam	Spillway.
	b) Non-overflow dam	Gravity dam, Earthen dam, Rockfill dam.
c) Classification by materials	a) Rigid dam	Gravity dam, Arch dam, Buttress dam, Steel dam.
	b) Non-rigid dam	Earth dam, Rockfill dam.

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Earthen dam:

→ Earth dams are made of locally available soils and gravels and hence are most common types of dams used upto moderate heights.

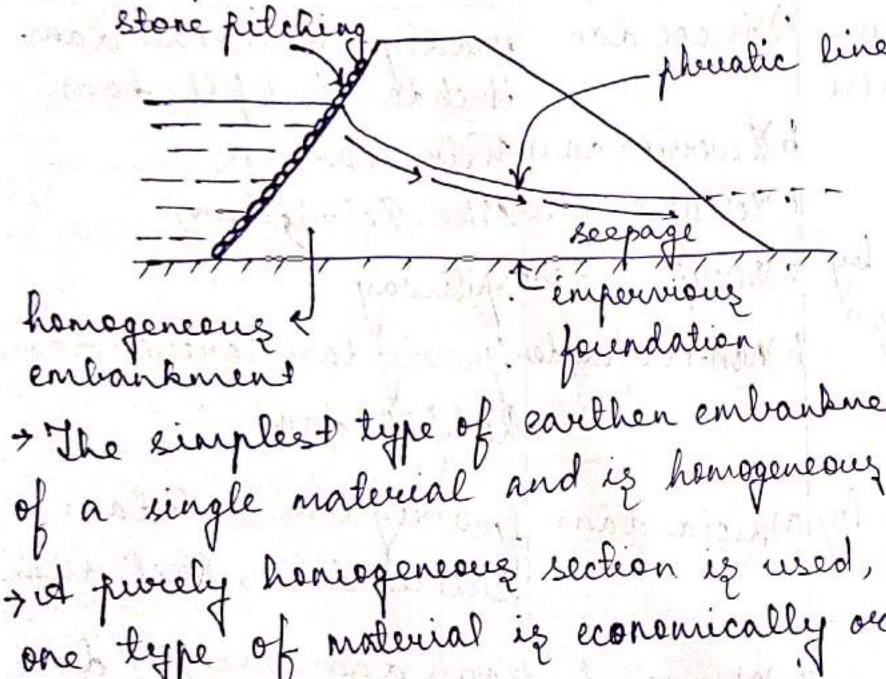
→ These are the most ancient type of embankments, as they can be built with the natural materials with a min of processing and primitive equipment.

→ These dams are cheaper and they can utilise the locally available materials and less skilled labour is required for their construction.

Types of earthen dam:

They are of 3 types.

1. Homogeneous embankment type:—

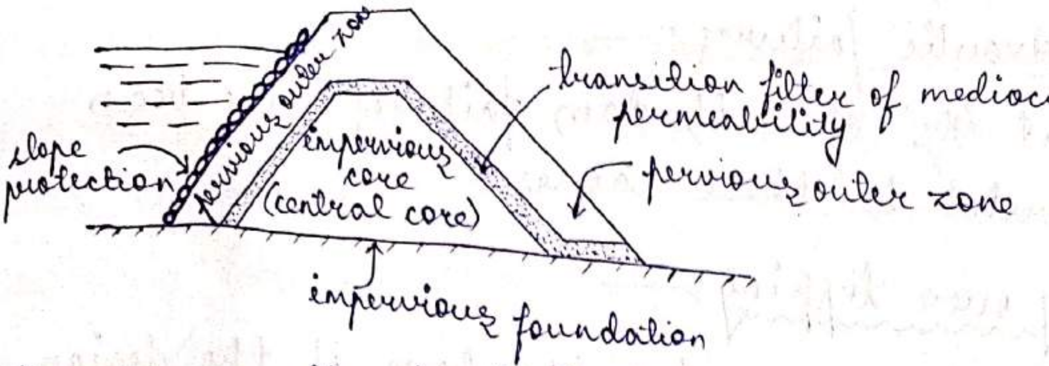


→ The simplest type of earthen embankment consists of a single material and is homogeneous throughout.

→ A purely homogeneous section is used, when only one type of material is economically or locally available.

→ Such a section is used for low to moderately high dams. Large dams are rarely designed as homogeneous embankment.

