LECTURENOTE

On

HYDRAULICS & IRRIGATION ENGG.(TH-2)

4^{th} Semester

Faculty Name- Supriya Bhanja

Department of Civil Engg.

1. Hydrostatics

1.1- Properties of fluid:

Fluid definition:

- A fluid is a Substance which deforms continuously when subjected to external shear stress however smaller the shear stress may be.
- A solid offers resistance to the force because very Strong intermolecular attraction exists in it. It has a definite shape.
- Both liquids and Gases come under the catagory of fluids. Liquids difficult to Compress where as gases are compressible easily.

Difference between Liquid and Gas:

- Liquid: has definite volume but no shape for all Practical purposes: Liquids have free surface.
  Ex: Water, oil etc.
- Gas: has no shape and volume. It is highly compressible. Gas has no free surfaces.
  Ex: Air and other gases.
- vapour: A gas whose temperature and pressure are Such that it is very near to the liquid phase.
  Ex: Steam, gases and vapours.

(1) Density (ρ) = It is the mass of the matter occupied in unit volume at a Standard temperature and Pressure. It is denoted by ρ.

$$\boxed{\rho = \frac{M}{V}}$$

- SI units = kg/m^3
- It is also known as Specific mass.
- It is an absolute quantity i.e, does not change from place to place.
- As pressure increases mass density also increases. (As more no. of molecules are forced in to a given volume)
- Density is measured by an instrument is called 'Pycnometer' and 'hydrometer'.

Matter	Density, ρ (kg/m³)
Air	1.2
Water	1000
Mercury	13600
Steel	7850
Wood	600
Gold	19600

(2) Specific gravity or Relative density:

It is the ratio of the mass density of any matter to the mass density of a standard fluid.

$$S = \frac{\text{Mass density of a matter}}{\text{Mass density of a standard fluid (i.e water)}}$$

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

- No units.
- For all matters, water is taken as a standard fluid.

Matter	Specific gravity
Air	0.0012
Water	1.0
Mercury	13.6
Steel	7.86
Wood	0.6
Gold	19.6
Concrete	2.4.

- Since the density of fluid varies with temperature, Specific gravity must be determined and specified at a particular temperature.

Q: Calculate the specific weight, specific mass, specific volume and specific gravity of a liquid having a volume of 6m³ and weight of 44KN. (Take specific weight of the water = 9.81 KN/m³, acceleration due to gravity, g = 9.81 m/sec²). (Opt.)

* Velocity: The rate of displacement of a moving object over time.

Acceleration = the rate of ~~chan~~ velocity change over time.

Sol^n Volume of the liquid (v) = $6 m^3$

Weight of the liquid (W) = 44 KN.

Specific weight, $\boxed{\gamma = \frac{W}{V}} = \frac{44}{6} = 7.333 \, KN/m^3$.

Mass density = $\boxed{\rho = \frac{\gamma}{g}} = \frac{7.333 \times 1000}{9.81} = 747.5 \, kg/m^3$.

Specific volume, $\boxed{v_s = \frac{1}{\rho}} = \frac{1}{747.5} = 0.00134 \, m^3/kg$

Specific gravity, $S = \frac{\gamma_{liquid}}{\gamma_{water}} = \frac{7.333}{9.81} = 0.747$.

13) Surface tension : (σ)

Surface tension is a measure of liquids tendency to make a spherical shape, caused by the mutual attraction of the liquids molecules.

•

• Cohesion: force of attraction between the molecules of the same liquid.

• Adhesion: force of attraction between the molecules of different liquids.

• Cohesion enables a liquid to resist very small tensile stress while adhesion enables a liquid to adhere to another body.

• 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.

- The surface energy per unit area of interface is called Surface tension. It is also expressed as work done per unit area.
- As surface tension As temperature increases → Surface tension decreases. (Because Cohesion decrease)
- A 'Tensiometer' is used to measure the surface tension of liquid.
- Due to cohesion, Surface tension causes pressure changes across curved surfaces. Increases in pressure of inside and out side are

(i) Liquid droplet:

$$\boxed{\Delta P = 4\sigma/d}$$

where, d = dia. of droplet.

(ii) Soap bubble:

$$\boxed{\Delta P = 8\sigma/d}$$

where, d = dia. of soap bubble.

(iii) Liquid jet:

$$\boxed{\Delta P = 2\sigma/d}$$

where, d = dia of jet.

Note Air bubble raise in a liquid treated as air droplet, $\boxed{\Delta P = \frac{4\sigma}{d}}$.

- A 20 mm diameter soap bubble has an internal pressure 27.576 N/m^2 greater than the outside atmospheric pressure, then the surface tension of soap-air interface is (in N/m) ________.

Sol^n The soap bubble has two surface with the air the inner and the outer, and almost the same radius since the soap film is very thin.

$$\Delta P = \frac{8\sigma}{d}$$

$$27.576 = \frac{8 \times \sigma}{20 \times 10^{-3}} \Rightarrow \sigma = 0.0689\ N/m$$

(4) Capillarity :

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 depression. Capillarity is due to both cohesion and adhesion.

Capillary rise (adhesive > cohesive) | Capillary depression. (cohesive > adhesive)

- Unit = cm or mm of liquids.
- $$h = \frac{4\sigma \cos\theta}{\gamma d}$$

where, 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.

$\theta = 0^\circ \rightarrow$ Water and glass

$\theta = 130^\circ \rightarrow$ Mercury and glass.

- for tube diameter more than 4mm capillary effect is neglected. Hence the diameter of glass tubes used for measuring pressure (manometer, piezometer etc). Should be large enough size.

Q) What is the diameter of glass tube is required if the capillary effects of the tap water not to exceed capillarity rise 10mm? (σ = 0.072 N/m)

Ans $h = \frac{4\sigma\cos\theta}{\rho g D} \Rightarrow 10 \times 10^{-3} = \frac{4 \times 0.072 \times 1}{1000 \times 9.81 \times D}$

$\Rightarrow D = 0.003$ m = 3mm. Ans

(5) Viscosity:

- A property by virtue of which its offers resistance to the movement of one layer of fluid over the adjacent layer.
- It is a measure of its resistance to flow i.e., shear or angular deformation. Due to,
  (i) Intermolecular cohesion (Liquids)
  (ii) Transfer of molecular momentum (interchange betw. layers) (Gases).

1.2 : PRESSURE AND IT'S MEASUREMENT:

(1) Fluid pressure :/Intensity of pressure: – **1 bar = 10^5 N/m²**

The normal force exerted by a fluid per unit area of the surface.

$$P = \frac{F}{A}$$

Unit = N/m^2 (pascal)

Q A 70 kg person walks on snow with a total foot imprint area of $500 cm^2$. What pressure does he exert on snow?

Ans $P = \frac{F}{A} = \frac{70 \times 9.81}{500 \times 10^{-4}} = 13.73 \times 10^3 N/m^2$

$= 13.73 \ KN/m^2$. Ans.

Types of pressure:

(a) Atmospheric pressure:

The normal pressure exerted by atmospheric air upon all surfaces with which it is in contact. It varies with the altitude. It measured by barometer, also called 'Barometric Pressure'.

(b) Gauge pressure:

When the pressure is measured either above or below atmospheric pressure as a datum, it is called 'Gauge Pressure'. This is measured with the help of a pressure measuring instrument. These can be positive or negative. ($P = \rho g h$ (N/m²))

(c) Absolute pressure:

When pressure is measured above absolute zero (or complete vaccume) it is called an "Absolute Pressure", i.e. the algebric sum of atmospheric and gauge pressures.

All values of absolute pressure are positive.

Relationships between Pabs, Patm & Pgauge:

Absolute pressure = Atmospheric pressure + positive gauge pressure.

Absolute pressure = Atmospheric pressure - vaccume pressure.

Q (Important) The gauge pressure and absolute pressure at the bottom of sea 1.0km if density of sea water is 1030 kg/m³ and atmospheric pressure is 101.3 KN/m².

Ans - $P_{gauge} = 1030 \times 9.81 \times 1000 = 10104.3$ Kpa.

$P_{abs} = P_{atm} + P_{gauge} = 10104.3 + 101.3$

$= 10205.6$ kpa.

(2) Pascal's Law:

It states that "at any point in a fluid at rest the intensity of pressure is exerted equally in all the direction."

It can be proved that $P_x = P_y = P_z$ (Independent upon θ)

(3) Pressure head:

Pressure head 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 may also be called static pressure head or simply static head.

$\psi = \frac{P}{\rho g}$

where ψ = Pressure head, P = fluid pressure, ρ = density, g = Acceleration.

Applications

A mercury barometer is one of the classic uses of static pressure head. Such barometers are an enclosed column of mercury standing vertically with gradations on the tube. The lower end of the tube is bathed in a pool of mercury open to the ambient to measure the local atmospheric pressure.

(4) Pressure gauges: Instrument for measuring the condition of a fluid (liquid or gas) that is specified by the force that the fluid which exert, when at rest, on a unit area, such as pounds per square inch or newtons per square centimeter.

(5) Pressure exerted on an immersed Surface:

Total pressure :-

When ever a surface either a plane or curve is completely submerged in the static fluid, the pressure force variations will take place across the surface. the resultant of all the pressure force variations is called 'total pressure'. It has unit of 'force' (N).

Centre of pressure (CP) :

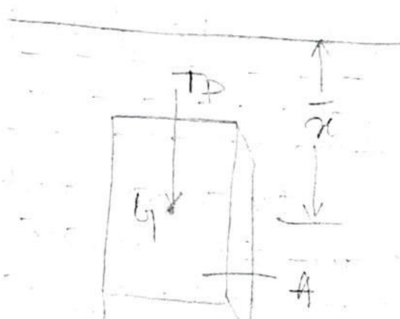
It is the point at which total pressure will act.

(a) Horizontal Surface :

Let $A \rightarrow$ Area of surface.

w = sp. wt. of liquid

$\bar{x}$ = Distance of CG from free surface.

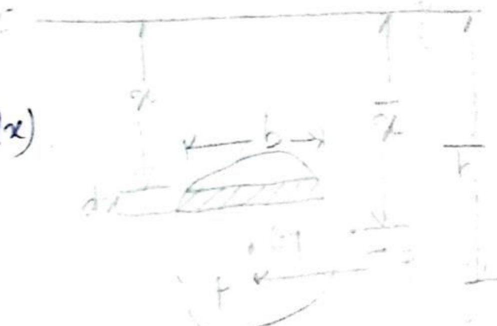


T.P = Pressure × Area

$$= \rho g \bar{x} \times A = wA\bar{x}$$

$$\boxed{TP = wA\bar{x} \;\&\; CP = \bar{x}}$$

(b) Vertical Surface:



Pressure force acting on elemental area = $\rho g \, x \cdot (b\,dx)$

Sum of the pressure forces

$= \int \rho g \, (b\,dx) \times x$

$= \rho g \int (b\,dx)\, x$ $\quad \{(b\,dx)\,x$ = first area moment$\}$

$TP = \rho g A \bar{x} = w A \bar{x}$

"Sum of the moments of individual forces is equal to the moment caused by the resultant force".

Moment caused by pressure force acting on elemental area about free surface = force × x

$= (P \times A) \times x$

$= \rho g x \cdot b\,dx \cdot x$

$= \rho g (b\,dx)\, x^2$

Sum of moments $= \int \rho g \, (b\,dx)\, x^2$

$= \rho g \int (b\,dx)\, x^2$

$[(b\,dx)\,x^2$: Second area moment $= I]$

$= \rho g I_0$

Parallel-Axis-theorem:

$\rho g I_0 = \rho g \, (I_G + A \bar{x}^2)$ ———— (i)

moment caused by TP about free surface

$= TP \times \bar{h}$

$= w A \bar{x} \times \bar{h}$ ———— (ii)

from (1) & (2) $\rho g A \bar{x} \times \bar{h} = \rho g \, (I_G + A \bar{x}^2)$

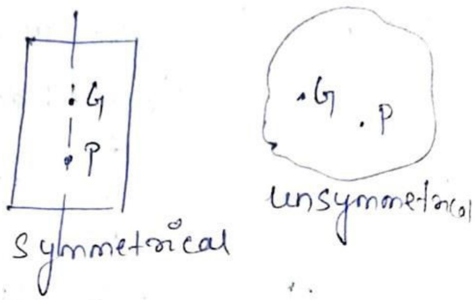
$\therefore \bar{h} = \frac{I_G}{A\bar{x}} + \frac{A\bar{x}^2}{A\bar{x}}$ $\quad | \quad \rho g A \bar{x} \times \bar{h} = \rho g I_0 \Rightarrow \bar{h} = \frac{I_0}{\ldots}$

$\bar{h} = \bar{x} + \frac{I_G}{A\bar{x}}$; $I_G \rightarrow$ Moment of inertia of the Surface about an axis passing through center of gravity.

$\therefore \bar{h} > \bar{x} \Rightarrow$ CP always lies below C.G.

$$\bar{h} - \bar{x} = \frac{I_G}{A\bar{x}}$$

* for symmetrical surfaces, CG & CP lies among the same line.



* volume of prism $= \frac{1}{2}\{\rho g h_1 + \rho g h_2) \times b \times l$

$= \frac{1}{2} \rho g (h_1 + h_2) \times b \times l$.

$\bar{x} = h_1 + \frac{b}{2}$

$= h_1 + \frac{h_2 - h_1}{2}$ $\Rightarrow \bar{x} = \frac{h_1 + h_2}{2}$

$\therefore$ volume of pressure prism. $= \frac{1}{2}(\rho g h_1 + \rho g h_2) \times b \times l$

$= \rho g \bar{x} \cdot A$

$= wA\bar{x} = TP$.

Note

1. volume of pressure prism represents the 'total pressure'
2. The centroid of the volume of the prism will be equal to the 'centre of pressure'.

$$TP = wA\bar{x}$$

$$CP = \bar{x} + \frac{I_G}{A\bar{x}}$$

$\bar{x}$ = Distance of CG from free surface

A = Area of Surface

I_G = MI of the surface about an axis passing through centre of gravity.

2. Kinematics of fluid flow

2.1 Basic equations for fluid flow and their Applications;

(1) Rate of discharge:- (Q)

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

$$Q = A \cdot V$$

where, A = Crossectional area.
V = Mean or Average velocity.

Units = m^3/sec.

(2) Equation of continuity of liquid flow:—

Basic: Principle of conservation of mass i.e mass can neither be created nor destroyed.

Statement: The time rate of change of mass in a fixed volume is equal to the net rate of flow of mass across the surface.

Divergence form: (Vector form)

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

where, ρ = Mass density of the fluid in motion.
V = Average or mean velocity of the fluid.
∇ = Del operator.

for compressible fluids and steady state $\frac{\partial \rho}{\partial t} = 0$

$$\nabla (\rho V) = 0$$

for incompressible fluid and steady state.

$$\nabla \cdot \rho V = 0$$

The above expressions are valid for 1D flow.

Other statements:

(a) Differential form: (In Cartesian Co-ordinates)

(i) for compressible fluids,

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

(ii) for incompressible fluids,

$$\left(\frac{\partial u}{\partial x}\right) + \left(\frac{\partial v}{\partial y}\right) + \left(\frac{\partial w}{\partial z}\right) = 0$$, the divergence of velocity vector $\nabla \cdot V = 0$

Assumptions:

(a) flow is steady.
(b) flow is incompressible.
(c) velocity is uniform over a cross section.

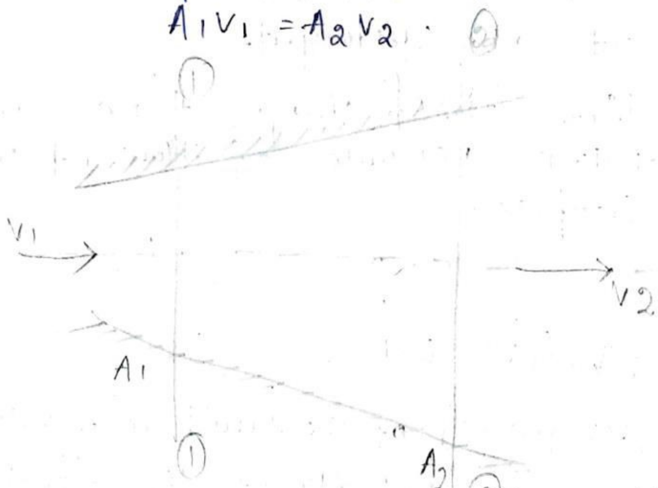
(b) In one dimensional analysis (flow through a stream tube):

for compressible fluids,

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

for incompressible fluids,

$$A_1 V_1 = A_2 V_2 .$$



Assumptions for incompressible fluid flow equation.

$$Q = A_1 V_1 = A_2 V_2 .$$

(i) flow is steady
(ii) flow is incompressible.
(iii) flow is one dimensional over the cross section.
(iv) velocity is uniform across section.
(v) No branching of steam tube.

When there is variation of velocity across the cross section of a tube, for an incompressible fluid discharge,

$$Q = \int_{A_1} V \cdot dA = \int_{A_2} V \cdot dA .$$

Continuity in polar co-ordinates:

V_r = Radial velocity component

V_θ = Tangential velocity component.

For steady and incompressible flow (ρ = constant)

$$\frac{\partial}{\partial r}(r u_r) \frac{\partial}{\partial \theta}(u_\theta) = 0$$

$$\Rightarrow V_r + \frac{\partial V_r}{\partial r} \cdot r + \frac{\partial V_\theta}{\partial \theta} = 0.$$

Q An oil flows through a 100mm diameter pipe at a mean velocity of 180 m/min. Take $\rho_{oil} = 879\, kg/m^3$. Find volume flow rate in m^3/s and litres/min. Weight of oil flow rate (kN/sec) and mass of oil flow rate (kg/sec).

Sol^n $Q = Av = \frac{\pi}{4}(0.1)^2 \times \frac{180}{60} = 0.0236\, m^3/sec$.

$= 0.0236 \times 1000 \times 60$ lpm $= 1416$ lpm.

$W = \rho g \cdot Q = 879 \times 9.81 \times 0.0236$.

$= 203\, N/sec = 0.203\, kN/sec$.

$m = \frac{W}{g} = \frac{203}{9.81} = 20.74\, kg/sec$.

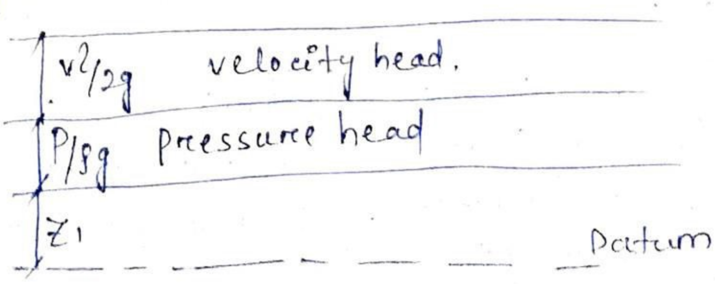
(3) Total energy of a liquid in motion:

(a) **Datum head**: A liquid particle 'Z' meters above a reference datum. is same said to possess a potential head or datum head 'Z'.

(b) Pressure head : $\left(\frac{P}{\gamma}\right)$ in metres. (It is due to energy expopexpossessed by a body).

(c) Velocity head: $\frac{v^2}{2g}$ (it is due to kinetic energy)

(d) Piezometric head: $\left(\frac{P}{\gamma}\right) + Z$ = Sum of datum head and pressure head.



Total energy:

A liquid in motion possesses pressure energy, Kinetic energy and Potential energy.

Pressure energy:

It is the energy possessed by a liquid by virtue of its pressure.

Kinetic energy:

It is the energy possessed by a liquid by virtue of its motion.

Potential energy:

It is the energy possessed by a liquid by virtue of its height above the ground level.

(4) Bernoulli's Equation:

(a) Integration of Euler's equation for steady, incompressible and frictionless, non viscous flow yields the Bernoull's energy enquation.

$$\therefore \frac{P}{\gamma} + \frac{v^2}{2g} + Z = \text{constant}$$

This is valid for ideal fluid flows.

i.e, total energy of the fluid remains constant.

Note It is applicable to all points in the flow field i.e, for all the stream lines, the value of constant is same.

Assumptions made are: / Limitations:

1. flow is steady
2. flow is irrotational
3. flow is incompressible i.e, density does not change.
4. flow is non viscous (ideal)
5. flow is continuous and homogenous.
6. velocity is uniform over a cross-section
7. No shear work.
8. No heat transfer.

(b) for real fluids there will be some loss of energy between two points.

$$\frac{P_1}{\gamma} + \frac{v_1^2}{2g} + z_1 = \frac{P_2}{\gamma} + \frac{v_2^2}{2g} + z_2 + h_{Loss}.$$

Energy Equation

Here h_{Loss} = Energy head loss.

In the above equation each term represents "Energy per unit weight".

(c) when the flow is steady but may not be irrotational. i.e, rotational flow: In this case, Bernoulli's equation is applicable only to particular stream line that is the value of constant is different for different stream lines.

(d) Basis for Bernoulli's equation is 'Law of Conservation of Energy'. Therefore, it is also called 'Energy equation'.

(5) Practical applications of Bernoulli's theorem:

(a) Pitot Tube:

Description: pitot tube consists of a glass tube bend through 90°. The lower end of the tube faces the direction of flow. The liquid rises up in the tube due to pressure exerted by the liquid flow.

Use: To measure velocity of flow at any section of a pipe or channel.

Basic principle:

If the velocity of flow at a particular point is reduced to zero, known as stagnation point, the pressure there is increased due to conversion of kinetic energy into pressure energy and level of water rises.

Stagnation pressure head = static pressure head 'h_0' + Dynamic pressure head 'h_D'.

$$h_s = h_0 + h_D$$

(h_D = difference between stagnation pressure and static pressure)

We have, $h_D = \frac{V^2}{2g} = h$

$\therefore V_{th} = \sqrt{2gh_D}$

Actual velocity, $V = C\sqrt{2gh}$.

where C = pitot tube constant

with U-tube manometer reading 'x'.

$$h = x\left[\left(\frac{S_m}{S} - 1\right)\right]$$

NOTE A pitot tube measures stagnation pressure head (or the total head) at dipped end.

Pitot Static tube:-

- It measures both static as well as stagnation pressures.
- It consists two concentric pitot tubes with an annular space.
- The outer tube has holes drilled perpendicular to flow directions which provides the liquid static head and inner tube work as normal pitot tube. At differential manometer connects to these tubes. It is also known prandle pitot tube ($c = 1$).

Q A pitot static tube having a coefficient of 0.98 is used to measure the velocity of water in a large pipe. The stagnation pressure recorded in 3 m and static pressure 2m. what velocity does it indicate?

Sol^n $V = C_D \cdot \sqrt{2g(h_{stag} - h_{static})}$

$= 0.98 \times \sqrt{2 \times 9.81 (3-2)}$

$= 4.34$ m/s.

2.2 Flow Over Notches and Weirs:

(1) Notch:

- An opening provided in the side of a tank or vessel. Such that the liquid surface.
- In the tank is below the top edge of opening.
- For measuring rate of flow in the tank.

(2) Weir:

- Concrete or masonry structure built across a river to allow the excess water to down stream.
- Also used for measuring the rate of flow in river.

(3) Classification of Notches and weirs:

(i) According to shape of opening:

(a) Rectangular

(b) Triangular

(c) Trapezoidal

(ii) According to shape of crest:

(a) Sharp crested

(b) Narrow Crested

(c) Broad Crested.

- Discharge on Rectangular sharp crested weir or Notches

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

C_d = Co-efficient of discharge.

H = Head above the crest (measured at a distance 4 to 5 times head above the crest)

L = Length of the crest.

- Discharge over Triangular weir or V-notch:

Preferred over rectangular weir for measuring low discharges.

Because even for low discharge the head over the crest is fairly large which can be measured more accurately.

$\boxed{Q = \frac{8}{15} C_d \sqrt{2g} \tan \frac{\theta}{2} H^{5/2}}$ $\boxed{C_d = 0.6}$

- Discharge over Trapezoidal weir (or) Notch:

$$Q = \left[\left(\frac{2}{3}\right) C_d L / \sqrt{2g} \tan\theta/2\right]\left[(H + h_a)^{5/2} + H^{5/2}\right]$$

where, L = crest length of weir.

- Sharp crested weirs:

Sharp crested or thin plate weirs are those overflow structures whose length of crest in the direction of flow is equal to or less than 2 mm.

- Narrow - Crested weir:

Narrow crested weir is hydraulically similar to an ordinary weir or to a rectangular weir. the equation of discharge over a narrow crested weir. $Q = C_d L \frac{2}{3} \sqrt{2g}$.

- Broad crested weir:

Broad crested weirs are robust structures that are generally constructed ~~form~~ from reinforced concrete and which usually span the full width of the channel. they are used to measure the discharge of rivers. ~~and~~ ~~are~~.

2.3 Types of flow through the pipe:

(I) Uniform flow and non-uniform flows:-

- Uniform flow:- when the velocity of flow of fluid does not change both in magnitude and direction from point to point in the flowing fluid, at any given instant of time.

$$\text{i.e} \left(\frac{\partial v}{\partial s}\right) = 0$$

ex- flow of liquids under pressure through long pipe line of constant diameter.

- Non-uniform flow:-

If the velocity of flow of fluid changes from point to point in the flowing fluid at any instant of time.

(II) Laminar and Turbulent flows:-

- Laminar flow:-

Laminar flow is defined as that type of flow in which the fluid particles move along well-defined paths or stream line and all the stream-lines are straight and parallel. Thus the particles move in laminar or smoothly over the adjacent layer. This type of flow is also called stream-line flow or viscous flow.

- Turbulent flow:-

Turbulent flow is that type of flow in which the fluid particles move in a zigzag way. Due to the movement of fluid particles in a zigzag way, the eddies formation takes place which are responsible for high energy loss.

(III) Steady and unsteady flow:

- Steady flow:

It is at any points of the flowing fluid, various characteristics such as velocity, pressure density temperature etc., do not change with time. Mathematically, $\left(\frac{\partial v}{\partial t}\right) = 0$, $\left(\frac{\partial p}{\partial t}\right) = 0$, $\left(\frac{\partial \rho}{\partial t}\right) = 0$ $\left(\frac{\partial T}{\partial t}\right) = 0$ etc

Ex. flow of fluid through a pipe at constant rate of discharge.

- Unsteady flow: Flow parameters at any point change with time.

i.e $\left(\frac{\partial v}{\partial t}\right) \neq 0$, $\left(\frac{\partial p}{\partial t}\right) \neq 0$ etc.

Ex. flow in which the quantity of liquid per second is not constant.

(iv) Reynold's number and its application:—

for a pipe flow, the type of flow is determined by a non-dimensional number called the Reynolds number (Re).

$$\boxed{Re = \frac{VD}{\nu}}$$

where, D = Diameter of pipe.
V = Mean velocity of flow in pipe.
ν = Kinematic viscosity of fluid.

If the Reynolds number < 2000, the flow is called Laminar.

2000 < Reynolds number > 4000 = Transitional flow.

Reynolds number > 4000 = Turbulent flow.

2.4 Losses of Head of a Liquid flowing through Pipes:

As fluid flows through a pipe certain resistance is offered to the flowing fluid, resulting in a loss of energy. Broadly these are of two types.

(a) Major Losses due to friction.

(b) Minor Losses due to various fittings, transitions, changes in velocity to change in cross-sections.

