HYDROSTATICS

Hydrostatic is that branch of science which relating to fluids at rest or to the pressures they exert or transmit **Hydrostatic Pressure**.

Fluid:-

Fluid is a substance that continuously deforms (flows) under an applied shear stress. Fluids are a subset of the phase of matter and include liquids, gases, plasmas and, to some extent, plastic solids. Fluids can be defined as substances which have zero shear modulus or in simpler terms a fluid is a substance which cannot resist any shear force applied to it.

- Fluid is a substance which is capable of flowing
- Conform the shape of the containing vessel
- Deform continuously under application of small shear force

1.1 PROPERTIES OF FLUID:-

Density:-

The density of a fluid, is generally designated by the Greek symbol $\rho(rho)$ is defined as the mass of the fluid over a unit volume of the fluid at standard temperature and pressure. It is expressed in the SI system as kg/m^3.

$$\rho = \lim \frac{\Delta m}{\Delta V} = \frac{dm}{dV}$$

If the fluid is assumed to be uniformly dense the formula may be simplified as:

$$\rho = \frac{m}{V}$$

Example: - setting of fine particles at the bottom of the container.

Specific Weight:-

The specific weight of a fluid is designated by the Greek symbol γ(gamma), and is generally defined as the weight per unit volume of the fluid at standard temperature and pressure. In SI systems the units is N/m^3.

$$\lambda = \rho * g$$

g = local acceleration of gravity and ρ = density

Note: It is customary to use:

$g = 32.174$ ft/s^2 = 9.81 m/s^2

$\rho = 1000$ kg/m^3

Relative Density (Specific Gravity):-

The relative density of any fluid is defined as the ratio of the density of that fluid to the density of the standard fluid. For liquids we take water as a standard fluid with density ρ=1000 kg/m^3. For gases we take air or O_2 as a standard fluid with density, ρ=1.293 kg/m^3.

Specific volume:-

Specific volume is defined as the volume per unit mass. It is just reciprocal of mass density. It is expressed in m^3/kg.

Viscosity:-

Viscosity (represented by μ, Greek letter mu) is a material property, unique to fluids, that measures the fluid's resistance to flow. Though a property of the fluid, its effect is understood only when the fluid is in motion. When different elements move with different velocities, each element tries to drag its neighboring elements along with it. Thus, shear stress occurs between fluid elements of different velocities.

Viscosity is the property of liquid which destroyed the relative motion between the layers of fluid.

- It is the internal friction which causes resistance to flow.
- Viscosity is the property which control the rate of flow of liquid

Viscosity is due to two factors-

a) Cohesion between the liquid molecules.
b) Transfer of momentum between the molecules.

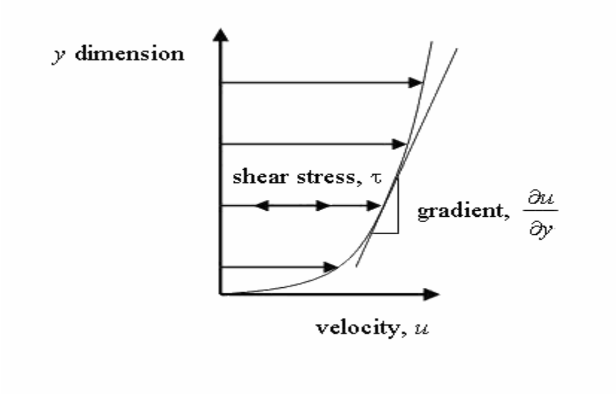


Fig. 1.1

The relationship between the shear stress and the velocity field was that the shear stresses are directly proportional to the velocity gradient. The constant of proportionality is called the coefficient of dynamic viscosity.

$$\tau = \mu \frac{\partial u}{\partial y}$$

UNIT OF VISCOSITY

- In mks system unit of viscosity is kgf-sec/m^2
- In cgs system unit of viscosity is dyne-sec/cm^2
- In S.I system unit of viscosity is Newton-sec/m^2

Kinematic viscosity:-

Another coefficient, known as the kinematic viscosity (ν, Greek nu) is defined as the ratio of dynamic viscosity and density.

I.et, $\upsilon = \mu / \rho$ = viscosity/density

In mks & S.I system unit of kinematic viscosity is meter^2/sec

In cgs system unit of kinematic viscosity is stoke.

SURFACE TENSION:-

Surface tension is defined as the tensile force acting on the surface of a liquid in contact with a gas or on the surface between two immiscible liquids such that the contact surface behaves like a membrane under tension. The magnitude of this force per unit length of the free surface will have the same value as the surface energy per unit area. It is denoted by Greek letter sigma(σ). In MKS units, it is expressed as kgf/m while in SI unit is N/m.

It is also defined as force per unit length, or of energy per unit area. The two are equivalent—but when referring to energy per unit of area, people use the term surface energy—which is a more general term in the sense that it applies also to solids and not just liquids.

Capillarity:-

Capillarity is defined as a phenomenon of rise or fall of a liquid surface in a small tube relative to the adjacent general level of liquid when the tube is held vertically in the liquid. The rise of liquid surface is known as capillary rise while the fall of the liquid surface is known as capillary depression. It is expressed in terms of cm or mm of liquid. Its value depends upon the specific weight of the liquid, diameter of the tube and surface tension of the liquid.

1.2 Pressure and its measurement:-

INTENSITY OF PRESSURE:-

Intensity of pressure is defined as normal force exerted by fluid at any point per unit area. It is also called specific pressure or hydrostatic pressure

P=df/da

- If intensity of pressure is uniform over an area "A" then pressure force exerted by fluid equal to

  Mathematically F=PA

- If intensity of pressure is not uniform or vary point to point then pressure force exerted by fluid equal to integration of P*A

  Mathematically F=∫PA

- Unit of pressure
  - $1N/m^2$ =1 Pascal
  - $1KN/m^2$= 1 kilo Pascal
  - Kilo Pascal= 1kpa = 10^3 Pascal
  - 1 bar = 10^5 Pascal = 10^5 N/m^2

Pascal's law:-

It states that the pressure or intensity of pressure at a point in a static fluid is equal in all direction.

Atmospheric Pressure:-

The atmospheric air exerts a normal pressure upon all surface with which it is in contact and it is called atmospheric pressure. It is also called parametric pressure.

Atmospheric pressure at the sea level is called standard atmospheric pressure.

S.A.P = 101.3 KN/m^2 = 101.3 kpa = 10.3m of H_2O

= 760 mm of Hg

=10.3 (milli bar)

Gauge pressure:-

It is the pressure which measure with help of pressure measuring device in which atmospheric pressure taken as datum.

The atmospheric pressure on scale is marked as zero.

Absolute pressure:-

Any pressure measure above absolute zero pressure is called absolute pressure.

Vacuum pressure:-

Vacuum pressure is defined as the pressure below the atmospheric pressure.

RELATIONSHIP BETWEEN ABSOLUTE PRESSURE, GAUGE PRESSURE, VACUUM PRESSURE:-

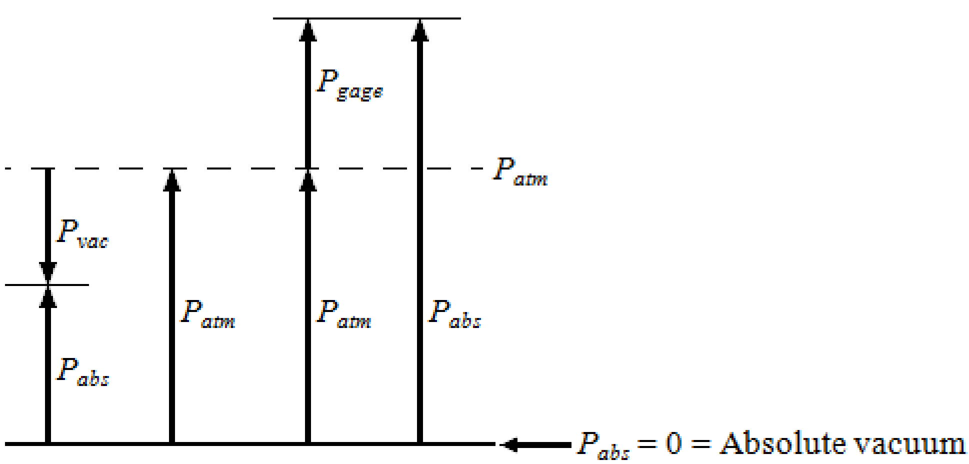


Fig. 1.2

- Equations

$P_{gage} = P_{abs} - P_{atm}$	gauge pressure
$P_{vac} = P_{atm} - P_{abs}$	vacuum pressure
$P_{abs} = P_{atm} + P_{gage}$	absolute pressure

- Nomenclature

P_{abs}	absolute pressure
P_{gage}	gage pressure
P_{vac}	vacuum pressure
P_{atm}	atmospheric pressure

Pressure Head:-

pressure head is the internal energy of a fluid due to the pressure exerted on its container. It may also be called **static pressure head** or simply **static head** (but not **static head pressure**). It is mathematically expressed as:

$$\psi = \frac{p}{\gamma} = \frac{p}{\rho g}$$

where

ψ is pressure head (Length, typically in units of m);
p is fluid pressure (force per unit area, often as Pa units); and
γ is the specific weight (force per unit volume, typically N/m^3 units)
ρ is the density of the fluid (mass per unit volume, typically kg/m^3)
g is acceleration due to gravity (rate of change of velocity, given in m/s^2)

If intensity of pressure express in terms of height of liquid column, which causes pressure is also called pressure head.

Mathematically, $h = P/w$

Pressure Gauges :-

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

1. manometers
2. mechanical gauges

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

a) Simple manometers

b) Differential manometer

Mechanical gauges:-mechanical gauges are defined as the devices used for measuring the pressure by balancing the fluid column by the spring or dead weight. The commonly used mechanical gauges are:-

a) Diaphragm pressure gauge

b) Bourdon tube pressure gauge

c) Dead weight pressure gauge

d) Bellows pressure gauge

1.3 PRESSURE EXERTED ON IMMERSED SURFACE:-

Hydrostatic forces on surfaces:-

Hydrostatic means the study of pressure exerted by a liquid at rest. The direction of such pressure is always perpendicular to the surface to which it acts.

Forces on Submerged Surfaces in Static Fluids

These are the following features of statics fluids:-

- Hydrostatic vertical pressure distribution
- Pressures at any equal depths in a continuous fluid are equal
- Pressure at a point acts equally in all directions (Pascal's law).
- Forces from a fluid on a boundary acts at right angles to that boundary.

Fluid pressure on a surface:-

Pressure is defined as force per unit area. If a pressure p acts on a small area δA then the force exerted on that area will be

$F = p\delta A$

TOTAL PRESSURE:-

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

Mathematically **total pressure**,

$P = p_1a_1 + p_2a_2 + p_3a_3 \ldots\ldots\ldots\ldots$

Where,

- p_1, p_2, p_3 = Intensities of pressure on different strips of the surface, and
- a_1, a_2, a_3 = Areas of corresponding strips.

The position of an immersed surface may be,

- Horizontal
- Vertical
- Inclined

Total Pressure On A Horizontal Immersed Surface

Consider a plane horizontal surface immersed in a liquid as shown in figure 1.

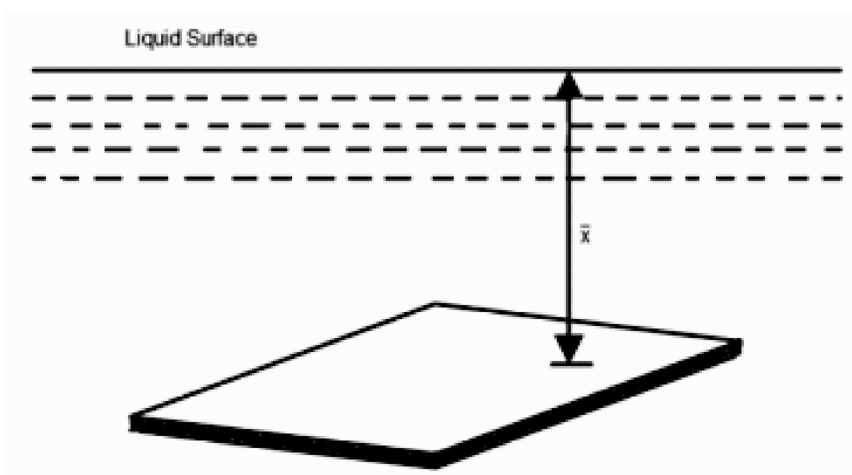


Fig. 1.3

- ω = Specific weight of the liquid
- A = Area of the immersed surface in in^2
- χ = Depth of the horizontal surface from the liquid level in meters

We know that the **Total pressure** on the surface,

P = Weight of the liquid above the immersed surface

= Specific weight of liquid * Volume of liquid

= Specific weight of liquid * Area of surface * Depth of liquid

= $\omega A \chi k N$

Total Pressure On A Vertically Immersed Surface

Consider a plane vertical surface immersed in a liquid shown in figure 2.

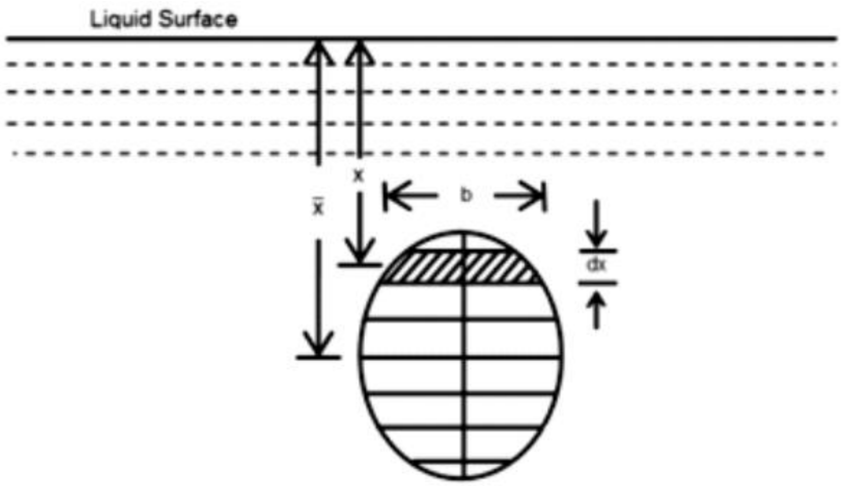


Fig. 1.4

Let the whole immersed surface is divided into a number of small parallel stripes as shown in figure.

Here,

- ω = Specific weight of the liquid
- A = Total area of the immersed surface
- χ = Depth of the center of gravity of the immersed surface from the liquid surface

Now, consider a strip of thickness *dx*, width *b* and at a depth *x* from the free surface of the liquid.

The intensity of pressure on the strip = $\omega\chi$

and the area of strip =b.d*x*

∴Pressure on the strip = Intensity of pressure * Area = $\omega\chi$ .bd*x*

Now, Total pressure on the surface,

$P = \int wx.bdx$.

$= w\int x.bdx$

But, $w\int x.bdx$ = Moment of the surface area about the liquid level = $A\bar{x}$

$\therefore P = wA\bar{x}$

1.4 FLOTATION AND BUOYANCY:-

Archimedes Principle:-

Archimedes' principle indicates that the upward buoyant force that is exerted on a body immersed in a fluid, whether fully or partially submerged, is equal to the weight of the fluid that the body displaces. Archimedes' principle is a law of physics fundamental to fluid mechanics. Archimedes of Syracuse formulated this principle, which bears his name.

Buoyancy:-

When a body is immersed in a fluid an upward force is exerted by the fluid on the body. This is upward force is equal to weight of the fluid displaced by the body and is called the force of buoyancy or simple buoyancy.

Centre of pressure:-

The center of pressure is the point where the total sum of a pressure field acts on a body, causing a force to act through that point. The total force vector acting at the center of pressure is the value of the integrated pressure field. The resultant force and center of pressure location produce equivalent force and moment on the body as the original pressure field. Pressure fields occur in both static and dynamic fluid mechanics. Specification of the center of pressure, the reference point from which the center of pressure is referenced, and the associated force vector allows the moment generated about any point to be computed by a translation from the reference point to the desired new point. It is common for the center of pressure to be located on the body, but in fluid flows it is possible for the pressure field to exert a moment on the body of such magnitude that the center of pressure is located outside the body.

Center of buoyancy:-

It is define as the point through which the force of buoyancy is supposed to act. As the force of buoyancy is a vertical force and is equal to the weight of the fluid displaced by the body, the center of buoyancy will be the center of gravity of the fluid displaced.

METACENTER:-

The metacentric height (GM) is a measurement of the initial static stability of a floating body. It is calculated as the distance between the centre of gravity of a ship and its metacentre. A larger metacentric height implies greater initial stability against overturning. Metacentric height also has implication on the natural period of rolling of a hull, with very large metacentric heights being associated with shorter periods of roll which are uncomfortable for passengers. Hence, a sufficiently high but not excessively high metacentric height is considered ideal for passenger ships.

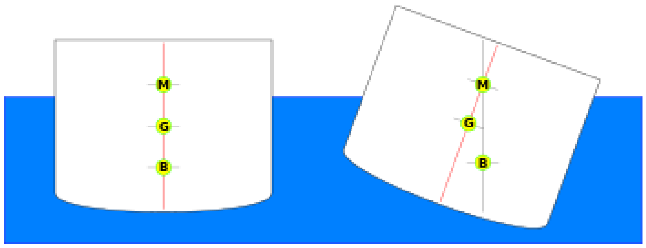


Fig. 1.5

The metacentre can be calculated using the formulae:

$$KM = KB + BM$$

$$BM = \frac{I}{V}$$

Metacentric height:-

The distance between the meta-center of a floating body and a center of gravity of the body is called metacentric height.

MG =BM-BG

MG=I/V-BG

Stability of a submerged body:-

Stable condition:-

- ❖ For stable condition w = f_b and the point "B" above the CG of the body.

Unstable equilibrium;-

- ❖ For unstable equilibrium w = f_b and the point B is below the CG of the body.

Neutral equilibrium:-

- ❖ If the force of buoyancy is act as CG of the body.

Stability of a floating body:-

- ❖ For stable condition w = f_b and the meta centre *"m"* is about the CG of the body.
- ❖ For unstable equilibrium w = f_b and the metacentre *"m"* is below CG of the body.
- ❖ In neutral equilibrium w = f_b and metacentre "m" is acting at CG of the body.

Chapter-II

KINEMATICS OF FLUID FLOW

2.1 Basic equation of fluid flow and their application:-

Energy of a Liquid in Motion:-

The energy, in general, may be defined as the capacity to do work. Though the energy exits in many forms, yet the following are important from the subject point of view:

1. Potential energy,
2. Kinetic energy, and
3. Pressure energy.

Potential Energy of a Liquid Particle in Motion:-

It is energy possessed by a liquid particle by virtue of its position. If a liquid particle is *Z m* above the horizontal datum (arbitrarily chosen), the potential energy of the particle will be *Z* metre-kilogram (briefly written as mkg) per kg of the liquid. The potential head of the liquid, at point, will be *Z* metres of the liquid.

Kinetic Energy of a Liquid Particle in Motion:-

It is the ehergy, possessed by a liquid particle, by virtue of its motion or velocity. If a liquid particle is flowing with a mean velocity of v metres per second; then the kinetic energy of the particle will be $V^2/2g$ mkg per kg of the liquid. Velocity head of the liquid, at that velocity, will be $V^2/2g$ metres of the liquid.

Pressure Energy of a Liquid Particle in Motion:-

It is the energy, possessed by a liquid particle, by virtue of its existing pressure. If a liquid particle is under a pressure of p kN/m2 (i.e., kPa), then the pressure energy of the particle-will be $\frac{p}{w.}$ mkg per kg of the liquid, where w is the specific weight of the liquid. Pressure head of the liquid under that pressure will be $\frac{p}{w.}$ metres of the liquid.

Total Energy of a Liquid Particle in Motion:-

The total energy of a liquid, in motion, is the sum of its potential energy, kinetic energy and pressure energy, Mathematically total energy,

$E = Z + V^2/2g + \frac{p}{w.}$ m of Liquid.

Total Head of a Liquid Particle in Motion:-

The total head of a liquid particle, in motion, is the sum of its potential head, kinetic head and pressure head. Mathematically, total head,

$H = Z + V^2/2g + \frac{p}{w.}$ m of liquid.

Example

Water is flowing through a tapered pipe having end diameters of 150 mm and 50 mm respectively. Find the discharge at the larger end and velocity head at the smaller end, if the velocity of water at the larger end is 2 m/s. Solution. Given: d_1 = 150mm = 0•15 m ; d_2= 50 mm= 0•05 m and V_1 = 2•5 m/s. Discharge at the larger end We know that the cross-sectional area of the pipe at the larger end,

$$a_1= \frac{\pi}{4}\times(0.15)2 = 17.67\times 10^{-3}m^2$$

and discharge at the larger end,

$Q_1 = a_1.v_1 = (17.67xl0^{-3})x2.5 = 44.2 \times 10^{-3}\ m^3/s$

= 44.2Jitres/s Ans.

Velocity head at the smaller end

We also know that the cross-sectional area of the pipe at the smaller end,

$$A_2= \frac{\pi}{4}\times(0.15)2 = 1.964\times 10^{-3}m^2$$

Since the discharge through the pipe is continuous, therefore

$$a_1.v_1 = a_2.v_2$$

or $v2 = \frac{a1.v1}{a2} = [(17.67 \times 10^{-3})\ x\ 2.5]/1.964 \times 10^{-3} = 22.5\ m/s$

:. Velocity head at the smaller end

$V_2^2/2g=(22.5)^2/2 \times 9.81=25.8\ m$ *Ans*

Bernoulli's Equation:-

It states, "For a perfect incompressible liquid, flowing in a continuous stream, the total nergy; of a particle remains the same, while the particle moves from one point to another." This statement is based on the assumption that there are no "losses due to friction in the pipe. Mathematically,

$$Z + V2/2g + \frac{p}{w.} = \text{Constant}$$

where

Z = Potential energy,

$V^2/2g$ =Kinetic energy, and

$\frac{p}{w.}$ = Pressure energy.

Proof

Consider a perfect incompressible liquid, flowing through a non-uniform pipe as shown in Fig-

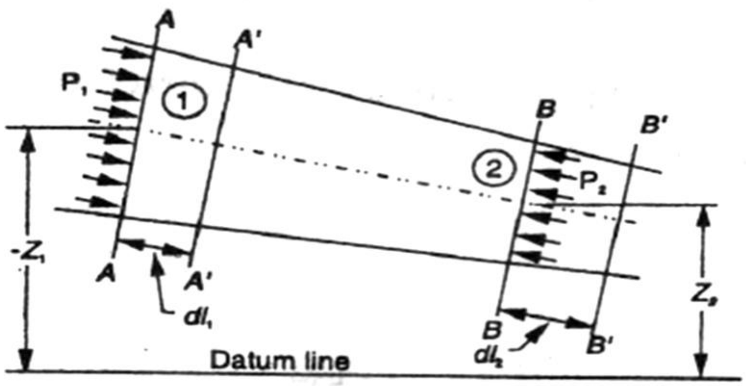


Fig. 2.1

Let us consider two sections AA and BB of the pipe. Now let us assume that the pipe is running full and there is a continuity of flow between the two sections.

Let
Z_1 = Height of AA above the datum,
P_1= Pressure at AA,
V_1 = Velocity of liquid at AA,
A_1 = Cross-sectional area of the pipe at AA, and
Z_2, P_2, V_2, A_2= Corresponding values at BB.
Let the liquid between the two sections AA and BB move to A' A' and B' B' through very small lengths dl_1 and dl_2 as shown in Fig. This movement of the liquid between AA and BB is equivalent to the movement 'of the liquid between AA and A' A' to BB and B' B', the remaining liquid between A' A' and BB being uneffected.
Let W be the weight of the liquid between AA and A' A'. Since the flow is continuous, therefore
$W = wa_1dI_1 = wa_2dL_2$
or $a_1 \times dl_1 = \frac{W}{w}$ ...(i)

Similarly $a_2dl_2 = \frac{W}{w}$

$\therefore a_1 . dL_1 = a_2 dL_2$ ...(ii)
We know that work done by pressure at AA, in moving the liquid to A' A'
= Force x Distance = $P_1. a_1 . dL_1$
Similarly, work done by pressure at BB, in moving the liquid to B' B'
$=-P_2a_2dl_2$
...(Minus sign is taken as the direction of P_2 is opposite to that of P_1)
:. Total work done by the pressure
$= P_1a1dl_1 - P_2a_2dl_2$
$=P_1a1dl_1-p_{2a}1dl_1$
…$(a_1dl_1=a_2dl_2)$
$= a_1.dl_1 (P_1 - P_2) = \frac{W}{w} (P_1 - P_2)$ …$(a_1.dl_1 = \frac{W}{w})$

Loss of potential energy = W (Z_1-Z_2)

and again in kinetic energy =W[(V_2^2/2g)-(V_1^2/2g)]= $\frac{W}{2g}$(v_2^2-v_1^2)

We know that loss of potential energy + Work done by pressure
= Gain in kinetic energy

$\therefore$ W (Z_1-Z_2)+ $\frac{W}{w}$ (P_1 - P_2) = $\frac{W}{2g}$(v_2^2-v_1^2)

(Z_1-Z_2)+(p_1/w)-(p_2/w)=v_2^2/2g-v_1^2/2g
Or Z_1 + v_1^2/2g+ (p_1/w)=Z_2+ v_2^2/2g+(p_2/w)
which proves the Bernoulli's equation.