2. Zoned embankment type:—

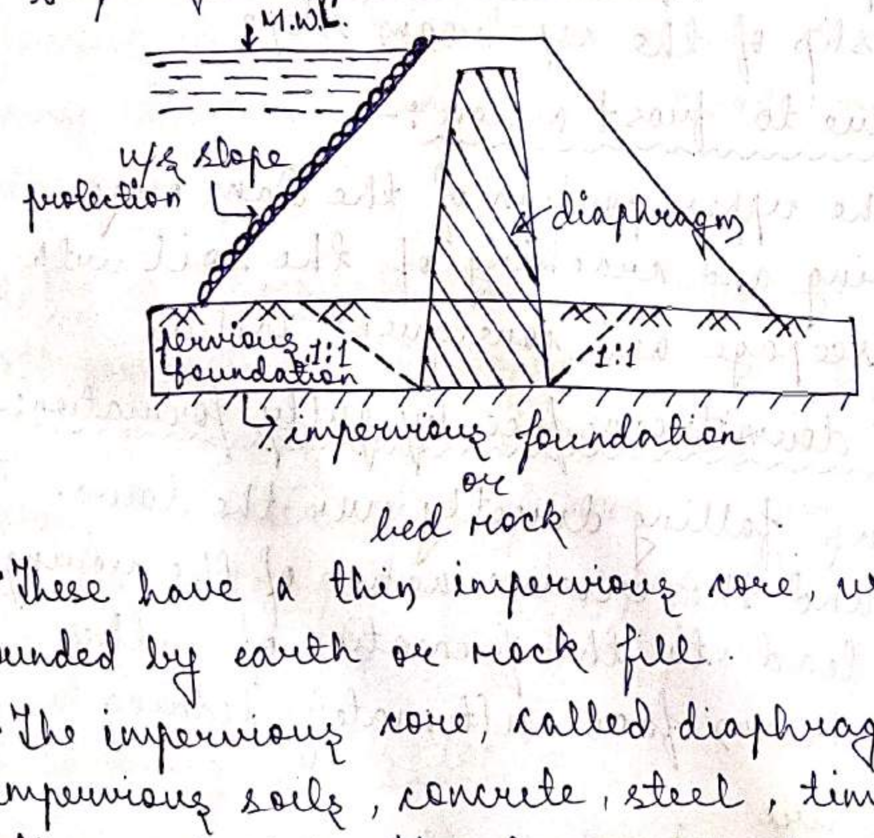


→ These are usually provided with a central impervious core, covered by a comparatively pervious transition zone, which is finally surrounded by a much more pervious outer zone.

→ The central core checks the seepage.

→ This type of embankments are widely constructed and the materials of zones are selected depending upon their availabilities.

3. Diaphragm type embankments:—



→ These have a thin impervious core, which is surrounded by earth or rock fill.

→ The impervious core, called diaphragm, is made of impervious soils, concrete, steel, timber or any other material. It acts as a water barrier to prevent seepage through the dam.

Causes of failure of earthen dams :****

1. Hydraulic failures :—

About 40% of earth dam failures have been attributed to these causes.

a) By over topping :—

→ The water may overtop the dam, if the design flood is under estimated or if the spillway is of insufficient capacity or if the spillway gates are not properly operated.

b) Erosion of upstream face :—

→ The waves developed near the top water surface due to the winds, try to notch-out the soil from the upstream face and may even, sometimes, cause the slip of the upstream slope.

c) Cracking due to frost action :—

→ Frost in the upper portion of the dam may cause heaving and cracking of the soil with dangerous seepage and consequent failure.

d) Erosion of downstream face by gully formation :—

Heavy rains falling directly over the downstream face and the erosive action of the moving water, may lead to the formation of gullies on the downstream face, ultimately leading to the dam failure.

e) Erosion of the d/s toe :—

→ The d/s toe of the earth dam may get eroded due to two reasons, i.e. i) the erosion due to cross currents that may come from the spillway buckets and ii) the erosion due to tail water.

2. Seepage failures :—

Controlled seepage or limited uniform seepage is inevitable in all earth dams and ordinarily it doesn't produce any harm.

a) Piping through foundation :—

→ Sometimes, when highly permeable cavities or fissures or strata of coarse sand or gravel are present in the foundation of the dam, water may start seeping at a huge rate through them.

b) Piping through the dam body :—

→ It generally get developed near the pipe conduits passing through the dam body. Contact seepage along the outer side of conduits may either develop into piping or seepage through leaks in the conduits may develop into piping.

c) Sloughing of d/s toe :—

→ The process of failure due to sloughing starts when the down-stream toe becomes saturated and get eroded, producing a small slump or a miniature slide.