(c) Laws of fluid friction for Laminar flow - The frictional resistance in the Laminar flow is -

(i) Proportional to the velocity of flow.

(ii) Independent of the pressure,

(iii) Proportional to the area of surface in contact

(iv) Independent of the nature of the surface in contact.

(v) Greatly affected by the variation of the temperature of the flowing fluid.

The reason for the frictional resistance in the case of Laminar flow being independent of the nature of the surface in contact, is that when a fluid flows past a surface with velocity less than critical velocity, a film of almost Stationary fluid is formed over the Surface, which prevents the flowing fluid to come in contact with the boundary Surface. Similarly in the case of laminar flow the resistance is due to viscosity only and the viscosity of a fluid depends on its temperature.

(d) Laws of fluids friction for Turbulent flow:—

The frictional resistance in the case of turbulent flow is -

(i) Proportional to $(velocity)^n$. where 'n' varies from 1.72 to 2.0.

(ii) Independent of the Pressure.

(iii) Proportional to the density of the flowing fluid
(iv) Slightly affected by the variation of the temperature of the flowing fluid.
(v) Proportional to area of surface in contact.
(vi) Dependent on the nature of the surface in contact.

Major Loss or friction Loss of head:

Frictional loss of Head (hf): The basic equation used is Darcy-WeisBach Equation.

$$h_f = \frac{f l v^2}{2gd}$$

where,
f = friction factor, which is a function of 'Re' and relative roughness.
d = Diameter of the pipe.
l = Length of the pipe.
V = Mean velocity in the pipe.

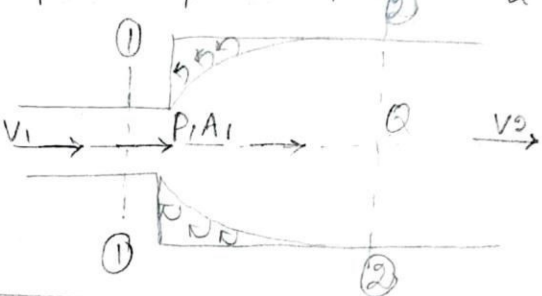
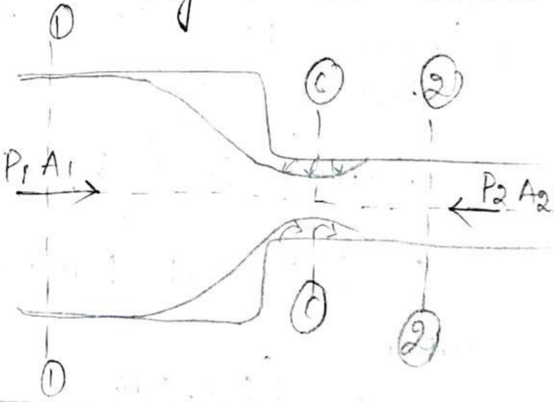
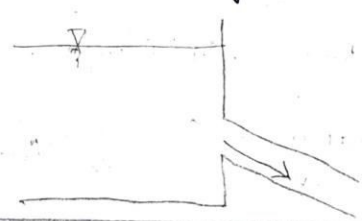
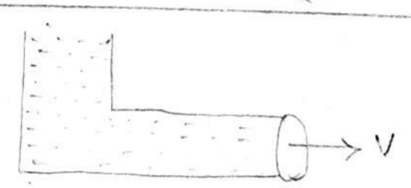
- Ratio $\frac{h_f}{l} = S_f$ represents the energy slope which is equal to the hydraulic gradient in uniform flow.
- In long pipe lines, 'hf' forms a major part of the total loss.
- The above equation is derived based on experiments of Froude, which revealed that
(a) The frictional resistance varies approximately with the square of velocity.
(b) The frictional resistance varies with the nature of the surface.

Q A pipe line of diameter of 150mm and 0.5 km long is used for conveying water having the velocity 2m/s. The friction factor f = 0.024. Determine head loss due to friction.

Soln $h_f = \frac{fl}{d} \cdot \frac{V^2}{2g} = \frac{0.024 \times 500 \times 2^2}{0.15 \times 2 \times 9.81} = 16.31$ m

Minor Losses in pipe flow:-

Table shows different pipe Losses other than pipe friction Losses. Any head Loss in pipe flow other than friction loss is considered as minor Loss. If minor loss more than 5% of major Loss i.e. friction Loss, than minor Losses are to be addedup.

Situation	Head Loss = h_L	Explanation.
(1) Sudden expansion	$h_L = \frac{(V_1 - V_2)^2}{2g}$	Expansion from section '1' to '2' 
(2) sudden Contraction	$h_L = \frac{(V_c - V_2)^2}{2g}$	V_2 = velocity in contracted section V_c = Velocity at vena contracta 
(3) Entrance to a pipe from a reservoir	$h_L = 0.5 \frac{V^2}{2g}$	V = velocity in pipe 
(4) At exit of a pipe	$h_L = \frac{V^2}{2g}$ V = Velocity in pipe	
(5) Bends, Pipe fittings	$h_L = \frac{K \cdot V^2}{2g}$ 'K' is a bend constant	

Q. Water is discharged from a tank maintained at a constant head of 5 m above the exit of a straight pipe 100 m long 15 cm diameter. Estimate the rate of flow if the friction factor for the pipe is given as 0.01 and minor losses accounted.

Sol. Since the free surface of water in the tank is 5 m above the exit pipe discharging into the atmosphere, the entire available head of 5 m is lost in overcoming the friction for flow through the pipe and as exit loss

Minor losses are considered

Entrance loss = $0.5 \times \frac{v^2}{2g}$

Exit loss = $\frac{v^2}{2g}$

friction loss, $h_f = \frac{fl}{d} \times \frac{v^2}{2g}$

Total Loss = $H = h_f + 0.5 \frac{v^2}{2g} + \frac{v^2}{2g}$

where,

$$5 = \left[\frac{0.01 \times 100}{0.15} \frac{v^2}{2 \times 9.81}\right] + \frac{0.5 v^2}{2 \times 9.81} + \frac{v^2}{2 \times 9.81}$$

$v = 3.466$ m/s.

Discharge $Q = 3.466 \times \frac{\pi}{4} (0.15)^2$ $(A \times V = Q)$

$= 0.061 \, m^3/s$

$= 61$ ltr/sec.

Hydraulic Gradient Line:

If the pressure heads at the different series sections of the pipe are plotted to scale as vertical ordinates above the axis of the pipe and all these points are joined by a straight line, a straight sloping line will be obtained, which is known as hydraulic gradient or hydraulic grade line (HGL).

Since at any section of the pipe the vertical distance between the pipe axis and the hydraulic gradient is equal to the pressure head at that section, it is also known as "pressure line".

HGL For Inclined pipe:

If Z' the height of pipe axis at any section above an arbitrary datum then the vertical height of the H.G. above datum at that section of pipe represents the piezometric head equal to $\left(\frac{P}{\gamma} + Z\right)$ in such a case it is called piezometric line.

Total Energy Line:

Total energy line is basically defined as the line which will give the sum of pressure head, potential head and kinetic head of a fluid flowing through a pipe with respect to some reference line.

Total energy line = pressure head + Potential head + kinetic head

$$\text{TEL} = P/\rho g + Z + v^2/2g$$

where, TEL = Total energy line

$P/\rho g$ = Pressure head

Z = potential head or datum head

$v^2/2g$: Kinetic head or velocity head.

Relation between hydraulic gradient line and total energy line:-

$HGL = EGL - V^2/2g$ EGL = Energy gradient line

At velocity $V = 0$, kinetic head will be zero and therefore hydraulic gradient line and energy gradient line will be same.

At velocity $V = 0$, $EGL = HGL$.

2.5 FLOW THROUGH OPEN CHANNELS:

- Flow in open channels is characterized by the existence of a free surface. The pressure on the free surface is constant and atmospheric at every point on the surface.
  Ex- Flow in irrigation channels, streams and rivers, navigation channels, drainage channels and sewers under ordinary conditions.
- Flow in open channels is largely turbulent with negligible surface tension.
- All open channels have a bottom slope and hence gravity force is the main force causing the flow. The component of the weight of the liquid along the slope acts as the driving force. The boundary resistance at the perimeter acts as the resisting force.
- As gravity force is the driving force, Froud number is the main non-dimensional number governing the flow phenomenon in open channel.
- The water surface represents the hydraulic gradient line.

Types of channel sections:-

Channel sections are classified according to their shapes such as:-

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

(1) Rectangular channel:—

Top width (T) = b

Depth = y

Area = (A) = b×y

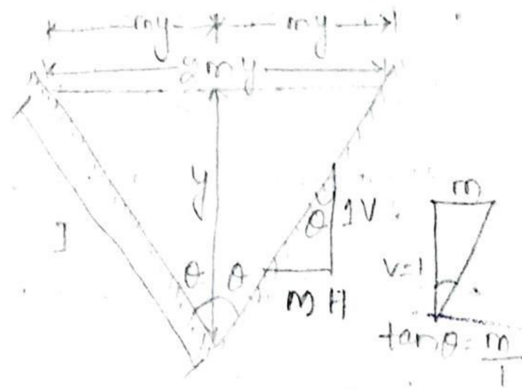
Perimeter (P) = b + 2y

Hydraulic Depth = $\frac{A}{T} = \frac{b \times y}{b} = y$
Hydraulic radius (R) = $\frac{A}{P} = \frac{b \times y}{(b+2y)}$

NOTE for wide rectangular channel 'y' much less than b. $y <<< b$
therefore 'R' is approximately equal to 'y' for wide ~~char~~ rectangular channel.

$$\left[R = \frac{by}{b+2y}, \quad R \simeq \frac{by}{b} \simeq y. \right]$$

(2) Triangular channel:



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

$= \frac{y}{2}$

Hydraulic Radius (R) $= \frac{A}{P}$

$= \frac{my}{2\sqrt{1+m^2}}$

* If Right angle triangle θ = 45° (semi)

$m = 1$	$D = y/2$
$T = 2y$	$P = 2y\sqrt{2}$
$A = y^2$	$R = \frac{y}{2\sqrt{2}}$

(3) Trapezoidal channel:

Hydraulic ~~R~~. depth of flow

$: D = \frac{A}{T}$

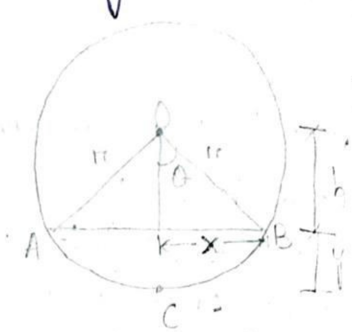
$$D = \frac{y(b+my)}{(b+2my)}$$

Hydraulic Radius $(R) = \frac{A}{P}$

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

* for trapezoidal section $\frac{y}{2} < D < y$.

(4) Circular channel:



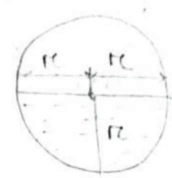
Hydraulic depth $= D = \frac{A}{T}$

$$D = \frac{r}{4\sin\theta}(2\theta - \sin 2\theta)$$

Hydraulic radius $= R = \frac{A}{P}$

$$R = \frac{r^2}{4r\theta}(2\theta - \sin 2\theta)$$

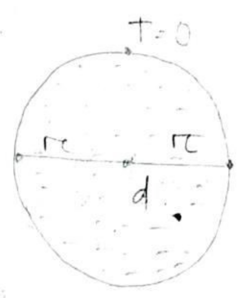
- Circular channel running half



Hydraulic depth $(D) = \frac{\pi d}{8}$

Hydraulic mean radius $(R) = \frac{d}{4}$

- Circular channel running full:



$A = \pi r^2$

$P = 2\pi r$

Hydraulic radius $(R) = \frac{A}{P}$

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

$$\boxed{R = \frac{d}{4}}$$

Chezy's and Manning's Equation :-

- Chezy's formula :-

Assumptions :

- Force resisting the flow per unit of wetted area is proportional to square of velocity.
- Force causing the flow = force of resistance.

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

V = velocity of flow.
C = chezy's constant.
R = Hydraulic radius.
S = Slope of the channel.

- Manning's formula :

$$\boxed{V = \frac{1}{n} \cdot R^{2/3} \cdot S^{1/2}}$$

V = Mean velocity in m/sec.
R = Hydraulic radius in 'm'.
n = Coefficient of roughness or Manning's Rugosity coefficient.

Q. A rigid boundary rectangular channel having a bed slope of 1/1250 has its width and depth of flow equal to 2m and 1m respectively. If the flow is uniform and the value of chezy's constant is 75, the discharge through the channel is

---

Soln According to chezy's formula;

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

$$= C\sqrt{\frac{A}{P} S}$$

$$= 75\sqrt{\frac{2}{5} \times \frac{1}{1250}}$$

$$= 1.34 \text{ m/s.}$$

$A = b \times y = 1 \times 2 = 2$

$P = b + 2y$
$= 1 + 2 \times 2$
$= 5.$

$Q = AV = 2 \times 1.34 = 2.6 \simeq 3 \text{ m}^3/\text{s}.$

Best economical Section:-

A channel section is considered as the most economical or most efficient when it passes a maximum discharge for given cross-section area resistance co-efficient and bottom slope. From the equation of continuity it is evident that for area of crosssection being constant, discha... is maximum. And from chezy's formula and Manning formula for a certain value of slope and surface ~~runoff~~ roughness, velocity is maximum when the hydraulic radius is maximum. And if we take the area as constant, hydraulic radius is maximum if the wetted perimeter is minimum. A Semicircular Section is the best economical channel but due to difficulty in creating it, a trapezoidal section can be considered most efficient.

3. PUMP:

Pump is a device that moves fluids (liquids or gases) by mechanical action, typically converted from electrical energy in to hydraulic energy.

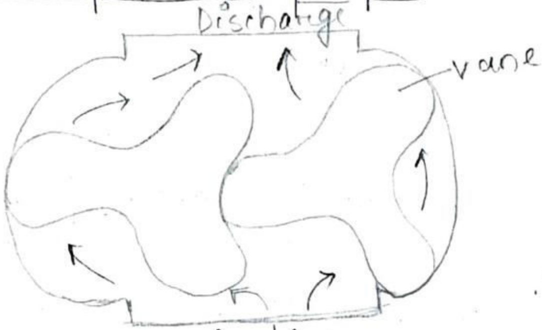
Pumps can be classified in to three major group according to the method they use to move the fluid:- (i) Direct lift, (ii) Displacement, (iii) Gravity

Pump

- Dynamic pressure pumps
  - Centrifugal pump
  - Propeller
  - Turbine
- Positive displacement pumps
  - Reciprocating
    - Piston
    - Diaphragm
  - Rotary
    - Gear
    - Screw
    - Vane

- Mechanical pumps may be submerged in the fluid they are pumping or be placed external to the fluid.
- Pumps can be classified by their method of displacement into positive-displacement pump, impulse pump, velocity pumps and valveless pumps. There are 3 basic types of pump: positive-displacement, centrifugal and axial flow pump.

Positive - displacement pumps:—



- A positive displacement pump makes a fluid move by trapping a fixed amount and forcing that trapped volume in to the discharge pipe. Some positive-displacement pumps use an expanding cavity on the suction side and a decreasing cavity on the discharge side. Liquid flows into the pump as the cavity on the suction side expands and the liquid flows in to pump as the cavity on the suction side expands and the liquid flows out of the discharge as the cavity collapses. The volume is constant through each cycle of operation.
- It is again classified into two types such as:—

  (i) Rotary
  (ii) Reciprocating.

- Rotary - positive displacement pump is again classified in to different catagories.

Such as:—

→ Gear pumps:— A simple types of rotary pump where the liquid is pushed around a pair of gears.

- Screw pump: the shape of the internals of this pump is usually two screws turning against each other to pump the liquid.
- Vane pump:

It is a positive displacement pump that consists of vanes mounted to a rotor that rotates inside a cavity. In some cases these vanes can have variable length or be tensioned to maintain contact with the walls as the pump rotates.

Centrifugal pump:

These pumps are used to transport fluids by the conversion of rotational kinetic energy to the hydrodynamic energy of the fluid flow. The rotational energy typically comes from an engine or electric motor.

Classification of centrifugal pump:—

On the basis of characteristics features, the centrifugal pumps are classified as follows:—

1. Types of casing:
   (i) Volute pumps.
   (ii) Turbine pump or diffusion pump.
2. Working head:
   (i) Low lift centrifugal pumps:— They work against heads up to 15 m.
   (ii) Medium lift centrifugal pumps:- Used to build up heads as high as 40 m.
   (iii) High lift centrifugal pumps:— employed to deliver liquids at heads above 40 m.
3. Liquid handled:—
   (i) Closed impeller pump
   (ii) Semi-open impeller pump.
   (iii) Open impeller pump.

4. Number of impellers per Shaft:-

(i) Single stage Centrifugal pump:- has one impeller, usually a low lift pump.

(ii) Multi - Stage Centrifugal pump:- has two or more impellers and pressure is built in steps; used usually for high working heads and the number of stages depends on the head required.

5. Number of entrances to the impeller:

(i) Single entry or single section pump:- water is admitted on one side of the impeller.

(ii) Double entry or double section pump:- water is admitted from both sides of the impeller; axial thrust is neutralised.

- Employed for pumping Large quantities of fluid.

6. Relative direction of flow through impeller:

(i) Radial flow pump:- Normally radial flow impellers are used in all centrifugal pumps.

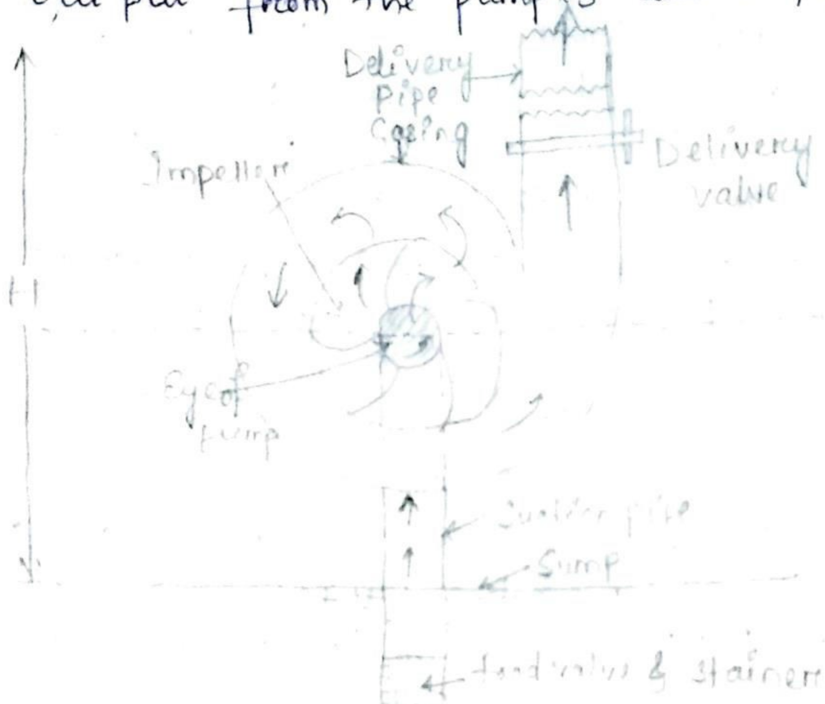
(ii) Axial flow pump:- Designed to deliver huge quantities of water at comparatively low heads; ideally suited for irrigation purposes.

(iii) Mixed flow pump:- Mostly employed for irrigation purposes.

Advantages:

1. The cost of a centrifugal pump is less as it has fewer parts.
2. Installation and Maintenance are easier and cheaper.
3. Its discharging capacity is much greater than that of a reciprocating pump.
4. It is compact and has smaller size and weight for the same capacity and energy transfer.
5. Its performance characteristics are superior.
6. It can be employed for lifting highly viscous liquid such as paper pulp, muddy and sewage water, oil etc.

7. It can be operated at very high speeds without any danger of separation and cavitation.
8. It can be directly coupled to an electric motor or an oil engine.
9. The torque on the power source is uniform, the output from the pump is also uniform.



1. **Impeller:-** An impeller is a wheel with a series of backward curved vanes. It is mounted on a shaft which is usually coupled to an electric motor.
2. Casing: The casing is an air-tight chamber surrounding the pump impeller. It contains suction and discharge ~~agg~~ arrangements, supporting for bearings, and facilitates to house the rotor assembly. It has provision to fix stuffing box and house packing materials which prevent external leakage. The essential purposes of the casing are:
   (i) To guide water to and from the impeller
   (ii) To partially convert the kinetic energy into pressure energy.

3. Suction pipe with a foot valve and a strainer :-

A pipe whose one end is connected to the inlet of the pump and other end dips into water in a sump is known as suction pipe. A foot valve which is a non-return valve or one-way type of valve is fitted at the lower end of the suction pipe. The foot valve opens only in the upward direction. A strainer is also fitted at the lower end of the suction pipe.

4. Delivery Pipe :-

A pipe whose one end is connected to the outlet of the pump and other end delivers the water at a required height is known as delivery pipe.

Workdone By the centrifugal Pump on water :-

In case of the centrifugal pump, work is done by the impeller on the water. The expression for the work done by the impeller on the water is obtained by drawing velocity triangles at inlet and outlet of the impeller in the same way as for a turbine. The water enters the impeller radially at inlet for best efficiency of the pump, which means the absolute velocity of water at inlet makes an angle of 90° with the direction of motion of the impeller at inlet. Hence, $\alpha = 90°$, $V_{w1} = 0$. For drawing the velocity triangles, the same notations are used as that for turbines.

Let, N = Speed of the impeller in r.p.m.

D_1 = Diameter of impeller at inlet.

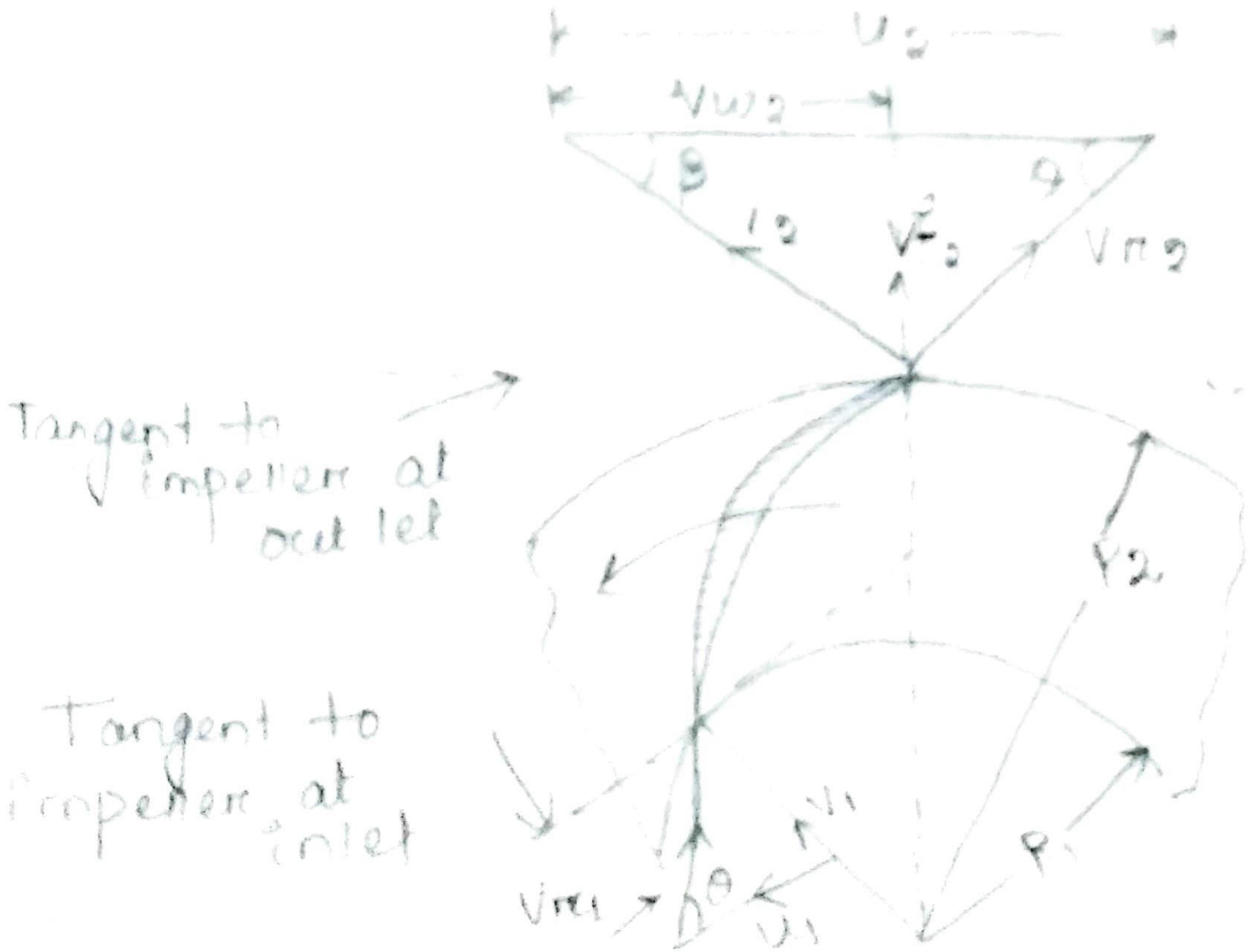
u_1 = Tangential velocity of impeller at inlet.

$$\boxed{u_1 = \frac{\pi D_1 N}{60}}$$

D_2 = Dia. of impeller at outlet.

u_2 = Tangential velocity of impeller at outlet.

$$\boxed{u_2 = \frac{\pi D_2 N}{60}}$$



Tangent to impeller at outlet
Tangent to impeller at inlet

Definitions of Heads and Efficiencies of a centrifugal Pump:-

Suction Head: (h_s)

It is the vertical height of the centre line of the centrifugal pump above the water surface in the tank or pump from which water is to be lifted. This height is also called as suction lift.

Delivery Head: (h_d)

The vertical distance between the centre line of the pump and the water surface in the tank to which water is delivered is known as delivery head.

Static head: (H_s)

The sum of suction head and delivery head is known as static head.

$$H_s = h_s + h_d.$$

Manometric head: (H_m)

It is defined as the head against which a centrifugal pump has to work.

(a) H_m = Head imparted by the impeller to the water − Loss of head in the pump.

(b) H_m = total head at outlet of the pump − Total head at the inlet of the pump.

$$= \left(\frac{P_o}{\rho g} + \frac{V_o^2}{2g} + Z_o\right) - \left(\frac{P_i}{\rho g} + \frac{V_i^2}{2g} + Z_i\right)$$

where, $\frac{P_o}{\rho g}$ = Pressure head at outlet of the pump.

$\frac{V_o^2}{2g}$ = velocity head at outlet of the pump.

= velocity head in delivery pipe = $\frac{V_d^2}{2g}$.

Z_o = vertical height of the outlet of the pump from datum line.

$\frac{P_i}{\rho g}$, $\frac{V_i^2}{2g}$, Z_i = Corresponding values of pressure head, velocity head and datum head at the inlet of the pump.

(c) $H_m = h_s + h_d + h_{fs} + h_{fd} + \frac{V_d^2}{2g}$.

where, h_s = Suction head.

h_d = Delivery head

h_{fs} = Frictional head Loss in Suction pipe.

h_{fd} = frictional head Loss in delivery pipe.

V_d = Velocity of water in delivery pipe.