Euler's Equation For Motion

The "Euler's equation for steady flow of an ideal fluid along a streamline is based on the Newton's Second Law of Motion. The integration of the equation gives Bernoulli's equation in the form of energy per unit weight of the flowing fluid. It is based on the 'following assumptions:

1. The fluid is non-viscous (i.e., the frictional losses are zero).
2. The fluid is homogeneous and incompressible (i.e., mass density of the fluid is constant).
3. The flow is continuous, steady and along the streamline.
4. The velocity of flow is uniform over the section.
5. No energy or force (except gravity and pressure forces) is involved in the flow.

Consider a steady' flow of an ideal fluid along a streamline. Now consider a small element AB of the flowing fluid as shown in Fig.

Let
dA = Cross-sectional area of the fluid element,
ds = Length of the fluid element,
dW = Weight of the fluid 5!1ement,
p = Pressure on the element at A,
p + dp = Pressure on the element at B, and
v = Velocity of the fluid element.

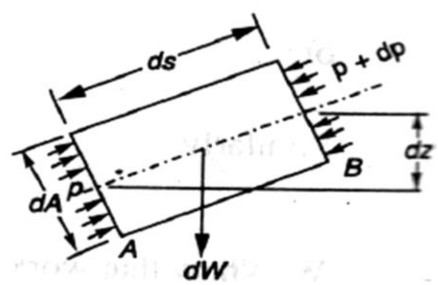


Fig. 2.2

We know that the external forces tending to accelerate the fluid element in the direction of the streamline
= p. dA - (p + dp) dA
= -dp.dA
We also know that the weight of the fluid element,
dW = ρ g. dA . ds
From the geometry of the figure, we find that the component of the weight of the fluid element ,in the direction of flow
= - ρ g . dA . ds cosθ
= - ρ g . dA . ds($\frac{dz}{ds}$) …cosθ =$\frac{dz}{ds}$
= - ρ g. dA. dz
$\therefore$ *mass of the fluid element* = ρ .dA.ds

,We see that the acceleration of the fluid element

$$\frac{dv}{dt} = \frac{dv}{ds} \times \frac{ds}{dt} = v.\frac{dv}{ds}$$

Now, as per Newton's Second Law of Motion, we know that

Force = Mass x Acceleration

$$(- dp . dA) - (\rho g . dA . dz-) = \rho . dA . ds \times \frac{dv}{ds}$$

$$\frac{dp}{\rho} + g.dz = v.dv$$ …(dividing both side by $-\rho dA$)

Or $$\frac{dp}{\rho} + g.dz + v.dv = 0$$

This is the required Euler's equation for motion and is in the form of a differential equation. Integrating the above equation, '

$$\frac{1}{\rho}\int dp + \int g.dz + \int v.dv = constant$$

$$\frac{p}{\rho} + g_z + v^2{}_{/2} = constant$$

$$P + wZ + Wv^2/2g = constant$$

$$\frac{p}{w} + Z + v^2/2g = constant$$ (Dividing by w)

or in other words, $\frac{p1}{w} + Z_1 + (v_1^2/2g) = \frac{p2}{w} + Z_2 + (v_2^2/2g)$

which proves the Bernoulli's equation.

Limitations of Bernoulli's Equation:-

The Bernoulli's theorem or Bernoulli's equation has been derived on certain assumptions, which are rarely possible. Thus the Bernoulli's theorem has the following limitations:

1. The Bernoulli's equation has been derived under the assumption that the velocity of every liquid particle, across any cross-section of a pipe, is uniform. But, in actual practice, it is not so. The velocity of liquid particle in the centre of a pipe is maximum and gradually decreases towards the walls of the pipe due to the pipe friction. Thus, while using the Bernoulli's equation, only the mean velocity of the liquid should be taken into account.
2. The Bernoulli's equation has been derived under the assumption that no external force, except the gravity force, is acting on the liquid. But, in actual practice, it is not so. There are always some external forces (such as pipe friction etc.) acting on the liquid, which effect the flow of the liquid. Thus, while using the Bernoulli's equation, all such external forces should be neglected. But, ifsorne energy is supplied to, or, extracted from the flow, the same should also be taken into account.
3. The Bernoulli's equation has been derived, under the assumption that there is. no loss of energy of the liquid particle while flowing. But, in actual practice, -it is rarely so. In a turbulent flow, some kinetic energy is converted into heat energy. And in a viscous flow, some energy is lost due to shear forces. Thus, while using Bernoulli's equation, all such losses should be neglected.

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

Example

The diameter of a pipe changes from 200 mm at a section 5 metres-above datum = to 50 mm at a section 3 metres above datum. The pressure of water at first section is 500 kPa. If the velocity of flow at the first section is 1 m/s, determine the intensity of pressure at the second section.

Solution.'Gi~en: d_1= 200 mm = 0.2 m; Z_1= 5 m; d2 = 50 mm = 0.05 m z_2 = 3 m; p = 500/ kPa = 500 kN/m2 and V_1 = 1 mls.

Let

V_2 = Velocity of flow at section 2, and

P_2 = Pressure at section 2. We know that area of the pipe at section 1 $a_1=\frac{\pi}{4}\times 0.2^2=31.42\times 10^{-3}m^2$

and area of pipe at section 2 $a_1=\frac{\pi}{4}\times 0.05^2=1.964\times 10^{-3}m^2$

Since the discharge through the pipe is continuous,therefore $a_1 . V_1 = a_2 . V_2$

$V_2=\frac{a1.v1}{a2}$ =[(31.42$\times 10^{-3}$)$\times$ 1]/ 1.964$\times 10^{-3}$=16m/s

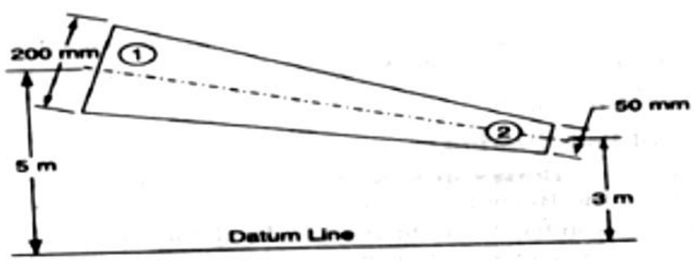


Fig. 2.3

Applying Bernoulli's equation for both the ends of the pipe,

$Z_1 + v_1^2/2g + (p_1/w) = Z_2 + v_2^2/2g + (p_2/w)$

$5+(1)^2/(2\times 9.81) + 500/9.81 = 3 + (16)^2/2X9.81 + \frac{p2}{9.81}$

P2 = 40 x 9.81 = 392.4 kN/m^2 = 392.4 kPa Ans

Rate of Discharge

The quantity of a liquid, flowing per second through a section of a pipe or a channel, is known as the rate of discharge or simply discharge. It is generally denoted by Q. Now consider a liquid flowing through a pipe.

Let, a = Cross-sectional area of the pipe, and

v = Average velocity of the liquid,

:. Discharge, Q = Area × Average velocity = a.v

Notes: 1. If the area is in m^2 and velocity in m/s, then the discharge,

$Q = m^2 \times m/s = m^3/s$ = cumecs

2. Remember that $1m^3$ = 1000 litres.

Equation of Continuity of a Liquid Flow

If an incompressible liquid is continuously flowing through a pipe or a channel (whose cross-sectional area may or may not be constant) the quantity of liquid passing per second is the same at all sections. This is known as the equation of continuity of a liquid flow. It is the first and fundamental equation of flow.

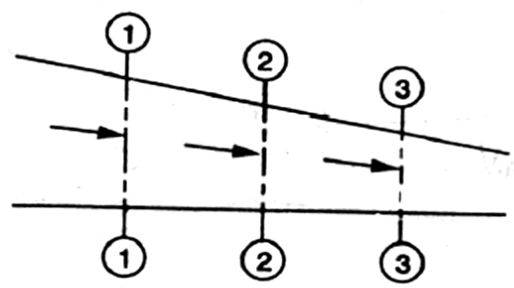


Fig. 2.8

CONTINUITY OF A LIQUID FLOW

Consider a tapering pipe through which some liquid is flowing as shown in Fig

Let , a_1 = Cross-sectional area of the pipe at section 1-1, and

v_1= Velocity of the liquid at section 1-1,

Similarly , a_2, v_2= Corresponding values at section 2-2,

and a_3, v_3 = Corresponding values at section 3-3.

We know that the total quantity of liquid passing through section 1-1,

$Q_1 = a_1.v_1$ ……………………………(i)

Similarly, total quantity of liquid passing through section 2-2,

$Q_2 = a_1.v_1$ ………………….(ii)

and total quantity of the liquid passing through section 3-3,

$Q_3 = a_3.v_3$ ………………….(iii)

From the law of conservation of matter, we know that the total quantity of liquid passing through the sections 1-1, 2-2 and 3-3 is the same. Therefore

$Q_1 = Q_2 = Q_3 =$ .... or $a_1. v_1 = a_2.v_2 = a_3.v_3$ .... and so on.

Example : Water is flowing through a pipe of 100 mm diameter with an average velocity
10 m/s. Determine the rate of discharge of the water in litres/s. Also determine the velocity of water
At the other end of the pipe, if the diameter of the pipe is gradually changed to 200 mm.

Solution. Given: d_1= 100 mm = 0.1 m; V_1 = 10 m/s and d_2= 200 mm = 0.2 m.

Rate of discharge

We know that the cross-sectional area of the pipe at point 1,

$$a_1=\left(\frac{\pi}{4}\right)x(0.1)^2=7.854x10^{-3}\ m^2$$

and rate of discharge, Q = $a_1.v_1$ = $(7.854\ x\ 10^{-3})x\ 10$ = $78.54\ X\ 10^{-3}\ m^3/s$

= 78.54 litres/s **Ans.**

Velocity of water at the other end of the pipe

We also know that cross-sectional area of the pipe at point 2,

$$a_2=\left(\frac{\pi}{4}\right)x(0.2)^2=31.42x10^{-3}\ m^2$$

and velocity of water at point 2 ,v_2= $\frac{Q}{a2}$ = $((78.54\ X\ 10^{-3})/(\ 31.42x10^{-3}))$=2.5m/s **Ans.**

2.2 Flow over Notches:-

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

A weir is a concrete or masonry structure, placed in an open channel over which the flow occurs. It is generally in the form of vertical wall, with a sharp edge at the top, running all the way across the open channel. The notch is of small size while the weir is of a bigger size. The notch is generally made of metallic plate while weir is made of concrete or masonry structure.

1. Nappe or Vein. The sheet of water flowing through a notch or over a weir is called Nappe or Vein.

2. Crest or Sill. The bottom edge of a notch or a top of a weir over which the water flows, is known as the sill or crest.

Classification Of Notches And Weirs:-

The notches are classified as :

I. According to the shape of the opening:

(a) Rectangular notch,

(b) Triangular notch,

(c) Trapezoidal notch, and

(d) Stepped notch.

2. According to the effect of the sides on the nappe:

(a) Notch with end contraction.

lb) Notch without end contraction or suppressed notch e,

Weirs are classified according to the shape of the opening the' shape of the crest, the effect of the sides on the nappe and nature of discharge. The following are important classifications.

Discharge Over A Rectangular Notch Or Weir

The expression for discharge over a rectangular notch or weir is the same.

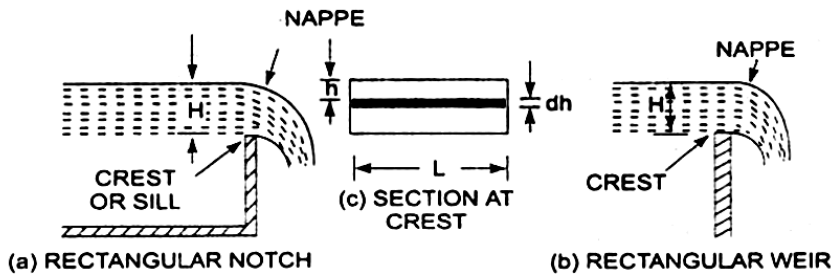


Fig. 2.9

Rectangular notch and 'weir:-

Consider a rectangular notch or weir provided in a channel carrying water as shown in Fig
Let H = Head of water over the crest L = Length of the notch or weir

The total discharge, $Q=\frac{2}{3}\times C_d \times L \times \sqrt{2g[H]}_{3/2}$

Problem - 1

Find the discharge of water flowing over a rectangular notch 0/2 In length when the constant head over the notch is 300 mm. Take *cd* = 0.60.

Solution. Given:

Length of the notch, L=2.0m

Head over notch, H = 300 m = 0.30 m

C_d=0.06

Discharge $Q=\frac{2}{3}\times C_d \times L \times \sqrt{2g[H]}_{3/2}$

$=\frac{2}{3}\times 0.6\times 2.0\times\sqrt{2}\times 9.81\times[0.30]^{1.5}$ m3/s

= 3.5435 x 0.1643 = 0.582 m3/s. Ans,

Problem 2

Determine the height of a rectangular weir of length 6 m to be built across a Rectangular channel. The maximum depth of water on the upstream side of the weir is 1.8m and discharge is 2000 litres/s. Take Cd = 0.6 and neglect end contractions.

Solution. Given:

Length of weir, L=6m

Depth of water, H1=1.8m

Discharge, Q = 2000 litIs = 2 m3/s

Cd/=0.6

Let H is the height of water above the crest of weir and H2 =height of weir

The discharge over the weir is given by the equation .

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

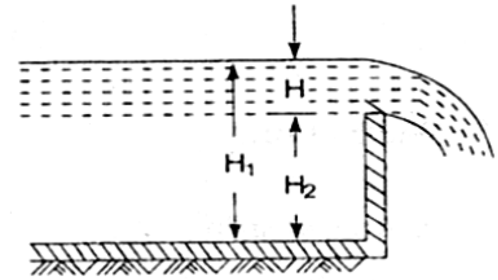


Fig. 2.10

$2=\frac{2}{3}\times 0.6 \times 6 \times \sqrt{2} \times 9.81 \times [H]^{3/2}$

$=10.623\ H^{3/2}$

$= H^{3/2}=\frac{2.0}{10.623}$

$H=\left(\frac{2.0}{10.623}\right)^{2/3}=0.328$ m

Height of weir, H2 = H1- H

= Depth of water on upstream side - H

= 1.8 - .328 = 1.472 m. Ans.

Discharge Over A Triangular Notch Or Weir:-

The expression for the discharge over a triangular notch or weir is the same. It is derived as :
Let H = head of water above the V- notch

θ = angle of notch

Total discharge, $Q=\frac{8}{15}\times C_d \times \frac{\tan\theta}{2} \times \sqrt{2g} \times H^{5/2}$

For a right angle V Notch ,if C_d=0.6

$\theta = 90^0$, $\tan\frac{\theta}{2} = 1$

Discharge, $Q = \frac{8}{15}\times 0.6 \times 1 \times \sqrt{2 \times 9.81} \times H^{5/2}$

$=1.417 \times H^{5/2}$

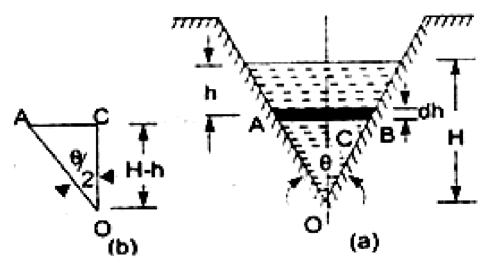


Fig. 2.11

Problem -1

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

Solution. Given an Angle of V-notch, e = 60°

Head over notch, H=0.3 m

C_d = 0.6

Discharge, Q over a V-notch is given by equation

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

$\frac{8}{15}\times C_d\times\frac{0.6\tan 60}{2}\times\sqrt{2\times 9.81}\times(0.3)^{5/2}$

= 0.8182 x 0.0493 = 0.040 m3/s. Ans,

Problem -2

Water flows over a rectangular weir 1 m wide at a depth of 150 mm and afterwards passes through a triangular right-angled weir. Taking C_d for the rectangular and triangular weir as 0.62 and 0.59 respectively, find the depth over the triangular weir.

Solution. Given:

For rectangular weir. Length= L = 1 m

Depth of water, H = 150mm=0.15m

C_d = 0.62

For triangular weir.

θ = 90°

C_d = 0.59

Let depth over triangular weir = H_1

The discharge over the rectangular weir IS given by equation

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

$=\frac{2}{3}\times 0.62\times 1.0\times\sqrt{2\times 9.81}\times(0.15)^{3/2}$

=0.10635 m^3/s

The same discharge passes through the triangular right-angled weir. But discharge. Q. is given by the equation

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

$0.10635=\frac{8}{15}\times 0.59\times\frac{\tan 90}{2}\times\sqrt{2g}\times H_1^{5/2}$ { $\theta = 90^0$ and $H=H_1$ }

$=\frac{8}{15}\times 0.59\times 1\times 4.429\times H_1^{5/2}$

$=1.3936\, H_1^{5/2}$

$H_1^{5/2}=\frac{0.10635}{1.3936}=0.07631$

$H_1=(0.07631)^{0.4}=0.3572$ m , Ans

Discharge Over A Trapezoidal Notch Or Weir:-

A trapezoidal notch or weir is a combination of a rectangular and triangular notch or weir. Thus the total discharge will be equal to the sum of discharge through a rectangular weir or notch and discharge through a triangular notch or weir.

Let H = Height of water over the notch

L = Length of the crest of the notch

C_{d1} = Co-efficient or discharge. for rectangular portioo ABCD of Fig.

C_{d2} = Co-efficient of discharge for triangular portion [FAD and BCE]

The-discharge through rectangular portion ABCD is given by

or $$Q_1=\frac{2}{3}\times C_{d1}\times L\times\sqrt{2g}\times H^{3/2}$$

The discharge through two triangular notches FDA and BCE is equal to the discharge through a single triangular notch of angle e and it is given by equation

$$Q_2=\frac{2}{3}\times C_{d2}\times\frac{\tan\theta}{2}\times\sqrt{2g}\times H^{5/2}$$

Discharge through trapezoldal notch or weir FDCEF = $Q_1 + Q_2$

$$=\frac{2}{3}\times C_{d1}L\sqrt{2g}\times H^{3/2}+\frac{8}{15}C_{d2}\times\frac{\tan\theta}{2}\times\sqrt{2g}\times H^{5/2}$$

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

Solution. Given:

Top width AE=1 m

Base width, CD=L=0.4 m

Head of water, H=0.20 m

For rectangular portion, C_{d1}=0.62

From ΔABC ,we have

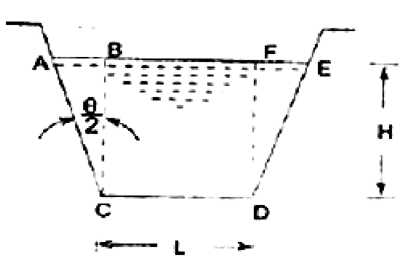


Fig. 2.12

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

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

Discharge through trapezoidal notch is given by equation

$Q=\frac{2}{3}C_{d1}\times L\times\sqrt{2g}\times H^{3/2}+\frac{8}{15}C_{d2}\times\frac{\tan\theta}{2\sqrt{2g}}\times H^{5/2}$

$=\frac{2}{3}\times 0.62\times 0.4\times\sqrt{2\times 9.81}\times(0.2)^{3/2}+\frac{8}{15}\times 60\times 1\times\sqrt{2\times 9.81}\times(0.2)^{5/2}$

$= 0.06549 + 0.02535 = 0.09084\ m^3/s = 90.84$ litres/s. Ans

Discharge Over A Stepped Notch:-

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

Consider a stepped notch as shown in Fig.

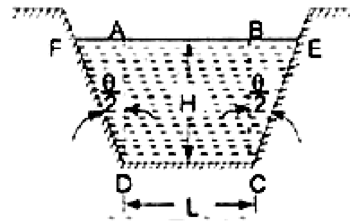


Fig. 2.12

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

L_1 = Length of notch 1,

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

C_d=Co-efficient of discharge for all notches

Total discharge $Q=Q_1+Q_2+Q_3$

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

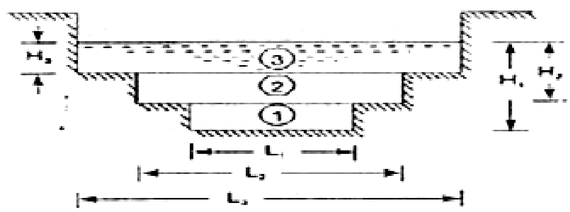


Fig. 2.13

Problem

Fig. 1 shows a stepped notch. Find the discharge through the notch if Cd for all section = 0.62.

Solution. Given:

L_1 = 40 cm, L_2 = 80 cm,

L_3 = 120cm

H_1 = 50 + 30 + 15 = 95 crn,

H_2=80 cm, H_3=50 cm,

C_d=0.62

Total Discharge, $Q=Q_1+Q_2+Q_3$

where

$Q_1=\frac{2}{3}\times C_d\times L_1\times\sqrt{2g}[H_1^{3/2}-H_2^{3/2}]$

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

$=154067 cm^3/s$ =154.067 lit/s

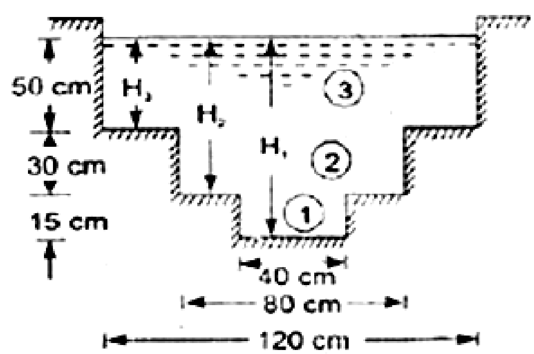


Fig. 2.14

$Q_2 = \frac{2}{3} \times C_d \times L_2 \times \sqrt{2g}[H_2^{3/2} - H_3^{3/2}]$

$= \frac{2}{3} \times 0.62 \times 80 \times \sqrt{2 \times 981} \times [80^{3/2} - 50^{3/2}]$

$=530141\ cm^3/s$

=530.144 lit/s

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

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

$=776771\ cm^3/s$

=776.771 lit/s

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

=154.067+530.144+776.771

=1460.98 lit/s Ans.

Velocity Of Approach

Velocity of approach is defined as the velocity with which the water approaches or reaches the weir or notch before it flows over it. Thus if V_a is the velocity of approach, then an additional head h_a equal

to $V_a^2/2g$ due to velocity of approach, is acting on the water. flowing over the notch. Then initial height of water over the notch becomes $(H + h_a)$ and final height becomes equal to h_a,' Then all the formulae are

changed taking into consideration of velocity of approach.

The velocity of approach, V_a is determined by finding the discharge over the notch or weir neglecting velocity of approach. Then dividing the -discharge-by the cross-sectional area of the channel .on the' upstream side of the weir or notch, the velocity of approach is obtained . Mathematically,

$V_a = \frac{Q}{Area\ of\ Channel}$

This velocity of approach is used to find an additional head ($h_a = V_a^2/2g$).Again the discharge is calculated and above process is repeated for more accurate discharge.

Discharge over a rectangular weir, with velocity of approach

$= \frac{2}{3} \times C_d \times L \times \sqrt{2g}[(H_1 + h_a)^{3/2} - h_a^{3/2}]$

Problem:-

Water is flowing in a rectangular channel of 1 m wide and 0.75 m deep. Find the discharge over a rectangular weir of crest length 60 cm if the head of water over the crest of weir is 20 cm and water from channel flows over the weir. Take Cd = 0.62. Neglect end contractions. Take velocity of approach into consideration.