3. Structural failures :—

About 25% of the dam failures have been attributed to structural failures. These are generally caused by shear failures, causing slides.

a) Foundation slide :—

→ When the foundation of the earth dam are made of soft soils such as fine silt, soft clay, etc, the entire dam may slide over the foundation.

b) Slide of embankment :—

When the embankment slopes are too steep for the strength of the soil, they may slide causing dam failure.

Protection measurement :

1. Location of the centre of the critical slip circle
2. Determination of pore pressure from flow net.
3. Stability of downstream slope during steady seepage.
4. Stability of upstream slope during sudden drawdown.
5. Stability of u/s slope portion of the dam, during sudden drawdown, from the consideration of horizontal shear developed at base under the u/s

slope of the dam.

6. Stability of d/s slope under steady seepage from the considerations of horizontal shear at base under the d/s slope of the dam.

7. Stability of the foundation against shear.

Gravity dam:

→ A gravity dam has been defined as a structure which is designed in such a way that its own weight resist the external forces.

→ This type of a structure is most durable and solid, and requires very little maintenance.

→ A drainage gallery is provided inorder to relieve the uplift pressure exerted by the seeping water.

→ They can be constructed with ease on any dam site, where there exists a natural foundation strong enough to bear the enormous weight of the dam.

→ Such a dam is generally straight in plan, although sometimes it may be slightly curve.

Types of gravity dam:

They are of 2 types.

1. High gravity dams :—

→ The height of the dam which exceeds the limiting height of low gravity dam is termed as high gravity dam.

→ In this dam, the maximum permissible compressive stress is exceeded if the resultant of all forces pass through the middle third to avoid excessive stresses, the resultant is maintained still near the centre of the base for which purpose the d/s slope is flattened and the u/s slope is also provided with a batter.

2. <u>Low gravity dam</u>:—

→ A low gravity dam is of limiting height such that the resultant of all forces passes through the middle third and the maximum compressive stress at the toe doesn't exceed the permissible limit, i.e.

$$\sigma_1 = wH(S - c + 1) = f$$

Limiting height,

$$H = \frac{f}{w(S+1)}$$ ignoring uplift to be on the safe side

→ The limiting height, for the usual stress of dam material is as follows.

$w = 1000 \text{ kg/m}^3$

$S = 2400 \text{ kg/m}^3$

$f = 30 \text{ kg/cm}^2 = 300 \text{ tonne/m}^2$

$$\therefore H = \frac{300}{1000(2400 - c + 1)} = \frac{300}{1(2.4 + 1)}$$

$$= 88 \text{ m}$$

Causes of failure of gravity dam:

1. By overturning about the toe :—

→ If the resultant of all the forces acting on a dam at any of its sections passes outside the toe, the dam shall rotate and overturn about the toe.

→ Practically such a condition shall not raise, as the dam will fail much earlier by compression.

2. By crushing :—

→ A dam may fail by the failure of its materials i.e. the compressive stresses produced may exceed the allowable stresses and the dam material may get crushed.

→ The vertical direct stress distribution at the base may be given by the eqn :