Efficiencies of a centrifugal pump:

In case of a Centrifugal Pump, the power is transmitted from the shaft of the electric motor to the shaft of the pump and then to the impeller. from the impeller, the power is given to the water. Thus power is decreasing from the shaft of the pump to the impeller and then to the water. The following are the important efficiencies of a centrifugal pump:

(a) Manometric efficiency, η_{man}.

(b) Mechanical efficiency, η_m

(c) overall efficiency. η_o.

Manometric efficiency (η_{man}):

$$\eta_{man} = \frac{\text{Manometric head}}{\text{Head imparted by impeller to water.}}$$

$$\boxed{\eta_{man} = \frac{g \times H_m}{V_{w_2} \times u_2}}$$

where, g = Acceleration due to gravity.

H_m = Manometric head.

V_{w_2} = Absolute velocity of water in outlet.

u_2 = Tangential velocity of impeller at outlet.

Mechanical Efficiency: (η_m):

$$\eta_m = \frac{\text{Power at the impeller}}{\text{Power at the shaft}}$$

$$\boxed{\eta_m = \frac{\frac{W}{g}\left(\frac{V_{w_2} u_2}{1000}\right)}{S.P}}$$

S.P = Shaft power.

W = wt. of water.

Overall efficiency (η_o):

$$\eta_o = \frac{\text{weight of water lifted} \times H_m}{1000} = \frac{W H_m}{1000}$$

$$\boxed{\eta_o = \eta_{man} \times \eta_m}$$

It is defined as the ratio of power output of the pump to the power input to the pump. The power output of the pump in KW.

Q A centrifugal pump delivers water against a net head of 14.5 m and design speed of 1000 r.p.m. The vanes are curved back to an angle of 30° with the periphery. The impeller diameter is 300 mm and outlet width is 50 mm. Determine the discharge of the pump if manometric efficiency is 95%.

Sol^n Given;

Net head, $H_m = 14.5$ m

Speed, $N = 1000$ r.p.m.

Vane angle at outlet, $\phi = 30°$.

Impeller diameter means the diameter of the impeller at outlet.

Dia, $D_2 = 300\text{mm} = 0.30\text{m}$.

Outlet width, $B_2 = 50\text{mm} = 0.05\text{ m}$.

Manometric efficiency, $\eta_{man} = 95\% = 0.95$

Tangential velocity of impeller at outlet,

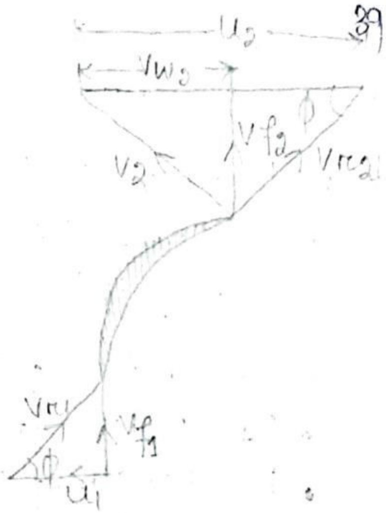
$$u_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times 0.30 \times 1000}{60} = 15.70 \text{ m/s}$$

Now using eq^n = $\eta_{man} = \dfrac{g H_m}{V_{w2} \times u_2}$

$$0.95 = \frac{9.81 \times 14.5}{V_{w2} \times 15.70}$$

$$V_{w2} = \frac{0.95 \times 14.5}{0.95 \times 15.70} = 9.54 \text{ m/s}$$

from outlet velocity triangle, we have



$$\tan\phi = \frac{V_{f_2}}{(u_2 - V_{w_2})}$$

$$\tan 30° = \frac{V_{f_2}}{(15.70 - 9.54)} = \frac{V_{f_2}}{6.12}$$

$$V_{f_2} = 6.16 \times \tan 30° = 3.556 \text{ m/s}$$

$$\text{Discharge, } Q = \pi D_2 B_2 \times V_{f_2}$$

$$= \pi \times 0.30 \times 0.05 \times 3.556 \text{ m}^3/\text{s}$$

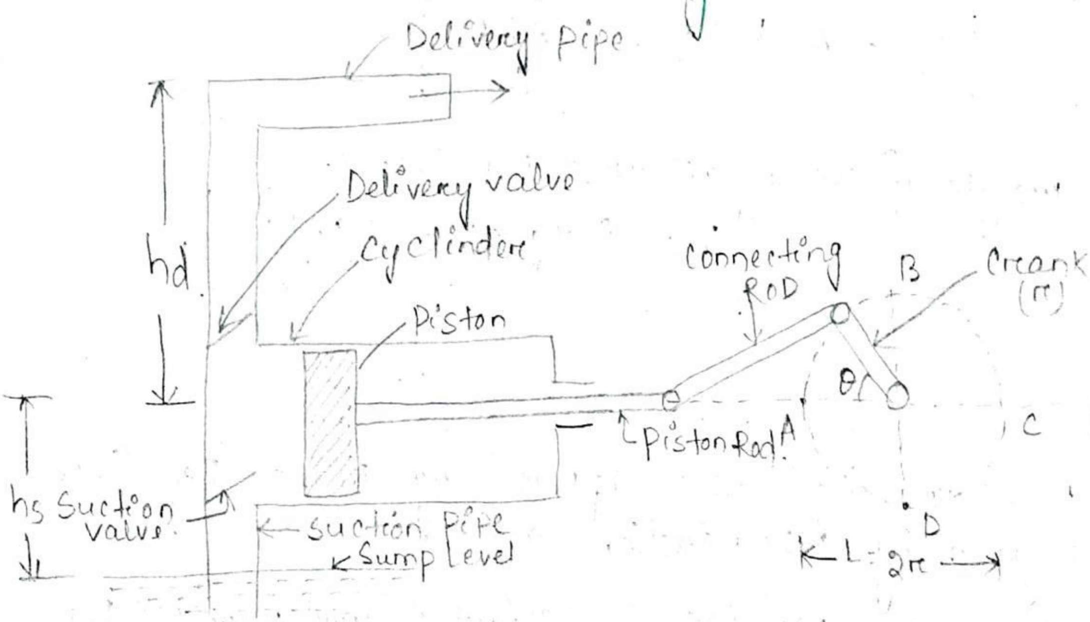
$$= 0.1675 \text{ m}^3/\text{s} \quad \text{Ans}$$

3.3 Reciprocating Pump:

Introduction:

If the mechanical energy is converted into hydraulic energy by sucking the liquid into a cylinder in which a piston is reciprocating, which exerts the thrust on the liquid and increases its hydraulic energy, the pump is known as reciprocating pump.

Main parts of a reciprocating pump:



1. A cylinder with a piston, piston rod, connecting rod and a crank.
2. Suction pipe.
3. Delivery pipe
4. Suction valve
5. Delivery valve.

Discharge through a Reciprocating Pump:

Let D: Dia. of the cylinder.

- A: Cross sectional area of the piston or cylinder $= \frac{\pi}{4} D^2$
- r: Radius of crank.
- N: r.p.m of the crank.
- L: Length of the stroke $= 2 \times r$
- hs: Height of the axis of the cylinder from water surface in sump.
- hd: Height of delivery outlet above the cylinder axis (also called delivery head).

Volume of water delivered in one revolution or discharge of water in one revolution = Area x Length of stroke

$= A \times L$.

No. of revolution per second $= \frac{N}{60}$.

∴ Discharge of the pump per second,

Q = Discharge in one revolution X No. of revolution per second.

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

weight of water delivered per second,

$$W = \rho \times g \times Q = \frac{\rho g ALN}{60}$$

Work done by Reciprocating Pump:

Work done by the reciprocating pump per second is given by the reaction as;

Work done per second = weight of water lifted per second x Total height through which water is lifted.

$= W \times (hs + hd)$

where, $(h_s + h_d)$ = Total height through which water is lifted.

$$W = \frac{\rho g \times ALN}{60}$$

work done per second = $\frac{\rho g \times ALN}{60} \times (h_s + h_d)$

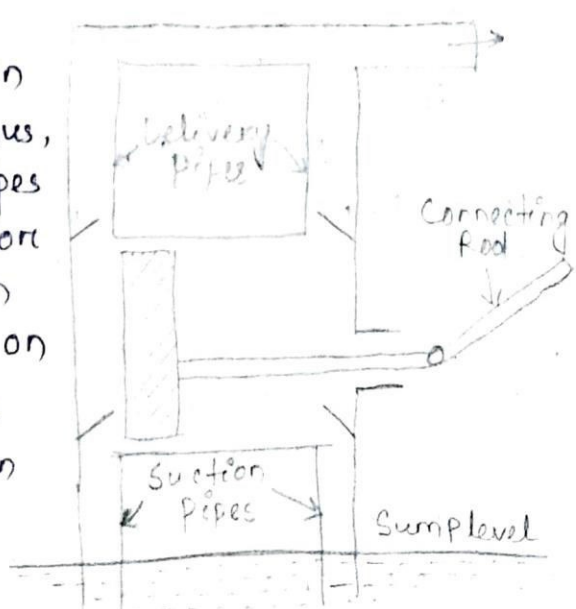
Power required to drive the pump, in KW

$$P = \frac{\text{work done per second}}{1000} = \frac{\rho g \times ALN \times (h_s + h_d)}{60 \times 1000}$$

$$\boxed{P = \frac{\rho g \times ALN \times (h_s + h_d)}{60{,}000} \text{ KW}}$$

Discharge, work done and power required to drive a Double - acting Pump:

In case of double-acting pump, the water is acting on both sides of the piston. Thus, we require two suction pipes and two delivery pipes for double - acting pump. when there is a suction stroke on one side of the piston, Thus for one complete revolution of the crank there are two delivery strokes and water is delivered to the pipes by the pump during these two delivery strokes.



Let D = Diameter of the piston.
d = Diameter of the piston rod.

∴ Area on one side of the piston,

$$A = \frac{\pi}{4} D^2$$

Work done by double-acting reciprocating pump:

Work done per second = weight of water delivered × Total height.

$= \rho g \times$ Discharge per second × Total height.

$= \rho g \times \frac{2ALN}{60} \times (h_s + h_d)$

$= 2\rho g \times \frac{ALN}{60} \times (h_s + h_d)$

∴ Power required to drive the double-acting pump in KW,

$P = \frac{\text{workdone per second}}{1000} = 2\rho g \times \frac{ALN}{60} \times \frac{(h_s+h_d)}{1000}$

$= \frac{2\rho g \times ALN \times (h_s + h_d)}{60{,}000}$

SLIP of a reciprocating pump:

Slip of a pump is defined as the difference between the theoretical discharge and actual discharge of the pump. The discharge of a single acting pump & of a double acting pump are theoritical discharge. The actual discharge of a pump is less than the theoritical discharge due to leakage. The difference of the theoritical discharge and actual discharge is known as slip of the pump.

Hence, Mathematically.

$\text{slip} = Q_{th} - Q_{act}$

But slip is mostly expressed as percentage slip which is given by,

$\text{Percentage slip} = \frac{Q_{th} - Q_{act}}{Q_{th}} \times 100$

$= \left(1 - \frac{Q_{act}}{Q_{th}}\right) \times 100$

$= (1 - C_d) \times 100 \quad \left(\because \frac{Q_{act}}{Q_{th}} = C_d\right)$

where C_d = Co-efficient of discharge.

Negative slip of the Reciprocating pump:

Slip is equal to the difference of theoretical discharge and actual discharge. If actual discharge is more than the theoretical discharge, the slip of the pump will become -ve. In that case, the slip of the pump is known as negative slip.

Negative slip occurs when delivery pipe is short, suction pipe is long and pump is running at high speed.

Classification of Reciprocating pumps:

The reciprocating pumps may be classified as:

1. According to the water being in contact with one side or both sides of the piston, and
2. According to the number of cylinders provided.

If the water is in contact with one side of the piston, the pump is known as single-acting. On the other hand, if the water is in contact with both sides of the piston, the pump is called double-acting. Hence, classification according to the contact of water is:

(i) Single-acting pump

(ii) Double-acting pump

According to the number of cylinder provided, the pumps are classified as:

(i) Single cylinder pump.

(ii) Double cylinder pump.

(iii) Triple cylinder pump.

Q A single-acting reciprocating pump, running at 50 rpm delivers 0.01 m^3/s of water. The diameter of the piston is 200 mm and stroke length 400mm. Determine:- (i) The theoretical discharge of the pump.

(ii) Co-efficient of discharge.

(iii) Slip and the percentage slip of the pump.

Sol

Given, speed of the pump, $N = 50$ rpm

Actual discharge $Q_{act} = 0.01\ m^3/s$.

Dia. of piston; $D = 200\ mm = 0.20\ m$.

$\therefore$ Area, $A = \frac{\pi}{4}(0.2)^2 = 0.031416\ m^2$

Stroke, $L = 400\ mm = 0.40\ m$.

(i) Theoretical discharge for single-acting reciprocating pump is ; $Q_{th} = \frac{A \times L \times N}{60} = \frac{0.031416 \times 0.40 \times 50}{60}$

$= 0.01047\ m^3/s$.

(ii) Co-efficient of discharge =

$$C_d = \frac{Q_{act}}{Q_{th}} = \frac{0.01}{0.01047} = 0.955$$

(iii) Using slip eqn: $Slip = Q_{th} - Q_{act}$

$= 0.01047 - 0.01 = 0.00047\ m^3/s$.

And percentage slip, $= \frac{(Q_{th} - Q_{act})}{Q_{th}} \times 100$

$= \frac{(0.01047 - 0.01)}{0.01047} \times 100$

$= \frac{0.00047}{0.01047} \times 100 = 4.489\ \%$. Ans.

Q. A double-acting reciprocating pump, running at 40 rpm, is discharging $1.0\ m^3$ of water per minute. The pump has a stroke of 400 mm. The diameter of the piston is 200 mm. The delivery and suction head are 20 m and 5 m respectively. Find the slip of the pump and power required to drive the pump.

Soln Given;

Speed of pump $N = 40\ rpm$.

Actual discharge; $Q_{act} = 1.0\ m^3/min = \frac{1.0}{60}\ m^3/s$

$= 0.01666\ m^3/s$.

Stroke; $L = 400\ mm = 0.40\ m$.

Diameter of Piston, $D = 200\ mm = 0.20\ m$.

$\therefore$ Area, $A = \frac{\pi}{4} D^2 = \frac{\pi}{4} (0.2)^2 = 0.031416 \, m^2$

Suction head = $h_s = 5m$.

Delivery head = $h_d = 20m$.

Theoretical discharge for double-acting pump is

$$Q_{th} = \frac{2ALN}{60} = \frac{2 \times 0.031416 \times 0.4 \times 40}{60} = 0.01675 \, m^3/s$$

Slip = $Q_{th} - Q_{act} = 0.01675 - 0.1666 = 0.0009 \, m^3/s$.

Power required to drive the double-acting pump:-

$$P = \frac{2 \times \rho g \times ALN \times (h_s + h_d)}{60,000} = \frac{2 \times 1000 \times 9.81 \times 0.031416 \times 0.4 \times 40 \times (5+20)}{60,000}$$

$= 4.109$ KW. Ans.

4. Water Logging & Drainage:—

* Introduction:—

In agricultural land, when the soil pores within the root zone of the crops get saturated with the subsoil water, the air circulation within the soil pores gets totally stopped. this phenomenon is termed as water logging. the water logging makes the soil alkaline in character and the fertility of the land is totally destroyed and the yield of crop is reduced.

Due to heavy rainfall for a longer period or due to continuous percolation of water from the canals, the water table gets raised near the surface of the soil. Then, by capillary action the water rises to the root zone of the crops and goes on saturating the soil. If this condition goes on for a longer period, the soil becomes alkaline and is damaging to the crops.

* Causes of water Logging:—

(1) Over irrigation:—

In inundation irrigation since there is no controlling system of water supply it may cause over irrigation. The excess water percolates and remains stored within the root zone of the crops. Again, in perennial irrigation system if water is supplied more than what is required. This excess water is responsible for water logging.

(2) Seepage from canals:-

In unlined canal system, the water percolates through the bank of the canal and gets collected in the low lying areas along the course of the canal and thus the water table gets raised. This seepage is more in case of canal in banking.

(3) Inadequate Surface drainage:-

When the rainfall is heavy and there is no proper provision for surface drainage the water gets collected and submerges vast area. When this condition continues for a long period, the water table is raised.

(4) Obstruction in Natural water Course:-

If the bridges or culverts are constructed across a water course with the opening with insufficient discharge capacity, the upstream area gets flooded and this causes water logging.

(5) Obstruction in Sub-soil Drainage:-

If some impermeable stratum exists at a lower depth below the ground surface, then, the movement of the sub soil water gets obstructed and causes water logging in the area.

(6) Nature of Soil:-

The soil having low permeability, like black cotton soil, does not allow the water to percolate through it. So, in case of over irrigation or flood, the water retains in this type of land and causes water logging.

(7) Incorrect method of cultivation:—
If the agricultural land is not levelled properly and there is no arrangements for the surplus water to flow out, then it will create pools of stagnent water leading to water logging.

(8) Seepage from Reservoir:—
If the reservoir basin consists of permeable zones, cracks and fissures which were not ~~deduct~~ detected during the construction of dam, these may cause seepage of water. this sub-soil water will move towards the low-lying areas and cause water logging.

(9) Poor irrigation management:—
If the main canal is kept open for a long period ~~unnessa~~ unnecessarily without computing the total water requirement of the crops, then this leads to over irrigation which shall result in water logging.

(10) Topography of the land:—
If the agricultural land is flat, i.e no countrey slope and consists of depressions or undulations, then this leads to water logging.

(11) Excessive rainfall:—
If the rainfall is excessive and the water gets no time to get drained off completely, then a pool of stagnant water is formed which might lead to water logging.

(12) Occasional flood!—
If an area gets affected by flood every year & there is no proper drainage system, the water table gets raised and this causes water logging.

* Effects of water logging :—

(1) Salinization of Soil :—

Due to water logging the dissolved Salts like sodium carbonate, Sodium chloride and sodium sulphate come to the surface of the soil. when the water evaporates from the surface the salts are deposited there. This process is known as salinization of soil. Excessive concentration of salt makes the land alkaline. It does not allow the plants to thrive and thus the yield of crop is reduced. this process is also known as Salt efflorescence.

(2) Lack of aeration :—

The crops require some nutrients for their growth which are supplied by some bacteria or micro-organisms by breaking the complex nitrogeneous compounds into simple compounds which are consumed by the plants for their growth. But the bacteria requires oxygen for their life and activity. when the aeration in the soil is stopped by water logging, these bacteria cannot survive without oxygen and the fertility of the land is lost which results in reduction of yield.

(3) Fall of Soil temperature :—

Due to water Logging, the soil temperature is lowered. At low temperature of the soil the activity of the bacteria becomes very slow and consequently the plants do not get the requisite amount of food in time.

Thus, growth of plants is hampered and the yield also is reduced.

(4) Growth of weeds and Aquatic plants :—

Due to water logging, the agricultural land is converted to marshy land and the weeds and aquatic plants are grown in plenty. These plants consume the soil foods in advance and thus the crops are destroyed.

(5) Diseases of crops :—

Due to low temperature and poor aeration, the crops gets some diseases which may destroy the crops are reduced the yield.

(6) Difficulty in cultivation :—

In water logged area it is very difficult to carry out the operation of cultivation such as tilling, ploughing, etc.

(7) Restriction of root Growth :—

When the water table rises near to root zone the soil gets saturated. The growth of the roots is confined only to the top layer of the soil. So, the crops cannot be matured properly and the yield is reduced.

* Prevention and remedies :—

(1) Prevention of percolation from Canals :—

The irrigation canals should be lined with impervious lining to prevent the percolation of water through the bed and banks of the canals. Thus the water logging may be prevented.

Intercepting drains may be provided along the course of the irrigation canals in places where the percolation of water is detected. The percolating water is intercepted by the drains and the water is carried to other natural water course.

(2) Prevention of percolation from Reservoirs:—

During the construction of dam, the geological survey should be conducted on the reservoir basin to detect the zone of permeable formations through which water may percolate. These zones should be treated properly to prevent the seepage. If afterwards it is found that there is still leakage of water through some zone, then sheet piling should be done to prevent the leakage.

(3) Control of intensity of irrigation:—

The intensity of irrigation may cause water logging so, it should be controlled in a planned way so that there is no possibility of water logging in a particular area.

(4) Economical use of water:—

If the water is used economically, then it may control the water logging and the yield of crops may be high. So, special training is required to be given to the cultivators to realise the benefits of economical use of water. It helps them to get more crops by eliminating the possibility of water logging.

(5) Fixing of crop patterns:—

Soil survey should be conducted to fix the crop pattern. The crops having high rate of evapotranspiration should be recommended for the area susceptible to water logging.

(6) Providing Drainage System:—

Suitable drainage system should be provided in the low lying areas so that the rain water does not stand for long days. A net work of sub-surface drains are provided which are connected to the surface drains. The surface drains discharge the water to the river or any water course.

(7) Improvement of Natural Drainage:—

Sometimes, the natural drainage may be completely silted up or obstructed by weeds, aquatic plants, etc. The affected section of the drainage should be improved by excavating and clearing the obstructions.

(8) Pumping of Ground water:—

A number of open wells or tubewells are constructed in the water logged area and the ground water is pumped out until the water table goes down to a safe level. The lifted ground water may be utilised for irrigation or may be discharged to the river or any water course.

(9) Construction of Sump well:—

Sump wells may be constructed within the water logged area and they help to collect the surface water. The water from the Sumpwell may be pumped to the irrigable lands or may be discharged to any river.

05 Diversion head works & Regulatory Structures:

5.1 Necessity of diversion head works and its objectives:—

When a weir or barrage is constructed across a perennial river to raise the water level and to divert the water to the canal, then it is known as diversion head work. The flow of water in the canal is controlled by canal head regulator.

Objectives:—

(a) To raise the water level at the head of the canal.

(b) To form a storage by constructing dykes on both the banks of the river so that water is available throughout the year.

(c) To control the entry of silt into the canal and to control the deposition of silt at the head of the canal.

(d) To control the fluctuation of water level in the river during different seasons.

★ Selection of site for Diversion head works:—

1. At the site, the river should be straight and narrow.
2. The river banks should be well defined.
3. The valuable land should not be submerged when the weir or barrage is constructed.
4. The elevation of the site should be much higher than the area to be irrigated.
5. The site should be easily accessible by roads or railways.
6. The materials of construction should be available in vicinity of the site.

7. The site should not be far away from the command area of the project, to avoid transmission loss.

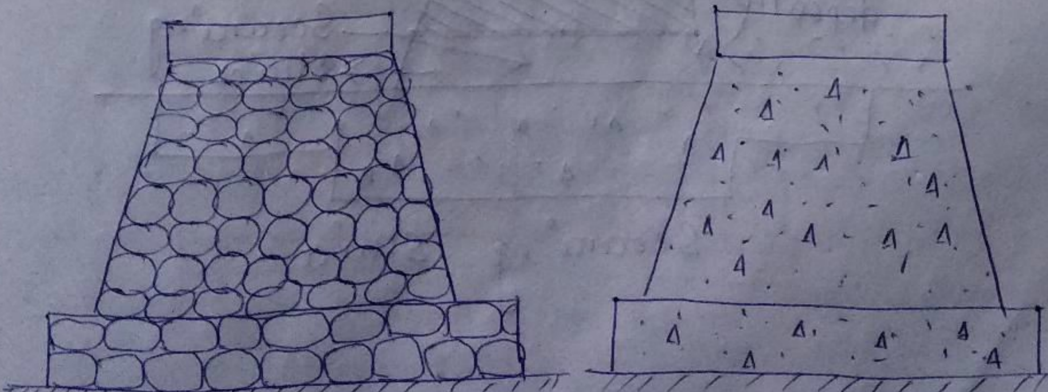
* Components of Diversion Head works:—

1. Weir or barrage
2. Divide wall
3. Scouring sluices or under sluices.
4. Fish Ladder.
5. Canal head regulator.
6. Silt excluder.
7. Guide bank.
8. Marginal embankment or Dyke.

(2) ~~(a) Weir~~ Divide wall:—

The divide wall is a long wall constructed at right angles to the weir or barrage, it may be constructed with stone masonry or cement concrete. On the upstream side, the wall is extended just to cover the canal head regulator & on the down stream side, it is extended up to the launching apron. The function of divide wall as follows:—

(a) To form a still water pocket in front of the canal head so that the suspended silt can be settled down which then later be cleaned through the scouring sluices from the time to time.



(a) Stone masonry (b) Concrete.

= Divide wall =

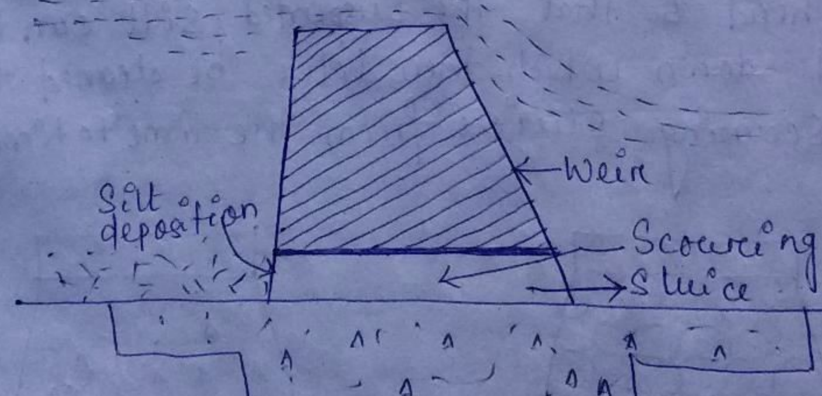
(b) It controls the eddy current or cross current in front of the canal head.

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

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

(3) Scouring sluices or Under sluices:—

The scouring sluices are the openings provided at the base of the weir or barrage. These openings are provided with adjustable gates. Normally, the gates are kept closed. The suspended silt goes on depositing in front of the canal head regulator. When the silt deposition becomes appreciable the gates are opened and the deposited silt is loosened with an agitator mounting on a boat. The muddy water flows towards the downstream through the scouring sluices. The gates are then closed. But at the period of flood, the gates are kept opened.

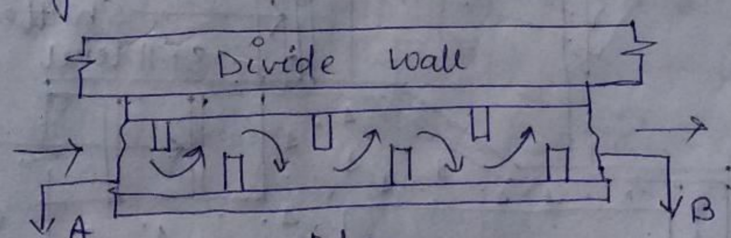


Scouring sluice.

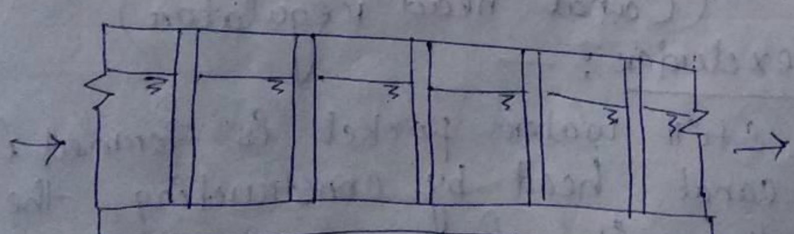
Fish Ladder:

(ii) The fish ladder is provided just by the side of the divide wall for the free movement of fishes. Rivers are important source of fishes. There are various types of fish in the river. The nature of the fish varies from types to type. But in general, the tendency of fish is to move from upstream to downstream in winters and from downstream to upstream in monsoons. This movement is essential for their survival. Due to construction of weir or barrage, this movement gets obstructed, and is detrimental to the fishes.