Solution. Given:

Area of channel, A = Width x depth = 1.0 x 0.75 = 0.75 m^2

Length of weir, L = 60 cm = 0.6 m

Head of water, H_1 = 20 cm = 0.2 m

$C_d = 0.62$

Discharge over a rectangular weir without velocity of approach is given by

$$Q=\frac{2}{3} C_d \times L \times \sqrt{2g} \times H_1^{3/2}$$

$$=\frac{2}{3} \times 0.62 \times 0.6 \times \sqrt{2 \times 9.81} \times (0.2)^{3/2}$$

$=0.0982\ m^3/s$

velocity of approach $V_a=\frac{Q}{A}=\frac{0.0982}{0.75}=0.1309\frac{m}{s}$

Additional head $h_a=V_a^2/2g$

$=(0.1309)^2/2 \times 9.81 = 0.0008733\ m$

Then discharge with velocity of approach is given by equation

$$Q=\frac{2}{3} \times C_d \times L \times \sqrt{2g}\,[(H_1+h_a)^{3/2}-h_a^{3/2}]$$

$$=2/3 \times 0.62 \times 0.6 \times \sqrt{(2 \times 9.81}[(0.2+0.00087)^{3/2}-(0.00087)^{3/2}]$$

= 1.098 [0.09002- .00002566]

= 1.098 x 0.09017

=0.09881 m^3/s. Ans

Types of Weirs :-

Though there are numerous types of weirs, yet the following are important from the subject point of view :

1. Narrow-crested weirs,
2. Broad-crested weirs,

3. Sharp-crested weirs,
4: Ogee weirs, and
5. Submerged or drowned weirs.

Discharge over a Narrow-crested Weir :-

The weirs are generally classified according to the width of their crests into two types. i.e. narrow-crested weirs and broad crested weirs.

Let b = Width of the crest of the weir, and
H = Height of water above the weir crest.

If 2b is less than H,the weir is called a narrow-crested weir. But if 2b is more than H . it is called a broad-crested weir.
A narrow-crested weir is hydraulically similar to an ordinary weir or to a rectangular weir .Thus, the same formula for discharge over a narrow-crested weir holds good, which we derived from an ordinary weir .

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

Where, Q = Discharge over the weir,

Cd = Coefficient of discharge,

L = Length of the weir, and

H = Height of water level above the crest of the weir.

Example A narrow-crested weir of 10metres long is discharging water under a constant head of 400 mm. Find discharge over the weir in litresls. Assume coefficient of discharge as 0.623.

Solution. Given: L = 10 m; H= 400 mm = 0.4 m and C_d = 0.623.
We know that the discharge over the weir,

$$Q = \frac{2}{3} \times C_d . L\sqrt{2g} \times H^{3/2}$$
$$= \frac{2}{3} \text{ x}0.623\text{x}10\sqrt{(2 \times 9.81)} \times (0.4)^{3/2}$$
$$= 46.55 \text{ m}^2/\text{s} = 4655 \text{ lit/s}$$

Discharge over a Broad-crested Weir :-

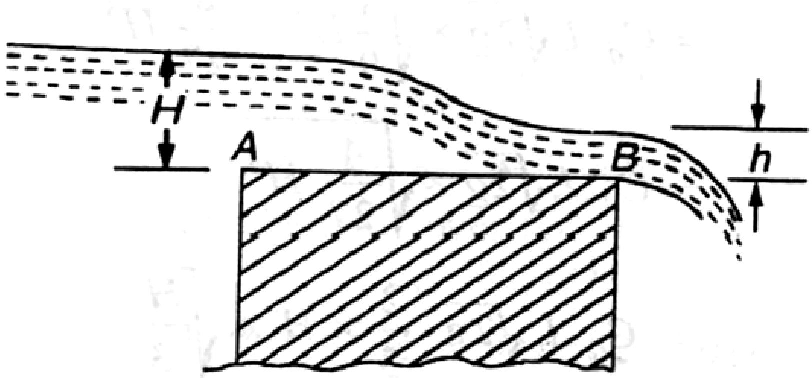


Fig. 2.15

Broad-crested weir

Consider a broad-crested weir as shown in Fig. Let A and B be the upstream and downstream ends of the weir.

Let H = Head of water on the upstream side of the weir (i.e., at A),

h = Head of water on the downstream side of the weir (i.e., at B),

v = Velocity of the water on the downstream side of the weir (i.e., at B),

C_d = Coefficient of discharge, and

L = Length of the weir.

$$Q = 1.71 C_d . L \times H^{3/2}$$

Example A broad-crested weir 20 m long is discharging water from a reservoir in to channel. What will be the discharge over the weir, if the head of water on the upstream and downstream sides is 1m and 0.5 m respectively? Take coefficient of discharge for the flow as 0.6 .

Solution. Given: L = 20 m; H = 1 m; h = 0.5 m and C_d = 0.6.

We know that the discharge over the weir,

$Q = C_d \times L . h\sqrt{2g(H-h)}$

$= 0.6 \times 2.0 \times 0.5 \times \sqrt{2 \times 9.81(1-0.5)}$ m^3/s

$= 6 \times 3.13 = 18.8$ m^3/s **Ans.**

Discharge over a Sharp-crested Weir :-

It is a special type of weir, having a sharp-crest as shown in Fig. The water flowing over the crest comes in contact with the crest -line and then springs up from the crest and falls as a trajectory as shown in Fig.

In a sharp-crested weir, the thickness of the weir is kept less than half of the height of water on the weir. i.e.,

$$b<(H/2)$$

where , b = Thickness of the weir,

and H = Height of water, above the crest of the weir.

The discharge equation, for a sharp crested weir, remains the same as that of a rectangular weir. i.e.,

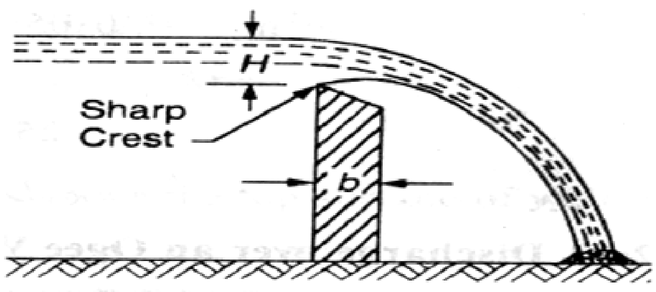


Fig. 2.16

Sharp-crested weir :-

$$Q = \frac{2}{3} \text{ X } C_d .L\sqrt{2g} \text{ x } H^{3/2}$$

Where, C_d = Coefficient of discharge, and
L = Length of sharp-crested weir

Example In a laboratory experiment, water flows over a sharp-crested weir 200 mm long under a constant head of 75mm. Find the discharge over the weir in litres/s, if $C_d = 0.6$.

Solution. Given: L = 200 mm = 0.2 m; H = 75 mm = 0.075 m and $C_d = 0.6$.

We know that the discharge over the weir,

$$Q = \frac{2}{3} \text{ X } C_d .L\sqrt{2g} \text{ x } H^{3/2}$$

$$= \frac{2}{3} \times 0.6 \times 0.2 \times \sqrt{2 \times 9.81} \times (0.075)^{3/2}$$

$=0.0073 \text{ m}^3/\text{s}$ =7.3 litres/s. **Ans.**

Discharge over an Ogee Weir :-

It is a special type of weir, generally, used as a spillway of a dam as shown in Fig.
, The crest of an agee weir slightly rises up from the
point A ,(i.e., crest of the sharp-crested weir) and after reaching the maximum rise of 0.115 H (where H is the height of a water above the point A) falls in a parabolic form as shown in Fig.
The discharge equation for an agee weir remains the same as that of a rectangular weir. i.e.,

$Q = \frac{2}{3} \text{ X } C_d .L\sqrt{2g} \text{ x } H^{3/2}$
Where C_d = Co-efficient of discharge and
L= Length of an ogee weir

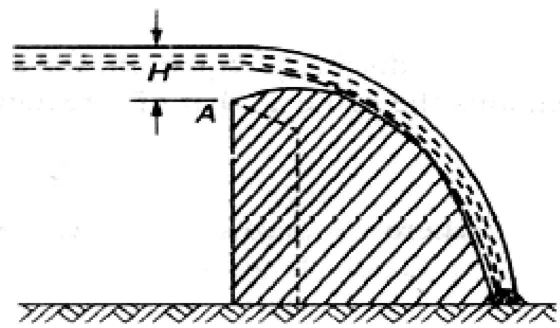


Fig. 2.17

Example

An ogee weir 4 metres long has 500 mm head of water. Find the discharge over the weir, if C_d = 0.62.

Solution. Given: L = 4 m; H = 500 mm = 0.5 m and C_d= 0.62.
We know that the discharge over the weir,

$Q = \frac{2}{3} \text{ X } C_d .L\sqrt{2g} \text{ x } H^{3/2}$

$= \frac{2}{3} \text{ X } 0.62 \text{ X } 4\sqrt{2 \text{ X } 9.81} \text{ X } (0.5)^{3/2} \text{ m}^3/\text{s}$

= 7.323 x 0.354 = 2.59 m^3/s= 2590 litres/s Ans

Discharge over a Submerged or Drowned Weir :-

When the water level on the downstream side of a weir is above the top surface of weir, it is known a submerged or drowned weir as shown in Fig

The total discharge, over such a weir, is found out by splitting up the height of water, above the sill of the weir, into two portions as discussed below:

Let H_1 = Height of water on the upstream side of the weir, and

H_2 =height of water on the downstream side of the weir.

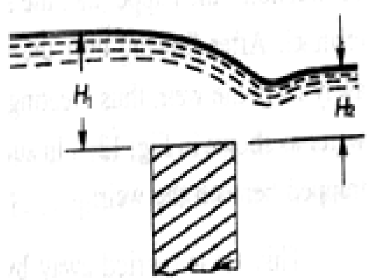


Fig. 2.18

The discharge over the upper portion may be considered as a free discharge under a head of water equal to $(H_1 - H_2)$. And the discharge over the lower portion may be considered as a submerged discharge under a head of H_2. Thus discharge over the free portion (i.e., upper portion),

$$Q1 = \frac{2}{3} X\ Cd\ .L\sqrt{2g}\ x\ (H1\text{-}H2)^{3/2}$$

Submerged weir :-

and the discharge over the submerged (i.e., lower portion),

$Q_2 = C_d \cdot L \cdot H_2 \cdot \sqrt{2g(H_1 - H_2)}$

:. Total discharge, $Q = Q_1 + Q_2$

Example A submerged sharp crested weir 0.8 metre high stands clear across a channel having vertical sides and a width of 3 meters. The depth of water in the channel of approach is 1.2 meter. And 10 meters downstream from the weir, the depth of water is 1 meter. Determine the discharge over the weir in liters per second. Take C_d as 0.6.

Solution. Given: L = 3 m and Cd = 0.6.

From the geometry of the weir, we find that the depth of water on the upstream side,

$H_1 = 1.25 - 0.8 = 0.45$ m and depth of water on the downstream side,

$H_2 = 1 - 0.8 = 0.2$ m

We know that the discharge over the free portion of the weir

$$Q_1 = \frac{2}{3} X\ Cd\ .L\sqrt{2g}\ x\ (H1\text{-}H2)^{3/2}$$

$$= \frac{2}{3} \times 0.6 \times 3 \times \left(\sqrt{2 \times 9.81}\right)(0.45 - 0.20)^{3/2}$$

$= 5.315 \times 0.125 = 0.664\ m^3/s = 664$ liters/s ... (i)

and discharge over the submerged portion of the weir,

$Q_2 = C_d \cdot L \cdot H_2 \cdot \sqrt{2g(H_1 - H_2)}$

$= 0.6 \times 3 \times 0.2 \sqrt{2 \times 9.81(0.45 - 0.2)}\ m^3/s$

$= 0.36 \times 2.215 = 0.797\ m^3/s = 797$ liters/s ... (ii)

:. Total discharge: $Q = Q_1 + Q_2 = 664 + 797 = 1461$ liters/ s **Ans.**

2.3 Flow over Weirs:-

An open channel is a passage through which the water flows under the force of gravity - atmospheric pressure. Or in other words, when the free surface of the flowing water is in contact, with the atmosphere as in the case of a canal, a sewer or an aquaduct, the flow is said to be through an open channel. A channel may be covered or open at the top. As a matter of fact, the flow of water in an open channel, is not due to any pressure as in the case of pipe flow. But it is due to the slope the bed of the channel. Thus during the construction of a channel, a uniform slope in its bed is provided to maintain the flow of water.

Chezy's Formula for Discharge through an Open Channel :-

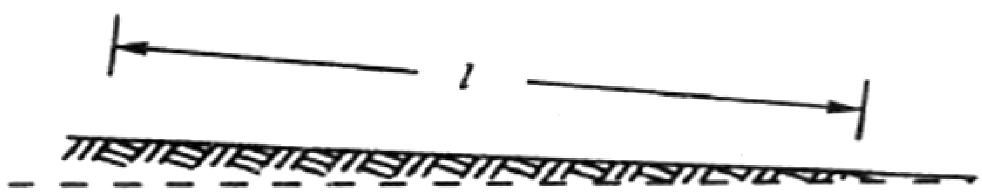


Fig. 2.19

Sloping bed of a channel :-

Consider an open channel of uniform cross-section and bed slope as shown in Fig.

Let

I = Length of the channel,

A = Area of flow,

v = Velocity of water,

p = Wetted perimeter of the cross-section, m=

f = Frictional resistance per unit area at unit velocity, and

i = Uniform slope in the bed.

$m = \frac{A}{P}$ ……..(known as hydraulic mean depth or hydraulic radious)

∴ Discharge Q= A X v=AC$\sqrt{mi}$

Example.
A rectangular channel is 1. 5 metres deep and 6 metres wide. Find the discharge through channel, when it runs full. Take slope of the bed as 1 in 900 and Chezy's constant as 50.
Solution. Given: d = 1.5 m; b = 6 m; i = 1/900 and C = 50.

We know that the area of the channel,

$A = b.d = 6 \times 1.5 = 9\ m^2$

and wetted perimeter, D = b + 2d = 6 + (2 x 1.5) = 9 m

:. Hydraulic mean depth, $m = \frac{A}{P} = 1$ m

and the discharge through the channel,

$Q = AC\sqrt{mi} = 9 \times 50\sqrt{(1 \times 1/900)} = 15 m^3/s$ Ans.

Manning Formula for Discharge :-

Manning, after carrying out a series of experiments, deduced the following relation for the value of C in Chezy's formula for discharge:

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

where N is the Kutter's constant
Now we see that the velocity,

$v = C\sqrt{mi} = M \times m^{2/3} \times i^{1/2}$

where

M =1/N and is known as Manning's constant.

Now the discharge,

$Q = \text{Area} \times \text{Velocity} = A \times 1/N \times m^2 \times i^{1/2}$

$= A \times M \times m^{2/3} \times i^{1/2}$

Example

An earthen channel with a 3 m wide base and side slopes 1 : 1 carries water with a depth of 1 m. The bed slope is 1in 1600. Estimate the discharge. Take value of N in Manning's formula as 0.04.

Solution.

Given: b = 3 m; Side slopes = 1 : 1; d = 1 m; i = 1/1600 and N = 0.04.

We know that the area of flow,

$A = \frac{1}{2} \times (3 + 5) \times 1 = 4 \text{ m}^2$

and wetted perimeter,

$P = 3 + 2 \times \sqrt{(1)^2+(1)^2} = 5.83 \text{ m}$

∴ hydraulic mean depth m = A/P=4/5.83=0.686 m

We know that the discharge through the channel

$Q = \text{Area} \times \text{Velocity} = A \times 1/N \times m^{2/3} \times i^{1/2}$

$= 4 \times 1/0.04 \times 0.686^{2/3} \times (1/1600)^{1/2}$

$= 1.945 \text{ m}^3/\text{s}$ Ans

Channels of Most Economical Cross-sections :-

A channel, which gives maximum discharge for a given cross-sectional area and bed slope is called a channel of most economical cross-section. Or in other words, it is a channel which involves least excavation for a designed amount of discharge. A channel of most economical cross-section is, sometimes: also defined as a channel which has a minimum wetted perimeter; so that there is a minimum resistance to flow and thus resulting in a maximum discharge. From the above definitions,

it is obvious that while deriving the condition for a channel of most economical cross-section, the cross-sectional area is assumed tobe constant. The relation between depth and breadth of the section is found out to give the maximum discharge.

The conditions for maximum discharge for the following sections will be dealt with in the succeeding pages :

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

Condition for Maximum Discharge through a Channel of Rectangular Section :-

A rectangular section is, usually, not provided in channels except in rocky soils where the faces of rocks can stand vertically. Though a rectangular section is not of much practical importance, yet we shall discuss it for its theoretical importance only.

Consider a channel of rectangular section as shown in Fig.

Let

b = Breadth of the channel, and
d = Depth of the channel.
A= b X d
Discharge Q = A x v = $AC\sqrt{mi}$
m=A/P
=d/2

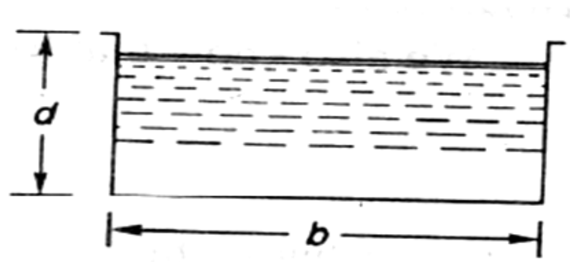


Fig. 2.20

Hence, for maximum discharge or maximum velocity, these two conditions (i.e., b = 2d and m = d/2) should be used for solving the problems of channels of rectangular cross-sections.

Example

A rectangular channel has a cross-section of 8 square metres. Find its size and discharge through the most economical section, if bed slope is 1 in 1000. Take C = 55.

Solution. Given: A = 8 m2

i= 1/1000 = 0.001 and C = 55.
Size of the channel
Let
b = Breadth of the channel, and
d = Depth of the channel.
We know that for the most economical rectangular section,
b = 2d
:. Area (A) 8=b X d= 2d X d =$2d^2$
= b=2 m

And b=2d=2 X 2= 4 m

Discharge through the channel

We also know that for the most economical rectangular section, hydraulic mean depth,

m=d/2=2/2=1 m

and the discharge through the channel,

$Q = AC\sqrt{mi} = 8 \times 55\sqrt{1 \times 0.001}$ m^3/s

= 440 x 0.0316 = 13.9 m^3/s , Ans.

Condition for Maximum Discharge through a Channel of Trapezoidal Section :-

A trapezoidal section is always provided in the earthen channels. The side slopes, in a channel of trapezoidal cross-section are provided, so that the soil can stand safely. Generally, the side slope in a particular soil is decided after conducting experiments on that soil. In a soft soil, flatter side slopes
should be provided whereas in a harder one, steeper side slopes may be provided.
consider a channel of trapezoidal cross- section ABCD as shown in FIg.

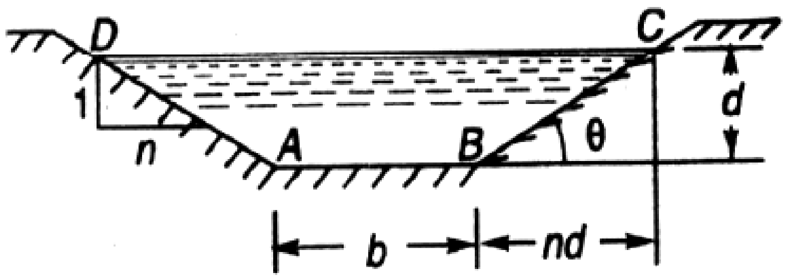


Fig. 2.21

Let
b = Breadth of the channel at the bottom,
d = Depth of the channel and
$\frac{1}{n}$ =side slope (i.e., 1 vertical to n horizontal)

Hence, for maximum discharge or maximum velocity these two
(i.e., b +2nd/2 = d $\sqrt{n2 + 1}$ and m = d/2) should be used for solving problems on channels of
trapezoidal cross-sections.

Example .
A most economical trapezoidal channel has an area of flow 3.5 m^2 discharge in the channel, when running 1 metre deep. Take C = 60 and bed slope 1 in 800.

Solution. Given: A = 3.5 m2 ; d = 1 m; C = 60 and i = 1/800.

We know that for the most economical trapezoidal channel the hydraulic mean depth

m = d/2 = 0.5 m

and discharge in the channel,

Q= A.C.$\sqrt{mi}$ = 5.25 m^3/s Ans.

Example .

A trapezoidal channel having side slopes of 1 : 1 and bed slope of 1 in 1200 is required to carry a discharge of 1800 m^3/min. Find the dimensions of the channel for cross-section. Take Chezy's constant as 50.

Solution.

Given side slope (n)=1

(i.e. 1 vertical to n horizontal),

i= 1/1200 ,Q= 180m^3/min = 3m^3/sec

and C = 50

Let b=breadth of the channel of its bottom and d= depth of the water flow.

We know that for minimum cross section the channel should be most economical and for economical trapezoidal section half of the top width is equal to the slopping side. i.e.

$b + 2nd/2 = d\sqrt{n2 + 1}$

or b = 0.828d

∴ Area A = d X (b + nd) = $1.828d^2$

We know that in the case of a most economical trapizodial section the hydraulic mean depth m=d/2

And discharge through the channel (Q)= A.C.$\sqrt{mi}$ =$1.866d^{5/2}$

∴ $d^{5/2}$ =3/1.866 = 1.608

Or d = 1.21 m

∴ b = 0.828 d = 0.828 X 1.21 = 1 m ANS

Condition for Maximum Velocity through a Channel of Circular Section :-

Consider a channel 'of circular section, discharging water under the atmospheric pressure shown in Fig.

Let r = Radius of the channel,

h = Depth of water in the channel, and

2θ = Total angle (in radians) subtended at the centre by the water

From the geometry of the figure, we find that the wetted perimeter of the channels,

$$P = 2r\theta \quad \text{...(i)}$$

and area of the section, through which the water is flowing,

$$A = r^2\theta - \frac{r2 \sin 2\theta}{2} = r^2\left(\theta - \frac{\sin 2\theta}{2}\right) \quad \text{...(ii)}$$

We know that the velocity of flow in an open channel,

Q= A.C.$\sqrt{mi}$

We know that the velocity of flow in an open channel , v= C$\sqrt{mi}$

Problem: Find the maximum velocity of water in a circular channel of 500 mm radius, if the bed slope is 1 in 400. Take manning's constant as 50.

Solution:-

Given d= 500mm = 0.5m or r = 0.5/2 = 0.25m, i=1/400 and M= 50

Let **2** θ = total angle (in radian) subtended by the water surface at the centre of the channel.

Now we know that for maximum velocity , the angle subtended by the water surface at the centre of the channel.

2 θ = $257^0 30'$ or θ = 128.75^0 = 128.75X$\frac{\pi}{180}$ = 2.247rad

∴ Area of flow, **A** = r^2 (θ - $\frac{\sin 2\theta}{2}$) = $171 m^2$

And perimeter P = 2r θ = 1.124m

∴ hydraulic mean depth m= A/P = 0.171/1.124 =0.152m

And velocity of water v= $MXm^{2/3}Xi^{1/2}$ = 0.71m/s ANS

Chapter-III

PUMPS

3.1 Centrifugal Pumps:-

The hydraulic machines which convert the mechanical energy to hydraulic energy are called pumps. The hydraulic energy is in the form of pressure energy. If the mechanical energy is converted, into pressure energy by means of centrifugal force acting on the fluid, the hydraulic machine is called centrifugal pump.

The centrifugal pump works on the principle of forced vortex flow which means that when a certain mass of liquid is rotated by an external torque, the rise in pressure head of the rotating liquid takes place. The rise in pressure head at any point of the rotating liquid is proportional to the square of tangential velocity of the liquid at that point (i.e. , rise in pressure head $= \frac{v^2}{2g} or \frac{\omega^2 r^2}{2g}$) . Thus at the outlet of the impeller, where radius is more , the rise in pressure head will be more & the liquid will be more & the liquid will be discharged at the outlet with a high pressure head. Due to this high pressure head, the liquid can be lifted to a high level.

Main Parts Of A Centrifugal Pump:-

The followings are the main parts of a centrifugal pump:

1. Impeller
2. Casing
3. Suction pipe with a foot valve & a strainer
4. Delivery Pipe

All the main parts of the centrifugal pump are shown in Fig 19.1

1. **Impeller**: The rotating part of a centrifugal pump is called ‘impeller’. It consists of a series of backward curved vanes. The impeller is mounted on a shaft which is connected to the shaft of an electric motor.