p = direct stress + bending stress

$$\therefore p_{max/min} = \frac{\Sigma V}{B} \pm \frac{M}{I} y$$

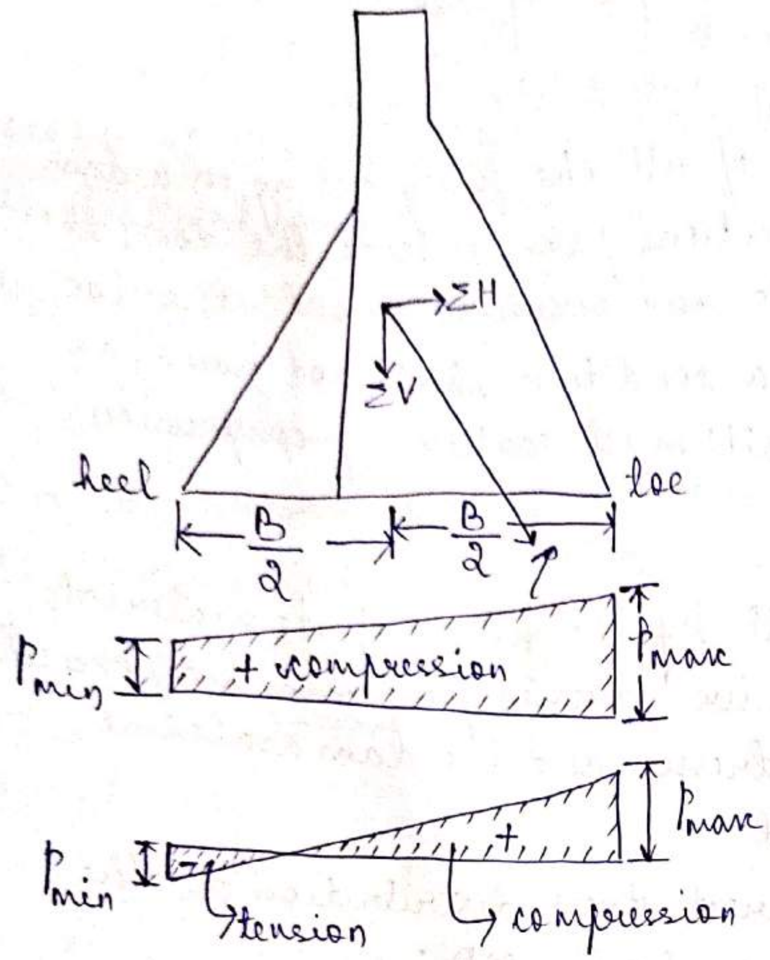
$$= \frac{\Sigma V}{B} \pm \frac{\Sigma V \cdot e}{B^2/6} = \frac{\Sigma V}{B}\left[1 \pm \frac{6e}{B}\right]$$

$$\Rightarrow p_{max/min} = \frac{\Sigma V}{B}\left[1 \pm \frac{6e}{B}\right]$$

e = eccentricity of the resultant force from the centre of the base

ΣV = total vertical force

B = base width



3. By development of tension :—

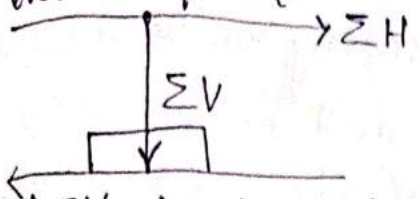
→ Masonry and concrete gravity dams are usually designed in such a way that no tension is developed anywhere, because these materials can't withstand sustained tensile stresses.

→ If subjected to such stresses, these materials may finally crack.

4. By shear failure called sliding :—

→ It will occur when the net horizontal forces above any plane in the dam or at the base of the dam exceeds the frictional resistance developed at that level.

→ external forces



$\mu\Sigma V$ = developed friction

i.e. $\Sigma H < \mu \Sigma V$

$$\Rightarrow \frac{\mu \Sigma V}{\Sigma H} > 1$$

⇒ F.S.S. (factor of safety against sliding)

$$= \frac{\mu \cdot \Sigma V}{\Sigma H}$$

→ S.F.F. (shear friction factor)

$$= \frac{\mu \cdot \Sigma V + B \cdot q}{\Sigma H}$$

B = width of dam at joint

q = average shear strength of the joint which varies from about 1400 kN/m² (14 kg/cm²) for poor rocks to about 4000 kN/m² (40 kg/cm²) for good rocks.

$\mu = 0.65 - 0.75$

<u>Protection measurement:</u>

1. Gravity method or 2-d stability analysis.
2. Elementary profile of a gravity dam.

<u>Spillway:</u>

→ It is a structure constructed at a dam site, for effectively disposing of the surplus water from u/s to d/s.