For the free movement of the fishes along the course of the river, the fish ladder is essential. In the fish ladder, the baffle walls are constructed in a zig-zag manner so that the velocity of flow within the ladder does not exceed 3m/sec. The width, length and height of the fish ladder depends on the nature of the river and the type of the weir or barrage.



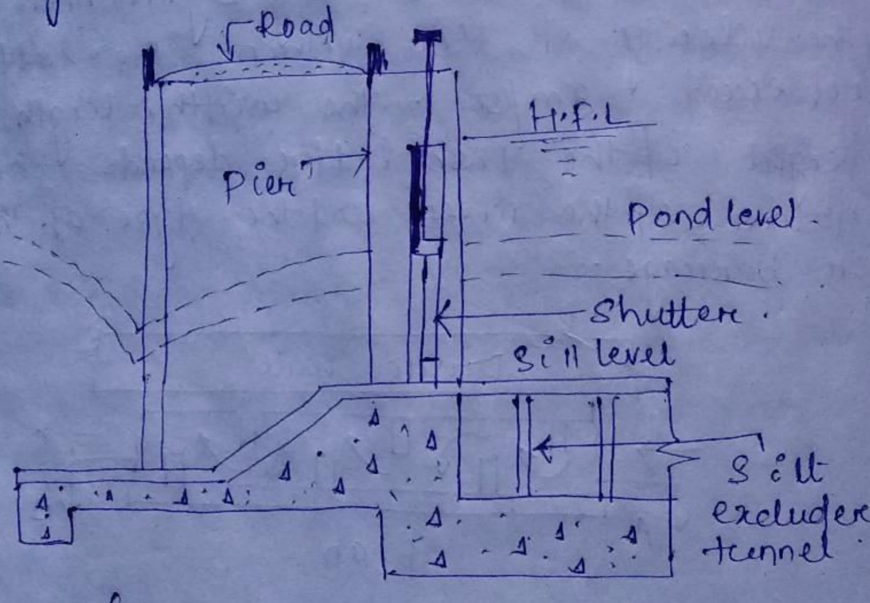
Plan



Section on AB
(fish ladder)

(5) Canal head regulator :—

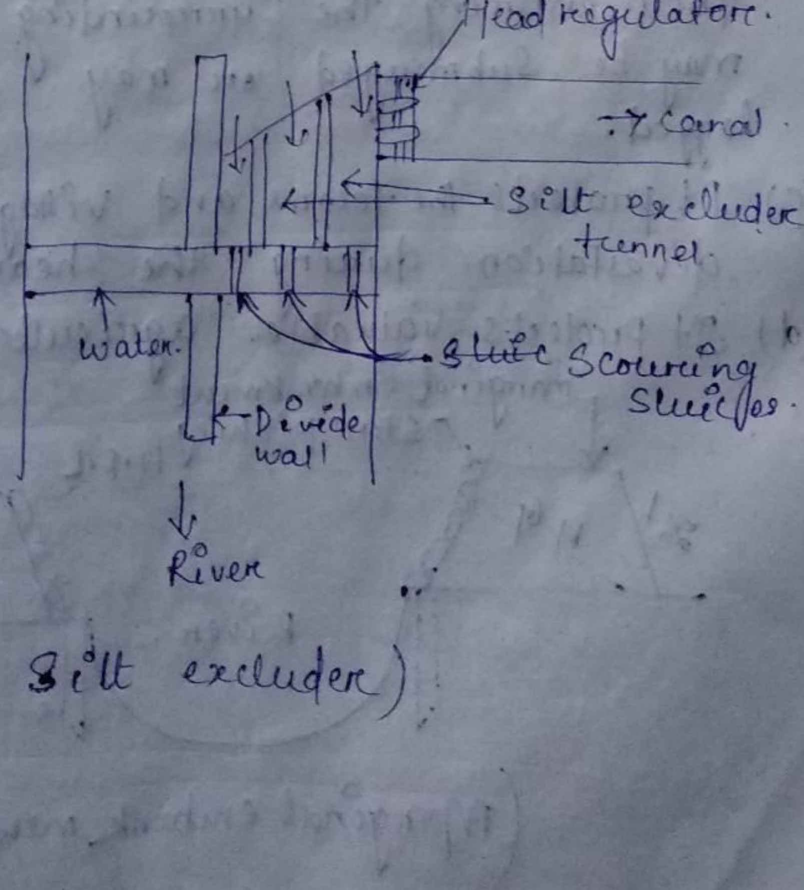
A structure which is constructed at the head of the canal to regulate flow of water is known as canal head regulator. It consists of a number of piers which divide the total width of the canal into a number of spans which are known as bays. The piers consists of a number tiers on which the adjustable gates are placed. The gates are ~~opened~~ operated from the top by suitable mechanical device. A platform is provided on the top of the piers for the facility of operating the gates. Again some piers are constructed on the down stream side of the canal head to support the roadway.



(Canal head regulator)

(6) Silt excluder :—

When still water pocket is formed in front of the canal head by constructing the divide wall, then it is formed that the lower layer of water contains heavy silt and the upper layer contains very fine silt. The fine silt is very fertile and it may be allowed to enter the canal. But the heavy silt causes sedimentation in the pocket. To eliminate the suspended heavy silt, the silt excluder is provided. It consists of a series of tunnels starting from the side of the head regulator up to the divide wall. The tunnel nearest to the head regulator is longest, and the successive tunnel decrease in length the tunnel nearest to the devide wall is shortest. The tunnels are covered by R.C.C slab. The top level of the slab is kept below the sill level of the head regulator. So, the comparatively clear water (containing fine silt) is allowed to flow in the canal through the head regulator. the suspended heavy silt carried by the water enters the silt excluder tunnels and passes out through the scouring sluices.



(Silt excluder)

7. Marginal Embankment or dyke:—

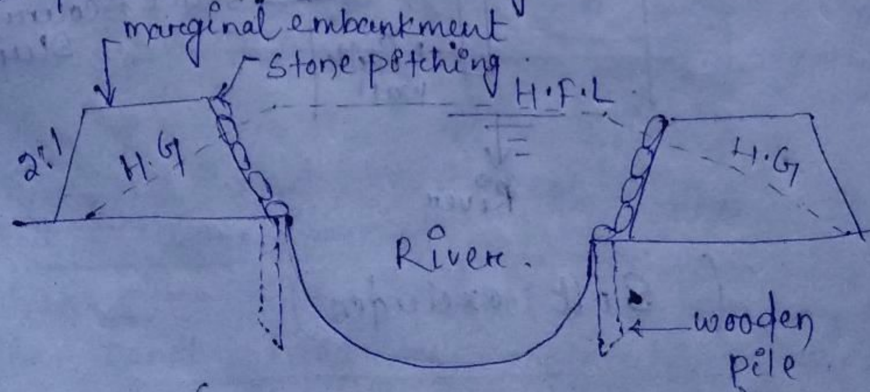
These are earthen embankments which are constructed parallel to the river bank on one or both the banks according to the condition. The top width is generally 3 to 4 m. The side slope on the river side is generally $1\frac{1}{2}:1$ and that on the country-side is 2:1. The height of the embankment depends on the ~~height~~ highest flood level. A suitable margin is provided between toe of the embankment and the bank of the river. It serves the following purposes:—

(a) It prevents the flood water or storage water from entering the surrounding area which may be submerged or may be water logged.

(b) It retains the flood water or storage water from entering the surrounding area which may be submerged or may be water logged.

(c) It protects the towns and villages from devastation during the heavy flood.

(d) It protects valuable agricultural lands.



(Marginal embankment)

8. Guide bank:—

when a barrage is constructed across a river which flows through the alluvial soil, the guide banks must be constructed on both the approaches to protect the structure from erosion. It is an earthen embankment with curved heads on both the ends.

The guide bank serves the following purposes:—

(a) It protects the barrage from the effect of scouring and erosion.

(b) It provides a straight approach towards the barrage.

(c) It controls the tendency of changing the course of the river.

(d) It controls the velocity of flow near the structure.

06 Cross-drainage work:—

In an irrigation project, when the network of main canal, branch canals, distributaries etc are provided, then these canals may have to cross the natural drainages like rivers, streams, nallahs, etc at different points within the command area of the project. The crossing of the canals with such obstacles cannot be avoided. So, suitable structures must be constructed at the crossing point for the easy flow of water of the canal and drainage in the respective directions. These structures are known as cross-drainage works.

Necessity of Cross-drainage works:—

(a) The watershed canals do not cross natural drainages. But in actual orientation of the canal network, this ideal condition may ~~be~~ not be available and the obstacles like natural drainages may be present across the canal. So the cross drainage works must be provided for running the irrigation system.

(b) At the crossing point, the water of the canal and the drainage get intermixed. So, far the smooth running of the canal with its design discharge the cross drainage works are required.

(c) The site condition of the crossing point may be such that without any suitable structure, the water of the canal and drainage cannot be diverted to their natural directions. So, the cross drainage works must be provided to maintain their natural direction of flow.

Types of cross-drainage works :—

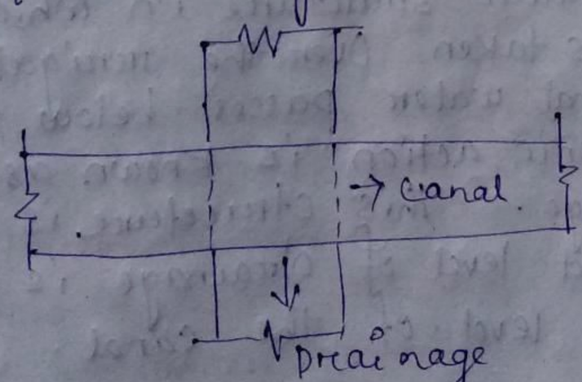
According to the relative bed levels, maximum water levels and relative discharges of the canals and drainages, the cross drainage work may be of the following types.

Type-1

Irrigation canal passes over the Drainage:—

(a) Aqueduct :—

The hydraulic structure in which the irrigation canal is taken over the drainage (such as river, stream etc) is known as aqueduct. This structure is suitable when bed level of canal is above the highest flood level of drainage. In this case the drainage water passes clearly below the canal.



(b) Siphon Aqueduct :—

In a hydraulic structure where the canal is taken over the drainage, but the drainage water cannot pass clearly below the canal. It flows under siphonic action. So it is known as siphon aqueduct. This structure is

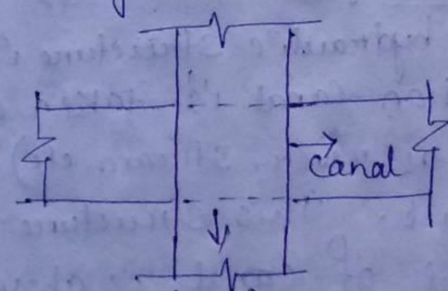
Suitable when the bed level of canal is below the highest flood level of the drainage.

Type -II

Drainage passes over the Irrigation canal :—

(a) Super passage :—

The hydraulic structure in which the drainage is taken over the irrigation canal is known as super passage, the structure is suitable when the bed level of drainage is above the full supply level of the canal. The water of the canal passes clearly below the drainage.



(b) Siphon Super passage :—

The hydraulic structure in which the drainage is taken over the irrigation canal, but the canal water passes below the drainage under siphonic action is known as siphon super passage. This structure is suitable when the bed level of drainage is below the full supply level of the canal.

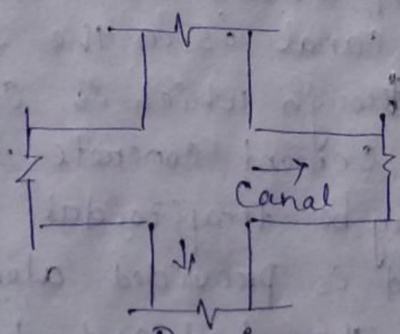
Type-III Drainage and Canal intersection Each other at the Same Level :—

(a) Level Crossing :—

When the beds of the drainage and canal are practically at the same level, then a hydraulic structure is constructed which is known as level crossing. This is suitable for the crossing of large drainage with main canal.

(b) Inlet and out let :—

In the crossing of small drainage with small channel no hydraulic structure is constructed. Simple openings are provided for the flow of water in their respective directions. This arrange-ments is known as inlet and outlet.



· Selection of type of cross-Drainage works:—

The following factors should be considered:—

(1) ~~Read~~ Relative Bed levels:—

According to the relative bed levels of the canal and the river or drainage, the types of cross-drainage works are generally selected. ~~which have~~

The following points should be remembered while recommending this types of works:—

(a) The crossing should be at right angles to each other.

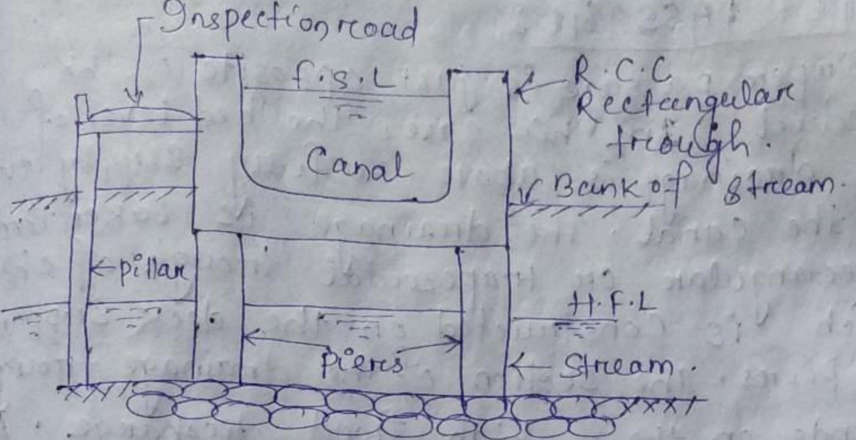
(b) Well defined cross-section of the river or drainage should be available.

(c) At the crossing point the drainage should be straight for a considerable length.

(d) The width of the drainage should be narrow as far as possible.
(2) Availability of suitable foundation.
(3) Economical consideration.
(4) Discharge of the drainage.
(5) construction problems.

- AQUEDUCT: —

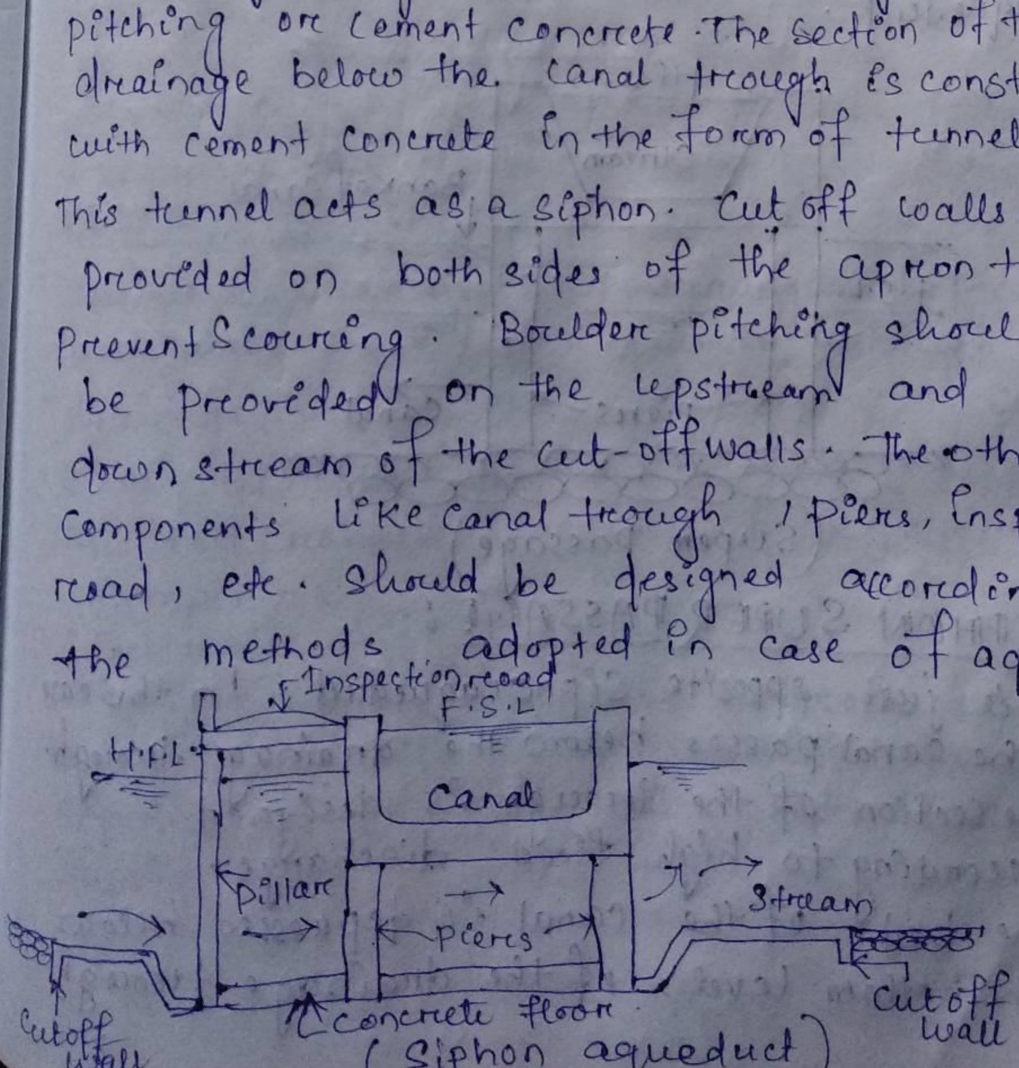
The aqueduct is just like a bridge where a canal is taken over the deck supported by piers instead of a road or railway. Generally, the canal is in the shape of a rectangular trough which is constructed with reinforced cement concrete. Some times, the trough may be trapizoidal section. An inspection road is provided along the side of the trough. The bed and banks of the drainage below the trough is protected by boulder pitching with cement grouting. The section of the trough is designed according to the full supply discharge of the canal. A free board of about 0.5 m should be provided. The height and section of piers are designed according to the highest flood level and velocity of flow of the drainage. The piers may be of brick masonry, stone masonry or reinforced cement concrete. Here, deep foundation (like well foundation) is not necessary for the piers. the concrete foundation may be done by providing the depth of foundation according to the availability of hard soil.



(Aqueduct)

SIPHON AQUEDUCT :-

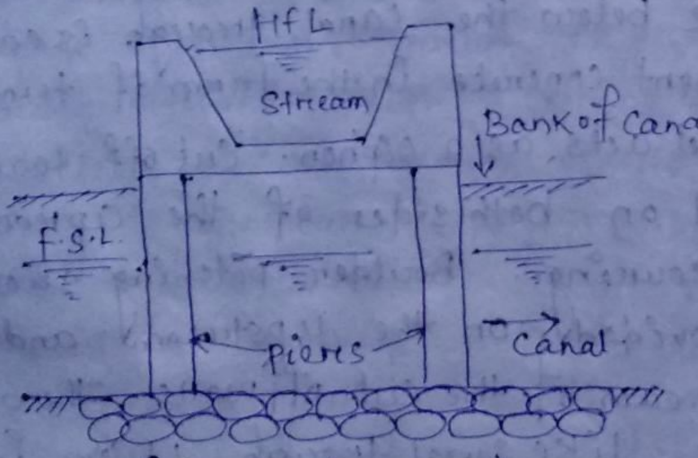
The siphon aquaduct, the bed of the drainage is depressed below the bottom level of the canal trough by providing sloping apron on both sides of the crossing. The sloping apron by may be constructed by stone pitching or cement concrete. The section of the drainage below the canal trough is constructed with cement concrete in the form of tunnel. This tunnel acts as a siphon. Cut off walls are provided on both sides of the apron to prevent scouring. Boulder pitching should be provided on the upstream and down stream of the cut-off walls. The other components like canal trough, piers, inspection road, etc. should be designed according to the methods adopted in case of aqueduct.



(Siphon aqueduct)

SUPER PASSAGE:

The super passage is just opposite of the aqueduct. In this case, the bed level of the drainage is above the fully supply level of the canal. The drainage is taken through a rectangular or trapezoidal trough of channel which is constructed on the deck supported by piers. The section of the drainage trough depends on the high flood discharge. A free board of about 1.5 m should be provided for safety. The trough should be constructed of reinforced cement concrete. The bed and banks of the canal below the drainage trough should be protected by boulder pitching or lining with concrete slabs. The foundation of the piers will be same as in the case of aqueduct.



(Super passage)

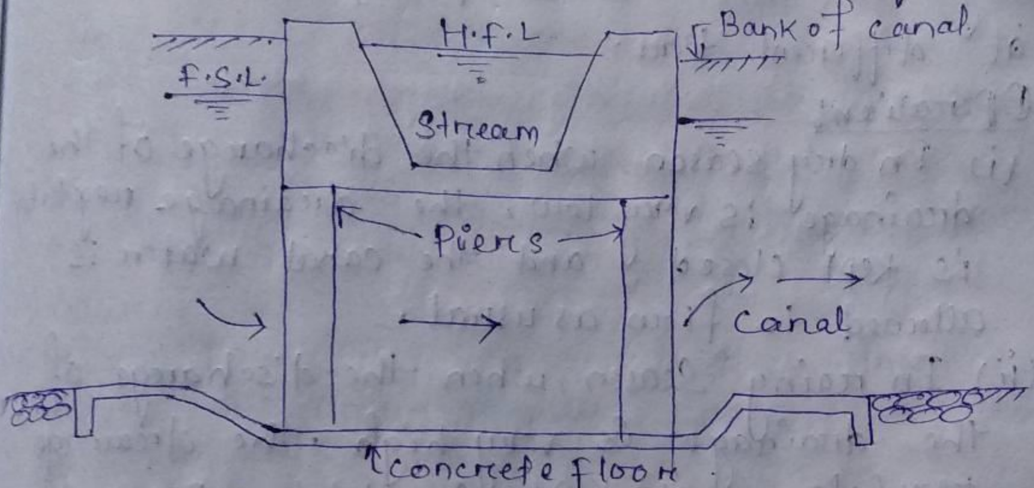
SIPHON SUPER PASSAGE:

1. It is just opposite siphon aqueduct. In this case, the canal passes below the drainage trough. The section of the trough is designed according to high flood discharge.
2. The bed of the canal is depressed below the bottom level of the drainage trough

by providing sloping apron on both side of the crossing.

The sloping apron may be constructed with stone pitching or concrete slabs.

The section of the canal below the trough is constructed with cement concrete in the form of tunnel which acts as siphon. Cut-off walls are provided on upstream and downstream side of sloping apron. Other components are same as in the case of siphon aqueduct.



(Siphon super passage)

LEVEL CROSSING:—

The level crossing is an arrangement provided to regulate the flow of water through the drainage and the canal when they cross each other approximately at the same bed level. The level crossing consists of the following components.

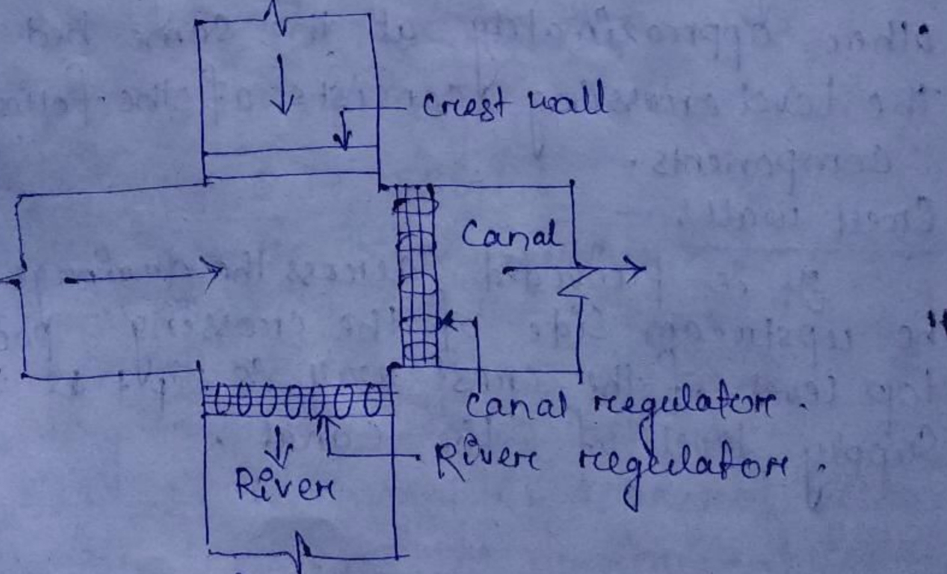
(1) Crest wall:—

It is provided across the drainage just at the upstream side of the crossing point. The top level of the crest wall is kept at the full supply level of the canal.

(2) Drainage Regulator:-
It is provided across the drainage just at the down stream side of the crossing point. The regulator consists of adjustable shutters at different tiers.

CANAL REGULATOR:-
It is provided across the canal just at the downstream side of the crossing point. This regulator also consists of adjustable shutters at different tiers.

Operation:
(i) In dry season, when the discharge of the drainage is very low, the drainage regulator is kept closed and the canal water is allowed to flow as usual.
(ii) In rainy season, when the discharge of the drainage is very high, the drainage regulator is kept completely open and the canal regulator is adjusted according to the requirement.
(iii) The level crossing is recommended for the crossing of main canal with large drainage.



(Level Crossing)

INLET AND OUTLET :-

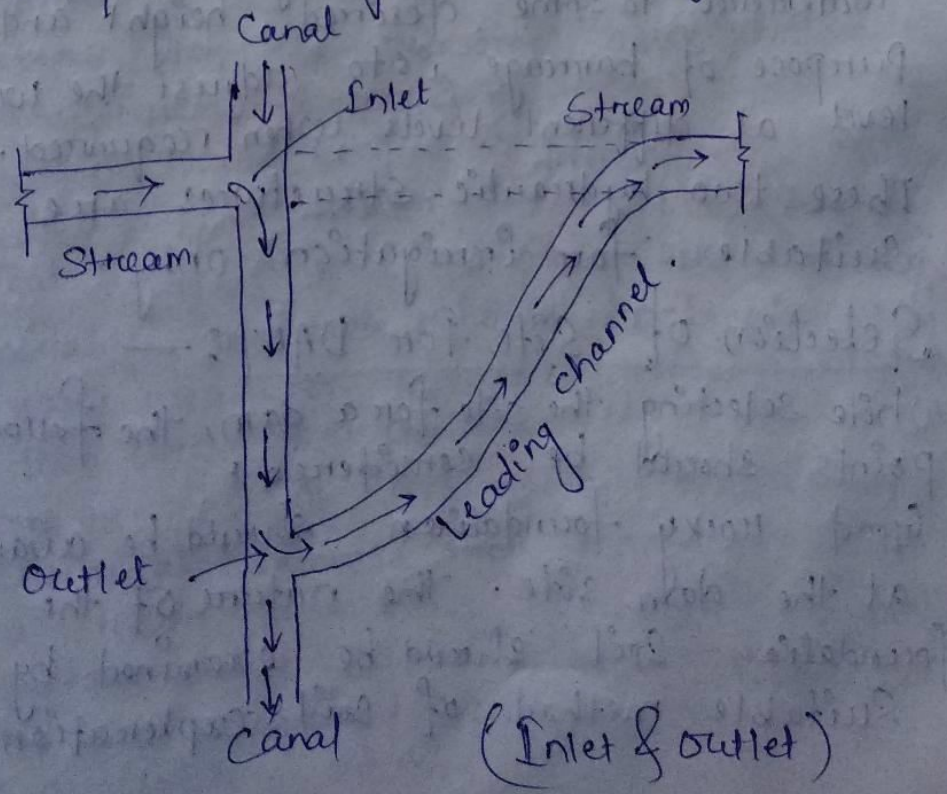
(1) In case of crossing of a small irrigation channel with a small drainage, no hydraulic structure is constructed. Because, the discharges of the drainage and the channel are practically low and these can be easily tackled by easy system like inlet and outlet arrangement.