2. **Casing:** The casing of a centrifugal pump is similar to the casing of a reaction turbine. It is an air-tight passage surrounding the impeller & is designed in such a way that the kinetic energy of the water discharged at the outlet of the impeller is converted into pressure energy

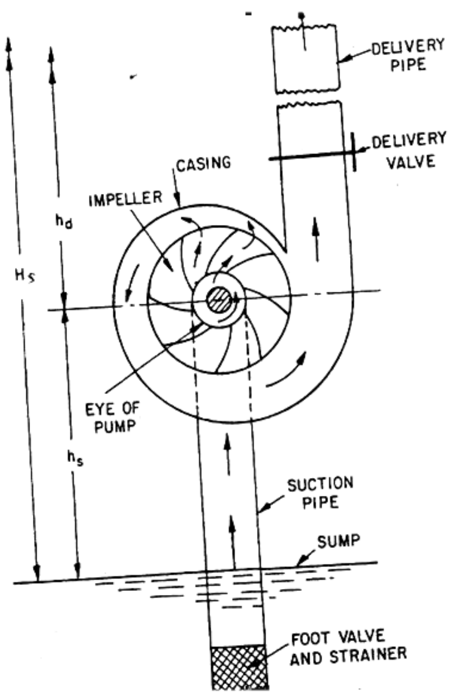
before the water leaves the casing & enters the delivery pipe. The following three types of the casings are commonly adopted:

a. Volute **casing** as shown in Fig.19.1

b. Vortex casing as shown in Fig.19.2(a)

c. Casing with guide blades as shown in Fig.19.2(b)

a) Volute casing as shown in Fig.3.1the Volute casing, which is surrounding the impeller. It is of spiral type in which area of flow increases gradually. The increase in area of flow decrease velocity of flow. Decrease in velocity increases the pressure of water flowing through casing. it has been observed that in case of volute casing, the efficiency of pump increases.



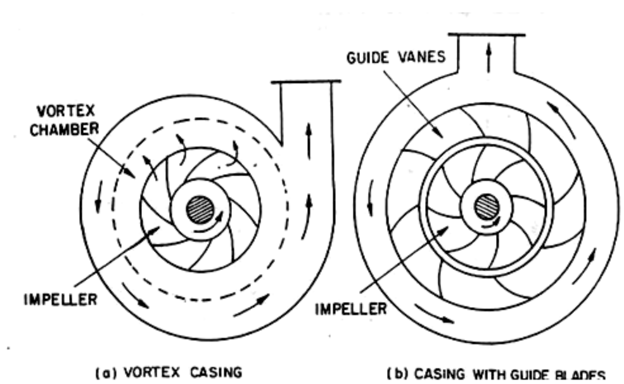
Main parts of a centrifugal pump

Fig. 3.1

b) Vortex casing. if a circular chamber is introduced between the casing and impeller as shown in fig.3.1,the casing is known as vortex casing .by introducing the circular chamber, loss of energy due to formation of eddies is reduced to a considerable extent. thus efficiency of pump is more than the efficiency when only volute casing is provided.

c) Casing with guide blades. This casing is shown in fig.3.1 in which the impeller is surrounded by a series of guide blades mounted on a ring which is known as diffuser. the guide vanes are designed in which a way that the water from the impeller enters the guide vanes without stock. Also the area of guide vanes increases, thus reducing the velocity of flow through guide vanes and consequently increasing the pressure of water. the water from guide vanes then passes through the surrounding casing which is in most of cases concentric with the impeller as shown in fig.3.1.

3. suction pipe with foot-valve and a strainer: A pipe whose one end is connected to the inlet of 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 valve is fitted at lower end of suction pipe. Foot valve opens only in upward direction. A strainer is also fitted at lower end of suction pipe.



fferent type of casing

Fig: 3.2

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

Efficiencies of a centrifugal pump: 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 & 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 & then to the water. The following are the important efficiencies of a centrifugal pump:

a. Manometric efficiencies η_{man}

b. Mechanical efficiencies η_m

c. Overall efficiencies η_o

a) **Manometric Efficiencies** η_{man} **:** The ratio of the manometric head to the head imparted by the impeller to the water is known as manometric efficiency. It is written as

η_{max} = Manometric head/Head imparted by impeller to water

$$= \frac{H_m}{\frac{V_{w2}u_2}{g}} = \frac{gH_m}{V_{w2}u_2} \ldots\ldots\ldots\ldots\ldots\ldots$$

The impeller at the impeller of the pump is more than the power given to the water at outlet of the pump. The ratio of the power given to water at outlet of the pump to the power available at the impeller, is known as manometric efficiency.

The power given to water at outlet of the pump= $\frac{WH_m}{1000} kW$

The power at the impeller = $\frac{Work\ done\ by\ impeller\ per\ second}{1000} kW$

$$\frac{W}{g} \times \frac{V_{w2}u_2}{1000} kW$$

$$= \quad \eta_{max} = \frac{\frac{WH_m}{1000}}{\frac{W}{g} \times \frac{V_{w2}u_2}{1000}} = \frac{gH_m}{V_{w2} \times u_2}$$

b) Mechanical efficiencies:-

The power at the shaft of the centrifugal pump is more than the power available at the impeller of the pump . The ratio of the power available at the impeller to the power at the shaft of the centrifugal pump is known as mechanical efficiency. It is written as

η_m = Power at the impeller/Power at the shaft

The power at the impeller in kW=Work done by impeller per second/10000

$$= \frac{W}{g} \times \frac{V_{w2}u_2}{1000}$$

$$\eta_m = \frac{\frac{W}{g}\left(\frac{V_{w2}u_2}{1000}\right)}{S.P.} \text{..............}$$

Where S.P.= Shaft Power

c) Overall efficiencies η_o

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

$$= \frac{Weight\ of\ water\ lifted \ * H_m}{1000} = \frac{WH_m}{1000}$$

Power input to the pump =Power supplied by the electric motor

= S.P. of the pump

$$= \eta_o = \frac{\left(\frac{WH_m}{1000}\right)}{S.P.} \text{...............}$$

$$= \eta_{man} \times \eta_m \text{...................}$$

Problem 3.1: The internal & external diameters of the impeller of a centrifugal pump are 200mm & 400mm respectively. The pump is running at 1200 r.p.m. The vane angles of the impeller at inlet & outlet are 20^0 & 30^0 respectively. The water enters the impeller radially & velocity of flow is constant. Determine the velocity of flow per metre sec.

Solution: **I**nternal Dia. Of impeller,=D_1=200mm=0.20m

External Dia. Of impeller ,=D_2=400mm=0.40m

Speed N=1200r.p.m

Vane angle at inlet , $\theta = 20^0$

Vane angle at outlet, $\phi = 30^0$

Water enter s radially means, $\alpha = 90^0$ and $V_{w1} = 0$

Velocity of flow , $= V_{f1} = V_{f2}$

Tangential velocity of impeller at inlet & outlet are,

$$u_1 = \frac{\Pi D_1 N}{60} = \frac{\Pi \times .20 \times 1200}{60} = 12.56 m/s$$

$$u_2 = \frac{\Pi D_2 N}{60} = \frac{\Pi \times .40 \times 1200}{60} = 25.13 m/s$$

From inlet velocity triangle,

$$\tan \phi = \frac{V_{f1}}{u_1} = \frac{V_{f2}}{12.56}$$

$$V_{f1} = 12.56 \tan \theta = 12.56 \times \tan 20 = 4.57 m/s$$

$$V_{f2} = V_{f1} = 4.57 m/s$$

Problem 3.2: A centrifugal pump delivers water against a net head of 14.5 metres & a design speed of 1000r.p.m .The values are back to an angle of 30^0 with the periphery. The impeller diameter is 300mm & outlet width 50mm. Determine the discharge of the pump if manometric efficiency is 95%.

Solution: Net head, $H_{m=}$ 14.5m

Speed, N =1000r.p.m

Vane angle at outlet, $\phi = 30^0$

Impeller diameter means the diameter of the impeller at outlet

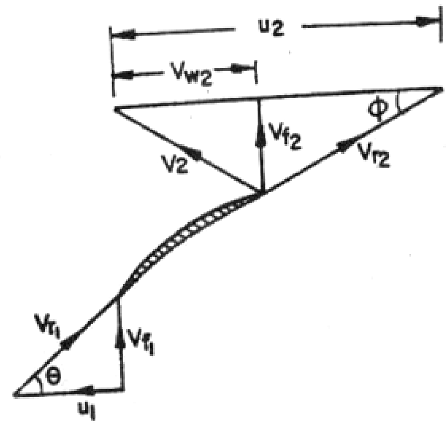
Diameter, $D_2 = 300mm = 0.30m$

Outlet width, $B_2 = 50mm = 0.05m$

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

Tangential velocity of impeller at outlet, $u_2 = \dfrac{\pi D_2 N}{60} = \dfrac{\pi \times .30 \times 1000}{60} = 15.70 m/s$

Now using equation



$$\eta_{\max} = \frac{gH_m}{V_{w2}u_2}$$

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

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

Fig. 3.3

Refer to fig(3.3). From outlet velocity triangle, we have

$$\tan\phi = \frac{V_{f2}}{(u_2 - V_{w2})}$$

$$\tan 30^0 = \frac{V_{f2}}{(15.70 - 9.54)} = \frac{V_{f2}}{6.16}$$

$$V_{f2} = 6.16 \times \tan 30^0 = 3.556 m/s$$

$$Discharge = Q = \pi \times D_2 \times B_2 \times V_{f2}$$

$$= \pi \times 0.30 \times 0.05 \times 3.556 m^3/s = 0.1675 m^3/s$$

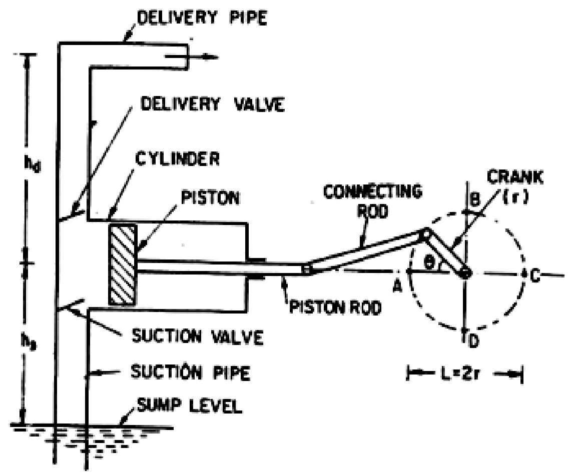
3.2 Reciprocating Pump:-

Introduction:-

We have defined the pumps as the hydraulic machines which convert the mechanical energy to hydraulic energy which is mainly in the form of pressure energy. If the mechanical energy is converted into hydraulic energy (or pressure energy) by sucking the liquid into a cylinder in which a piston is reciprocating (moving backwards and forwards), which exerts the thrust on the liquid & increases its hydraulic energy (pressure energy), the pump is known as reciprocating pump.

Main parts of a reciprocating pump:-

The following are the main parts of a reciprocating pump as shown in fig (3.4)



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, and
5. Delivery valve.

Fig. 3.4

Discharge through a Reciprocating Pump: Consider a single acting reciprocating pump as shown in fig ().

Let D= dia. Of the cylinder

A= C/s 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*r

h_s = height of the axis of the cylinder from water surface in sump

h_d = Height of the 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 * Length of stroke = A*L

Number of revolution per second, = $\frac{N}{60}$

Discharge of the pump per second , Q= Discharge in one direction × No. of revolution per second

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

Wt. of water delivered per second, W = $\rho g Q = \frac{\rho g A L N}{60}$ ……………………………

Work done by Reciprocating Pump : Work done by the reciprocating pump per sec. is given by the reaction as

Work done per second = Weight of water lifted per second × Total height through which water is lifted

$$= W \times (h_s + h_d)$$

Where $(h_s + h_d)$= Total height through which water is lifted

From equation () Weight, W is given by $W = \frac{\rho g A L N}{60}$

Substituting the value of W in equation () we get

Work done per second =

$$\frac{\rho g A L N}{60}(h_s + h_d) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

Power required to drive the pump, in kW $P = \frac{Work\ done\ per\ second}{1000}$ = $\frac{\rho \times g \times ALN(h_s + h_d)}{60 \times 1000}$

$$= \frac{\rho g A L N (h_s + h_d)}{60{,}000} kW \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

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

→ History of development of irrigation in India
→ Types of irrigation
→ Sources of irrigation water

Irrigation :-

→ The artificial process of supplying or providing water to the agricultural land for raising crops is known as irrigation.

→ The supply of water to land or crops to help growth, typically by means of channels.

Necessity of irrigation in India :-

→ India is a tropical country with a vast diversity of climate, topography & vegetation. Rainfall in India varies considerably in its placed of occurance as well as in its amounts.

→ Even at a particular place the rainfall is highly irregular as it occurs only during a few particular months of the year.

→ Therefore crops can not be raised successfully over the entire land without providing artificial irrigation of fields.

→ More than 70% of our population directly depends upon agriculture & the remaining depends indirectly on agriculture.

→ Out of the total geographical area of about 328 million hectors, about 184 million hector is the cultivable area.
→ In order to ensure full growth of crops in this area it is necessary to provide adecutete irrigation facilities in India.

Types of Irrigation :-

→ Irrigation may broadly be classified into two types.
(1) surface irrigation
(2) sub-surface irrigation

(1) Surface irrigation :-

→ water is applied & distributed over the soil surface by gravity.
→ Surface irrigation is of 2 types.
(a) Flow irrigation
(b) Lift irrigation

(a) Flow irrigation :-

→ When water is available at a higher level & it is supplied to the lower level by the more action of gravity then it is called flow irrigation.

(b) Lift irrigation :-

→ If the water is lifted up by some mechanical or manual means such as pumps etc & then supplied for irrigation then it is called lift irrigation.
→ Flow irrigation is further sub-divided into two types
(i) Perennial Irrigation
(ii) Flood Irrigation

Irrigation

- Surface
  - Flow
    - Perennial
    - Flood
  - Lift
- sub-surface
  - Natural sub-irrigation
  - Artificia sub-irrigatio

(i) Perennial irrigation :-

→ In perennial system of irrigation constant & continuous water supply is assured to the crops in accordance with the requirements of the crops throughout the crop period.

→ In this system of irrigation water is supplied through storage canal head works & canal distribution system.

☆ When the water is directed into the canal by constructing a weir or a barrage across the river it is called direct irrigation.

→ If a dam is constructed across a river to store water during monsoons, so as to supply water in the off-taking channels during periods of low flow then it is termed as storage irrigation.

(ii) Flood irrigation :-

→ This kind of irrigation is sometimes called inundation irrigation. In this method of irrigation soil is kept submerged & thoroughly flooded with water so as to cause thoroughly saturation of the land

Dt-11/01/2017

Sub surface irrigation :-

(a) Natural
(b) Artificial

- In this type of irrigation water does not wet the soil surface.
- The under ground water nourishes the plant roots by capillarity.

(a) Natural sub-surface irrigation :-

- Leakage water from channels etc. goes under ground & during passage through the sub-soil, it may irrigate crops shown on lower land by capillarity.
- Some-times leakage causes the water table to rise up which helps in irrigation of crops by capillarity.
- When under ground irrigation is achieved simply by natural processes without any additional extra efforts it is called natural sub-irrigation

(b) Artificial sub irrigation :-

- When a system of open jointed draines is artificially laid below the soil so as to supply water to the crops by capillarity then it is known as artificial sub irrigation.
- It is very costly process & hence adopted in India on a very small scale.

Sources of irrigation water :-

- There are various ways in which the irrigation water can be applied to the fields. Their main classification is - as follows.

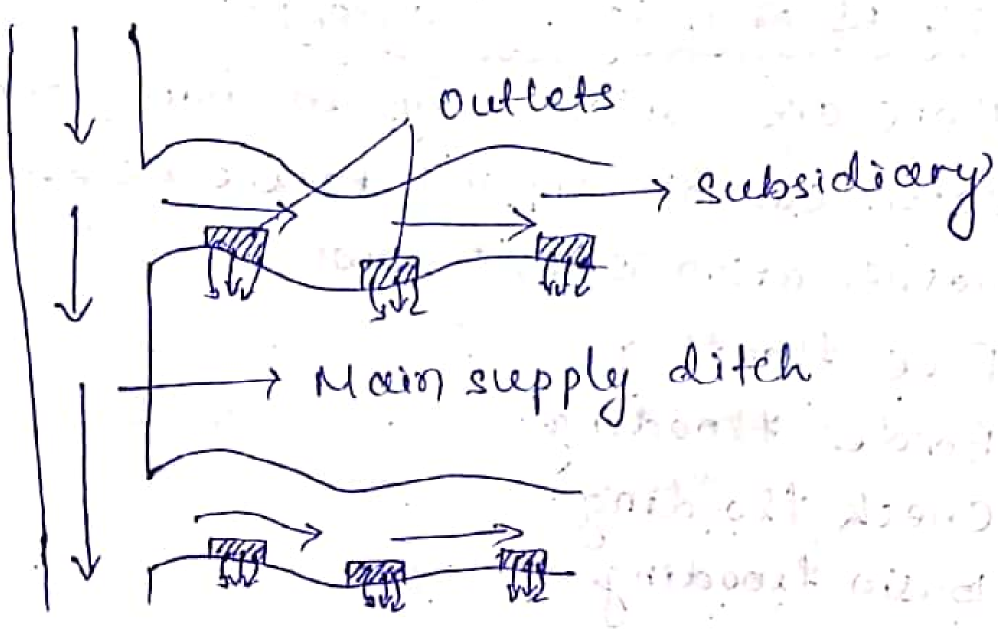
1) Free flooding
2) Border flooding
3) Check flooding
4) Basin flooding.
5) Furrow Irrigation method
6) Sprinkler Irrigation method
7) Drip Irrigation method

1) Free flooding or Ordinary flooding :-

- In this method ditches are excavated in the field & they may be either on the contour or up & down the slope. water from these ditches flows across the field.
- After water leaves the ditches no attempt is made to control the flow by means of levees.
- These type of wild flooding is most suitable for close growing crops.
- Distance between contour ditches is about 20-50 metre apart.

☆ Ditches - A narrow channel dug at the side of a road or field to hold or carry away water.

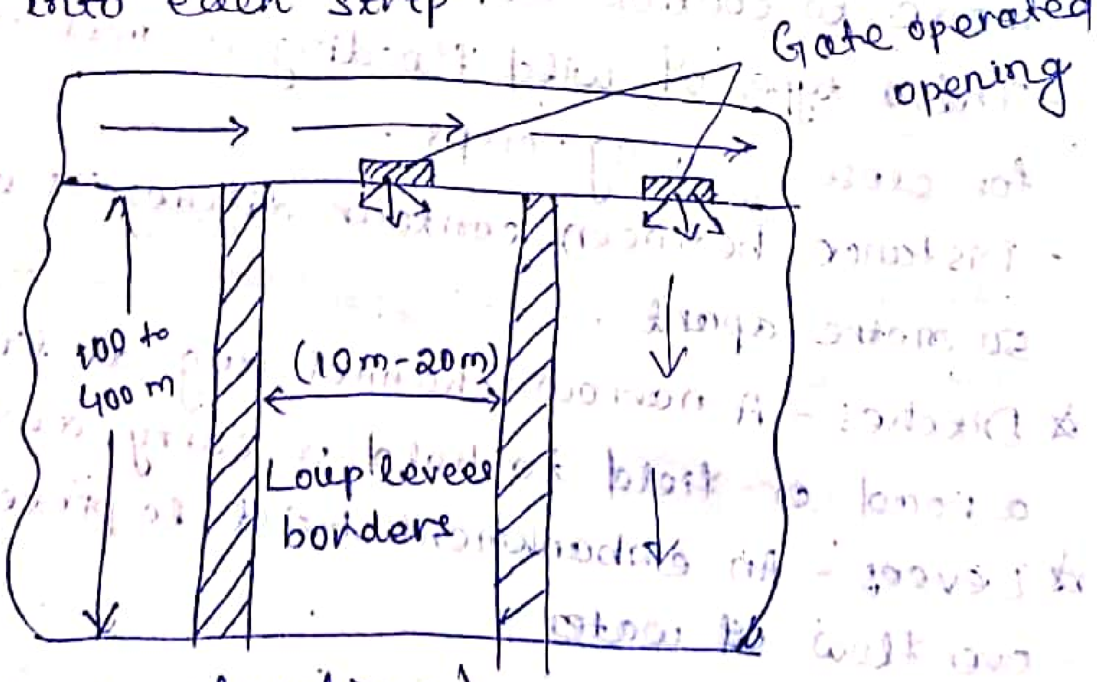
☆ Levees - An embankment built to prevent the over flow of water.



(Free flooding)

(2) Border flooding :-

- In this method the land is divided into a number of strips separated by low levees called borders. The land areas confined in each strip is of the order of 10 m. to 20 m ~~ato~~ in width & 100- 400 metre in lengths.
- water is made to flow from the supply ditch into each strip.

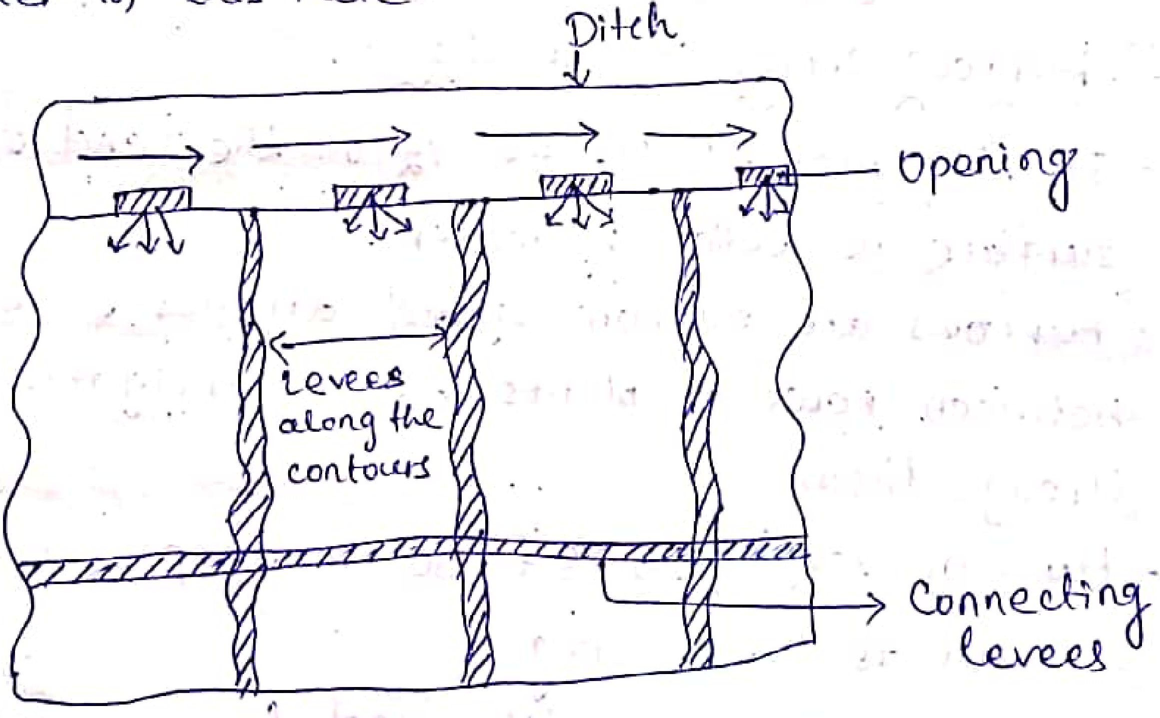


(Border flooding)

- The water flows slowly towards the lower end & infiltrates into the soil.