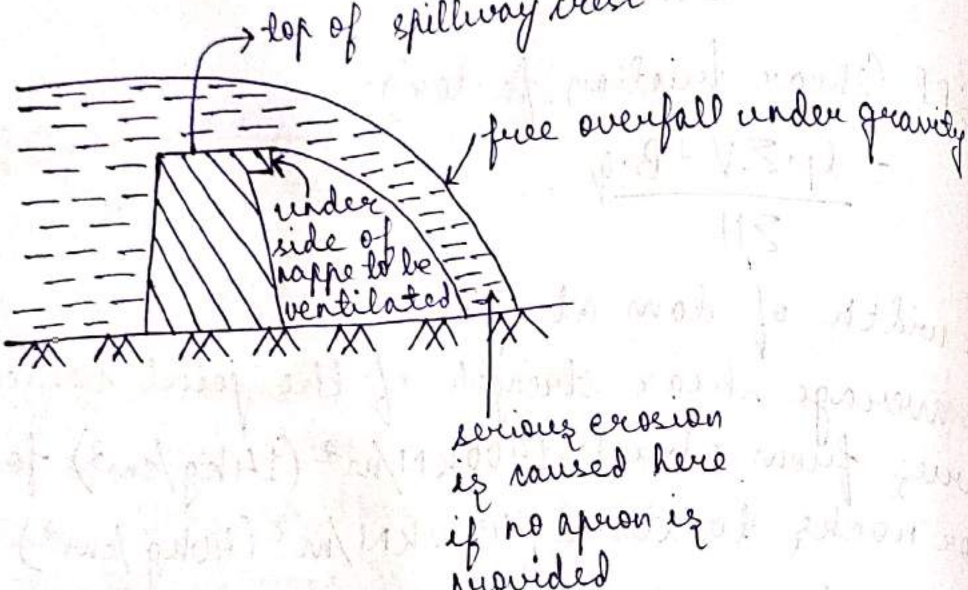
→ A spillway is essentially a safety valve for a dam.

→ It must be properly designed and must have adequate capacity to dispose of the entire surplus water at the time of the arrival of the worst design flood.

Types of spillways:

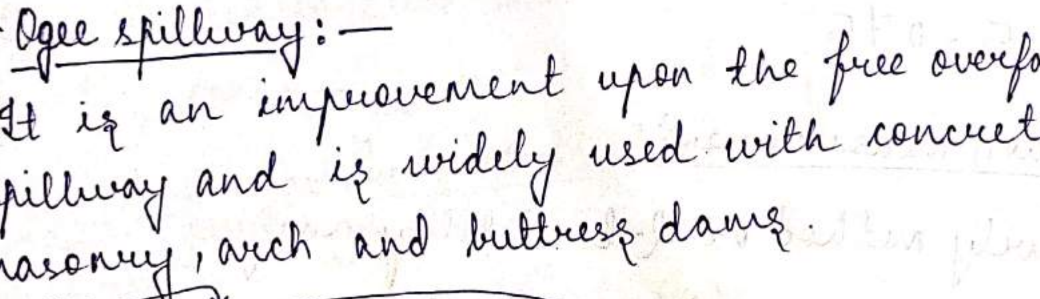
1. Straight drop spillway or overfall spillway:—

→ This is the simplest type of spillway and may be constructed on small bunds or on thin arch dams, etc.



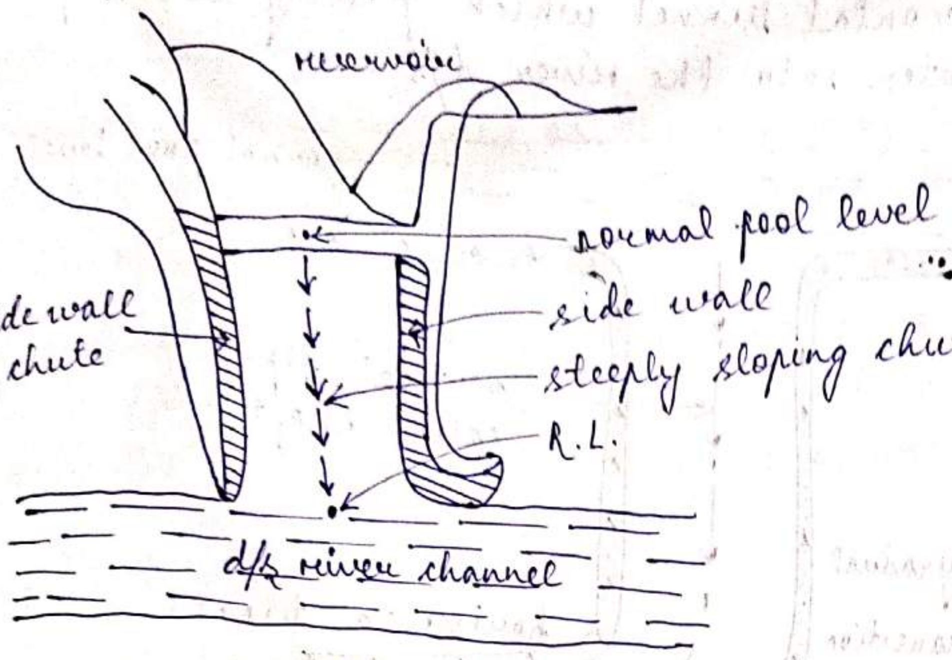
2. Ogee spillway:—

→ It is an improvement upon the free overfall spillway and is widely used with concrete, masonry, arch and buttress dams.