(2) In this system an inlet is provided in the channel bank simply by open cut and the drainage water is allowed to join the channel.

(3) Then at a suitable point on the down stream side of the channel an out let is provided by open cut and the water from the irrigation channel is allowed to flow through a leading channel towards the original course of the drainage.

(4) At the points of inlet and out let the bed and banks of the drainage are protected by stone pitching.

(5) The bed and banks of the irrigation channel between inlet and out let points should also be protected by stone pitching.



(Inlet & outlet)

07: DAMS

Introduction:—

- An impervious high barrier which is constructed across a river valley to form a deep storage reservoir is known as dam.
- It is suitable in hilly region where a deep gorge section is available for the storage reservoir.
- The dam is meant for serving multipurpose functions such as:-
    - a) Irrigation
    - b) Hydroelectric power generation.
    - c) Flood control.
    - d) Water supply
    - e) Fishery
    - f) Recreation.
- Weir and barrage are also impervious barriers across the river which are suitable in plain terrain but not in hilly region.
- The purpose of weir is only to raise the waterlevel to some desired height and the purpose of barrage is to adjust the water level at different levels when required.
- These two hydraulic structures are suitable for irrigation only.

Selection of Site for DAM:—

While selecting the site for a dam, the following points should be considered,

(1) Good rocky foundation should be available at the dam site. The nature of the foundation soil should be examined by suitable method of soil exploration.

2. The river valley should be narrow and well defined so that the length of the dam may be short as far as possible.
3. Site should be in deep gorge section of the valley so that large capacity storage can be formed with minimum surface area and minimum length of dam.
4. Valuable property and valuable land should not be submerged due to the construction of dam.
5. The proposed river or its tributaries should not carry large quantity of sediment. If unavoidable, the sources of sediments should be located and necessary measures should be recommended to arrest the sediment.
6. The site should be easily accessible by road or railway for the transport of construction materials, equipments, etc.
7. The construction materials should be available in the vicinity of the dam site.
8. Sufficient space should be available in the vicinity of the dam site for the construction of labour ~~cons~~ colony, godowns and staff quarters for the personnel associated with the constructional activity.
(9) The basin should be free from cracks, fissures etc. to avoid percolation loss. It is done by physical verification and other observations. If unavoidable, the area should be located and necessary measures should be recommended to make the area leak proof.
(10) From the rainfall records in the catchment area or empirical formulae the maximum discharge of the river should be computed. From the computed value, it should be ascertained whether the required quantity of water shall be available or not.

- **Classification Of Dam:—**

Dams may be classified on the following basis.

A. Based on material of construction:—

1. Rigid dam:—

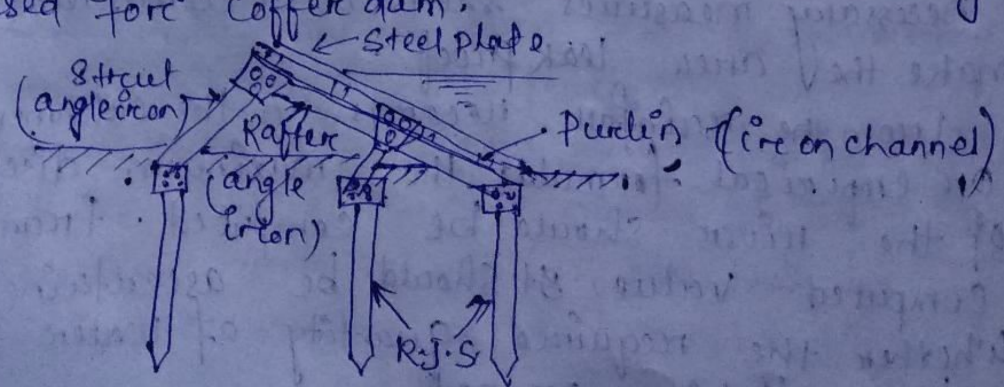
It is constructed with rigid materials like masonry, concrete, steel or timber. It is designated as, (a) Masonry dam
(b) Concrete dam
(c) Steel dam
(d) Timber dam

2. Non-rigid dam:—

It is constructed with non rigid materials such as earth, clay, rock materials, etc. It is designated as, (a) Earthen dam
(b) Rock fill dam
(c) Composite dam.

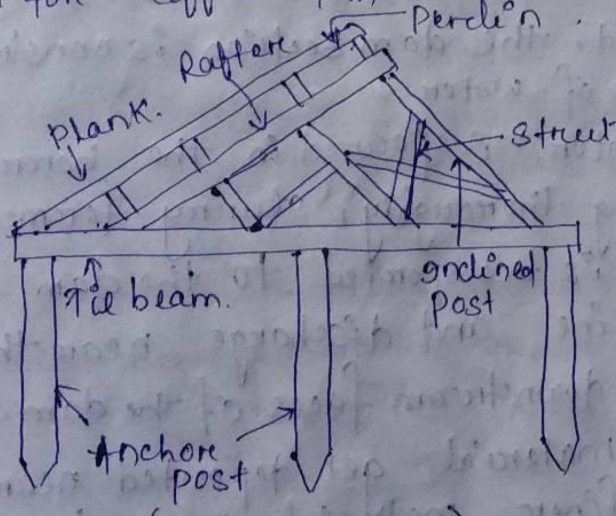
Steel dam:—

Steel dam is constructed with R.S. joists, iron angles and steel plates. R.S. joists are driven in to the ground with which struts (iron angles) are fixed. Rafters (iron angle) are fixed with the struts to form the inclined dam profile. Purlines are fixed on rafters at suitable interval. Then steel plates are fixed with the purline to form the water retaining member. This dam is mainly used for coffer dam.



Timber Dam:-

Timber dam is a temporary structure constructed to retain water at a depth of about 10 m. When timber is available in large quantities, this type of dam is constructed at a moderate cost. Anchor posts are driven into the ground and a tie beam is fixed over the posts. The tie beam consists of inclined posts and rafter. The posts are stiffened with struts. The rafter consists of purlins. Then planks are fixed on the purlins which form the membrane for retaining water. This type of dam is mainly used for coffer dam.



(Timber beam)

Earthen DAM:-

Earthen dams are constructed purely by earth work in trapezoidal section. These are most economical and suitable for weak foundation. Earthen dams are classified as follows:-

Based on method of construction:-

Rolled fill Dam:-

(i) In this method, the dam is constructed in successive layers of earth by mechanical compaction.

(ii) The selected soil is transported from borrow pits and laid on the dam section, to layer of about 45 cm.

(iii) The layers are thoroughly compacted by rollers of recommended weight and type.

(iv) When the compaction of one layer is fully acheived the next layer is laid and compacted in the usual way.

(v) The designed dam section hence is completed layer by layer.

Hydraulic fill DAM :—

(i) In this method, the dam section is constructed with the help of water.

(ii) Sufficient water is poured in the borrowpit and by pugging thoroughly, slurry formed.

(iii) This slurry is transported to the dam site by pipe line and discharge near the upstream and downstream faces of the dam.

(iv) The coarser material get deposited near the face and the finer material move towards the centre and get deposited there.

(v) Thus the dam section is formed with faces of coarse material and central core is of impervious material like clay and silt. In this case, compaction is not necessary.

Semi-Hydraulic fill Dam :—

(i) In this method the selected earth is transported from the borrowpit and dumped within the section of the dam, as done in the case of rolled fill dam.

ii) while dumping no water is used. But, after dumping the water jet is forced on the dumped earth.

iii) Due to the action of water the finer materials move towards the centre of the dam and an impervious core is formed with fine materials like clay. The outside body is formed by coarse material, In this case also compaction is not necessary.

Homogeneous Type Dam:-

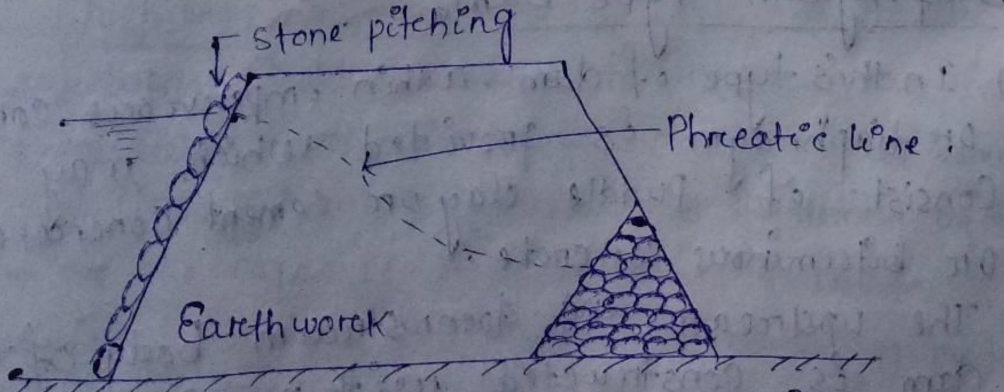
i) This type of dam is constructed purely with earth in trapezoidal section having the side slopes according to the angle of repose of the soil.

ii) The top width and height depends on the depth of water to be retained and the gradient of the seepage line.

iii) the phreatic line (top level of the seepage line) should pass well within the body of the dam.

iv) This type of dam is completely pervious.

v) the upstream face of the dam is protected by stone pitching. Now-a-days, the earthen dam is modified by providing horizontal drainage blanket or rock toe.



(Homogeneous type DAM)

Zoned Type Dam:—

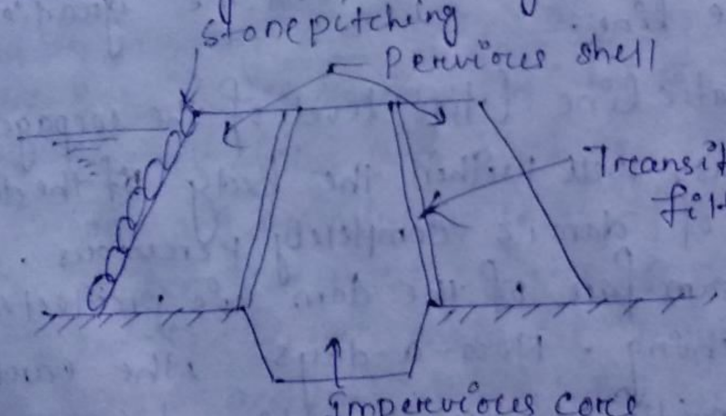
(i) This type of dam consists of several materials, the impervious core is made of puddle clay and the outer pervious shell is constructed with the mixture of earth, sand, gravel, etc.

(ii) The core is trapezoidal in section and its width depends on the seepage characteristics of the soil mixture on the upstream side.

(iii) The core is extended below the base of the dam to control the sub-soil seepage.

(iv) Transition filter are provided on both sides of the impervious core to control seepage.

(v) The transition filter is made of gravel and coarse sand. The upstream face of the dam is protected by stone pitching.



(Zoned type DAm)

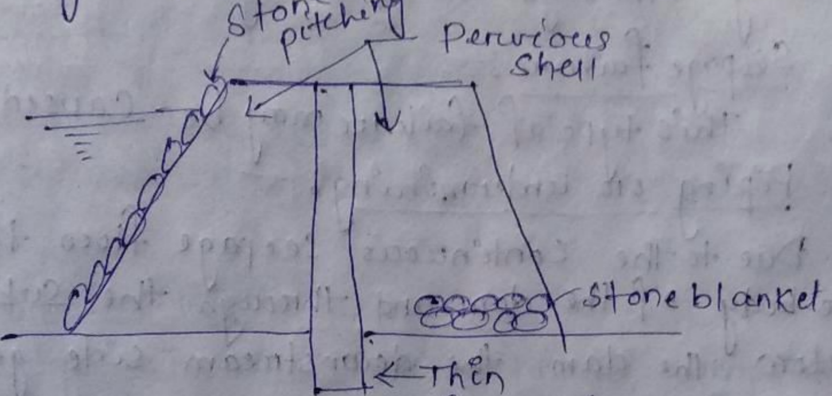
Diaphragm Type Dam:—

(i) In this type of dam, a thin impervious core or diaphragm is provided which may consist of puddle clay or cement concrete or bituminous concrete.

(ii) The upstream and downstream body of the dam is constructed with pervious shell which consists of the mixture of soil, sand, gravel etc.

(iii) The thickness of the core is generally less than 3m. A blanket of stones is provided on the toe of the dam for the drainage of the seepage water without damaging the base of the dam, the upstream face is protected by stone pitching.

(iv) The side slope of the dam should be decided according to the ~~dam should be decided according~~ angle of repose of the soil mixture.



(Diaphragm type dam)

- **Causes of failure of Earthen DAM:—**

The failure of the earthen dam may be caused due to the following reasons.

1. Hydraulic failure:—

This type of failure caused by:—

(a) Overtopping:—

If the actual flood discharge is much more than the estimated flood discharge or the free board is kept insufficient or there is settlement of the dam or the capacity of spillway is ~~inff~~ insufficient, then it results in the overtopping of the dam. During the overtopping the crest of the dam may be washed out and the dam may collapse.

(b) Erosion:—
If the stone protection of the upstream side is sufficient, then the upstream face may be damaged by erosion due to wave action. The downstream side also may be damaged by tail water, rain water, etc. The toe of the dam may also get damaged by the water flowing through the spillways.

(2) Seepage failure:—
This type of failure may be caused by;

(a) Piping or undermining:—
Due to the continuous seepage flow through the body of the dam and through the sub-soil below the dam, the downstream side gets eroded or washed out and a hollow pipe like groove is formed which extends gradually towards the upstream through the base of the dam. This phenomenon is known as piping or undermining. This effect weakens the dam and ultimately causes the failure of the dam.

(b) Sloughing:—
The crumbling of the toe of the dam is known as sloughing when the reservoir runs full for a longer time, the downstream based of the dam remains saturated. Due to the force of the seepage water the toe of the dam goes on crumbling gradually. Ultimately the base of the dam collapses.

(3) Structural failure:—
This type of failure may be caused by;

(a) Sliding of the side slopes:—
Sometimes, it is found that the side slope of

the dam slides down to form some steeper slope. The dam goes on depressing gradually and then overtopping occurs which leads to the failure of the dam.

(b) Damage by burrowing animals:—

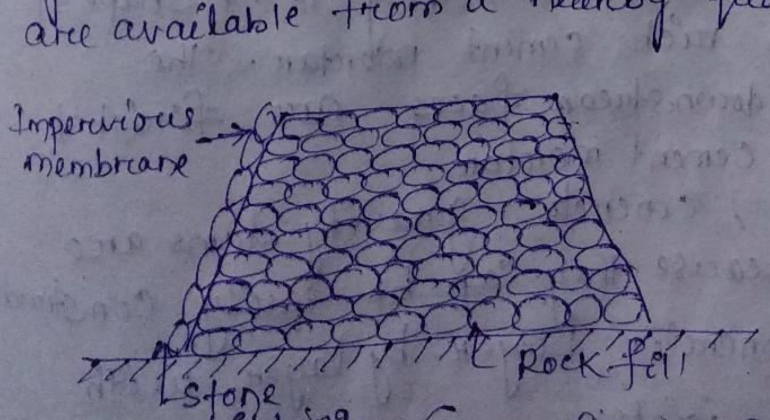
Some burrowing animals like craw fish, snakes squirrel, rats, etc caused damage to the dam by digging holes through the foundation and body of the dam.

(c) Damage by earthquake:—

Due to earthquake cracks may develop on the body of the dam and the dam may eventually collapse.

ROCK FILL DAM:—

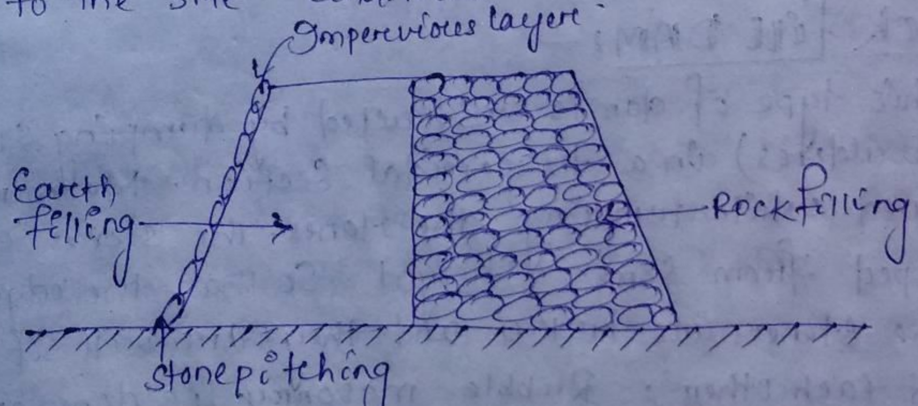
This type of dam is constructed by dumping stones (i.e boulders) in a trapezoidal section. No mortar is used while dumping the stones. The stones are dropped from some height so that the edges of the stones are broken and they are well set with each other. Rubble masonry is done on the upstream side which is grouted by cement. Finally an impervious membrane is provided over the rubble masonry by concrete or asphalt to make the surface water tight. This type of dam is suitable when plenty of stones are available from a nearby quarry.



(Rock-fill Dam)

Composite Dam:—

This type of dam consists of rock fill on the downstream side and earth-fill on the upstream side. The rockfill section is constructed in the usual way. The earth-fill section is constructed with selected earth which is compacted properly. The upstream side is protected by stone pitching which is grouted with cement mortar. An impervious membrane of cement concrete or asphalt is provided over the stone pitching to make the surface water tight. The height of the dam depends on the depth of water to be retained and the side slope is fixed according to the site condition.



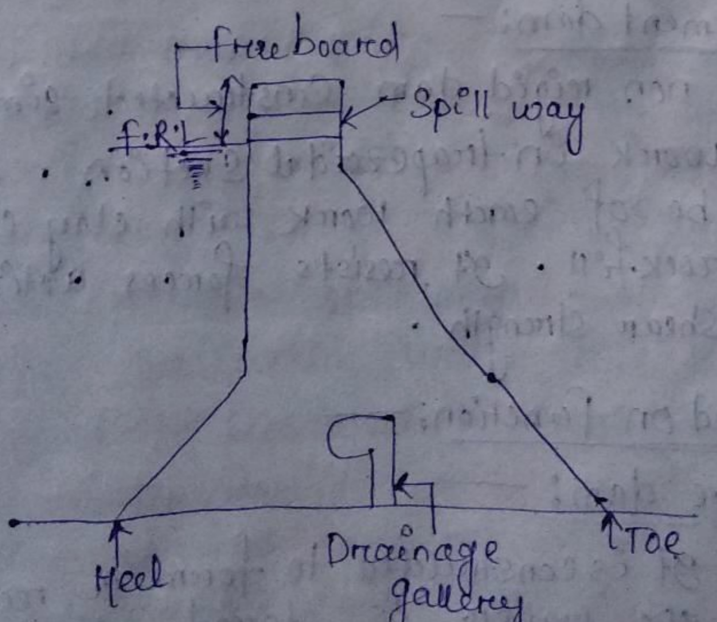
(Composite dam)

B. Based on Structural behaviour:—

*** Gravity dam:—**

- The solid gravity dam may be constructed with rubble masonry of concrete. The rubble masonry is done according to the shape of the dam with rich cement mortar. The upstream & downstream faces are finished with rich cement mortar.
- Now-a-days, concrete gravity dams are prefered, because they can be easily constructed by laying concrete layer by layer with construction joints.

- But good rocky foundation must be available to bear the endremous weight of the dam. the distance between the heel and toe is ~~constructed~~ considered as the base width.
- It depends, on the height of the dam. Again, the height depends on the nature of foundation. If good rocky foundation is available, the height may be have 200 m.
- If hard foundation is not available, the height of the dam should be limited to about 20m.
- The upstream and downstream base of the dam is made sloping. the horizontal trace (or line) passing through the upstream top edge is known as axis of the dam or the base line.
- They the layout of the dam is done corresponding to this base line. Drainage gallery is provided at the base of the dam.
- Spillways are provided at the full reservoir level to allow the surplus water to flow to the downstream. the solid gravity dam resists all the forces acting on it by its self weight.



Solid gravity dam

★ Arch DAM:—
A dam which is constructed in the form of an arch supported an abutments is called the arch dam. It transfers the major water pressure to the abouteements by the arch action. A part of the water pressure is transferred to the foundation by cantilever action.
The arch dam may be constructed in masonry or concrete. The abutments of the arch should be very strong because the major thrust developed by the water pressure is carried by it. The arch dam is suitable for 'V-shaped' valley.

★ Buttress dam:—
It behaves like a retaining wall. It consists of sloping deck on the upstream side which is supported by a number of buttress in the form of triangular reinforced concrete wall or counterforts. It resists the forces acting on it by the buttresses.

★ Embankment dam:—
It is non rigid dam constructed simply by earth work in trapezoidal section. Sometimes, it may be of earth work with clay core wall or rock fill. It resists forces acting on it by its shear strength.

C Based on function:—

1. Storage dam:—
It is constructed to form a reservoir in which the water is stored during the period of rainy season or flood and

utilised for the irrigation in the period of draught. The water is also utilised for the generation of hydroelectric power, water supply etc.

2. Detention dam:—

It is mainly constructed to detain the flood water temporarily in a reservoir and then released gradually so that the downstream area may not be damaged due to sudden flood water.

3. Diversion dam:—

It is constructed to divert the water from a perennial river to a channel for the purpose of irrigation or to a conduit for the purpose of generation of hydroelectric power.

4. Coffer dam:—

When an area in the river bed is enclosed temporarily by sheet piling for excluding water for the sake of construction of well foundation. (i.e, Pier foundation) then it is known as coffer dam.

D. Based on Hydraulic Behaviour:—

1. Over flow dam:—

The dam which consists of crest shutters or waste weirs on the top to allow the surplus water to over flow, is known as overflow dam.

2. Non overflow dam:—

The dam in which spillways are provided to discharge the surplus water and the water is not allowed to flow over the crest, is known as non-overflow dam.

Causes of failure of Gravity Dam:—

1. **By over turning:—**

The solid gravity dam may fail by over turning at its toe when the total horizontal forces acting on the dam are greater than the total vertical force (i.e. its self weight). In such a case, the resultant force passes through a point outside the middle-third of the base of the dam. The overturning may be caused at the down-stream edge of any horizontal section.

2. **By sliding:—**

The total horizontal forces acting on a dam tend to slide the entire dam at its base or along any horizontal section of the dam. The sliding may take place when the total horizontal forces acting on the dam are greater than the combined resistance offered by shearing resistance of the joint and the static friction.

3. **By Over stressing:—**

If the permissible working compressive stress of concrete or masonry exceeds due to some adverse conditions, then the dam may fail by crushing due to overstressing of the concrete or masonry.

4. **By cracking:—**

The tensile stresses should not be allowed to develop on the upstream face of the dam. If due to some reasons, the tension is developed in the dam section, crack will form in the body of the dam and ultimately this will cause the failure of the dam.

Precautions against failure:—

To avoid failure of the dam, the following precautions should be taken while designing the dam section.

1. To avoid overturning, the resultant of all forces acting on the dam should remain within the middle-third of the base width of the dam. This condition should be achieved in both the cases, when the reservoir is full and also when it is empty.
2. In the dam, the sliding should be fully resisted when the condition for no sliding exists in the dam section.

   The condition for no sliding is given by

   $$\tan\theta = \frac{\Sigma P}{\Sigma W}$$

   and $\tan\theta < \mu$.

   where, ΣP, sum of horizontal forces, ΣW = sum of vertical forces, μ = coefficient of friction of the materials of dam.
3. In the dam section, the compressive stresses of concrete or masonry should not exceed the permissible working stresses to avoid failure due to crushing.
4. There should be no tension in the dam section to avoid the formation of cracks. This condition may be achieved by maintaining the middle-third rule.
5. The factor of safety should be taken 4 to 5.

Spillways

Necessity of spillways:

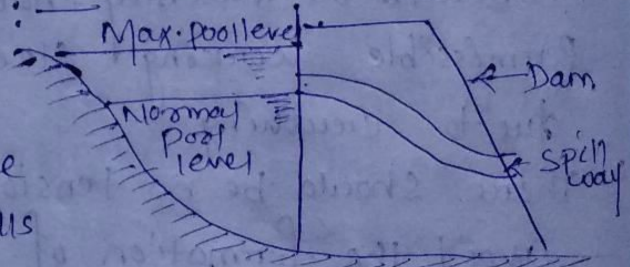
The spillways are openings provided at the body of the dam to discharge safely the excess water or flood water when the water level rises above the normal pool level.

The spillways are provided on the dam for the following reasons.

(a) The height of the dam is always fixed according to the maximum reservoir capacity. The normal ~~reservoir~~ pool level indicates the maximum capacity of the reservoir. The water is never stored in the reservoir above this level. The dam may fail by over turning so, for the safety of the dam the spillways are essential.

(c) To protect the downstream base and floor or the dam from the effect of scouring and erosion, the spillways are provided so that the excess water ~~form~~ flows smoothly.

Types of spillway:—



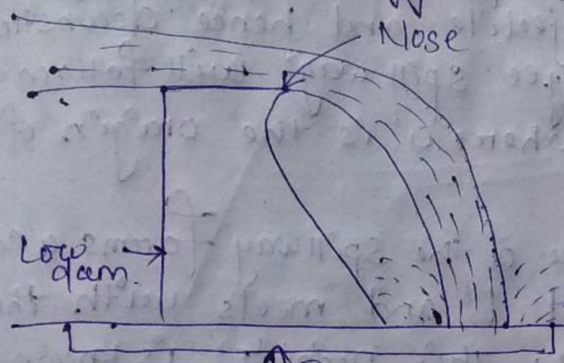
(Spillway)

Drop Spillway:—

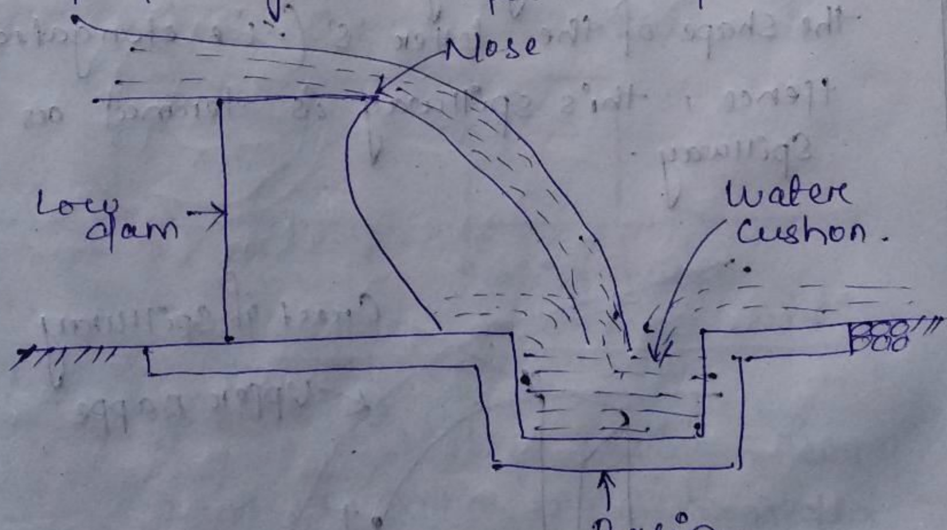
In drop spillway, the flowing water falls freely and almost vertically on the down stream side of the hydraulic structure. This type of spill way is suitable for weirs or low dams. The crest of the spill way is provided with nose so that the water jet may not strike the down stream base of the structure.