(3) Check flooding:-

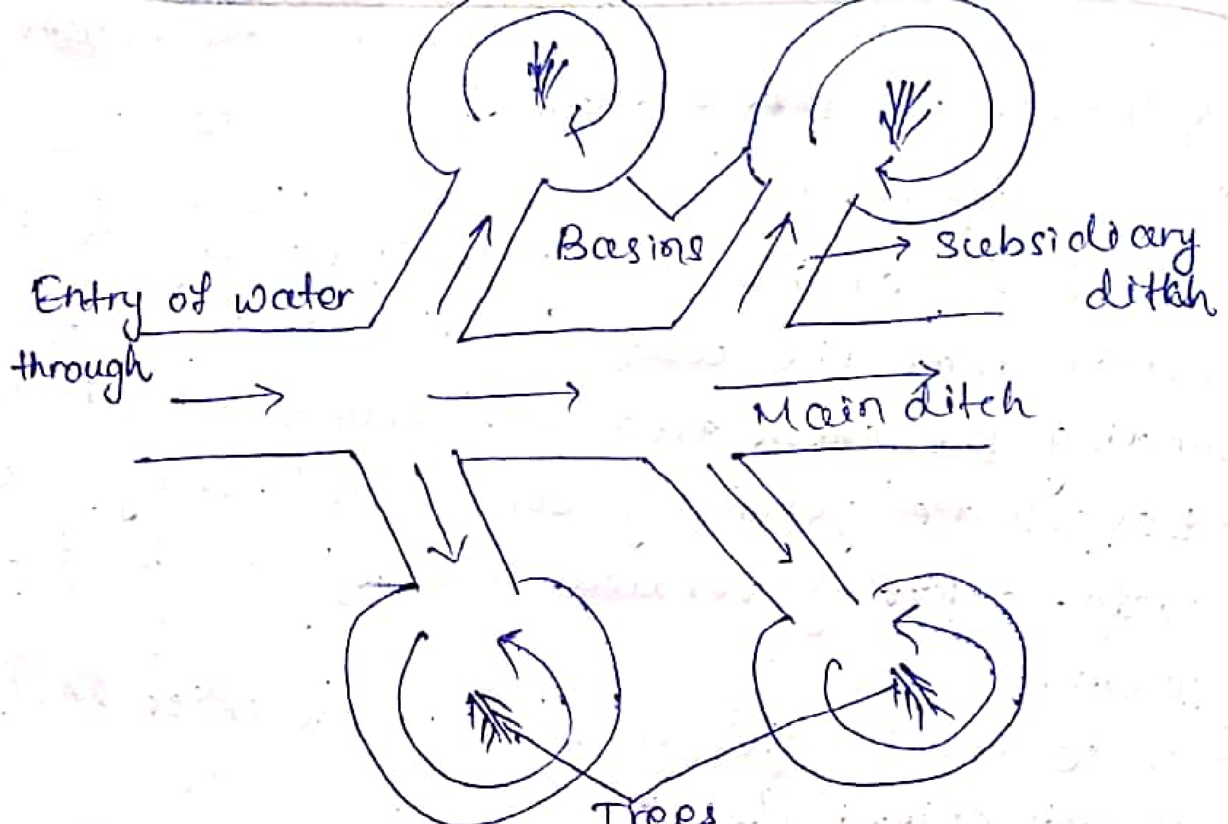
- Check flooding is similar to ordinary flooding except that the water is controled by surrounding the check area with low & flat levees.
- Levees are generally constructed along the contours having vertical interval of about 5 to 10 cm.
- These levees are connected with cross levees at convenient places.
- Here the check is filled with water at a fairly high rate & allowed to stand untill the water in this rate.



(Check flooding)

4) Basin flooding:-

- This method is a special type of check flooding & is adopted specially for orchard trees.
- One or more trees are generally placed in the

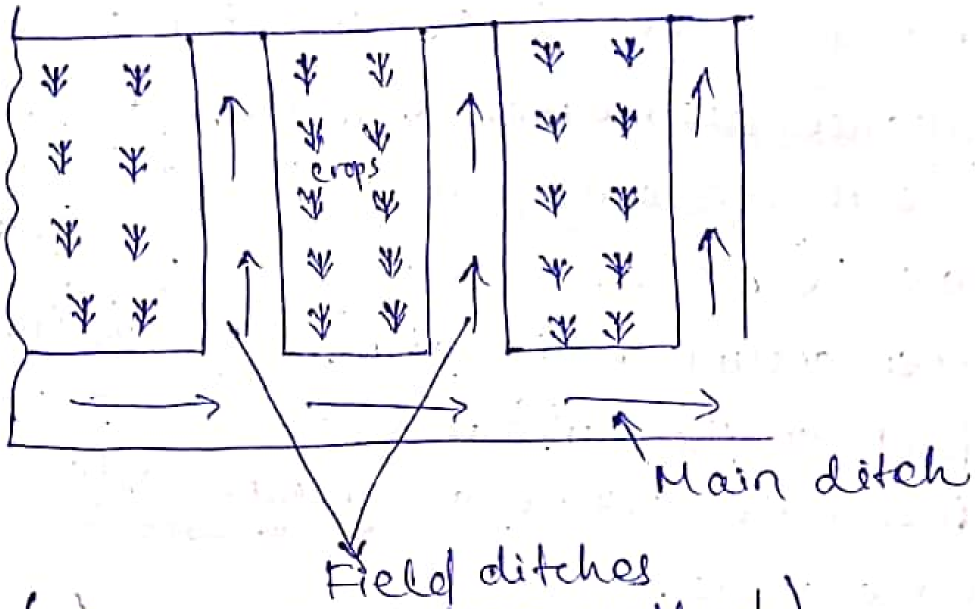


(Basin flooding)

basin. & the surface is flooded as in check method by ditch water.

(5) Furrow irrigation method:-

- In this method 1/5 to 1/2 of the land of the surface is wetted by water.
- Furrows are narrow filled ditches excavated between rows of plants & carry irrigation water through them.
- Furrows vary from 8 to 30 cm deep & may be as much as 400 m long.
- Deep furrows are widely used for row crops.



(Furrow irrigation Method)

(6) Sprinkler irrigation method :-

- In this method water is applied to the soil in the form of a spray through a network of pumps & pipes.
- It is very costly process & it can be used for all types of soils & for widely different topographie & slopes.
- It can be used for many crops because it fulfill the normal requirements of uniform distribution of water.

7) Drip irrigation method :-

- Drip irrigation is also called trickle irrigation & is the latest field irrigation technique & is meant for adoptation at places where their exist acute scarcity of irrigation water & other salt problems.
- In this method water is slowly & directly applied to the root zone of the plant.

CHAPTER-2 HYDROLOGY

→ Hydrology is the science of which deals with the occurance, distribution & movement of water on the earth including that in the atmosphere & below the surface of the earth. ~~including~~

→ Water occurs in the atmosphere in the form of vapour, on the surface as water, snow or ice & below the surface as ground water occuping all the voids.

Precipitation /Rainfall :-

→ The water which comes back to the surface of the earth in its various forms like rain, snow, hail etc is known as precipitation.

hail - Small pieces of ice

Hydrological cycle :-

(1) Precipitation
(2) Evaporation
(3) Infiltration
(4) Condensation

} Key words.

→ It is the process of depletion & replanishment of water resources.

→ The water of the universe always changes from one state to another state under the effect of the sun.

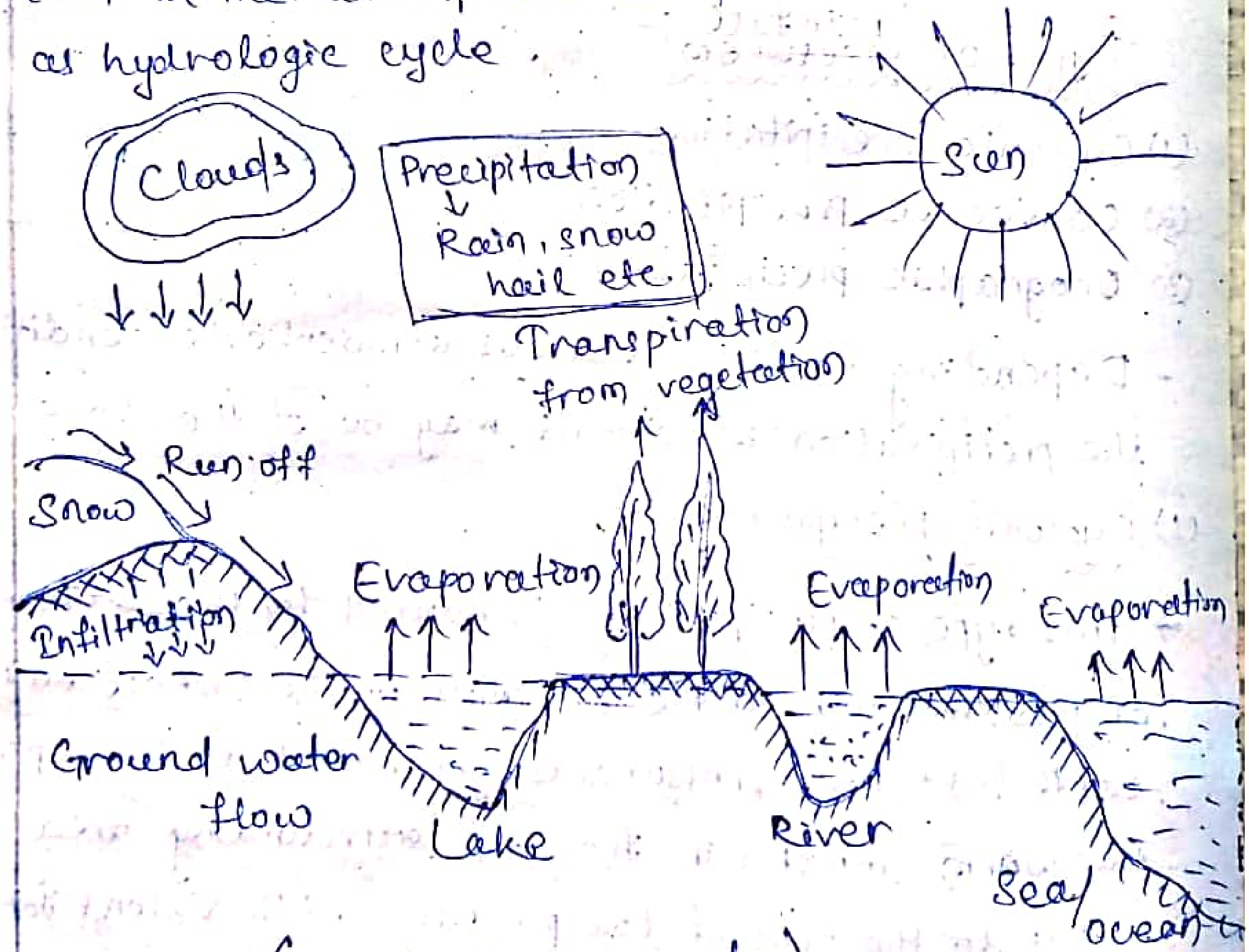
→ The water from the surface sources like lakes, rivers, oceans etc. converts to vapour by evaporation due to solar heat.

→ The vapour goes on accumulating continuously in the atmosphere.

→ This vapour is again condensed due to the sudden fall of temperature & pressure. Thus clouds are formed. These cloud again cause the precipitation.

→ Some of the vapours is converted to ice at the peak of the mountains.

→ The ice again melts in summer & close as river to meet the sea or ocean. This process of evaporation, precipitation & melting of ice goes on continuously like an endless chain & thus a balance is maintain in the atmosphere. This phenomenon is known as hydrologic cycle.



(Hydrologic cycle)

Precipitation & rainfall & its measurement :-

→ From the principle of hydrology cycle, water goes on evaporation continuously from the water surface on earth by the effects of sun.

→ The water vapour goes on collecting in the atmosphere upto a certain limit. When this limit exceed & temp. & pressure called to certain value the water vapour will get condensed & their by cloud is formed & return to the earth in the form rain, snowfall, hail etc.

→ This is known as rain fall or precipitation.

Types of ~~measurem~~ rainfall :-

(1) Cyclonic precipitation
(2) Convective Precipitation
(3) Orographic precipitation

- Depending upon the various atmospheric condition the precipitation & rainfall may be of the above type

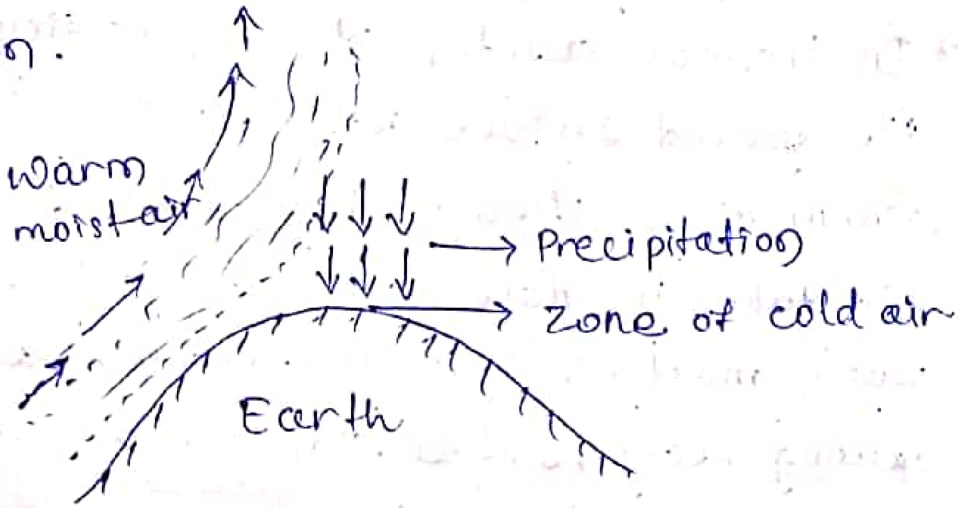
(1) Cyclonic precipitation :-

→ This type of precipitation is caused by the difference of pressure with in the air mass on the surface on the earth. If low pressure is generated at some place the warm moist air from the surrounding area rushes to the zone of low pressure with violent force. The warm moist air rises up with whirling motion. & gets condensed at higher altitude & ultimately heavy rainfall occurs.

→ It is of two types.
(a) Frontal
(b) Non-frontal

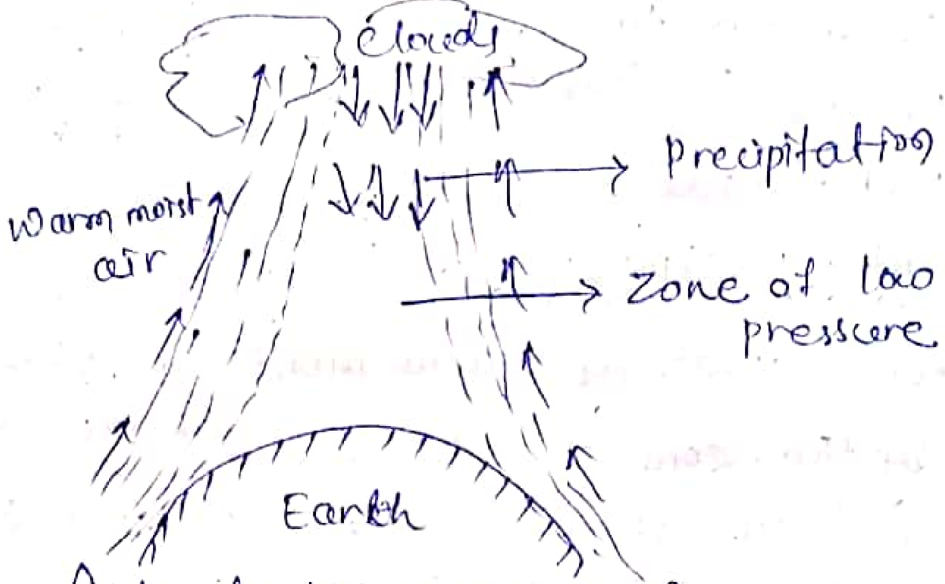
(a) Frontal precipitation :-

→ When the moving warm moist air mass is obstructed by the zone of cold air mass the warm moist air rises up (as it is lighter than cold air mass). to higher altitude where it gets condensed & heavy rainfall occurs. This is known as frontal precipitation.



(Frontal precipitation)

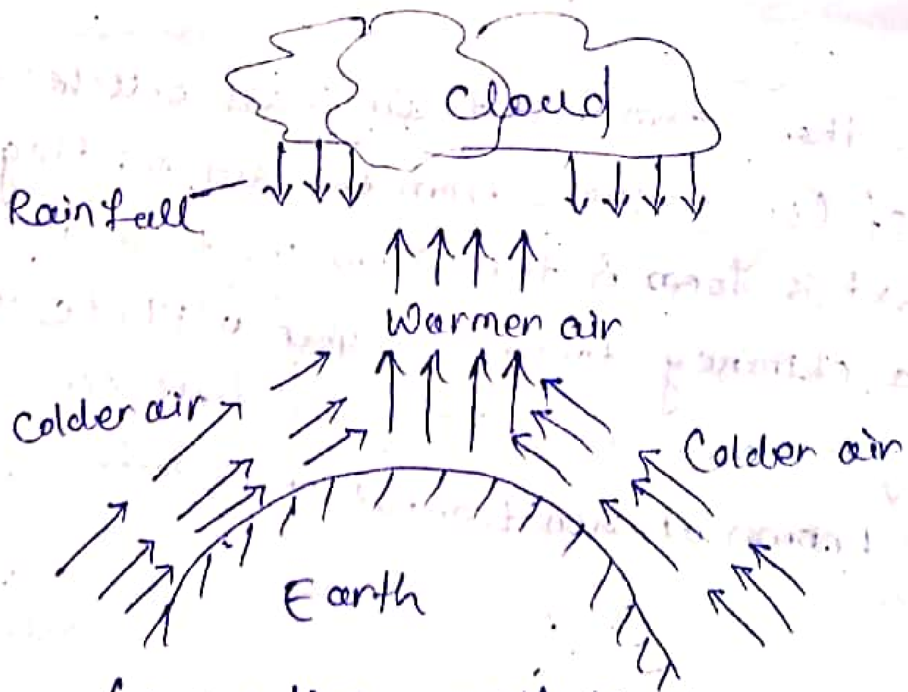
(b) Non-frontal
→ When the warm moist air mass crashes to the zone of low pressure from the surrounding air a pocket is form & the warm moist air rises up like a chimney towards higher altitude this air mass gets condensed & heavy rainfall occur. This is known as non-frontal precipitation.



(Non-frontal precipitation)

(2) Convective precipitation :-

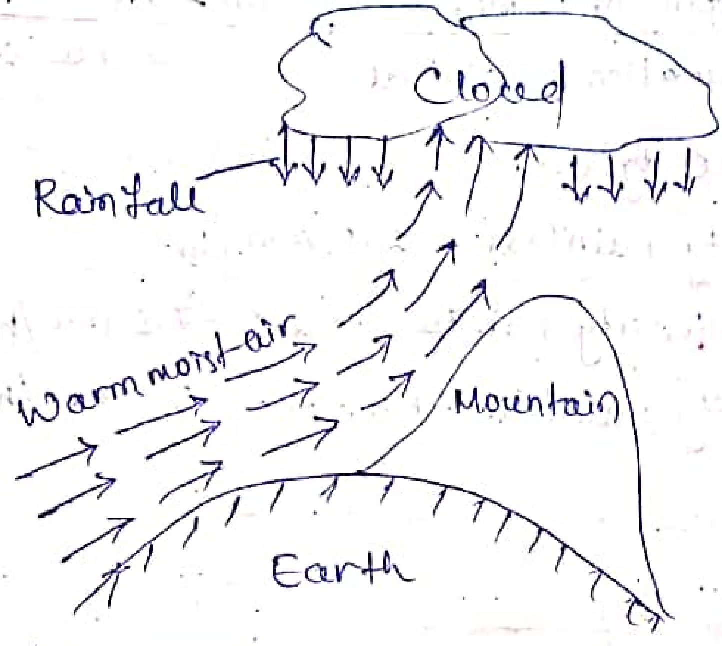
→ In tropical country when a perticular hot day, the ground surface gets heated unequally, the warm air is lifted to high altitude & the cooler air takes its place with high velocity thus the warm moist air mass is condensed at high altitude causing heavy rainfall. This is known as convective precipitation of rainfall.



(Convective precipitation)

(3) Orographic precipitation :-

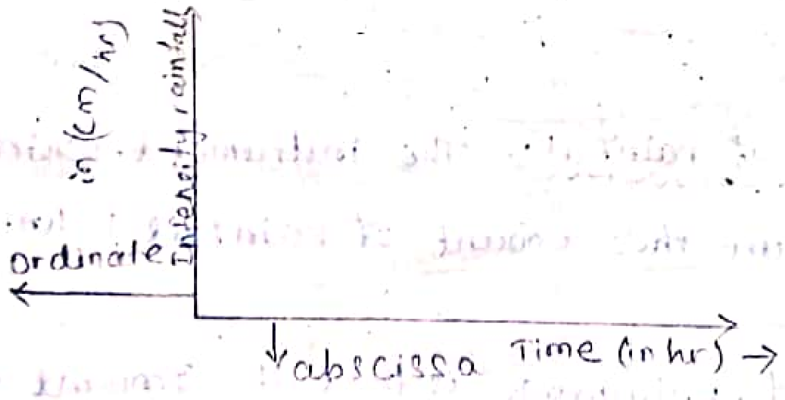
→ The moving warm moist air when obstructed by some mountain, rises up to high altitude it then gets condensed & precipitation occur this is known as orographic precipitation.



(Orographic precipitation)

Hyetograph :- The graphical representation of rainfall & run off is known as hyetograph.

→ The graph is prepared with intensity of rainfall (in cm/hr) on ordinate & time (in hours) as abscissa.



→ The infiltration capacity curve is drawn on this graph to show the amount of infiltration loss (shown by dotted portion).

→ The upper portion indicates the effective rainfall (shown by hatched line).

→ The centroid of the effective rainfall is ascertained of the graph for determination of total turn off at any specified period.

Intensity of rainfall :- It is defined as the rate at which rainfall occurs & expressed as cm/hr or mm/hr.

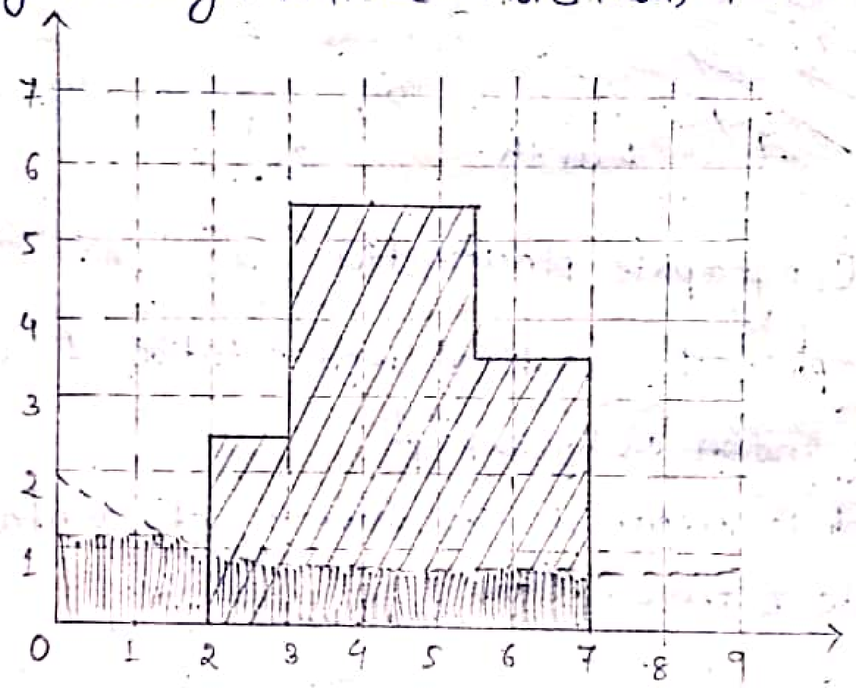
$$i = \frac{P}{t} = \frac{\text{depth of rainfall}}{\text{duration of rainfall}} = \frac{\text{amount of rainfall}}{\text{duration}}$$

→ It is of three types.

(i) Light intensity rainfall – 2.5 mm/hr

(ii) Moderate intensity rainfall – 2.5 – 7.5 mm/hr

(iii) Heavy intensity rainfall :- More than 7.5 mm/hr.



Measurement of rainfall :- The instrument which is used to measure the amount of rainfall is known as rain gauge.

- The principle of raingauge is that the amount of rainfall in a small area will present the amount of rainfall in a large area provided the metrological charecteristics of both small & large area are similar.