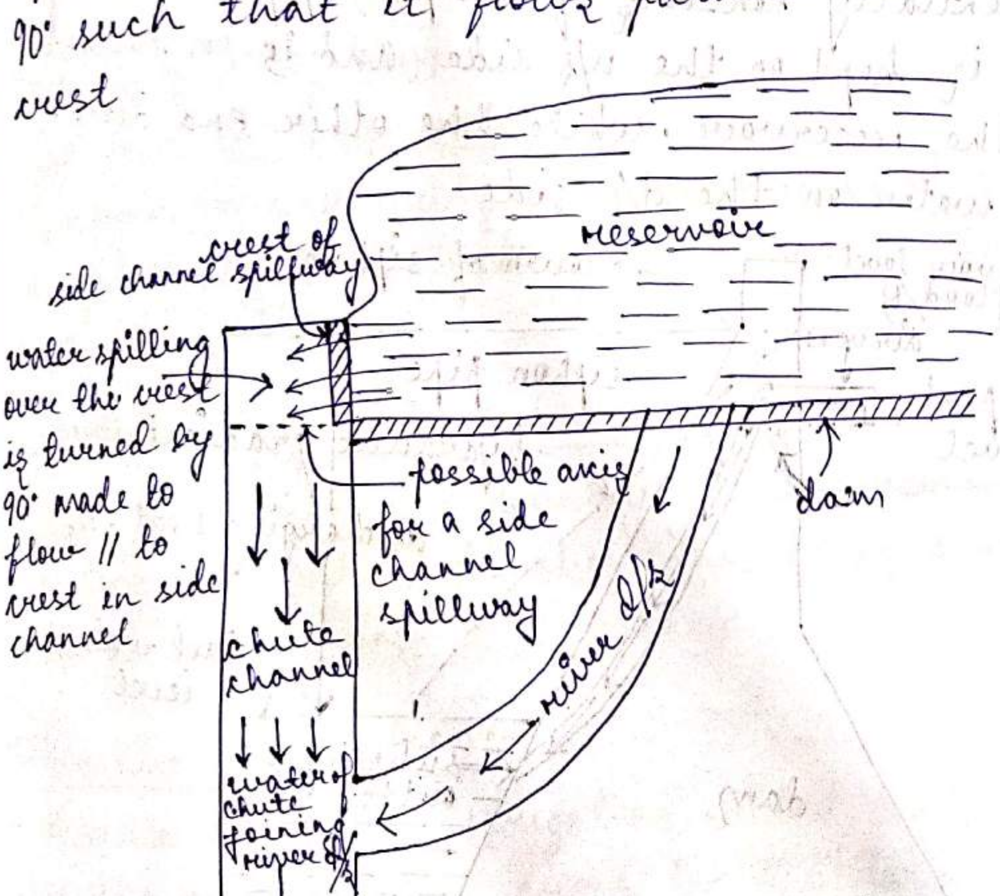
3. Chute spillway :—

→It is the simplest type of a spillway which can be easily provided independently and at low cost.