To protect the structure from the effect of scouring horizontal impervious apron should be provided on the downstream side.

Sometimes a basin is constructed on the downstream side to form a small artificial pool which is known as water cushion. This cushion serves the purpose of energy dissipator.



(a) Drop Spillway with impervious apron.



(b) Drop spillway with water cushion.

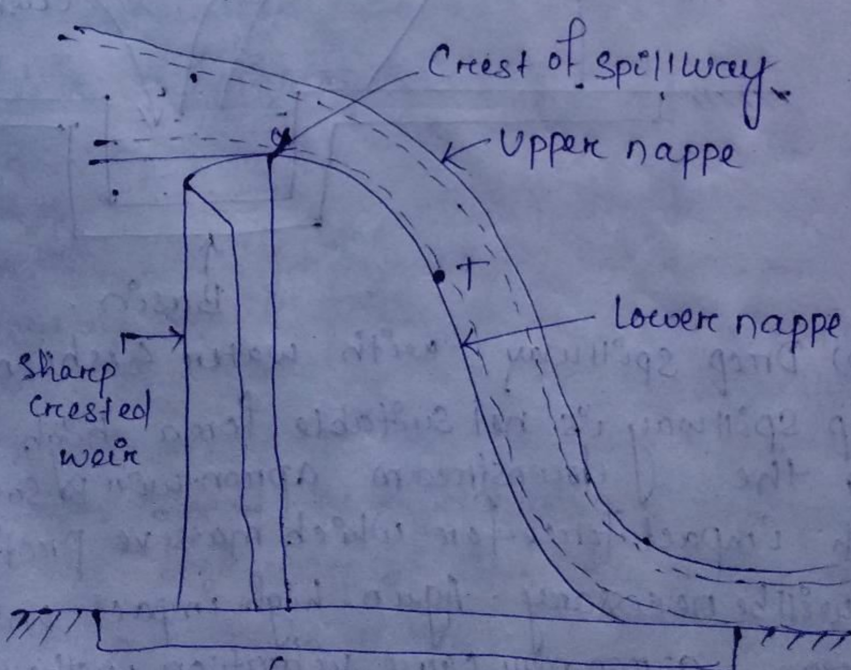
The drop spillway is not suitable for a high dam, because the downstream apron will be subjected to high impact force for which massive protection works will be necessary. Again, high impact on the downstream apron may cause vibration in the structure which may create cracks in the foundation. Thus, the stability of the structure will be in danger due to undermining.

Ogee spillway:—

It is a modified form of drop spillway. Here, the downstream profile of the spillway is made to coincide with the shape of the lower nappe of the free falling waterjet from a sharp crested weir.

In this case, the shape of the lower nappe is similar to a projectile and hence downstream surface of the oggee spill way will follow the parabolic path where 'O' is the origin of the parabolla.

The downstream face of the spillway forms a concave curve from a point 'T' and meets with the downstream floor. This point 'T' is known as point of tangency. Thus the spillway takes the shape of the letter 'S' (i.e elongated form). Hence, this spillway is termed as ogee spillway.



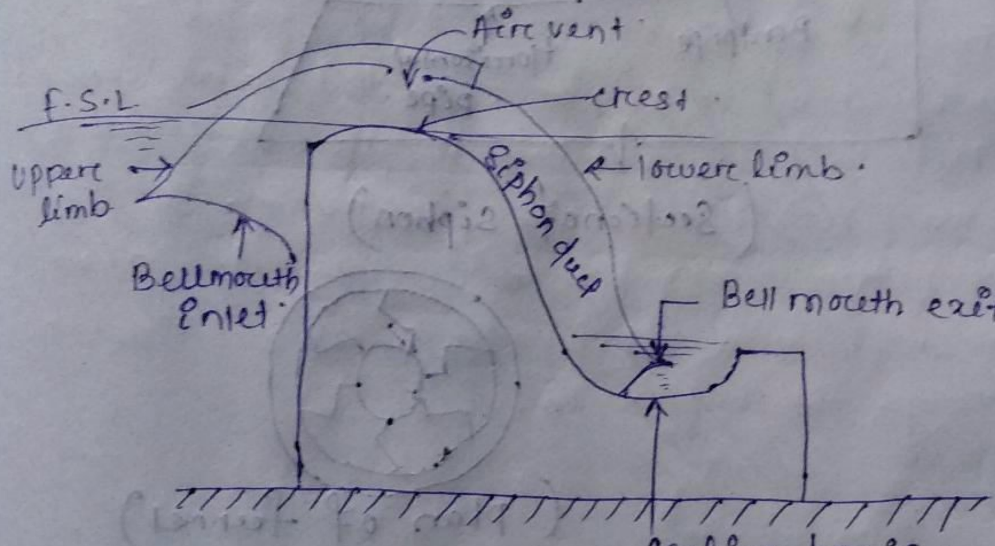
(oggee spellway)

Siphon spillway :—

The spill way which acts on the principle of siphon is known as siphon spillway. the siphon spill way may be of two types.

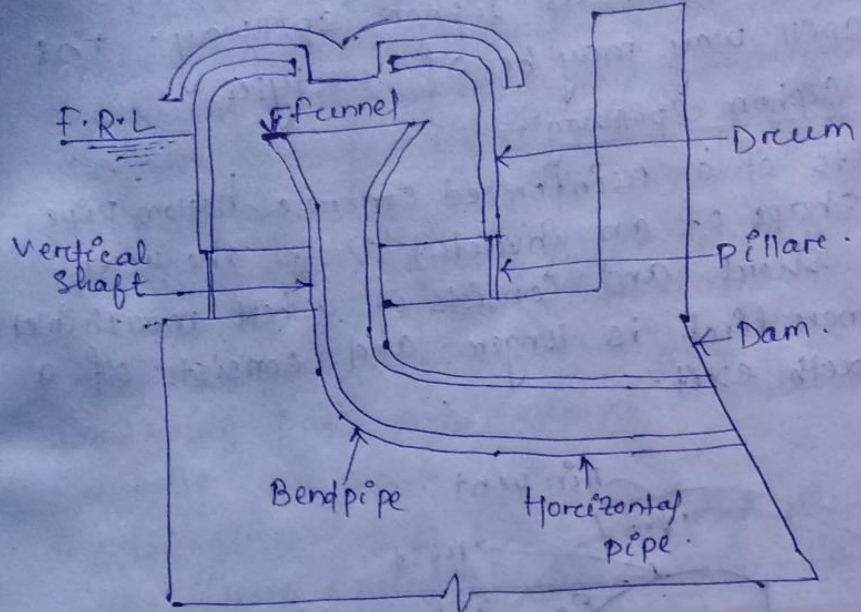
(a) Saddle Siphon Spillway :—

It consists of a reinforced concrete hollow pipe in the shape of an inverted 'U'. The upper limb is short and consists of a bell mouth inlet. The lower limb is longer and, consists of a bell mouth exit.



(b) Volute siphon spillway :—

It consists of a vertical shaft having a funnel at the top end and the bottom end is connected to a bend pipe. The bend pipe again, is connected to a horizontal pipe which carries the flowing water away from the base of the dam. The top level of the funnel is kept just at the full reservoir level. The funnel consists of several volutes. (Curved vanes or blades) ;

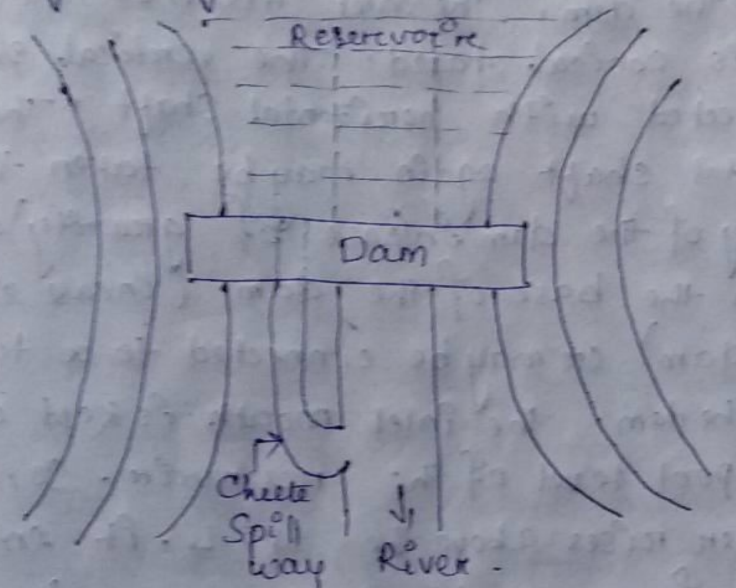


(Section of siphon)

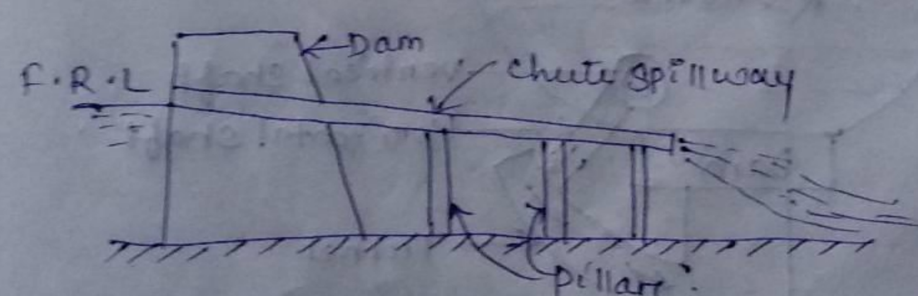
(plan of funnel)

Chute or Trough spill way :—

This spillway is simply a rectangular open channel (known as chute) provide on the dam to discharge the surplus water from the reservoir to the same river on the downstream side. the spillway may be provided along the abutement of the dam or along the edge of the reservoir at the full supply level. the chute is constructed by joining pre-cast R.C.C. channels in a longitudinal slope of 1 in 4 or 1 in 6. The channels are supported on pillars. The section of the channel is designed according to the volume of surplus water or flood discharge this spill way may be provided at one side or both sides of the dam. Apron should be provided at the downstream end of the chute. the apron is made of boulder pitching with cement grouting.



(a) (Position)

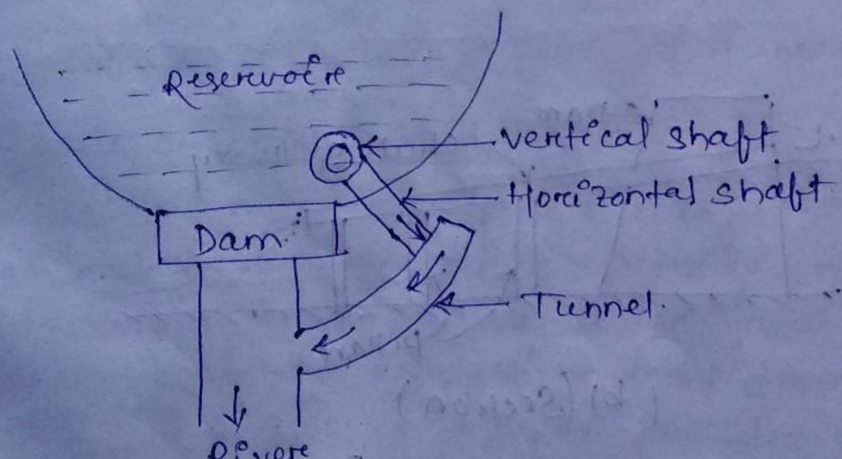


(b) (Section)

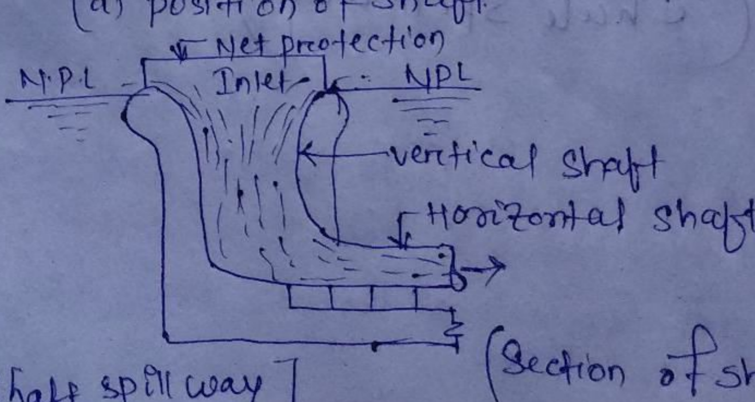
(Chute spill way)

Shaft spill way :—

• It consists of a vertical shaft which is constructed with masonry work or plain cement concrete or reinforced cement concrete on the bed of the reservoir just at the upstream side of the dam. The inlet mouth of the vertical shaft is conical shaped. the vertical shaft is connected with horizontal shaft. The horizontal shaft again may be taken through the body of the dam in (case of gravity) dam or through the base of the dam. (incase of earthen dam) or may be connected to a tunnel outside the dam. the inlet mouth is kept at the normal pool level of the reservoir. So, when the water rises above the N.P.L. it enters the shaft from all directions and flows out through the shaft.



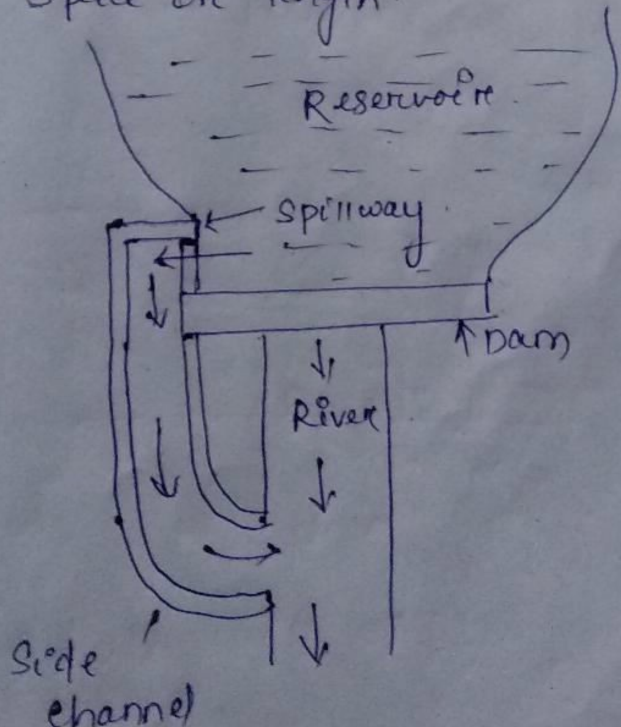
(a) position of shaft



[Shaft spill way] (Section of shaft)

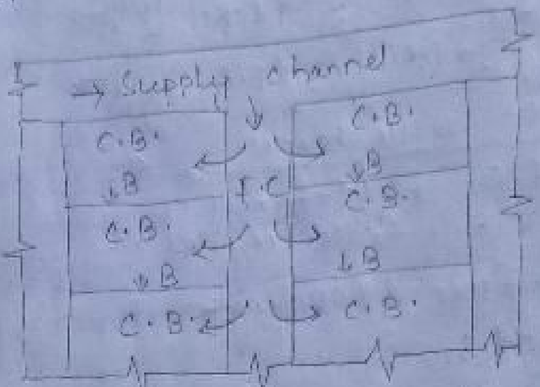
Side channel spill way:—

The side channel spill way is completely sp separate from the main body of the dam. The spill way is constructed at right angle to the dam and at any side according to the site condition. The crest of the spill way is kept at the normal pool level of the reservoir. When the water rises above the normal pool level, it spills over the crest of the spill way and flows through the side channel and ultimately meets the same river on the down stream side. This type of spill way is recommended for the sites where other type of spill ways are found unsuitable. The side walls of the channel may be constructed with brick masonry or stone masonry. The longitudinal slope of the channel depends on the available space or length.



(Side channel spill way)

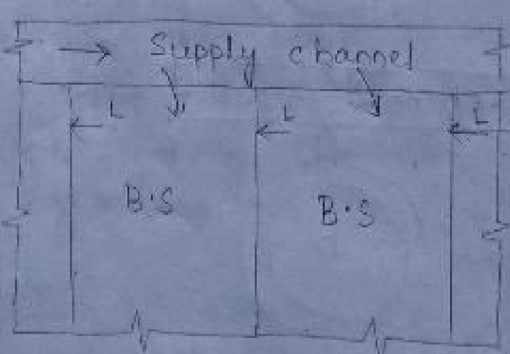
Each basin is flooded with water to the desired depth and the water is retained for some hours so that it can infiltrate in to soil.



=Check flooding=

(d) Border strips:-

In this method, the agricultural area is divided into series of long narrow strips (Known as Border strips) by levees, i.e small bunds. The strips are aligned along the country slope so that the water can flow easily throughout the area. This method is suitable when the area is at level with gentle country slope.

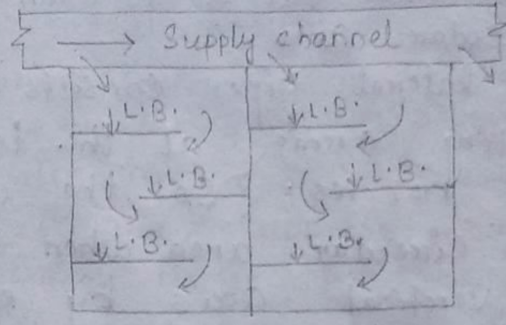


B.S = Border strips

L = Levees.

Zig-Zag method:

(e) In this method, the agricultural area is sub-divided in to small plots by low bunds in a zig-zag manner. The water is supplied to the plots from the field channel through the openings. The water flows in a zig-zag [...] over the entire area. When the desired depth is attained, the openings are closed.

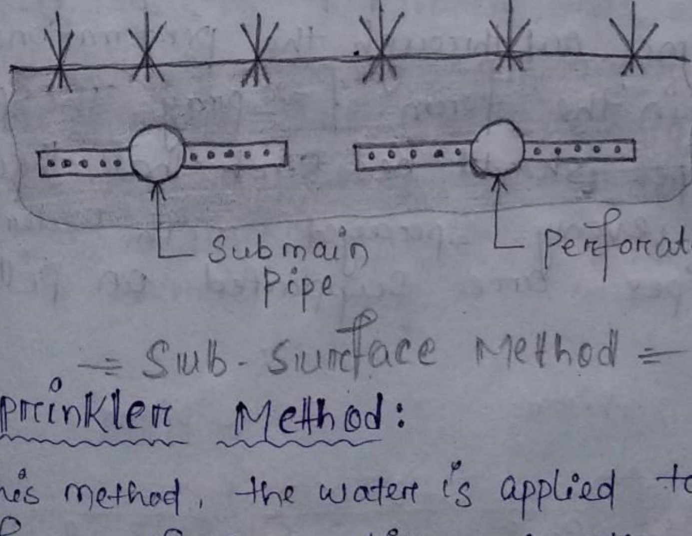


L.B. = Low bunds.

Zig-zag method.

(II) Sub-surface Method:

In this method the water is applied to the root zone of the crops by a underground network of pipes. The network consists of main pipe, sub-main pipes, and lateral perforated pipes. the perforated pipes allow the water to drip out slowly and thus the soil below the root zone of the crops absorbs water continously. This method is suitable for permeable soil like sandy soil. This method is also known as drip method or trickle method of irrigation.



= Sub-surface Method =

III) Sprinkler Method:

In this method, the water is applied to the land in the form of spray like rain. The spraying of water is achieved by the network of mainpipe, Submain pipes and lateral pipes.
The lateral pipes may be perforated at the top and sides through which the water comes out in the form of spray and spreads over the crop in a particular area.

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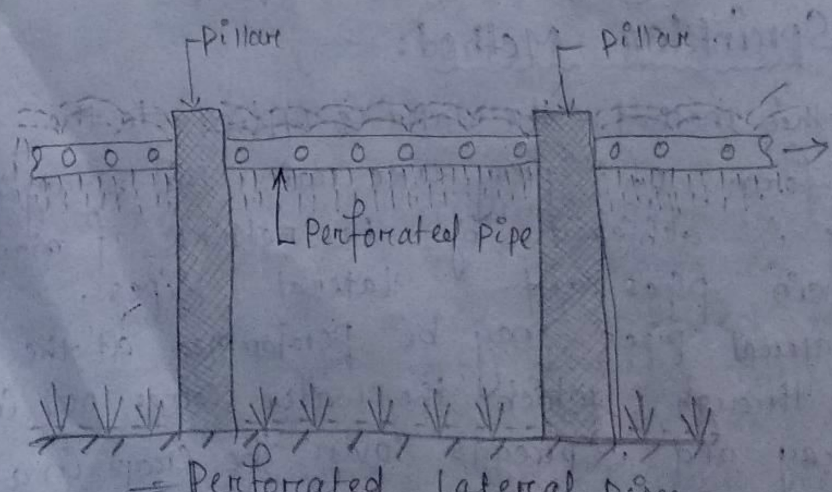
Again, the lateral pipes may contain series of nozzles through which the water comes out as fountain & spreads over in a particular area.

Now-a-days, the lateral pipes consists of riser pipes with rotating arms at the top. the arms are fitted with nozzles. So, the water gets distributed on a circular area when the arms are rotated on the vertical axis by electrical motor coupled with belt and pulley system. The network of pipe lines are supported on pillars and the water is forced through the pipe lines by pumping unit. The following are different forms of sprinklers.

(a) perforation on lateral pipes.
(b) fixed nozzles on lateral pipes.
(c) Rotating sprinklers.

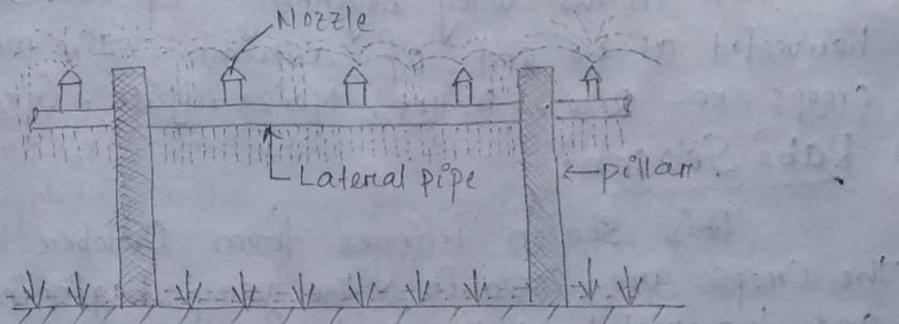
(a) Perforation on Lateral pipes:-

In this type, the lateral pipes are perforated along the top and sides. The water is sent under pressure by a pumping unit through the main pipe, sub-main pipes and lateral pipes. The water comes out through the perforations in all directions in the form of spray. The spacing of lateral pipes should be such that the whole area may be evenly sprayed with water. The Lateral pipes are supported on pillars.



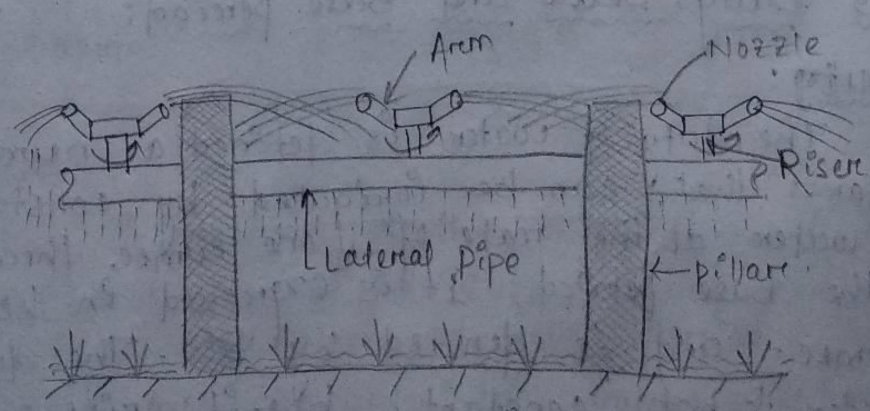
Perforated Lateral pipes

(b) Fixed Nozzles on Lateral pipes:
In this type, a series of nozzles are fixed along the lateral pipes. The spacings of the nozzles are such that the water may cover the whole area evenly. The lateral pipes are supported on pillars. When the water is forced under pressure through the network of pipes, it comes out as fountain through the nozzles and spreads over the land.



= fixed nozzles =

(c) Rotating sprinkless:
In this type, the riser pipes are fixed on the lateral pipes at a reglular intervals. On the top of the riser pipe are two arms which can rotate about a vertical axis. The upper ends of the arms consists of nozzles. When the water is forced under pressure through the main, submain and lateral pipes, it rises up and comes out through the nozzles in the form of spray. As the arms rotate, a circular area is covered by each riser.



= Rotary sprinklers =

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2.2 Crop Season:

The period during which some particular types of crops can be grown every year on the same land is known as crop season. The following are the main crop seasons.

(a) **Kharif Season:**

This season ranges from June to October. The crops are sown in the very beginning of monsoon and harvested at the end of autumn. The major Kharif crops are- Rice, Millet, Maize, Jute, Groundnut, etc.

(b) **Rabi Season:**

This season ranges from October to March. The crops are sown in the very beginning of winter and harvested at the end of spring. The major Rabi crops are- wheat, Gram, Mustard, Rapeseed, Linseed, pulses, Onion, etc.

Again there are several crops which are not included in Kharif and Rabi as they require more time and they cover both the main seasons. As for example, cotton requires eight months to mature and sugarcane requires about whole year to mature. Hence, they are designated as follows,

(i) Cotton - eight month's crop.
(ii) Sugarcan - perennial crop.

2.3 Duty, Delta and Base period:

Duty:

The duty of water is defined as number of hectares that can be irrigated by constant supply of water at the rate of one cumec throughout the base period. It is expressed in hectares/cumec and is denoted by 'D'. The duty of water is not constant, but it varies with various factors like soil condition, method of ploughing, method of application of water, etc. The duties of some common crops are given in the below table.

Crop	Duty in hectares/Cumec
Rice	900
Wheat	1800
Cotton	1400
Sugar cane	800.

Delta:

Each crop requires certain amount of water per hectare for its maturity. If the total amount of water supplied to the crop (from first to last watering) is stored on the land without any loss, then there will be a thick layer of water standing on that land. This depth of water layer is known as Delta for the crop. It is denoted by 'Δ' and expressed in cm. Delta for some crops is given in the below table.