Types of Raingauge :-

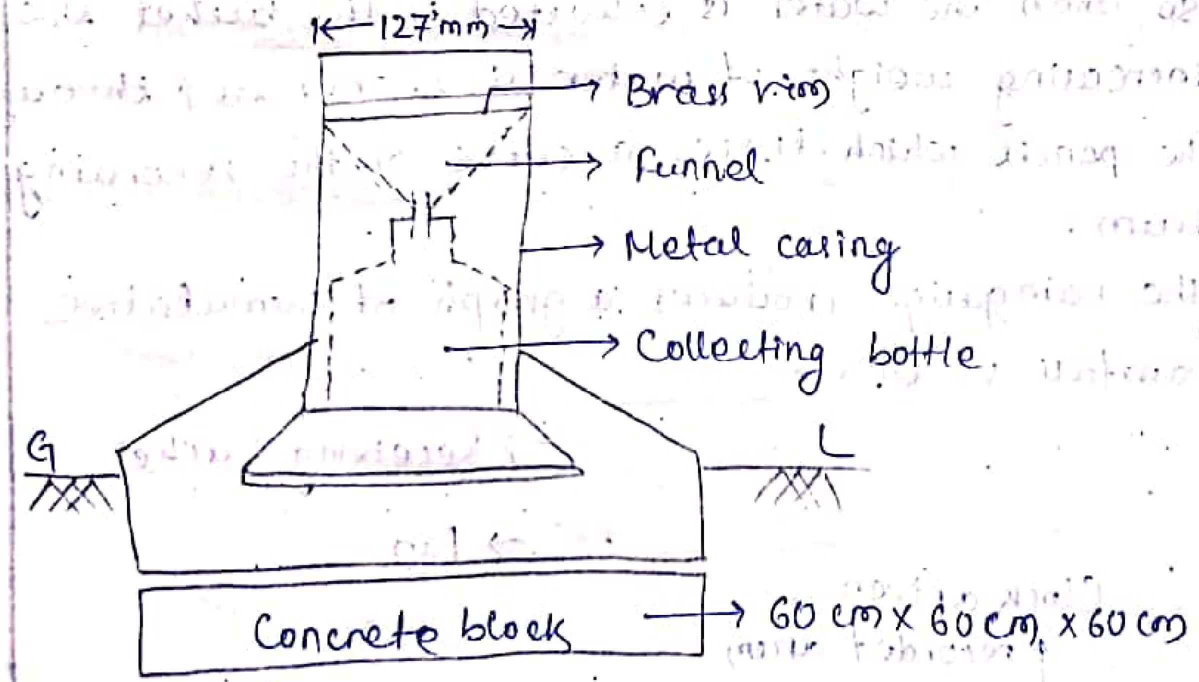
1) Non-recording type raingauge (Non-Automatic)
2) Recording type raingauge (Automatic)
   - a) Weighing bucket raingauge
   - b) Tipping bucket raingauge
   - c) Float type raingauge

1) Non-recording type raingauge :-

→ Symon's raingauge is a non-recording type raingauge which is most commonly used. It consist of metal casing of diameter 127 mm, which is set on concrete foundation.

→ A glass bottle of capacity about 100 mm of rainfall is placed within the casing.

→ A funnel with brass rim is placed on the top of the bottle.



(Symon's raingauge)

→ The rainfall is recorded at every 24 hours. In case of heavy rainfall the measurement should be taken 2-3 times daily, so that bottle does not overflow.

→ To measure the amount ... is taken off & the collected water is measured.

(2) Recording type raingauge:-

→ In this type of raingauge the amount of rainfall is automatically recorded on a graph paper by some mechanical device & no portion is required for measuring the amount of rainfall from the container.

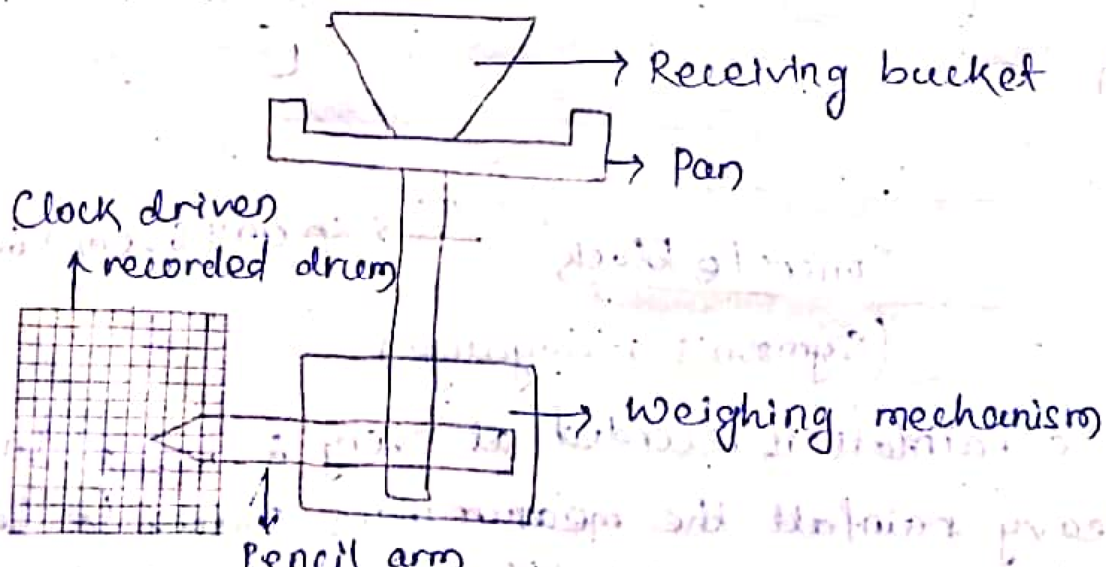
(a) Weighing bucket raingauge :-

→ This type of raingauge consist of a receiving bucket which is placed on pan. The pan is again fitted with some weighing mechanism.

→ A pencil arm is pivoted with the weighing mechanism is such a way that the movement of the bucket can be tressed by a pencil on the moving recording drum.

→ So when the water is collected in the bucket the increasing weight of water is transmitted through the pencil which traces a curve on the recording drum.

→ The raingauge produces a graph of cumulative rainfall vs time.



(Weighing bucket raingauge)

(b) Tipping bucket raingauge :- It consist of a circular collector of diameter 30 cm in which the rain water is initially collected.

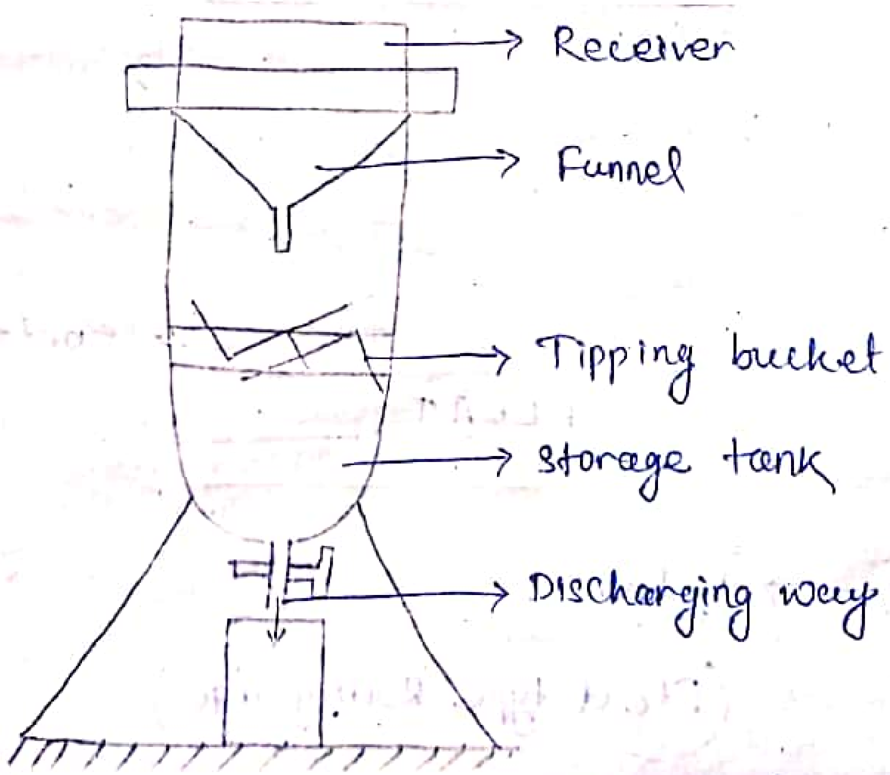
→ The rainwater is then passes through a funnel fitted to the circular collector & gets collected in two compartment tipping bucket pivoted below the funnel.

→ When 0.25 mm rain water is collected in one bucket then it tips & discharges the water to the storage tank.

→ At the same time the other bucket comes below the funnel & rainwater goes on collecting in it & then it tips & discharges the water.

→ In this way a circular motion is generated by the buckets which is transmitted to a pencil (which traces a wave like curve) on the sheet mounted on a revolving drum.

→ The total rainfall may be ascertained from the graph.



(Tipping bucket raingauge)

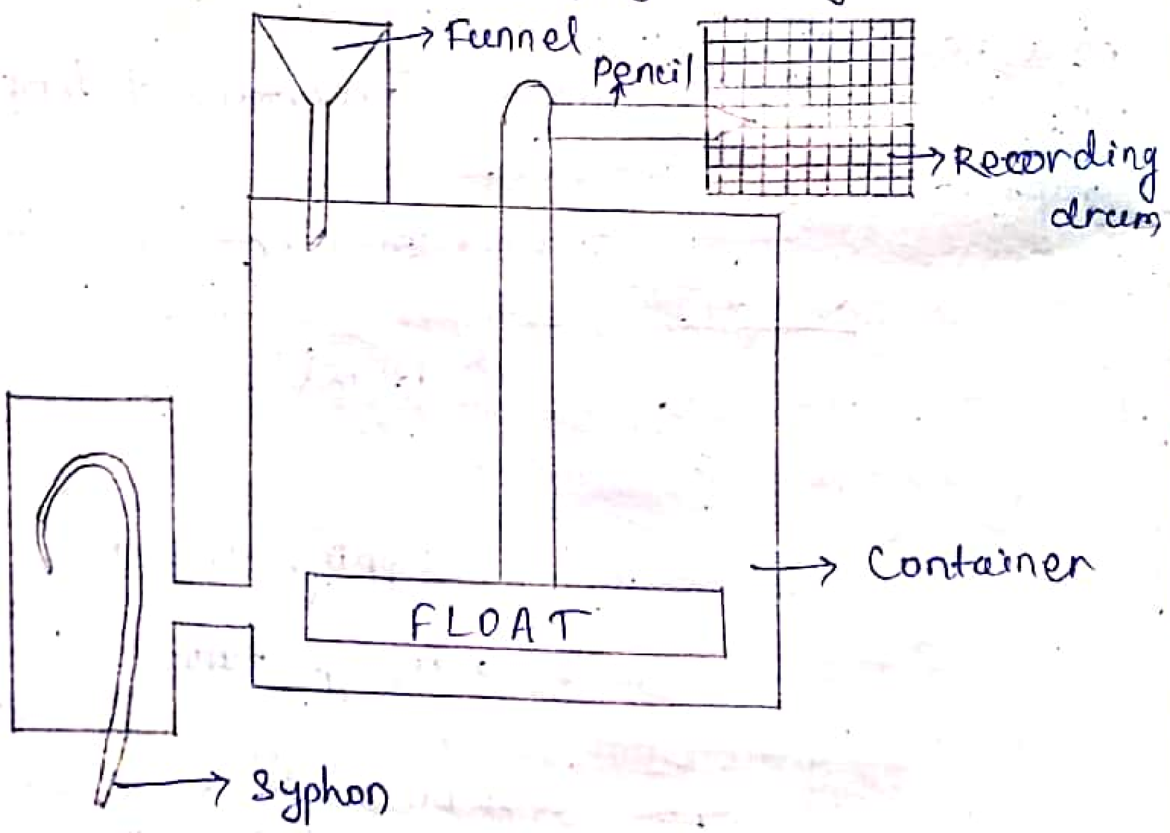
→ In this type of raingauge a funnel is provided at one end of rectangular container & rotating recording drum is provided at the another end.

→ The rain water enters the container through the funnel.

→ A float is provided with the container which rises up as the rainwater gets collected there,

→ The float consist of a rod which contains a pencil arm for recording the amount of rainfall on the graph paper dropped on the recording drum.

→ It consist of a syphon which start functioning when the float rises to some definite height & the container goes on emptying gradually.



(Float type Raingauge)

Catchment area :-

→ A hydrological catchment is defined as the area of land point (usually the sea).

→ A hydrological catchment can vary widely in size & other characteristics such as slope, geology, land use & may content different combination of fresh water bodies (surface water & ground water) & costal water.

Run off :- Run off or surface run off in hydrology is defined as the quantity of water discharged in surface streams.

→ Run off includes the waters that travel over the land surface & also interflows, that is the water that infiltrate the soil surface & travels by means of gravity towards a stream channel.

Estimation of flood discharge :-

→ The flood discharge may be estimated by two methods (a) Dicken's formula:

$$Q = C \times A^{3/4}$$

where, Q = Discharge in Cumec

A = catchment area in sq. km

C = A constant depending upon the factors affecting flood discharge.

= 11.5 is considered

(b) Ryve's formula

$$Q = C \times A^{2/3}$$

Where, Q = Discharge in cumec

A = Catchment area in sq km

C = Average value considered as 6.8.

Hydrograph :-

→ The hydrograph is a graphical representation of the discharge of river (in cumec) against the time (in hr/ days).

→ In rainy season at the biging of the rainfall there is only base flow (shown by the line AB)

→ After some period when the some losses (like evaporation & infiltration) are fulfilled, the surface run off start & hence the discharge of river goes increasing. Hence the limb of the curve rises which is called rising limb (shown by the line BC).

→ The line ~~reachest~~ reachest to the peak value at C.

→ Again when the rain stops the flow in the river decreases & the limb of the curve declines. This limb is known as the resession limb (shown by the line CD).

→ The discharge at the point 'C' indicate the max^m discharge.

→ The total area under the curve ABCDE indicates the total run off which includes the base flow & the direct runoff so to get the actual runoff the base flow is to be deducted by separating it from the total area.

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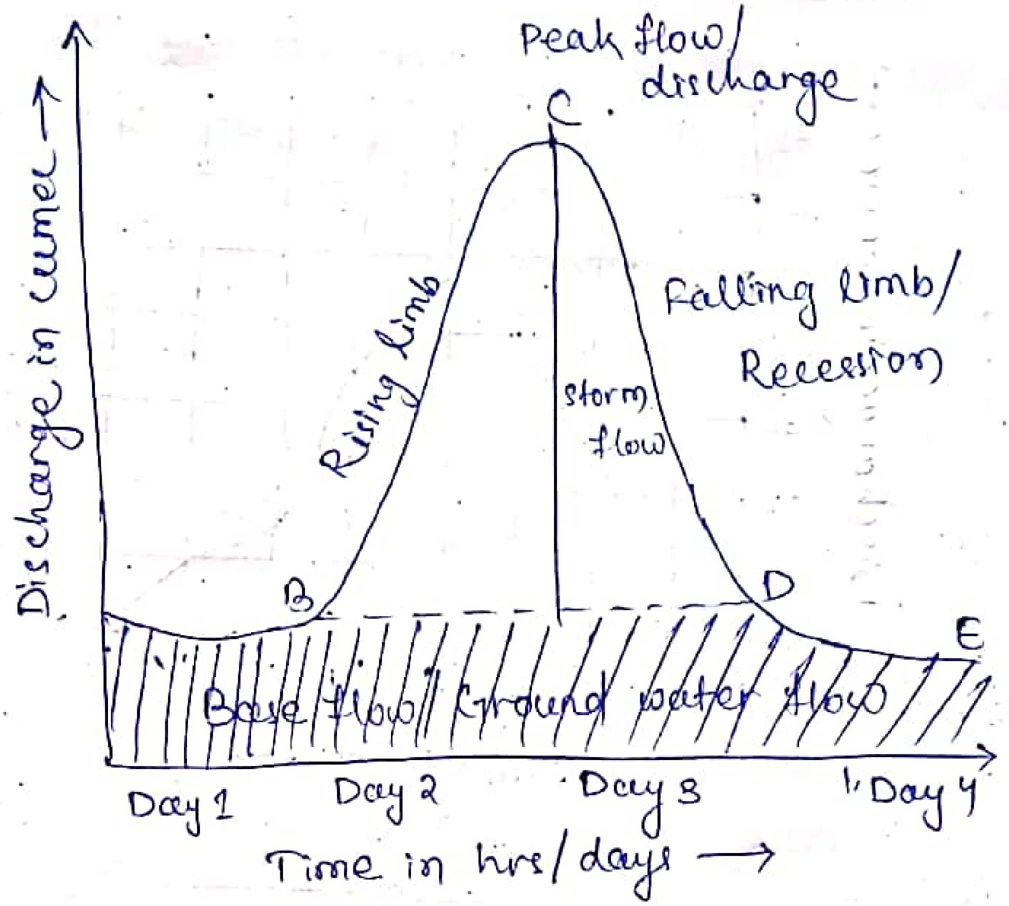

Unit hydrograph:-

→ A unit hydrograph may be defined as a hydrograph which is obtained from 1 cm. of effective rainfall (that is run off) per unit duration.

→ Here effective rainfall means the rainfall excess ie - run off which directly flows to the river or stream.

→ The unit duration is the period during which the effective rainfall is assume to be uniformly distributed.

→ The unit duration may be considered as 1hr, 2 hrs, 3 hrs, 4 hrs,..etc.

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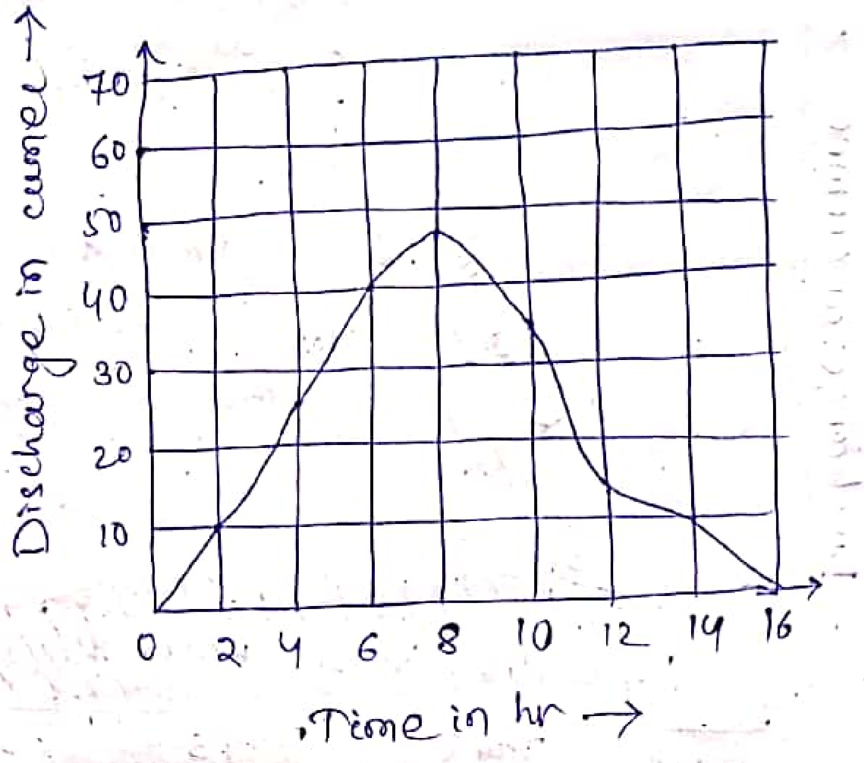

CHAPTER - 3

WATER REQUIRMENTS OF CROPS

→ The water requirements of crops is the amount of water that is required to meet the evapotranspiration rate so that crops may alive.

→ The evapotranspiration rate is the amount of wate that is lost to the atmosphere through the leaves of the plant as well as the soil surface.

Crop seasons:-

→ The period during which some perticular types of crops can be grown every year on the same land is known as crop seasons.

→ There are two types of crop season.

1) Khariff season

2) Rabi season

1) Khārif season :-

→ This season ranges from June to October.

→ The crops are sown in the very beginning of monsoon & harvested at the end of autumn.

Ex- Rice, Jute, Ground nut, ~~etc~~ tobacco, bajra etc.

2) Rabi season :-

→ This season ranges from October to March.

→ The crops are sown in the very beginning of winter & harvested at the end of spring.

Ex- Wheat, Mustard, Onion, gram, potato, barley etc.

✓ Duty (D) :- The duty of water is defined as no. of ~~hectors~~ hectares that can be irrigated by const. supply of water at the rate of one cumec through out the base period.

→ It is expressed in hectares / ~~per~~ cumec.

→ It is denoted by 'D'.

→ The duty of some common crops are

Crop	Duty in h/c
Rice →	900
Wheat →	1800
Cotton →	1400
Sugar cane →	800

✓ Delta :- Each crop requires certain amount of water per hectare for its maturity.

→ It is the total amount of water supplied to the crop (from first watering to last watering) each stored on the land with-out loss then there will be a thick layer of water standing on the land. This depth of water layer is known as delta

→ It is denoted by 'Δ'.

→ It is expressed in cm.

Kharif crop		'Δ' in cm
Rice	→	125
Maize	→	45
Ground nut	→	30
Millet	→	30

Rabi crop		'Δ' in cm
Wheat	→	40
Mustard	→	45
Gram	→	30
Potato	→	75

Base (B) :- Base period is the whole period from irrigation water 1st watering for preparation of the ground for planting the crop to its last watering before harvesting.

→ It is denoted by 'B'.

→ It is expressed in ~~base~~ days.

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

Relation between base, duty & delta :-

- Let there be a crop of base period 'B' days. Let 1 cumec of water be applied to this crop on the field for 'B' days.

The volume of water to this crop during 'B' days

$\Rightarrow V = (B \times 1 \times 24 \times 60 \times 60)\ m^3$

$\Rightarrow V = 86400\ B\ m^3$

Duty :- 1 m^3 supplied for 'B' days which matures 'D' hectares of land.

∴ This quantity of water (V) matures 'D' hectares of land or 10^4 D sq.m. of area.

⇒ Total depth of water applied on this land

$$= \frac{\text{Volume}}{\text{Area}} = \frac{86400\ B\ m^3}{10^4\ D\ m^2} = 8.64\ B/D\ m.$$

$$\Rightarrow \boxed{\Delta = 8.64\frac{B}{D}\ m = 864\frac{B}{D}\ cm}$$

Where, Δ = Delta in metre

B = Base period in days

D = Duty in hectares/cumec

Q. Find the delta for a crop when its duty is 864 hectares/cumec on the field. The base period of this crop is 120 days.

D = 864 hectares/cumec

B = 120 days

$\Delta = 864 \times \frac{120}{864} = 120\ cm$

Q. A crop requireds a total depth of 92 cm of water for a base period of 120 days. Find the duty of water.

$\Delta = 92$ cm

$B = 120$ days

$\Delta = 864 \frac{B}{D}$

$\Rightarrow D = 864 \frac{B}{\Delta} = 864 \times \frac{120}{92} = 1126.95 \simeq 1127$ h/c

Kor period :- The first watering is known as kor watering. Crops required maximum water during 1st watering after the crops have grown few cm.

→ The portion of the base period in which kor watering is needed is known as kor period.

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

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

For kharif crop :-

$\Delta = 60$ cm $= 0.6$ m

$B = 3$ weeks $= 21$ days

$A = 5000$ h

$D = 8.64 \frac{B}{\Delta} = 8.64 \frac{21}{0.6} = 302.4$ h/c

$Q = \frac{A}{D}$ ~~= 16.53~~

$= \frac{5000}{302.4} = 16.53$ cumec

For Rabi :-

$\Delta = 25$ cm $= 0.25$ m

$B = 4$ weeks $= 28$ days

$A = 4000$ h

$D = 8.64 \frac{B}{\Delta} = 8.64 \times \frac{28}{0.25} = 967.68$ h/c

Discharge $Q = \frac{A}{D} = \frac{4000}{967.68} = 4.13$ cumec

Gross Command Area (GCA) :-

→ It is the total area bounded within the irrigation boundry of a project which can be economically irrigated by the networks of canal, is known as Gross Command Area.

→ It includes both the culturable & unculturable area.

Culturable area :-

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

Unculturable area :-

→ The area where the agriculture can not be done & crop can not be grown is known as unculturable area.

Culturable command Area :-

→ The total area within an irrigation project where the cultivation can be done & crops can be grown is known as culturable command area (CCA).

→ CCA is of two catagories.

(1) Culturable cultivated area

(2) Culturable uncultivated Area

(1) Culturable cultivated Area :-

→ It is the area with in CCA where the cultivation has been actually done at present.

(2) Culturable uncultivated Area :-

→ It is the area with in CCA where the cultivation has been possible but it not been cultivated as present due to some reasons.

Intensity of irrigation :-

→ The total CCA may not be cultivated at the same time in a year due to various reason. Some area may remains vacent every year. So the intensity of irrigation may be defined as a ~~ratio~~ ratio of cultivated land for a perticular crop to the total culturable command area.

$$\text{Intensity of Irrigation} = \frac{\text{Cultivated Land}}{\text{Total CCA}} \times 100$$

Ex → CCA of an irrigation field is 120 hectares. out of which 90 hectares of the Land is cultivated during Kharif season. Then calculate the intensity of irrigation.

The intensity of irrigation during Kharif season will be $= \frac{90}{120} \times 100 = 75\%$

Q. A water course has a CCA of 1200 h. The intensity of irrigation ~~for crop~~ for crop A is 40%. The crop has a ~~bror~~ Kar period of 20 days & Kar depth.

is 10 cm. Calculate the discharge of the water course.