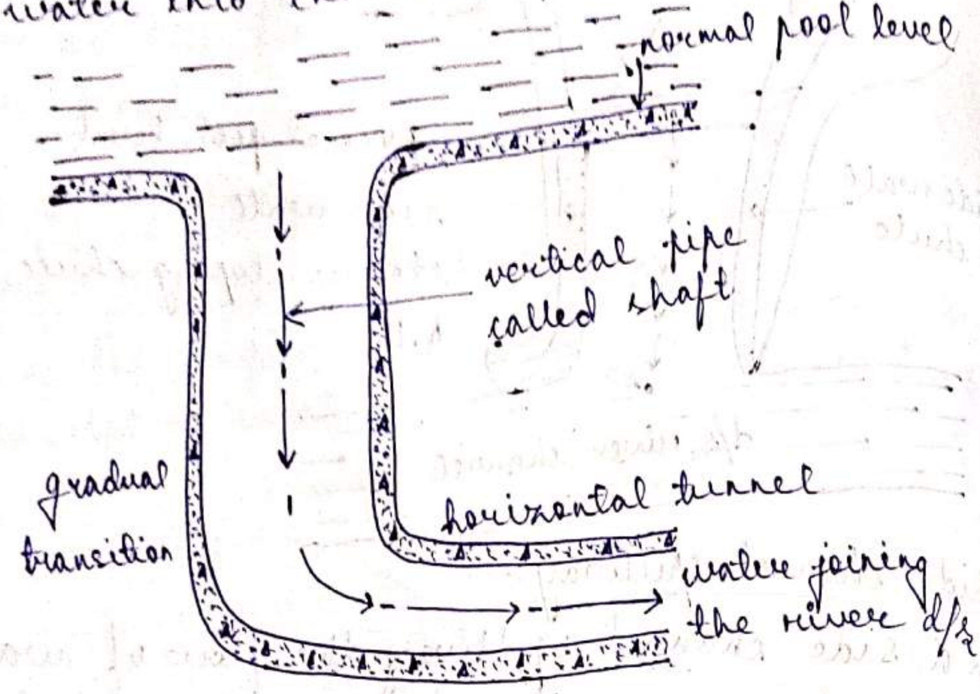


4. Side channel spillway :—

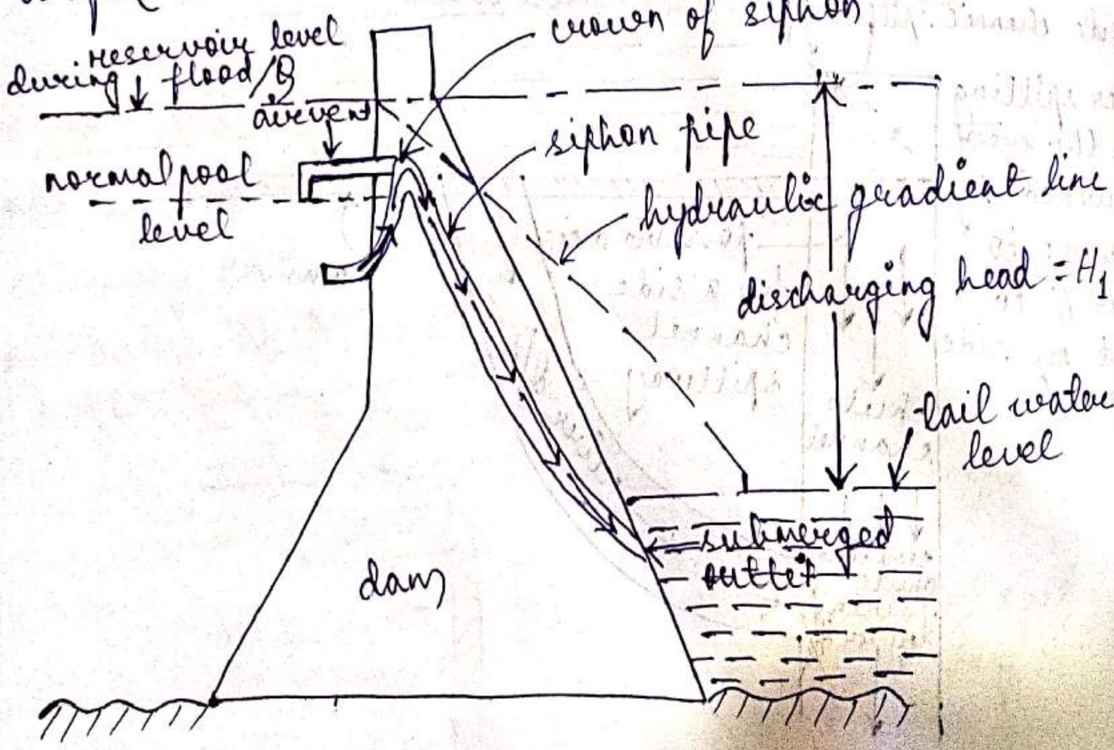
→In a side channel spillway the flow of water after spilling over the crest is turned by 90° such that it flows parallel to the weir crest



5. Shaft spillway:—
→ In this, the water from the reservoir enters into a vertical shaft which conveys the water into a horizontal tunnel which finally discharges the water into the river d/s.



6. Syphon spillway:—
→ It essentially consists of a siphon pipe, one end of which is kept on the u/s side and is in contact with the reservoir, while the other end discharges water on the d/s side.



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