Kharif crop	Delta in cm
Rice	125
maize	45
Ground nut	30
millet	30
Rabi crop	**Delta in cm**
wheat	40
Mustard	45
Gram	30
patato	75

Base period:

The base is defined as the period from the first to the last watering of the crop just before its maturity. It is also known as base period. It is denoted as 'B' and expressed in number of days., The base period for some common crop is given below.

Crop	Base in days
Rice	120
wheat	120
Maize	100
Cotton	200
Sugarcane	320

Relation Between Baseperiod, Delta and Duty:-

Let, D = Duty of water in hectares / cumec.
B = Base in days.
Δ = Delta in m.

from the definition, one cumec of water flowing continously for 'B' days gives a depth of water Δ over an area 'D' hectares. that is,

1 cumec for B days gives Δ over D hectare

or, 1 cumec for 1 days gives Δ over $\frac{D}{B}$ hectares

or, 1 cumec for 1 day = $\frac{D}{B} \times \Delta$ hectare-meter

So, 1 cumec-day = $\frac{D}{B} \times \Delta$ hectare meter ——— (1)

Again 1 cumec-day = $1 \times 24 \times 60 \times 60 = 86400 \ m^3$

= 8.64 hectare-meter ——— (2)

(1 hectare = 10,000 m^2)

from, equation (1) & (2)

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

$$\therefore \boxed{\Delta = \frac{8.64 \times B}{D} = \text{in m.}}$$

Definition of important terms:

1. **Gross Command Area (G.C.A):**

The whole area enclosed between an imaginary boundary line which can be included in an irrigation project for supplying water to agricultural land by the network of canals is known as Gross command area (G.C.A). It includes both culturable and unculturable areas.

2. **Unculturable Area:**

The area where the agriculture cannot be done and crops cannot be grown is known as unculturable area. The marshy land, barren lands, lakes, ponds, forests, villages etc. are considered as unculturable area.

3. **Culturable Area:**

The area where the agriculture can be done satisfactorily is known as culturable area.

4. **Culturable Command Area (C.C.A):**

The total area within an irrigation project where the cultivation can be done and crops can be grown is known as culturable command area (C.C.A). Again C.C.A may be of two catagories.

(a) **Culturable Cultivated Area:**—

It is the area within CCA where the cultivation has been actually done at present.

(b) **Culturable Uncultivated Area:**—

It is the area within the C.C.A where cultivation is possible but it is not being cultivated at present due to some reason.

5. **Intensity of irrigation:**—

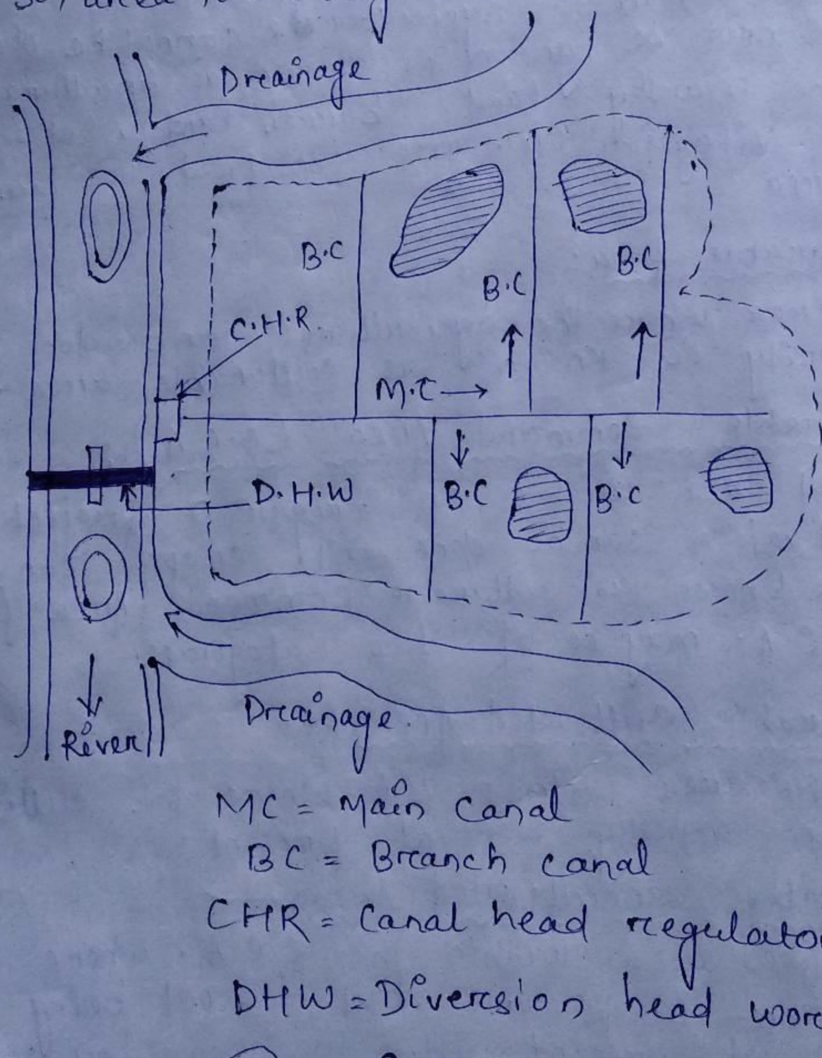
The total culturable command area may not be cultivated at the same time in a year due to various reason. Some area may remain vacant every year. Again, various crops may be

6

Cultivated in the Culturable command area. So, the intensity of irrigation may be defined as a ratio of cultivated land for a particular crop to the total culturable command area. It is expressed as a percentage of C.C.A. for example If total culturable command area is 1000 hectares where wheat is cultivated in 250 hectares, then

Intensity of irrigation for that wheat $= \frac{250}{1000} \times 100$
$= 25\%$

So, area to be irrigated = CCA x Intensity of irrigation



MC = Main Canal
BC = Branch canal
CHR = Canal head regulator
DHW = Diversion head works.
○ = Culturable area
(hatched) = Unculturable area.
- - - - - = Gross command area.

= GCA =

6. Crop Ratio :-

It is defined as the ratio of the areas of two main crop seasons, e.g. Kharif and Rabi.

for example :-

If the area under Kharif crop is 2500 hectares and the area under Rabi crop is 5000 hectares then, crop ratio of Kharif to Rabi is 1:2.

(i.e. $C.R = \frac{2500}{5000} = 1:2$)

The crop ratio should be so selected that the discharge of the canal for supplying water to Kharif and Rabi may be nearly equal.

7. Cash crop :-

The crops which are cultivated by the farmers to sell in the market to meet their current financial requirements are known as cash crops. The crops like vegetables, fruits, etc, are considered as cash crops.

8. Crop rotation :-

The process of changing the type of crop for the cultivation on the same land is known as crop rotation. It is found that if same crop is cultivated on the same land every year, the fertility of the land gets reduced and the yield of crop also gradually reduces. This is so because the necessary salts required for the growth of a particular crop get exhausted. It is found by experiment that if the principle of crop rotation is practised, the fertility of the soil can be restored.

few crop rotation possible are —

(i) Rice - Gram.
(ii) Wheat - Millet - Gram.
(iii) Rice - Gram - Wheat.

10. Crop period:-
The crop period is defined as the total period from the time of sowing a crop to the time of harvesting it. That means, it is the period in which the crop remains in the field.

11. Overlap allowance:-
Sometimes a crop of one season may overlap the next crop season by a few days more which it requires to mature. During this period of overlaping the irrigation water is to be supplied simultaneously to the crops of both the seasons. Due to the extra demand of water during this period, the discharge of the canal has to be increased. So, for the purpose of canal design, a provision should be made for this extra demand. This provision is termed as overlap allowance. This is expressed in percentage.

12. Time factor:-
The ratio of the number of days the canal has actually been kept open to the number of days the canal was designed to remain open during the base period is known as Time factor.

for example:- A canal was designed to be kept open for 15 days, but it was practically kept open for 10 days for supplying water to the culturable area. Then the time factor is $\frac{10}{15}$.

So, Time factor = $\dfrac{\text{No. of days the canal practically kept open.}}{\text{No. of days the canal was designed to keep open.}}$

$$= \frac{\text{Actual discharge}}{\text{Designed discharge}}$$

12. Capacity factor:

Generally, a canal is designed for a maximum discharge capacity. But, actually it is not required that the canal runs to that maximum capacity all the time of the base period. So, the ratio of the average discharge to the maximum discharge (designed discharge) is known as capacity factor.

For example, a canal was designed for the maximum discharge of 50 cumec, but the average discharge is 40 cumec.

So, capacity factor $= \frac{40}{50} = 0.8$.

13. Number of watering:—

The total depth of water required by a crop is not supplied at one time. But, it is supplied over the base period by stages depending upon the requirement. The initial watering which is done on the land to provide moisture to the soil just before sowing any crop is known as paleo or paleva.

* The first watering is done when the crop has grown to about three centimetres. This watering is known as Kor watering and the period is known as Kor period. Subsequent watering is done at some regular intervals during the base period till the crop attains maturity.

The number of watering depends on the type of soil, base period, soil condition, climatic condition etc.

14. Cumec day:-
The quantity of water flowing continuously for one day at the rate of one cumec is known as cumec-day.

$$1 \text{ cumec-day} = \frac{1 m^3}{sec} \times 24 \times 60 \times 60 \text{ sec.}$$

$$= 24 \times 60 \times 60 \; m^3$$

$$= \frac{24 \times 60 \times 60}{10,000} \times 1 m$$

$$(1 \text{ hactare} = 10,000 m^2)$$

$$= 8.64 \text{ hactare-meter.}$$

15. Arid region:-
The area where the rainfall is very scanty and occurs irregularly and where the agriculture is not at all possible is known as arid region.

2.5 Factors Affecting Duty:—

1. Soil characteristics:—
If the soil of the canal bed is porous and coarse grained, it leads to more seepage loss and consequently low duty. If the soil is compacted and closed grained, the seepage loss will be less and the duty will be high.
If the agricultural land consists of sandy soil, the percolation loss will be high causing the duty to be low. If it consists of alluvial soil, the percolation loss will be less & the soil retains the moisture for longer period and consequently the duty will be high.

2. Climatic condition: —

when the atmospheric temperature of the command area becomes high, the evaporation loss is more and the duty becomes low and vice versa.

3. Rainfall: —

If the rainfall is sufficient during the crop period, less quantity of irrigation water shall be required and therefore the duty will be more and vice versa.

4. Base period: —

When the base period is longer, the water requirement will be more and the duty will be low & vice versa.

5. Types of crop: —

The water requirement of various crops are different. So, the duty varies from crop to crop.

6. Topography of Agricultural Land: —

If the agricultural land is uneven, the water requirement will be more and hence the duty will be low. If the land has slight slope, the duty will be high as water requirement is optimum. As the ground slope increases the duty decreases because there is wastage of water.

7. Methods of ploughing: —

Proper deep ploughing which is done by tractors requires overall less quantity of water and hence the duty is high. But, shallow ploughing with bullocks requires overall more quantity of water, and hence the duty is low.

8. Methods of irrigation:—
The duty of water is high in case of perennial irrigation system as compared to that in inundation irrigation system. It is so because in perennial irrigation system head regulator is used whereas in inundation system there is no regulator.

9. Water tax:—
If some tax is imposed on the basis of the volume of water consumption, the farmer will use the water economically, and thus the duty will be high.

2.6 Methods of Improving duty:—

1. Proper ploughing:—
Ploughing should be done properly and deeply so that the moisture retaining capacity of the soil is increased.

2. Method's of supplying water:—
The method of supplying water to the agricultural land should be decided according to the field and soil conditions. for example:
furrow method – for crop sown in rows.
Contour method – for hilly areas.
Basin method – for orchards.
flooding method – for plain lands.

3. Canal lining:—
To reduce percolation loss the canals should be lined according to site condition.

4. Transmission loss:—
To reduce transmission loss the canals should be taken close to the irrigable lands as far as possible.

5. Crop rotation:—

The principle of crop rotation should be adopted to increase the moisture retaining capacity and fertility of the soil.

6. Implementation of Tax:—

The water tax should be imposed on the basis of volume of water consumption.

* Numerical problems on Base, Delta and Duty:—

Q A channel is to be designed for irrigating 5000 hectares in Kharif crop and 4000 hectares in Rabi crop. The water requirement for Kharif and Rabi are 60 cm & 25 cm, respectively. The Kor period for Kharif is 3 weeks and for Rabi is 4 weeks. Determine the discharge of the channel for which it is to be designed.

Soln Using the relation.

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

Discharge for Kharif crop.

Here, $\Delta = 60cm = 0.6m.$

$B = 3 \text{ weeks} = 21 \text{ days}.$

$\therefore \text{Duty} = \frac{8.64 \times 21}{0.6} = 302.4$ hectares/cumec.

Area to be irrigated = 5000 hectares.

Required discharge of channel $= \frac{5000}{302.4} = 16.53$ cumec.

Discharge for Rabi crop.

Here, $\Delta = 25\text{ cm} = 0.25m.$

$B = 4 \text{ weeks} = 28 \text{ days}.$

$\therefore \text{Duty} = \frac{8.64 \times 28}{0.25} = 967.68$ hectares/cumec.

Area to be irrigated = 4000 hectares.
Required discharge of channel = $\frac{4000}{967.68}$
= 4.13 cumec.

So, the channel is to be designed for the maximum discharge of 16.53 cumec, because this discharge capacity of the channel will be able to supply water to both the seasons.

3. FLOW Irrigation :—

3.1 Canal irrigation :—

The irrigation system in which the water flows under gravity from the source to the agricultural land is known as flow irrigation. The flow irrigation involves,

(a) The construction of weir or barrage across a river (Known as diversion head work).
(b) The construction of dam across a river valley (to form a storage reservoir),
(c) the excavation of canal system (Network of canals to recover the command area.).

This type of irrigation is popular now-a-days because a vast area can be irrigated under this system. Some important projects (such as Bhakra Nangal project, Damodar valley project, etc). have been implemented in India to develop agriculture and to make the country self sufficient in food. The flow irrigation may be of two types, Inundation irrigation and perennial irrigation.

In inundation irrigation, the canals are excavated from the banks of the inundation river. The bed level of the canal is such that the water can flow in rainy season only when the water level in the river rises above the canal bed. The construction of hydraulic structures is not necessary in this system. There is no head regulator to control the flow of water through the canal. In this system water is not available throughout the year.

In Perennial irrigation either a weir or a barrage is constructed across the perennial river to raise the water level or a dam is constructed to form a storage reservoir. Then the canals is constructed from the source to the agricultural lands. Here, head regulator is constructed to control the flow of water through the canal. In this system, water is available throughout the year.

3.1.1 Types of canals:—

1. Based on Purpose:—

Based on the purpose of service, the canals are designated as:—

(a) irrigation canal
(b) Navigation canal
(c) Power canal
(d) feeder canal.

(a) Irrigation canal:—

The canal which is constructed to carry water from the source to the agricultural land for the purpose of irrigation is known as irrigation canal such as Bhakra canal, Rajasthan canal, etc.

(b) Navigation Canal:—
The canal which is constructed for the purpose of inland navigation is known as navigation canal. This type of canal is also utilised for irrigation such as Ganga - Bramhaputra navigation cum irrigation canal.

(c) Power Canal:—
The canal which is constructed to supply water with very high force to the hydroelectric power station for the purpose of moving turbine to generate electric power is known as power canal of hydel canal such as Nangal Hydel canal.

(d) feeder canal:—
The canal which is constructed to feed another canal or river for the purpose of irrigation or navigation is known as feeder canal such as farakka barrage feeder canal.

2. Based on Nature of supply:—
Based on the nature of supply, the canals are designated as:—
(a) Inundation canal
(b) Perennial Canal.

(a) Inundation canal:—
The canal which is excavated from the banks of the inundation river to carry water to the agricultural land in rainy season only when the river flows to its full capacity is known as inundation canal. No regulator is provided at the head of such canal.

The flow of water through the canal depends on the fluctuation of water level in the river. When the water level rises above the bed level of the canal the water starts flowing through the canal. When the water level falls below the bed level of the canal, the flow of water through the canal stops.

(b) Perennial canal :-

The canal which can supply water to the agricultural land throughout the year is known as perennial canal. This type of canal is taken from the upstream side of the diversion head works (weir or barrage) or from the storage reservoir with regulator at the head of the canal.

3. Based on Discharge:—

(a) main canal :-

The Large canal which is taken directly from the diversion headwork or from storage reservoir to supply water to the network of other small canals is known as main canal. The irrigation water is not directly supplied to the field from the main canal. The water is taken to the field through the branch canal, distributory channel and field channel. So the main canal is the backbone of the canal system.

(b) Branch canal :-

The branch canals are taken from either side of the main canal at suitable points so that the whole command area can be covered by the network. The discharge capacity of the branch canal is smaller than that of the main canal.

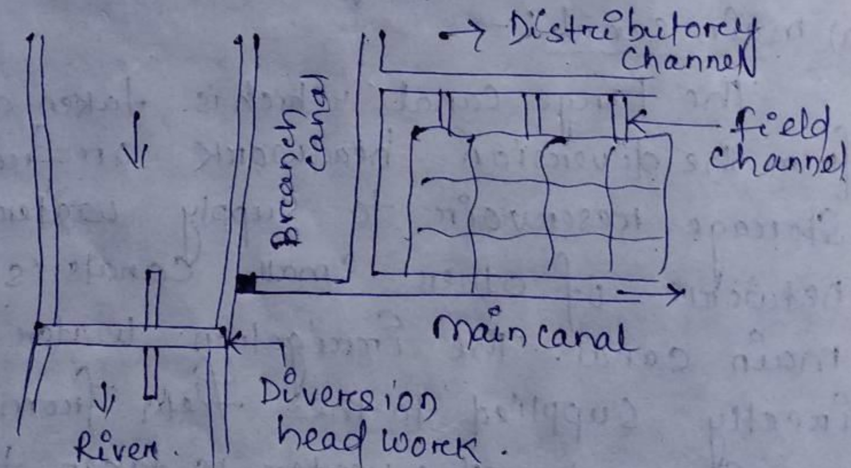
The discharge varies from 5 to 10 cumec.

(c) Distributory channels:—

The distributory channels are taken from the branch canals to supply water to different sectors. The discharge capacity of these channels varies from 0.25 to 3 cumec. Again, these are designated as major distributory and minor distributory according to their function in the total network.

(d) field channels:—

These are taken from the outlets of the distributory channels by the cultivators to supply water to their own lands. these channels are maintained by the cultivators.

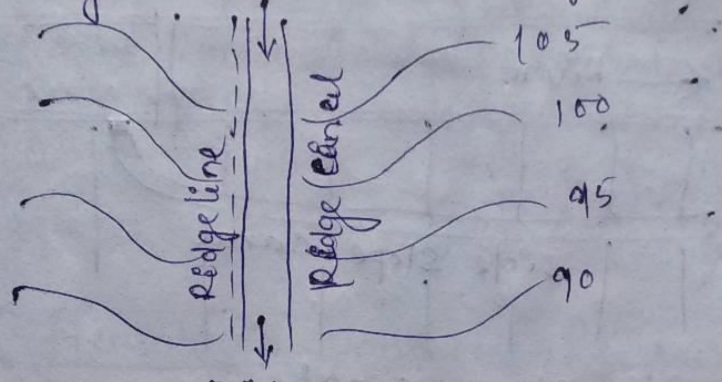


—: Canal System:—

4. Based on Alignment:—

a) Ridge or watershed canal:—

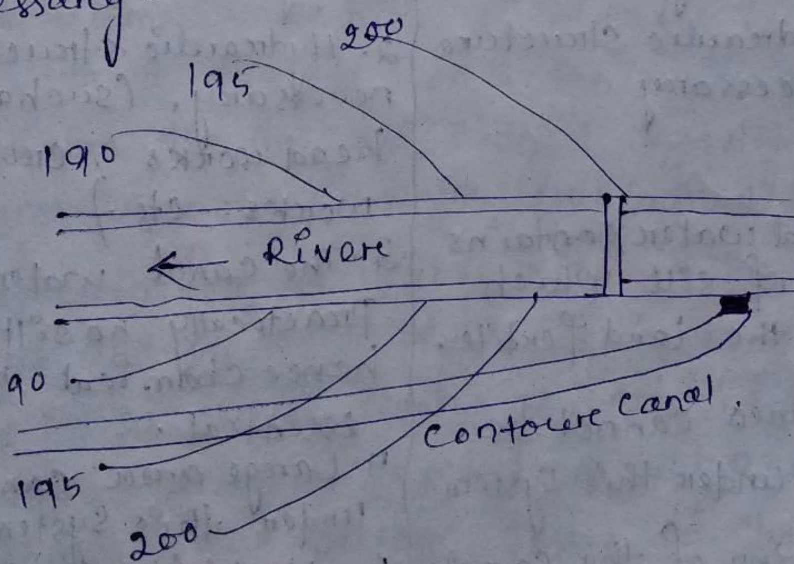
The canal which is aligned along the ridge line (watershed line) is known as ridge canal or watershed canal. the advantages of this type of canal is that it can irrigate the areas on both sides. Again there is no possibility of crossing any natural drainage and hence no cross-drainage work is necessary.



= Ridge canal =

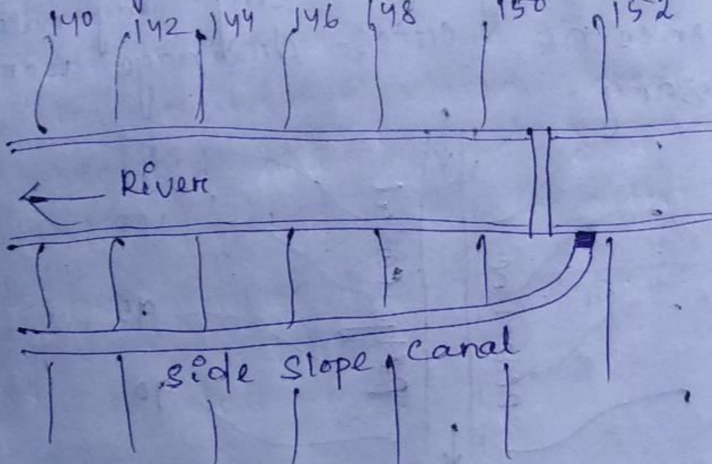
b) Contour Canal:—

the canal which is aligned approximately parallel to the contour lines is known as contour canal. this canal can irrigate the areas on one side only. this canal may cross natural drainage and hence cross-drainage works are necessary.



(c) Side slope canal:—

The canal which is aligned approximately at right angles to the contour lines is known as side slope canal. It can irrigates the area on one side only. Again, it does not cross any natural drainage and hence the cross drainage works are not necessary.



= Side slope canal =

Difference between Inundation and perennial irrigation:—

Inundation irrigation	Perennial irrigation
1. The irrigation water is available in rainy season only.	1. The irrigation water is available throughout the year.
2. No hydraulic structure is necessary.	2. Hydraulic structures are necessary. (Such as diversion head works, cross-drainage works. etc.)
3. The canal water contains plenty of silt which makes the land fertile.	3. The canal water contain practically no silt and hence chemical manure is essential.
4. Large area cannot be included under this system.	4. Large area can be included under this system.
5. The silting of the canal bed is a major problem.	5. Negligible silting takes place in the canal bed.
6. Water tax cannot be imposed.	6. Water tax can be imposed.
7. Initial cost is low.	7. Initial cost is high.

8. No technical persons are required for the operation of the irrigation system.	8. Technical persons are always required for the operation of the irrigation system.
9. The main canal is not provided with regulator and hence there is a possibility of over irrigation.	9. The main canal is provided with head regulator and hence there is no possibility of over irrigation.

2.3 Different Components of irrigation canals and their functions:-

Losses of water in canal:-

During the passage of water from the main canal to the outlet at the head of the water course, water may be lost either by evaporation from the surface or by seepage through the peripheries of the ~~canals~~ channels. these losses are sometimes very high, of the order of 25 to 50% of the water diverted into the main canal. In determining the designed channel capacity, a provision for these water losses must be made. The provision for the water lost in the water-courses and in the fields is however, already made in the outlet discharge factor, and hence, no extra provision is made on that account. Evaporation and seepage losses of channels are discussed below:

(1) Evaporation:—

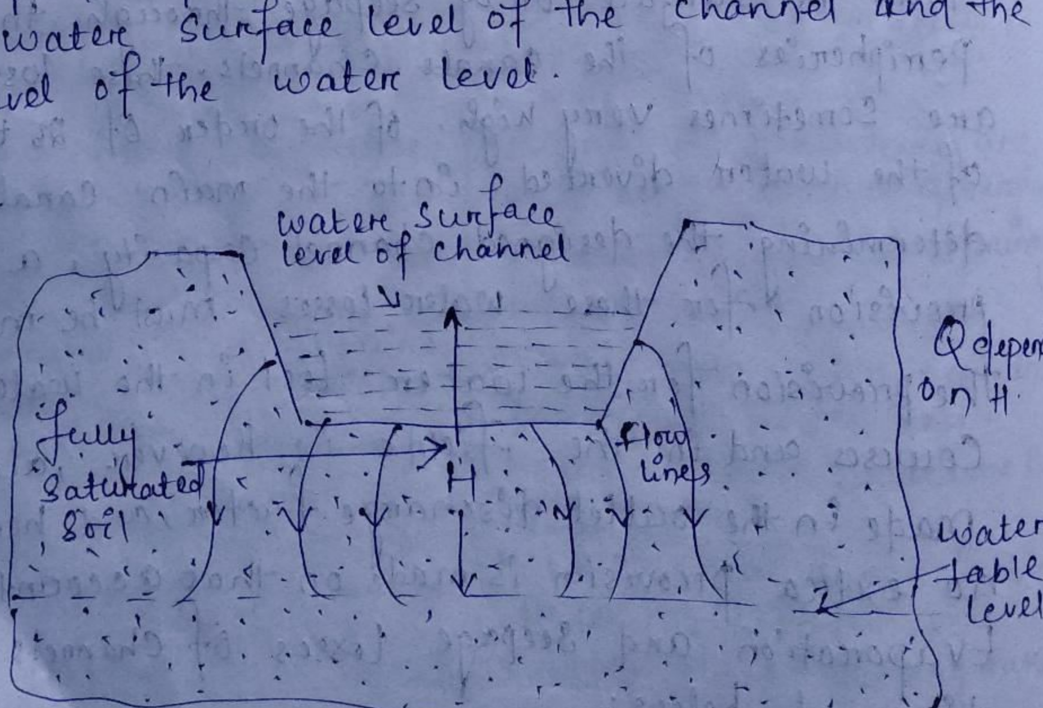
The water lost by evaporation is generally very small, as compared to the water lost by seepage in certain channels.

Evaporation losses, are generally of the order of 2 to 3% of the total losses. They depend upon all those factors on which the evaporation depends, such as temperature, wind velocity, humidity etc. In summer season, these losses may be more but shall not exceed about 7% of the total water diverted in to the main canal.

(2) Seepage: There may be two different conditions of seepage. (i) percolation
(ii) Absorption.