Solⁿ:-

Area under Irrigation = 1200 × 40%

= 1200 × 0.40 = 480 h.

Kar period = b = 20 days

Kar depth = Δ = 10 cm = 0.10 m

Duty d = $8.64 \frac{b}{\Delta}$

= $8.64 \times \frac{20}{0.10}$ = 1728 h/c

Discharge (Q) = $\frac{Area}{duty}$

= $\frac{480 h}{1728 h/c}$ = 0.27 c

Q. A water course has CCA of 2600 h. Out of which the intensity of irrigation for perennial sugarcane & rice crops are 20% & 40% respectively. The duty for these crops at the head of water course are 750 h/c & 800 h/c respectively. Calculate the discharge of the water course.

Sugarcane :-

Area under irrigation = 2600 × 20%

= $2600 \times \frac{20}{100}$ = 520 h

Duty d = 750 h/c

Discharge (Q) = $\frac{Area}{duty}$

= $\frac{520}{750}$ = 0.69 cumec

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Area under irrigation of rice

$= 2600 \times 0.40 = 1040$ h.

Duty = 800 h/c

Discharge (Q) = $\frac{Area}{Duty} = \frac{1040}{800} = 1.3$ cumec

Q. An irrigation canal has GCA of 80,000 h. Out of which 85% is culturable irrigable. The intensity of irrigation for Kharif season is 30% & for rabi season is 60%.. Find the discharge required at the head of canal if the duty at its head is 800 h/c for kharif season & 1700 h/c for rabi season.

GCA = 80,000 h

Area under CCA = 80000 × 85%

$= 80000 \times 0.85 = 68000$ h

For Kharif season :-

Intensity = 30%

Area under irrigation = 68000 × 30%

$= 68000 \times 0.30 = 20400$ h.

Duty d = 800 h/c

Discharge (Q) = $\frac{Area}{duty} = \frac{20400}{800} = 25.5$ cumec

For Rabi season :-

Intensity = 60%

Area under irrigation = 68000 × 60%

$= 68000 \times 0.60 = 40800$

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Duty $d = 1700$ h/c

Discharge (Q) = $\frac{\text{Area}}{\text{duty}} = \frac{40800}{1700} = 24$ cumec.

Field capacity:-

→ Immediately after a range of irrigation water application when all the gravity water has drained down to the water table a certain amount of water is retained on the surfaces of soil grains by molecular attraction by wore bond.

→ This water can not be easily drain under the action of gravity & this is called the field capacity

→ It is the water content of a soil after free drainage has taken place for a sufficient period.

→ The field capacity of water is expressed as the ratio of the weight of water retained in unit area to the weight of same volume of dry soil in unit area.

Depth of water stored in root zone:-

→ In order to estimate the depth of water stored in the root zone of soil containing water.

Let 'd (m)' be the depth of root zone &

'F_c' be the field capacity.

Let γ_d = Dry unit weight of soil.

γ_w = Unit weight of water.

Let us consider unit area as 1 m^2 area of soil. ~~Then Fc = Wt of water retained~~

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~~Then,~~

~~$F_c = \frac{\text{Wt. of water retained in unit area}}{\gamma_d \times 1 \times d}$~~

Hence, the volume of soil = $d \times 1\ m^3$

Dry unit weight of soil is γ_d KN/m^3,

Then weight of $d\ m^3$ of soil is = γ_d KN/m^3 × $d\ m^3$

$$\Rightarrow F_c = \frac{\text{Weight of water retained in unit area}}{\gamma_d \times 1m^2 \times d}$$

Hence,

weight of water retained in unit area of soil = $\gamma_d \times d \times F_c$

∴ Volume of water stored in unit area of soil

$$= \frac{\gamma_d \times d \times F_c}{\gamma_w}$$

⇒ Total water storage capacity of soil in 'd' depth of water = $\frac{F_c \times \gamma_d \times d}{\gamma_w}$

Available moisture depth (d_w) is given by

$$d_w = \left(\frac{\gamma_d \times d}{\gamma_w}\right)(F_c - \text{wilting coefficient})$$

$$d_w = \left(\frac{\gamma_d \times d}{\gamma_w}\right)(F_c - W_c)$$

$$d_w = S_g \times d\,(F_c - W_c)$$

$$\left(S_g = \frac{\gamma_d}{\gamma_w}\right)$$

~~Wilting co-efficient~~ :-

Permanent wilting point :-

→ Permanent wilting point is also called wilting coefficient. It is defined as the amount of moisture held by soil which can not be abstracted by the roots for transpiration. At this point the wilting of the plant occurs. It is also expressed in percentage.

→ The permanent wilting point depends upon the rate of water used by the plant, the depth of the root zone & the water holding capacity of the soil.

→ Permanent wilting point is higher in a hot climate than in a cool climate.

Q. The field capacity of a certain soil is 15% & the moisture content of the soil before irrigation is 8%. Determine the depth up to which the soil will be wetted with an application of ~~1~~60 mm of water. Take the γ_d is 15.3 KN/m³.

Given data :-

$F_c = 15\% = 0.15$

Moisture content before irrigation = 8% = 0.08

~~before = 8% = 0.08~~

depth d = 60 mm

$\gamma_d = 15.3 \ KN/m^3$

Depth of water stored = $\frac{\gamma_d}{\gamma_w} \times$ ~~(d)~~ depth of root zone $\times (F_c - W_c)$

$$\Rightarrow 60 = \frac{15.3}{9.81} \times d \times (0.15 - 0.08)$$

$$\Rightarrow d = \frac{60 \times 9.81}{15.3 \times (0.15 - 0.08)} = 550 \text{ mm}$$

Q. Find the field capacity of a soil for the following data.

Given data:-

Root zone depth (d) = 2 m

Existing water content = 5 %

Dry density of soil = 15 KN/m³

Water applied to the soil = 500 m³

Area of plot = 1000 m²

Water loss due to evaporation & deep percolation = 10 %.

Soln:- Total water applied = 500 m³

Loss of water 10 %

~~Use~~ Water used in the soil = 100 − 10 = 90 %

$$\text{Water used} = \frac{500}{100} \times 90 = 450 \text{ m}^3$$

Weight of water retained = 450 × 9.81

= 4414.5 KN

Weight of dry soil = $\gamma_d \times 1 \times d$

= 15 × 1000 × 2 = 30000 KN

$$F_c = \frac{4414.5}{30000} = 0.147 = 14.7\%$$

Total field capacity = 14.7 + 5 = 19.7 %

Q. A loam soil has field capacity 22 % & wilting coefficient of 10 %. The dry unit weight of soil is 15 KN/m³. If the depth of root zone is 70 cm determine the storage capacity of the soil. Irrigation water is applied when moisture content falls to 14 %.

If the water application efficiency is 75%. Determine the water depth required to be applied in the field.

Given data :-

$\gamma_d = 15\ KN/m^3$

$\gamma_w = 9.81\ KN/m^3$

Field capacity $F_c = 22\% = 0.22$

Wilting coefficient $= 10\% = 0.10$

Depth of root zone $= 70\ cm = 0.70\ m$

Maximum storage capacity $= \left(\frac{\gamma_d \times d}{\gamma_w}\right)(F_c - W_c)$

$= \left(\frac{15 \times 0.70}{9.81}\right)(0.22 - 0.10)$

$= 1.07 \times 0.12 = 0.128 = 12.8\ cm$

Water application efficiency $= 75\% = 0.75$

When $W_c = 14\% = 0.14$

Storage capacity $= \frac{\gamma_d \times d}{\gamma_w}(F_c - W_c)$

$= \left(\frac{15 \times 0.70}{9.81}\right) ~~(0.14 - 0.10)~~ (0.22 - 0.14)$

$= ~~1.07 \times 0.04 = 0.0428 = 4.28~~$

$= 1.07 \times 0.08 = 0.085 = 8.5\ cm$

Q. The root zone of an irrigation soil has dry weigh of 15 KN/m³ & a field capacity of 30%. The root zone depth of a certain crop is 0.8 m having perma wilting coefficient 8%. Determine

(i) Depth of moisture in the root zone at Fc

(ii) Depth of moisture in the root zone in the permanent wilting coefficient.

(iii) Depth of water

Data Given :-

$\gamma_d = 15\ KN/m^3$

$F_c = 30\% = 0.3$

$W_c = 8\% = 0.08$

$d = 0.8\ m$

(i) Depth of moisture in the root zone at Fc

$$= \frac{\gamma_d}{\gamma_w} \times F_c = \frac{15}{9.81} \times 0.3 = 0.45\ m$$

(ii) Depth of moisture in the root zone in permanent wilting coefficient $= \frac{\gamma_d}{\gamma_w} \times W_c = \frac{15}{9.81} \times 0.08 = 0.12\ m$

(iii) $d = \frac{\gamma_d}{\gamma_w} \times d\ (F_c - W_c)$

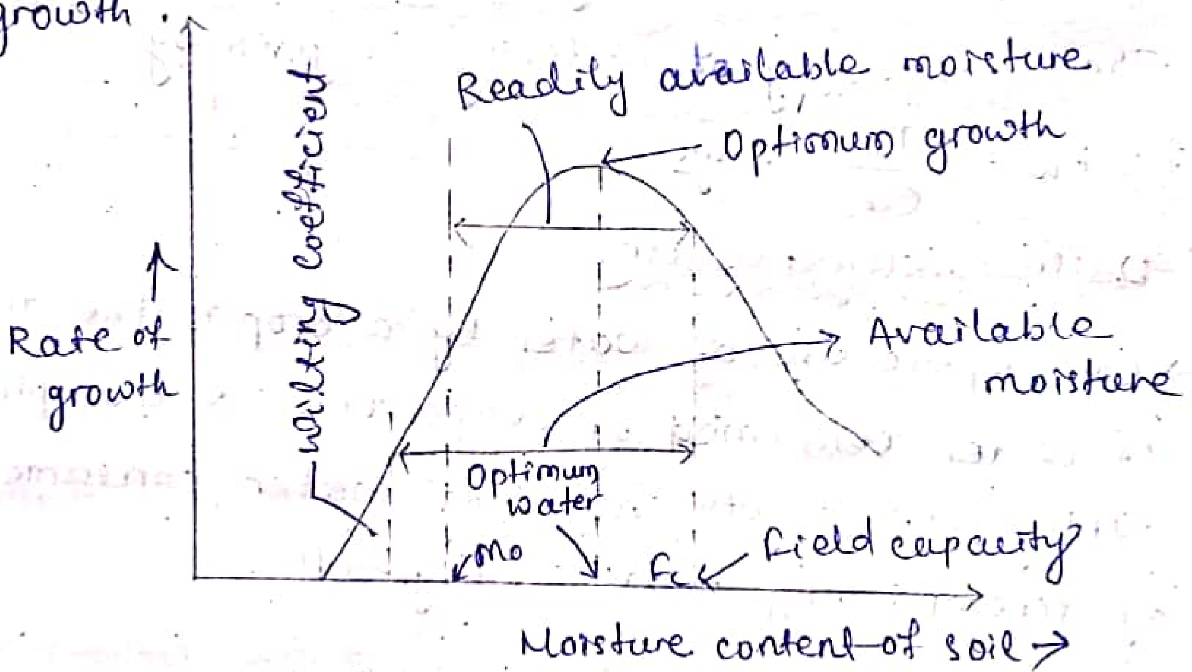
$$= \frac{15}{9.81} \times 0.8 \times (0.3 - 0.08) = 0.26$$

Frequency of Irrigation :-

→ Irrigation water is applied to the field to raise the moisture content of the soil up to its field capacity.

→ The application of water is then stopped. The water content also reduces gradually due to transpiration & evaporation. If the moisture content is dropped below the requiside amout, of the growth of the plants gets disturb. So the moisture content requires to the immediately replanished by irrigation & it should be raised to the field capacity. This process is known as frequency of irrigation.

→ It is essential to maintain readily available water in the soil if crops are to make satisfactory growth.



→ Available moisture is the moisture between wilting point & field capacity.

→ The readily available moisture is that moisture which is easily extracted by the plant & is approximately 75% - 80% of the available moisture.

→ If d is the depth of root zone in m.

Fc is the field capacity & Mo is the lower limit of readily available moisture content.

Then the depth of water, dw.

dw to be given during each watering is found from the expression

$$d_w = \frac{\gamma_d}{\gamma_w} \times d \left(F_c - m_o\right) \text{ m} \ell.$$

Where, γ_d = Dry unit weight of soil,

γ_w = Unit weight of water

d = Depth of root zone.

F_c & m_o to be expressed in ratio.

If 'C_u' is the the daily consumptive use rate Then frequency of watering is given by

$$F_w = \frac{d_w}{C_u} \text{ days}$$

Daily consumptive use:-

→ Consumptive use of water by a crop is the depth of water consumed by evaporation & transpiration during crop growth including water consumed by accompanying ~~add~~ weed growth.

Time required to irrigate a certain area:-

Let t be the time required to apply the desired water depth dw. To bring the water level in the soil from m_o to the field capacity fc over a irrigation field of area A.

If 'q' is the discharge in the ~~field~~ channel in cumec. Then, $t = \frac{A \cdot d_w}{q}$ sec.

If Area A is expressed in hectare.

Then, $t = \frac{d_w}{q} \times A \times 10^4$ sec.

Q. After how many days will you supply water to soil in order to ensure efficient irrigation of the given crop. If

(i) Field capacity of soil (F_c) = 27% = 0.27

(ii) Permanent wilting coefficient (w_c) = 14% = 0.14

(iii) Dry density of soil γ_d = 15 KN/m³

(iv) Depth of root zone = 75 cm

(v) Daily consumptive use of water for the given crop C_u = 11 mm

Available moisture = 0.27 − 0.14 = 0.13

~~Readily available moisture = 0.13 × 75/100 =~~

~~but~~ Let the readily available moisture be 80% of available moisture.

Readily available moisture = $0.13 \times \frac{80}{100} = 0.104$
$= 10.4\%$

Lower limit of readily available moisture

m_o = F_c − Readily available moisture

$= 0.27 - 0.104 = 0.166$

· Depth of water stored in root zone during each watering $d_w = \frac{\gamma_d}{\gamma_w} \times d\,(F_c - m_o)$

$= \frac{15}{9.81} \times 0.75 \times (0.27 - 0.166)$

$= 0.119$ m $\approx$ 11.9 cm

$F_w = \frac{d_w}{C_u} = \frac{11.9}{1.1} = 10.81$ days

$= 11$ days

Hence water should be applied after every 11 days.

Chapter-4 FLOW IRRIGATION

→ The irrigation system in which the water flows under gravity from the source to agricultural lan[d] is known as flow irrigation.

Perennial irrigation :-

→ In this irrigation water is available through out the year. Hydrolic structures are necessary across the river for rising the water level.

Types of canal :-

(1) Based on the purpose.

→ Based on the purpose of service the canals are of four types.

(a) **Irrigation canal :-**

→ The canal which is constructed to carry out water from the source to the agricultural land for the purpose of irrigation is known as irrigation canal.

(b) **Navigation canal :-**

→ The canal which is constructed for the purpose of inland navigation is known as navigation 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.

(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.

(2) Based on the nature of supply :-

→ Based on the nature of supply the canal are 2 types.

(a) Inundation canal :- The canal which is excavated from the banks of the inundation river to carry the water to agricultural land in rainy season only is known as inundation canal.

(b) Perennial canal :- The canal which can supply water to the agricultural land throughout the year is known as perennial canal.

(3) Based on discharge :-

According to discharge capacity the canals are.

(a) Main canal :- The large canal which is taken directly from the diversion head work or from the storage to supply water to the network of the small canal is known as main canal.

(b) Branch canal :- The branch canal are taken from either side of the main canal at suitable points so that the whole command area can be covered by the networks.

(c) Distributory ~~canal~~ channel :- These channels are taken from the branch canals to supply water to different sectors.

(d) Field channels :- These channels are taken from the out lets of the distributory channel by the cultivator to supply water to their own lands.

(4) Based on alignment :-

→ Depending upon the alignment the canal are following types.

(a) Ridge or water shed canal :- The canal which is aligned along the ridge line is known as ridge canal. These canals usually take-off from the contour canal.

(b) Contour canal :- The canal which is aligned approximately parallel to the contour lines is known as contour canal.

(c) Side slope canal :- The canal which is aligned approximately at right angle to the contour lines is known as side slope canal.

✓ Canal section :-

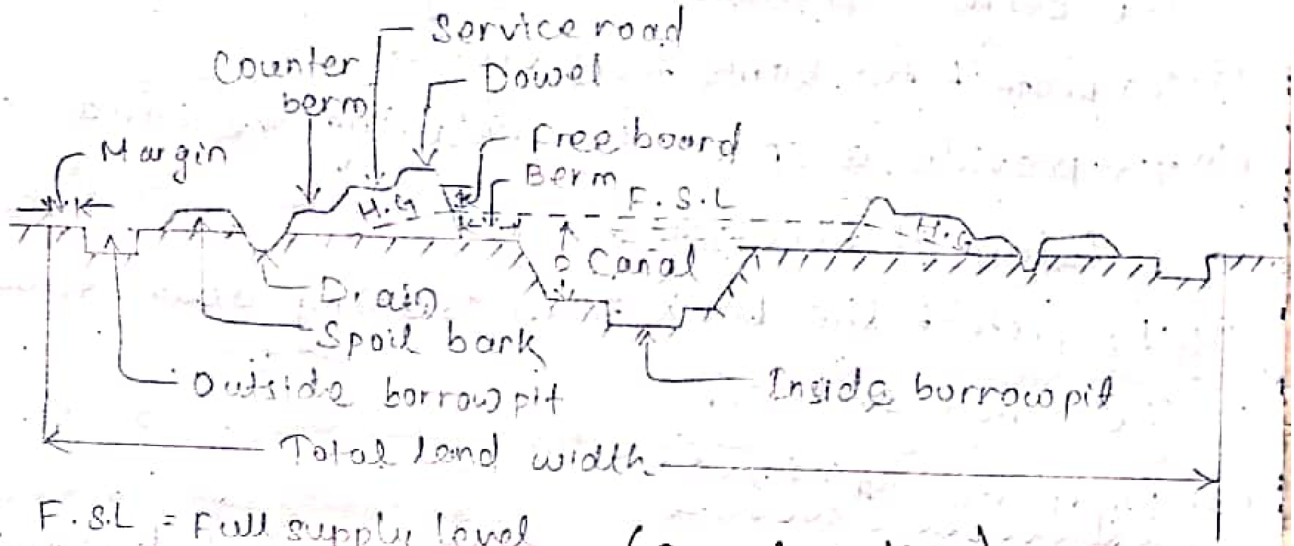
Terms related to canal section :-

(1) Canal bank
(2) Berm
(3) Hydraulic gradient
(4) Counter beam
(5) Free board
(6) Side slope
(7) Service road & 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 necessery to retained water in the canal to the full supply level.

→ According to different side conditions the bank of the canals are of two types :

(i) Canal bank of cutting :-

→ The bank are constructed on the both side of the canal to provide only a inspection road.

→ The side slope will 1.5 : 1 or 2:1 according to the nature of the soil.

(ii) Canal bank in full banking :-

→ Both canal bank are constructed above the ground level. The height of the bank will be high & the section will be large due to hydraulic gradient.

(2) Berm :- The distance between toe of the bank & the top edge of the cutting is called berm.

- The berm is provided following reasons :

(i) To protect the bank from erosion

(ii) To provide a space for widening the canal section in future if necessary.

(iii) To protect the bank from sliding down towards the canal section.

(3) Hydraulic gradient :-

→ When water is retained by the canal bank the seepage occurs through the body of the bank.

→ Due to the resistance of soil the saturation line forms a slopping line which may pass through contry side of the bank.

→ The ~~saturat~~ slopping line is known as hydraulic gradient.

Soil		Hydraulic Gradient
Clayey soil	→	1:4
Sandy soil	→	1:6
Alluvial soil	→	1:5

(4) Free Board :-

→ It is the distance between the full supply level & top of the bank.

→ The amount of free board varies from 0.6 m to 0.75 m.

→ It is provided for the following reasons.

(i) To keep a sufficient margin so that the canal water does not over top the bank.

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

(5) Dowel :-

→ The protective small embankment which is provided on the canal side of the service road for safety of the vehicles playing on it is known as Dowel or dowla.

→ The top width is generally 0.5 m & the height of above the road level is about 0.5 m.

(6) Service road :-

→ The road is provided on the top of the canal bank for inspection & maintainance work is known a service road or inspection road.

→ For main canal the service roads are provided on both sides of the bank but for branch canal the road is provided on one side of the bank only.

→ The width of the service road for main canal varies from 3-4 m.

(7) Counter berm :-

→ When the water is retained by a canal bank the hydraulic gradient line passes through the body of the bank, the gradient should not intercept the outer side of the bank.

→ It should pass through the base & a minimum cover of 0.5 m should always be maintained. It may occur that the hydraulic gradient line inter... of the bank in that case a projection is provided on the bank to obtain minimum cover. This projection is known as counter berm.

(8) Borrow pit:-

→ When the canal is constructed in partially cutting & partially banking the excavated earth may not be sufficient for forming the required bank.

→ In such case the extra earth required for the construction of banks is taken from some pits which are known as borrow pits.

→ The borrowpit may be inside or outside of the canal The maximum should be 1m.

(9) Spoil bank:-

→ When the canal is constructed in full cutting the excavated earth may be much sufficient for forming the bank.

→ In such case the extra earth is deposited in the form of small bank which is known as spoil bank.

→ The spoil banks are provided on one side or both side of the canal bank depending upon the quantity of extra earth & available space.

(10) Side slope:-

→ The side slope of the canal bank & canal section depends upon the angle of repose of the soil existing on site. So to determine the side slope of different sections the soil sample should be collected from the site & should be tested in the soil testing laboratory.

Type 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

(ii) Land width :-

→ The total land width required for construction of canal depends upon the nature of site condition. such as fully in cutting or fully in banking or partially in cutting or partially in banking.

→ To determine the total width the following dimension should be added.

(i) Top width of the canal
(ii) Twice the berm width
(iii) Twice the bottom width of bank
(iv) A margin of 1m from the heel of the bank on both side.
(v) Twice of the width of the external borrowpit if any required.
(vi) A margin of 0.5 m from the outer edge of borrowpit on both sides if external borrowpit becomes necessary.

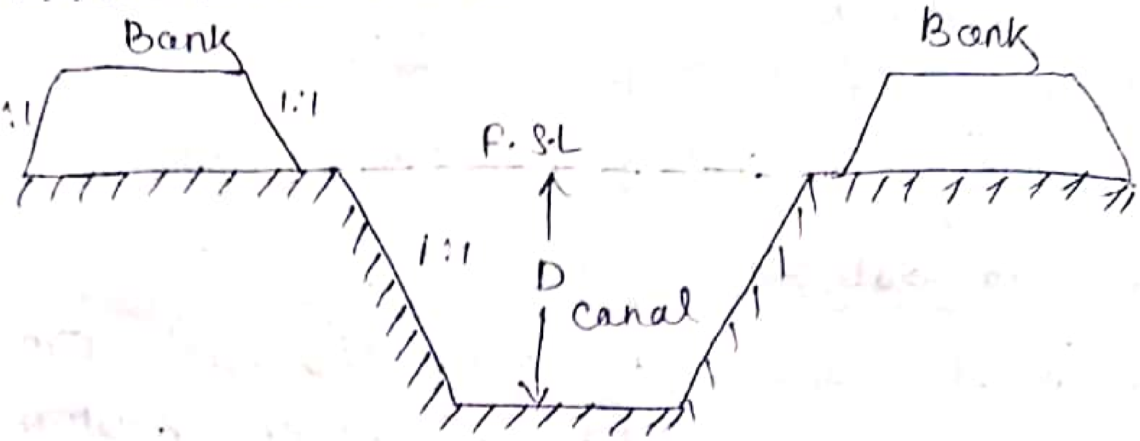
Balancing depth :-

→ If the quantity of excavated earth can be fully utilised when making the bank on both side then that canal section is known as economical section.