(i) Percolation:

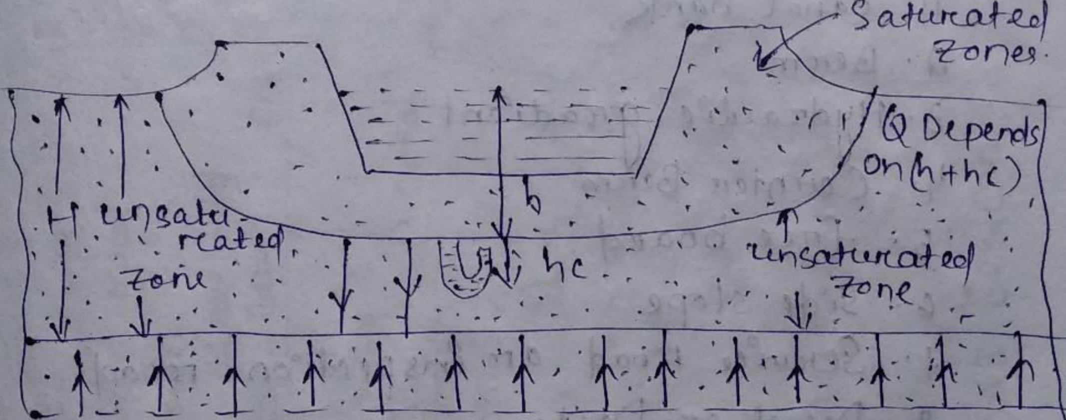
In percolation, there exists a zone of continuous saturation from the canal to the water table and a direct flow is established. Almost all the water lost from the canal, joins the ground water reservoir. The loss of water depends upon the difference of the top water surface level of the channel and the level of the water level.



= Percolation =

(ii) <u>Absorption:</u>

In absorption, a small saturated soil zone exists around the canal section, and is surrounded by zone of decreasing saturation. A certain zone just above the water table is saturated by capillarity. Thus, there exists an unsaturated soil zone between the two saturated zones. In this case, the rate of loss is independent of seepage Head (H) but depends only upon the water head 'h' (i.e distance between water surface level of canal and the bottom of the saturated zone) plus the capillary head 'hc'.



The seepage losses depends upon the following factors:

(i) Types of seepage, i.e whether 'percolation' or 'absorption'.

(ii) Soil permeability.

(iii) the condition of the canal; the seepage through a silted canal is less than that from a new canal.

(iv) Amount of silt carried by the canal; the more the silt, lesser are the losses.

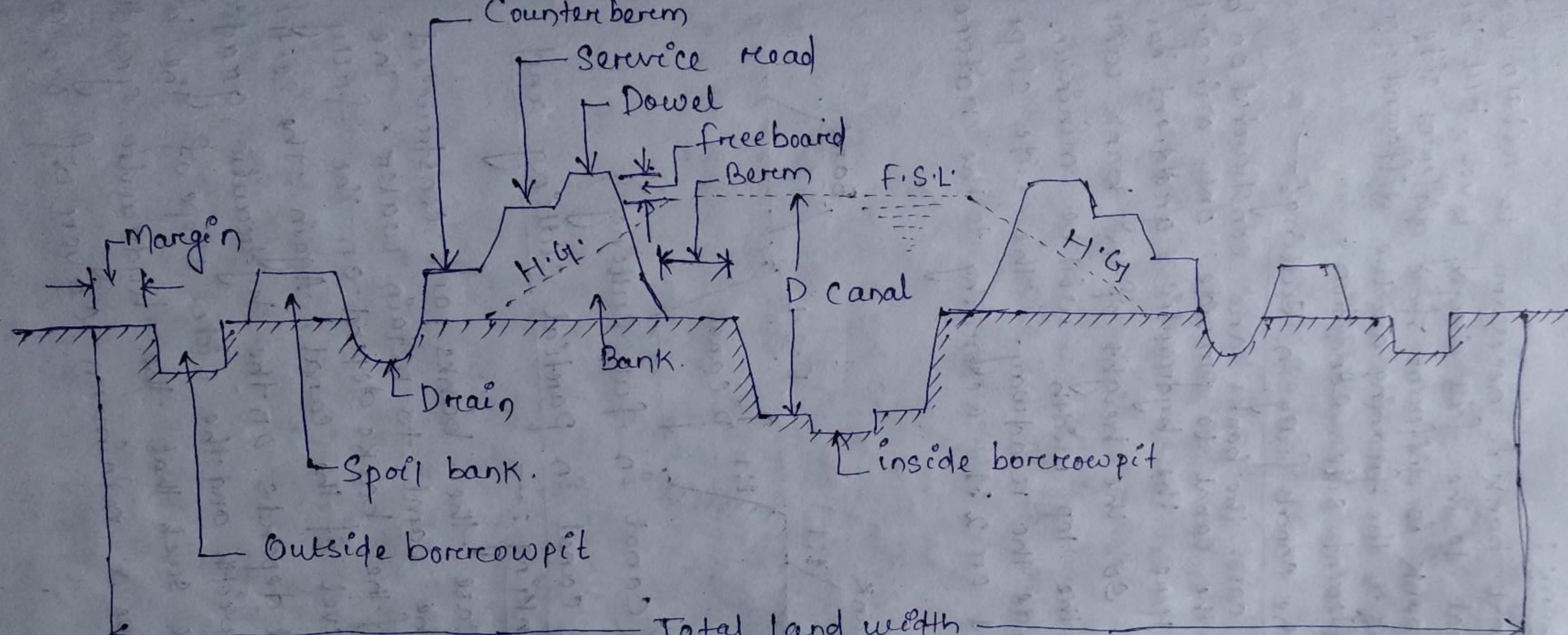
(v) Velocity of canal water; the more the velocity, the lesser will be the losses.

(vi) Cross-section of the canal & its wetted perimeter.

3.3 Different components of irrigation canals and their functions:—

The canal section may be in fully cutting or fully banking or partially cutting and partially banking according to the natural ground surface and the permissible bed slope of the canal. But there are several terms in the canal section with which a civil engineer should be acquainted to design the section and to execute the work. The following are the different terms related to the canal section.

1. Canal bank
2. Berm
3. Hydraulic gradient
4. Counter Berm
5. free board
6. Side slope
7. Service road or inspection road:
8. Dowel or Dowla
9. Borrow pit
10. Spoil bank
11. Land width.



F.S.L = full supply level
D = full supply depth.

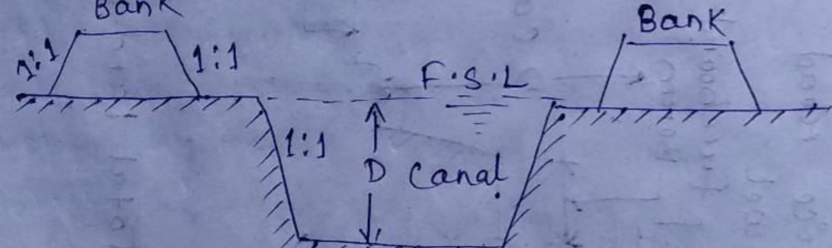
Canal Section.

(1.) Canal bank:

The canal bank is necessary to retain water in the canal to the full supply level. But the section of the bank is different for different site conditions. The following are the different forms for different side condition.

(a) When the canal fully in cutting:—

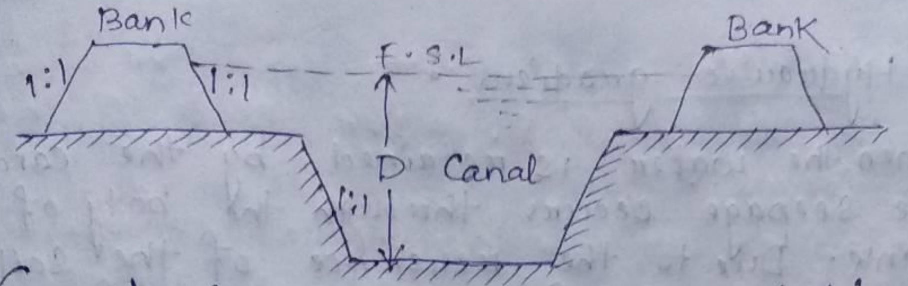
In this case, the banks are constructed on both sides of the canal to provide only a inspection road. Here, the hydraulic gradient has no function. So, the height of the bank will be low and the top width will be minimum just to provide the roadway. The side slope will be $1\frac{1}{2}:1$ or $2:1$ according to the nature of the soil.



(Canal in full cutting)

(b) When the canal in partial cutting and Banking:—

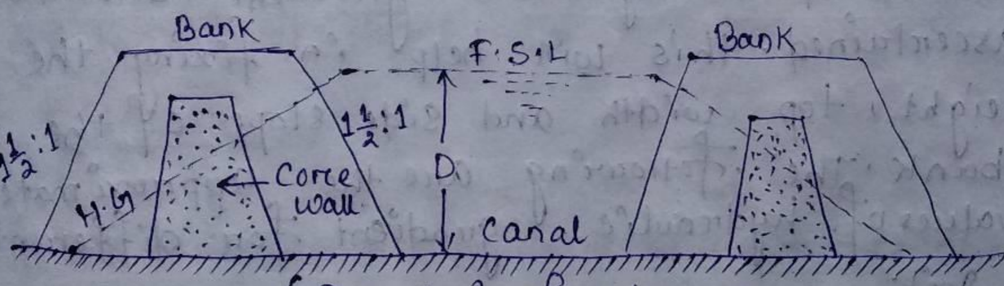
In this case, the banks are constructed on sides of the canal to retain water. The height of the banks depend on the fully supply level of the canal. Again, the section of the canal depends on the hydraulic gradient. The top width and the side slope of the bank should be such that the hydraulic gradient should have a minimum cover of 0.5 m.



(Canal in partial cutting and partial banking.)

(c) <u>When the canal in full banking</u> :-

In this case, the canal and both the canal banks are constructed above the ground level. The height of the bank will be high and its section will be large due to the hydraulic gradient. But to minimise the cross section of the bank a core wall of puddle clay is provided which deflects the hydraulic gradient down wards.



(Canal in full banking.)

(2) <u>Berm</u> :

The distance between the toe of the bank and the top edge of cutting is termed as berm. The berm is provided for the following reasons,

(a) To protect the bank from erosion.
(b) To provide a space for widening the canal section in future if necessary.
(c) To protect the bank from sliding down towards the canal section.
(d) The silt deposition on the berm makes an impervious lining.
(e) If necessary borrowpit can be excavated on the berm.

(3) Hydraulic gradient :—

when the water is retained by the canal bank, the seepage occurs through the body of the bank. Due to the resistance of the soil, the saturation line forms a sloping line which may pass through countryside of the bank. This sloping line is known as the hydraulic gradient or saturation gradient. The soil below this line is saturated, but the soil above this line is dry. The hydraulic gradient depends on the permeability of the soil. So, while constructing the bank, the soil should be tested in soil testing laboratory and the nature of the hydraulic gradient should be ascertained. This will help in fixing the height, top width and side slope of the bank. The following are the approximate values of hydraulic gradient for different soil.

Soil	H.G
Clayey soil	1:4
Alluvial soil	1:5
Sandy soil	1:6

(4) Counter berm:—

When the water is retained by a canal bank the hydraulic gradient line passes through the body of the bank. For stability of the bank, this gradient should not intersect the outer side of the bank. It should pass through the base and a minimum cover of 0.5 m should always be maintained.

Some times, it may occur that the hydraulic gradient line intersects the outer side of the bank. In that case, a projection is provided on the bank to obtain minimum cover. This projection is known as counter berm. The width of this berm depends on the site condition.

(5) Free board:—

It is the distance between the full supply level and top of the bank. the amount of free board varries from 0.6 m. to 0.75 m.

It is provided for the following reasons:—

(a) To keep a sufficient margin so that the canal water does not over lap the bank in case of heavy rainfall or fluctuation in water supply.

(b) To keep the saturation gradient much below the top of the bank.

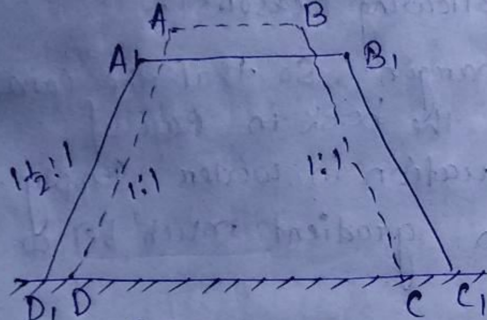
(6) Side slope:—

The side slopes of the canal bank and canal section depend on the angle of repose of the soil existing on the site. so; to determine the side slopes of different sections, the soil samples should be callected from the site and should be tested in the soil testing laboratory. The necessity of such test is that if the permissible slop (to maintain angle of repose) is not provided in an embankment or cutting, then the soil in that place will go on sliding gradually until the angle of repose for that particular soil is attained.

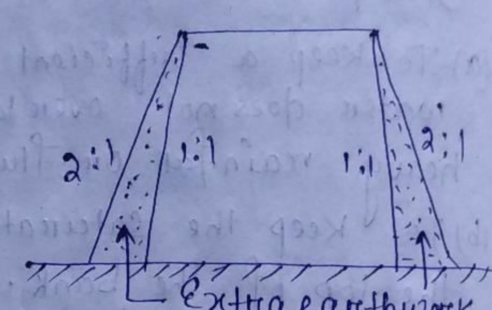
for instance, suppose an embankment was constructed with side slope 1:1 but according to the nature of the soil, the side slope should be $1\frac{1}{2}:1$. Then the initial shape

ABCD will automatically take the final shape A_1, B_1, C_1, D_1 after slide in the due course.

Again, an opposite incident may occur, suppose an embankment was constructed with side slope 2:1, but latter it was found that the side slope of 1:1 was sufficient to maintain the angle of repose for that soil. In this case, an unnecessary earthwork was done.



(Sliding of bank)



(Extra earth filling)

The permissible side slopes for some soil are given;

Types of soil	side slope in cutting	side slope in banking
Clayey soil	1:1	$1\frac{1}{2}:1$
Alluvial soil	1:1	2:1
Sandy loam	$1\frac{1}{2}:1$	2:1
Sandy Soil	2:1	3:1

(7) Service road:—

The road way which is provided on the top of the canal bank for inspection and maintenance works is known as service road or inspection road. for main canal, the service roads are provided on both the banks. But for branch canals, the road is provided on one bank only. The width of the service roads for main canal varies from 6m to 6m. the width of the road for the branch canal varies from 3 to 4m.

The initial purpose of the service road is to conduct inspection and maintenance works. But finally these roads serve the purpose of communication between the different villages and for transporting agricultural goods. therefore it becomes necessary to construct metalled road to serve these purposes.

(8) Dowel or Dowla:-

The protective small embankment which is provided on the canal side of the service road for the safety of the vehicles plying on it is known as dowel or dowla. practically it acts as a curb on the canal side of the road. It is provided above the F.S.L. with a provision of freeboard. The top width is generally 0.5 m and the height above the road level is about 0.5m. The side slope is similar to the side slope of the bank.

(9) Spoil Bank:

When the canal is constructed in full cutting, the excavated earth may not be completely required for forming the bank. In such a case, the extra earth is deposited in the form of small banks which are known as spoil banks. the spoil banks are provided on one side or both sides of the canal bank depending on the quantity of excess earth and the available space.

The spoil banks run parallel to the main bank. But are not continuous, sufficient spaces are left between the adjacent spoil banks for proper drainage.

(10) Borrowpit:—

when the canal is constructed in partial cutting and partial banking, the excavated earth may not be sufficient for forming the required bank. In such a case, the extra earth required for the construction of banks is taken from some pits which are known as borrowpits. The borrowpits may be inside or outside, the canal.

(11) Land width:—

The total Land with required for the construction of a canal depends on the nature of the site condition, such as fully in cutting or fully in banking or partly in cutting and partly in banking. These conditions arises according to the designed bed level of the canal and the natural ground surface. So, total land width differs with the site condition. However, to determine the total land width the following dimensions should be added.

1) Top width of the canal
2) Twice the berm width
3) Twice the bottom width of banks.
4) A margin of one metre from the heel of the bank on both sides.
5) Width of external borrowpit if any.
6) A margin of 0.5m from the outer edge of borrowpit on both sides, if external borrowpit becomes necessary.

8.4 Various types of Canal Lining :—

The following are the different types of linings which are generally recommended according to the various site condition.

1. Cement concrete lining
2. Precast concrete lining
3. Cement mortar lining
4. Lime concrete lining
5. Brick lining
6. Boulder lining
7. Shot crete lining
8. Asphalt lining
9. Bentonite and clay lining
10. Soil -cement lining.

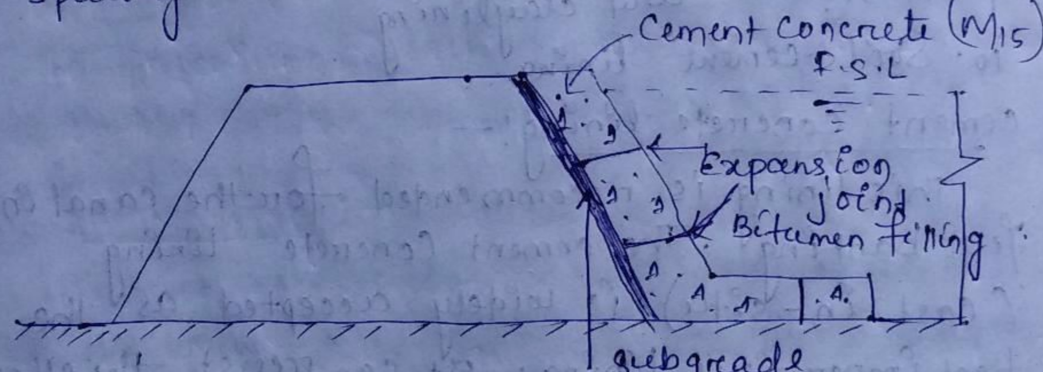
(1) Cement Concrete lining :—

This lining is recommended for the canal in full banking. The cement Concrete lining (cast-in-situ) is widely accepted as the best impervious lining. It can resist the effect of scouring and erosion very efficiently. The velocity of flow may be kept above 2.5 m/sec. It can eliminate completely growth of weeds. The lining is done by the following steps.

(a). Preparation of Sub grade :—

The ~~cement~~ sub-grade is prepared by ramming the surface properly with a layer of sand (about 15cm). Then, a slurry of cement and sand (1:3) is spread uniformly over the prepared bed.

(b) Laying of concrete:
The cement concrete of grade M15 is spread uniformly according to the desired thickness (generally, the thickness varies from 100mm to 150mm). After laying, the concrete is tapped gently until the slurry comes on the top. The curing is done for two weeks. As the concrete is liable to get damaged by the change of temperature, the expansion joints are provided at appropriate places. Normally no re-inforcement is required for this cement concrete. But in special cases, a network of 6mm diameter rods may be provided with spacing 10 cm centre to centre.



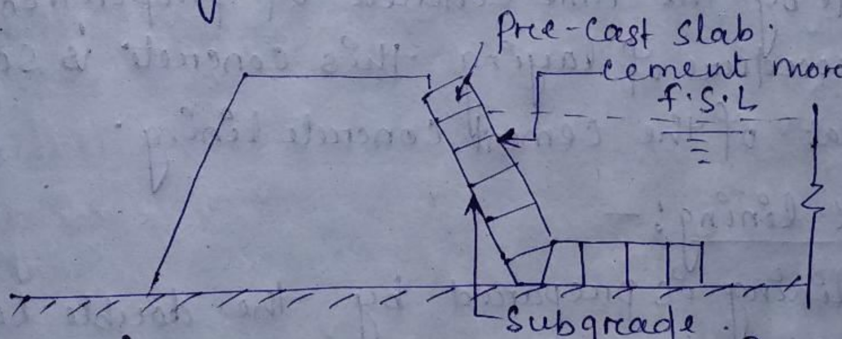
(2) Pre-cast Concrete Lining:
This lining is recommended for the canal in full banking. It consists of pre-cast concrete slab of size 60cm x 60cm x 5cm which are set along the canal bank and bed with cement mortar (1:6). A network of 6mm dia. rod is provided in the slab with spacing 10cm centre to centre. The proportion of the concrete is recommended as 1:2:4. Rebates are provided on all the four sides of the slab so that proper joints may be obtained when they are placed side by side.

the joints are finished with cement mortar (1:3). Expansion joints are provided at a suitable interval. The slabs are set in the following sequence.

(a) The subgrade is prepared by properly ramming the soil with a layer of sand. The bed is levelled so that the slabs can be placed easily.

(b) The slabs are stacked as per estimate along the course of the canal. The slabs are placed with cement mortar (1:6) by setting the rebates properly. The joints are finished with cement mortar (1:3).

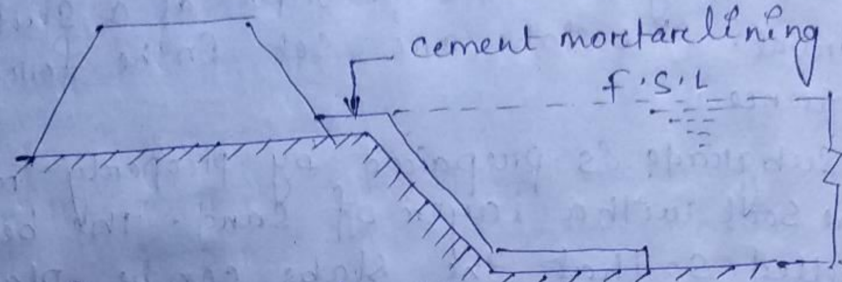
(c) The curing is done for a week.



(Pre cast Concrete Lining)

(3) <u>cement mortar lining</u>:—

This type of lining is recommended for the canal fully in cutting where hard soil or clayey soil is available. The thickness of the cement mortar (1:4) is generally 2.5 cm. The sub-grade is prepared by ramming the soil after cutting. Then, over the compacted sub-grade, the cement mortar is laid uniformly and the surface is finished with neat cement polish. This lining is impervious, but it is not durable. The curing should be done properly.



(Cement mortar lining)

(4) Lime concrete lining:-

when hydraulic lime, surki and brick ballast are available in plenty along the course of the canal or in the vicinity of the irrigation project, then the lining of the canal may be made by the lime concrete of proportion 1:1:6. the procedure of laying this concrete is same as that of the cement concrete lining.

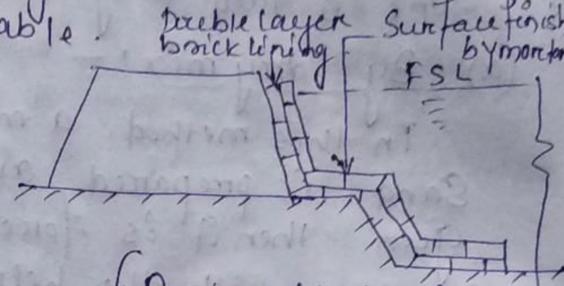
(5) Brick lining:-

This lining is prepared by the double layer brick flat soling laid with cement mortar (1:6) over the compacted sub-grade. the first class bricks should be recommended for the work. The surface of the lining is finished with cement plaster (1:3). The curing should be done properly.

This lining is always preferred for the following reasons.

(a) this lining is economical.
(b) Work can be done very quickly.
(c) Expansion joints are not required.
(d) Repair works can be done easily.
(e) Bricks can be manufactured from the excavated earth near the site.

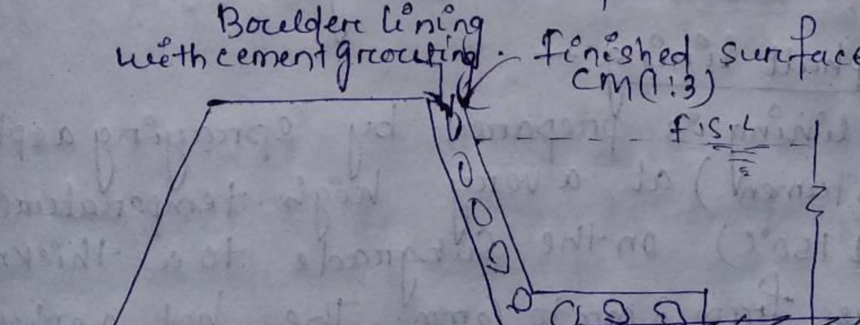
However this lining has certain disadvantages:—
(a) It is not completely impervious.
(b) It has low resistance against erosion.
(c) It is not so much durable.



(Brick lining)

(6) Boulder lining:

In hilly areas where the boulders are available in plenty, this type of lining is generally recommended. The boulders are laid in single or double layer maintaining the slope of the banks are the bed level of the canal. The joints of the boulders are grouted with cement mortar (1:6). The surface finished with cement mortar (1:3). Curing is necessary in this lining too. This lining is very durable and impervious. But the transporting cost of material is very high. So, it cannot be recommended for all cases.



(7) Shot crete lining:—

In this system, the cement mortar (1:4) is directly applied on the sub-grade by an equipment known as cement gun. The mortar is termed as shot crete and the lining is known as short crete lining. The process is also known as guniting, as a gun is used for laying the mortar. Sometimes, this lining is known as gunited lining. The lining is done in two ways.

(a) By dry mix! —

In this method, a mixture of cement and moist sand is prepared and loaded in the cement gun. Then it is forced through the nozzle of the gun with the help of compressed air. The mortar spreads over the subgrade to a thickness which varies from 2.5 cm to 5 cm.

(b) By wet mix! —

In this process, the mixture of cement, sand and water is prepared according to the approved consistency. The mixture is loaded in the gun and forced on the subgrade. This type of lining is very costly and it is not durable. It is suitable for resurfacing the old cement concrete lining.

(8) Asphalt lining! —

This lining is prepared by spraying asphalt (i.e bitumen) at a very high temperature (about 150°C) on the subgrade to a thickness varies from 3 mm to 6 mm. The hot asphalt when becomes cold forms a water proof membrane over the subgrade. This membrane is covered with a layer of earth and gravel. The lining is very cheap and can control the seepage of water very effectively but it cannot control the growth of weeds.

(9) Bentonite and clay lining:—

In this lining a mixture of bentonite and clay are mixed throughly to form a sticky mass. this mass is spread over the sub grade to form an impervious membrance which is effective in controlling the seepage of water, but it cannot control the growth of weeds. these linings is generally recommended for small channels.

(10) Soil - Cement lining:—

this lining is prepared with a mixture of soil and cement. the usual quantity of cement is 10 percent of the weight of dry soil. the soil and cement are thoroughly mixed to get an uniform texture. the mixture is laid on the subgrade and it is made thoroughly compact. The lining is efficient to control the seepage of water, but it cannot control the growth of weeds. so, this is recommended for small channels only.

• Advantages of canal lining:—

1. It reduces the loss of water due to seepage & hence the duty is enhanced.
2. It controls the water logging & hence the bad effects of water-logging are eliminated.
3. It provides smooth surface & hence the velocity of flow can be increased.
4. Due to the increased velocity the discharge capacity of a canal is also increased.
5. Due to the increased velocity, the evaporation loss also be reduced.
6. It eliminates the effect of scouring in the canal bed.

7. The increased velocity eliminates the possibility of silting in the canal bed.
8. It controls the growth of weeds along the canal sides and bed.
9. It provides the stable section of the canal.
10. It reduces the requirement of land width for the canal, because smaller section of the canal can produce greater discharge.
11. It prevents the sub-soil salt to come in contact with the canal water.
12. It reduces the maintenance cost for the canals.

Disadvantages:—

(1) The initial cost of the canal lining is very high. So it makes the project very expensive with respect to the output.
2. It involves much difficulties for repairing the damaged section of lining.
3. It takes too much time to complete the project work.
4. It becomes difficult, if the outlets are required to be shifted or new outlets are required to be provided, because the dismantling of the lined section is difficult.