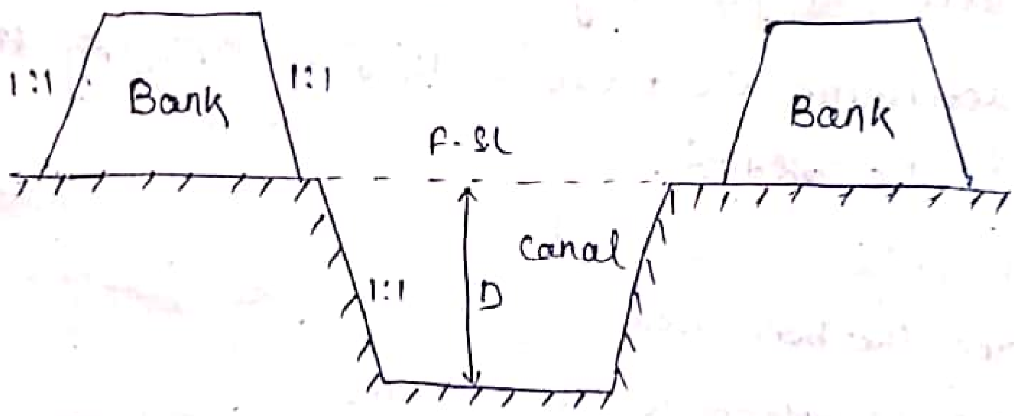
→ The depth of cutting for the ideal condition is known as balancing depth.

Sketches of different canal cross section :-

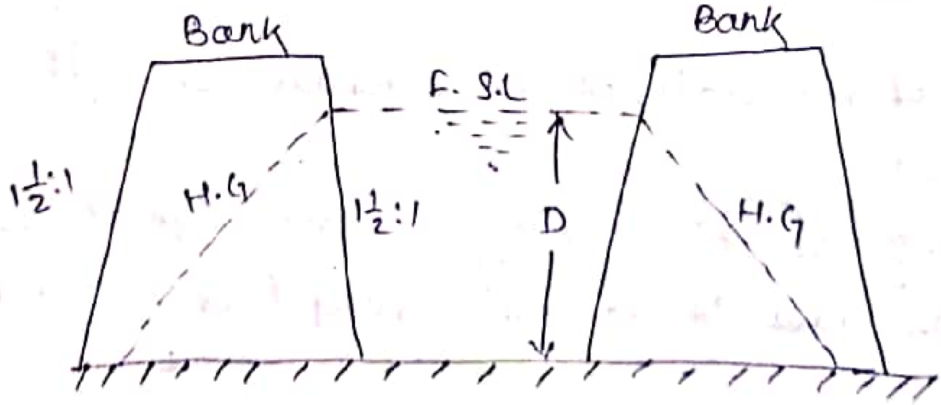
a) Canal in fully cutting :-



b) Canal in partially cutting & partially banking :-



c) Canal in fully banking :-



Canal Lining :-

→ Canal Lining is the process of reducing seepage loss of irrigation water by adding an inpermeable layer to the edges of the trench.

→ The seepage can result in losses of 30-50% of Irrigation water from canals so adding lining can make irrigation system more efficient.

Objects of canal lining :-

1) To control seepage.
2) To prevent water logging.
3) To increase the capacity of canal.
4) To control the growth of weeds.
5) To protect the canal from damage by flood.

Advantages of canal lining :-

→ It reduces the loss of water due to seepage & hence the duties is enhanced.
→ It controls the water logging & hence the bed effects of water logging are eliminated.
→ It provides smooth surface & hence the velocity of flow can be increased.
→ Due to increased velocity the discharge capacity of a canal is also increased.
→ Due to increased velocity the evaporation loss also be reduced.
→ The increased velocity eliminates the posibility of silting in the canal bed.
→ It controls the growth of weeds along the canal sides & bed.
→ It provides the table section of the canal.
→ It prevents the subsoil salts to come in contac with the canal water.

→ It reduces the maintainance cost of the canal.

Disadvantages :-

→ The initial cost of canal lining is very high.

→ It take too much time to complete the project work

→ It involve much difficulties for preparing of damaged section of laying.

Types of lining :-

→ The followings are the types of lining according to their site conditions.

(1) Cement concrete lining
(2) Pre-cast concrete lining
(3) Cement mortar lining
(4) Lime concrete lining
(5) Brick lining
(6) Boulder lining
(7) Short crete liniqg.
(8) Asphalt lining
(9) Clay lining
(10) Soil cement lining.

(1) Cement concrete lining :-

→ This type of lining is recomanded for canal in full banking.

→ It is widely accepted as best impervious lining.

→ The velocity of flow may be kept above 2.3 m/sec

→ It can eliminate completely growth of weeds.

→ Following are the step for cement-concrete lining.

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properly with a layer of sand about 15 cm then a slurry of cement & sand (1:3) is spread uniformly over the prepared bed.

(b) Laying of concrete:-

→ The cement concrete of grade M_{15} is spread uniformly according to the desired thickness 100-150 mm after laying the concrete is tapped untill the slurry comes on the top then the curing is done for 2 weeks.

(2) Pre-cast concrete lining:-

→ The lining is recomanded for the canal in full banking.

→ It consist of pre-cast concrete slabs of size (60 cm × 60 cm × 5 cm) which are laid along the canal bank & bed. with cement mortar (1:6).

→ A network of 6 mm diameter rod is provided in the slab with spacing 10 cm centre to centre distance.

→ The slabs are laid in the following sequence

- The sub-grade is prepared by properly ramming the soil with a layer of sand.
- The slab are stacked as per estimate along the coarse of the canal.
- The curing is done for a week.

(3) Cement mortar lining:-

→ This type of lining is recomanded for the canal in fully cutting where hard soil or clayey soil is available.

→ The thickness of cement mortar (1:4) is generally 2.5 cm.
This lining is impervious but is not durable the curing should be done properly.

(4) Lime concrete lining :-

→ When hydraulic lime, surkhi & brick ballast are available in planty along the coarse of the canal or in the utility of the Irrigation project then the lining of the canal may be made by lime concrete of properHon (1:1:6) (1:

→ The thickness of concrete varies from 150 mm - 225 mm & the curing should be done for longer period.

→ This lining is less durable than cement concrete lining.

(5) Brick lining :-

→ This lining is prepared by durable layer brick flat soling laid with cement mortar (1:6) over the compacted sub-grade.

→ The 1st class brick should be recommanded for the work.

→ The curing should be done properly.

→ The lining is preferred for following reasons.

(i) The lining is economical.
(ii) Work can be done very quickly.
(iii) Repair work can be done easily.

Disadvantages :-

→ It is not so much durable.
→ It is not completely impervious.

~~not detected during the construction of dam, these may cause seepage of the water. This sub-soil water will move towards the low line areas causes the water logging.~~

(6) Boulder Lining :-

→ In hilly areas where the boulder are available in plenty this type of lining is generally recommanded.

→ The boulder are laid in single or double layer maintaining the slope if the banks & the level of the canal.

→ The lining is very durable & impervious but the transporting cost of material is very high.

(7) Shot-crete lining :-

→ In this system the cement mortar is directly applied on the sub-grade by an equipment known as cement gun.

→ The mortar is termed as shot-crete & the lining is known as shot-crete lining.

→ The process is known as guniting, as gun is used for line the mortar.

→ This line is done in 2 ways.

(i) By dry mix

(ii) By wet mix

(8) Asphalt lining :-

→ The lining is prepared by spraying asphalt at a very high temperature (About 150°c) on the sub-grad

to a thick varies from 3mm – 6mm.
→ The hot asphalt when becomes cold forms a water proof membrane over the sub-grade.
→ This membrane is covered with a layer of earth & gravel the lining is very cheap.

(9) Bentotibe & clay lining :-

→ A mixture of bentotine & clay are mixed together to form a sticky mass.
→ The mass is spread over the sub-grade to form an impervious membrane which is effective in controlling the seepage of water but it can't control the growth of weeds.
→ The lining is recomanded for small channels.

Soil cement lining :-

→ The lining is prepared with a mixture of soil & cement. The usual quantity of cement is 10% of the weight of dry soil, the soil & cement are thoroughly mixed to get an uniform ~~texture~~ mixture.
→ The mixture is laid on the surface of the sub-grade & it is made thoroughly compact.
→ The lining is efficient to control the seepage of water but can't control the growth of weeds.
→ selection of types of lining.

(1) Imperviousness
(2) Smoothness
(3) Durability
(4) Economic
(5) Site condition
(6) Life of project

→ In agricultural land when the soil pores with in the root zone of the crops gets saturated with the sub-soil water. The air circulation inside the soil pores get totally stopped. The phenomenon is called as water logging.

→ The water logging makes the soil alkaline in character & the fertility of the land is totally destroyed & the yield crops get reduced.

IMP LONG
Causes of water logging :-

→ The following are the main causes of the water logging.

(I) Over irrigation :-

→ In inundation irrigation since there is no controlling system of water supply it may cause over irrigation.

→ The access water percolates & remain stored within the root zone of the crops.

→ Again in perennial irrigation system if water is supplied more than its required than the access water is responsible for water logging.

(II) Seepage from canals :-

→ In unlined canal system the water percolates through the bank of the canals & get collected in low lying area along course of the canal & thus water table gets raised.

→ This seepage more in case of canal in banking.

(III) In-adequate surface drainage :-

→ When the rainfall is heavy & their is no proper provision of surface drainage then the water gets collected & submerges in the vast area. When this condition continues for a longer period the water table is raised.

(IV) Obstruction in natural water courses :-

→ If the bridges & culverts are constructed across a water ~~courses~~ courses with insufficient discharge capacity the upstream area gets flooded & this causes water logging.

(V) Obstruction in sub-soil drainage :-

→ If some impermeable stratum exist in a lower depth below the ground surface then the movement of the sub-soil water gets obstructed & causes the water logging in the area.

(VI) Nature of the soil :-

→ The soil of low permeability like black cotton soil does not allow the water to percolate through it. So incase of over irrigation or flood the water retained in this type of land & causes water logging.

(VII) Seepage from reservoir :-

→ If the reservoir basin consist of permeable zones cracks & fissures which are not detected during the construction of dam these may cause seepage of the water. This sub-soil water will move towards the low lying areas causes the water logging.

(viii) Incorrect method of cultivation :-

→ If the agricultural land is not well leveled & there is no arrangement of surplus for the water to flow out then it will create the ~~pools~~ pools of the stagnant water leading to water logging.

(ix) Poor irrigation management :-

→ If ~~poor~~ the main canal is kept open for a long period unnecessarily without computing the total water requirement of the crops then this leads to the over irrigation which may causes water logging.

(x) Excessive rainfall :-

→ If the rainfall is excessive & water gets no time to get drained-off completely then a pool of stagnant water leading to water logging.

(xi) Topography of the land :-

→ If the agricultural land is flat that is with no ~~in~~ ~~contr~~ country slope & consist of depression or undulation then this leads to water logging.

Long Effects of water logging :-

→ The followings are the effects of water logging.

(a) Sterilization of the soil :-

→ Due to the water logging the dissolved salts like, sodium carbonate, sodium chloride & 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 sterilization of the soil.

→ Excessive concentration of the soil makes the land alkaline so it does not allow the plant to strive & thus the yield of the crop is reduced.

(b). Lack of aeration :-

→ The crops required some nutrients for the growth which are supplied some bacteria & some micro-organism by breaking the complex nitrogeneous compound into simple compounds which are consumed by the plants for the growth.

→ But the bacteria required the oxygen for their life & activity.

→ When the aeration of the soil is stopped by the water logging these bacteria can not survive without oxygen ~~th~~ & the fertility of the land is loss which results in reduction of ~~soil~~ yield.

(C) Fall of soil temperature :-

→ Due to the water logging the soil temperature is lowered. At low temp. of the soil the activity of the bacteria becomes very slow & consequently the plant do not ~~get~~ get requiside amount of food in time. Thus the growth of the plant is hampered & the yield is reduceed.

(d) Growth of weeds & aquatic plants :-

→ Due to the water logging the agricultural land is converted to marshy land & the weeds & the aquatic plants are grown in plenty.

→ This plants consume the soil food in advance & thus the crops gets destroyed.

(e) Disease of the crops :-

→ Due to the low temperature & poor aeration the crops gets some disease which may destroyed the crops or reduce the yield.

(f) Difficulty in cultivation :-

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

(g) Restriction of the root growth :-

→ When the water table rises near to root zone the soil gets saturated. The growth of the root is confirmed only to the top layer of the soil. So the crops can not be matured properly & the yield is reduced.

Control/Prevention of water logging :-

→ The following measures may be taken to control the water logging.

i) Prevention of percolation from canal :-

→ The irrigation canal should be lined with the impervious Lining to prevent the percolation through the bed & banks of the canal.

→ Thus the water logging may be control

(2) Prevention of percolation from reservoir :-

→ During the construction of dam the geological survey should be conducted on the reservoir basin to detect the zone of cracks & fissures through which water may percolates.

→ These zone should be treated properly to prevent the seepage.

(3) Economical use of water :-

→ If water is used economically then it may control the water logging & the yields crops may be high.

→ So the special training should be given to the cultivators to release the benefits of economical use of water.

4) Fixing of crop pattern :-

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

5) Providing drainage system :-

→ Suitable drainage system should be provided in the low lying area so that the rain water does not stand for long period.

6) 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 improve by excavating & clearing the obstruction.

(7) Pumping of ground water :-

→ A no. of open wells or tube wells are constructed in water logged area & the ground water is pumped out untill the water table goes down to a shape level.

(8) Construction of sump well :-

→ Sump wells may be constructed within the water logged area & they helps to collect the surface water.

→ The water from the sump well may be pumped to the irrigable lands & may be discharged to any river.

~~~o~~~
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Any hydraulic structure which supplies water to the off taking canal is called a head work. Head work may be divided into two classes.

(a) Diversion head work

(b) Storage head work

(a) Diversion head work :-

→ A diversion head work is that which divert the required supply into the canal from the river.

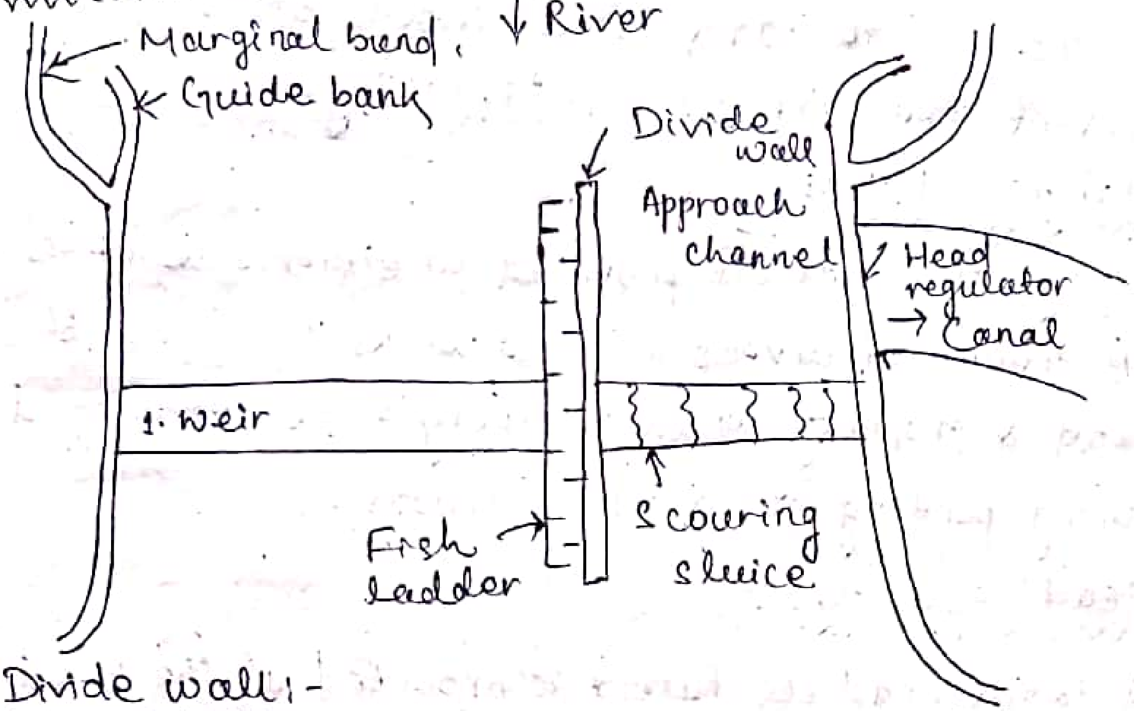
(b) Storage head work :-

→ A storage head work is the construction of a dam across the river. It stores water during the period of excess supplies in the river & release it when demand overtakes available supplies.

Necessity of ~~diversion~~ head work :-

1. The necessity of diversion head work in the irrigation projects is to divert the river water into the canal & a constant & continuous water supply is ensured into the canal even during the period of low flow.
2. It controls the silt entry into the canal.
3. It raises the water level in the river so that the commanded area can be increased.
4. It reduces fluctuations in the level of supply in the river.
5. It regulates the intake of water into the canal.
6. It stores water for tiding over small periods of short supplies.

General layout & different part of a diversion head work :-



Divide wall :-

→ A divide wall is constructed parallel to the direction of flow of river to separate the weir section & the under sluices section to avoid across flows. If there are under sluices at both the sided; there are 2 divide walls.

Scouring sluices :-

→ Provideing adjacent to the canal head regulator should be able to pass fair wheather flow for which the crest shutters on the weir proper need not be dropped.

Fish ladder :-

→ A passage provide adjacent to the divide wall on the weir side for the fish to travel from upstream to downstream & vice versa. Fish migrate upstream or downstream in search of food or to rich their spreading places.

Guide Banks:-

→ Guide banks are provided on either side of the diversion head work for a smooth approach & to prevent the river from out flanking.

Marginal bunds :-

→ Marginal bunds are provided on either side of the riv up stream of diversion head works to project the land & property which is likely to be submerged during ponding of water in floods.

Head regulators :-

→ A canal head regulators is provided at the head of the canal off taking from the diversion head work. It regulates the supply of water into the canal controls the entry silt into the canal & prevents the entry of river flood into canal.

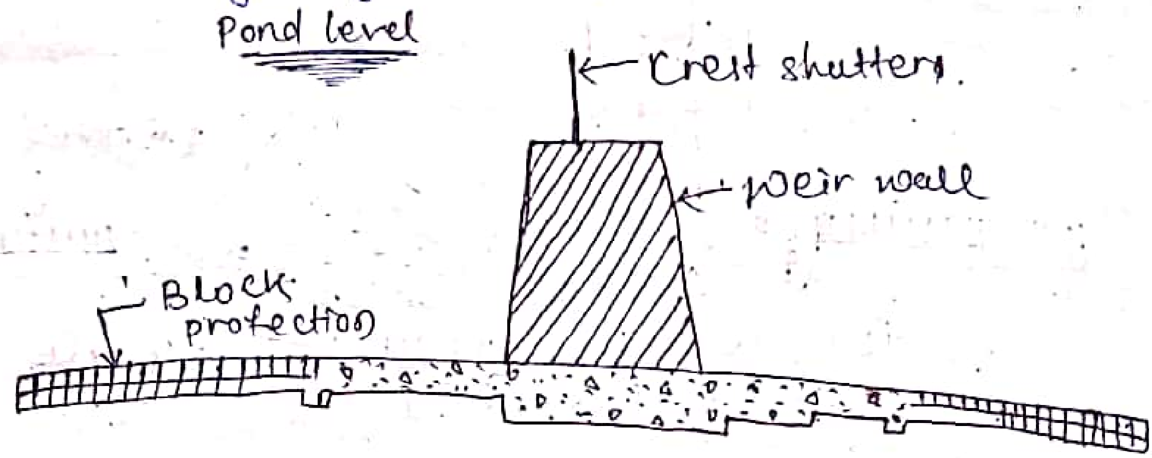
→ A diversion head work is further divided into two parts..

(a) Weir :- The weir is a solid obstruction put across the river to raise its water level & divert the water into the canal.

→ Here the water level is raised up to the required height & the surplus water is allowed to flow over the weir.

→ Generally it is constructed across an inundation river. Weir are commonly used to aler the flow of rivers to prevent flooding, measure discharge & help render river navigable.

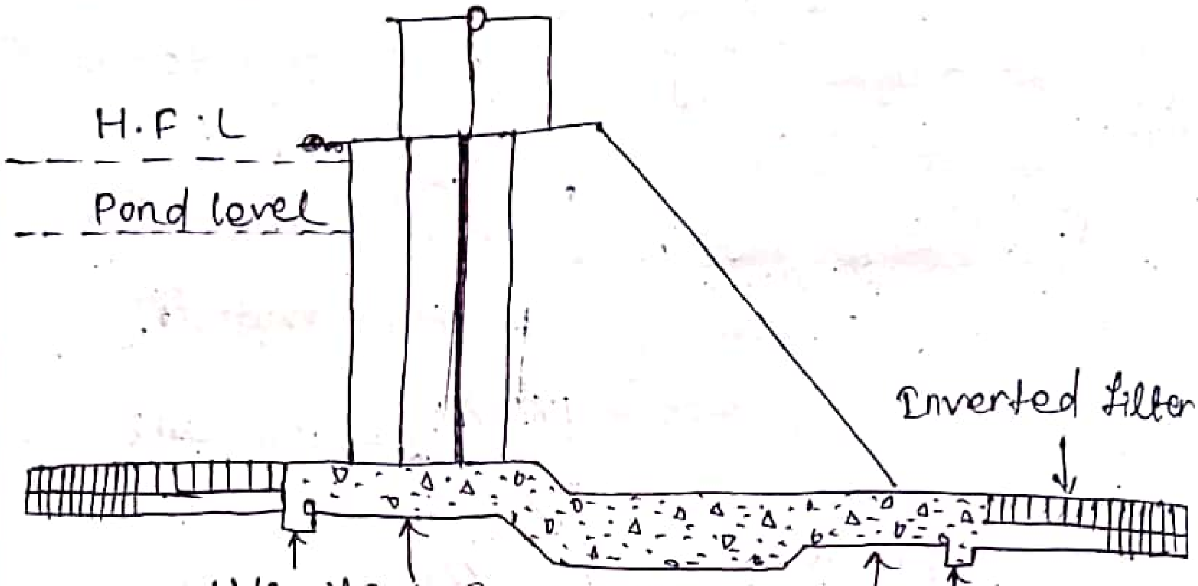
→ If a weir also stores water from tiding over small period of short supplies, it is called a storage weir.
→ The main difference between a storage weir & a dam is only in height & the duration for which the storage is stored. A dam stores the supply for a comparatively longer duration.



(VERTICAL DROP WEIR)

(b) Barrage :- The function of barrage is similar to that of a weir but the heading up of water is efficient by the gates alone.
→ It consist of a number of large gates that can be opened or closed to control the amount of water passing through the str. & thus regulates & stabilise river water.
→ No solid obstruction is put across the river. The crest level in the barrage is kept at a low level. During the floods the gates are raised to clear off the high flood level, enabling the high flood to pass down stream with minimum afflux. When the flood recedes, the gates are lowered & the flow is obstructed, thus raising the water level to the upstream of the barrage.

→ Due to this, there is less silting & better control over the levels.



(BARRAGE)

Barrage

(i) Low set crest.
(ii) Gated over entire length.
(iii) Gates are of greater height.
(iv) Gates are raised clear off the high floods.
(v) Perfect control on riverflow.
(vi) Longer construction period.
(vii) Costly structure.
(viii) Silt removal is done through under sluices.

Weir

(i) High set crest.
(ii) Shutters in part length.
(iii) Shutters are of smaller height.
(iv) Shutters are dropped to pass floods.
(v) No control of river in low floods.
(vi) Shorter construction period.
(vii) Relatively cheaper structure.
(viii) No means for silt disposal.

Functions of Regulatory structures:-

→ A regulatory structure is provided at the head of the off-taking canal & serves the following functions

(1) It regulates the supply of water entering the canal.
(2) It controls the entry of silt in the canal.

(3) It prevents the river floods from entering the canal.

Head Regulators & Cross regulators :-

Head regulators & cross regulators regulate the supplies of the off-taking channel & parent channel respectively. The distributory head regulator is provided at the head of the distributory & controls the supply entering the distributory. A cross regulator is provided on the main canal at the down stream of the off-take to head up the water level & to enable the off-taking channel to draw the required supply.

Functions of distributory head regulators :-

(1) These regulate or control the supplies to the off-taking channel.

(2) To control silt entry into the off-take canal.

(3) To serve as a meter for measuring discharge.

Funⁿ of cross regulators :-

(1) To effectively controls the entire canal irrigation system.

(2) When the water level in the main channel is low, it helps is heading up water on the upstream & to feed the off take channels to their full demand in rotation.

Falls :-

Irrigation canals are constructed with some permissible bed slopes so that there is no silting or scouring in the canal bed. But it is not always possible to run the canal at the desired bed slope throughout the alignment due to the fluctuating nature of the country slope.

→ Generally the slope of the natural ground surface is not uniform through the alignment. Sometimes the ground surface may be steep & sometimes it may be very irregular with abrupt change of grade.

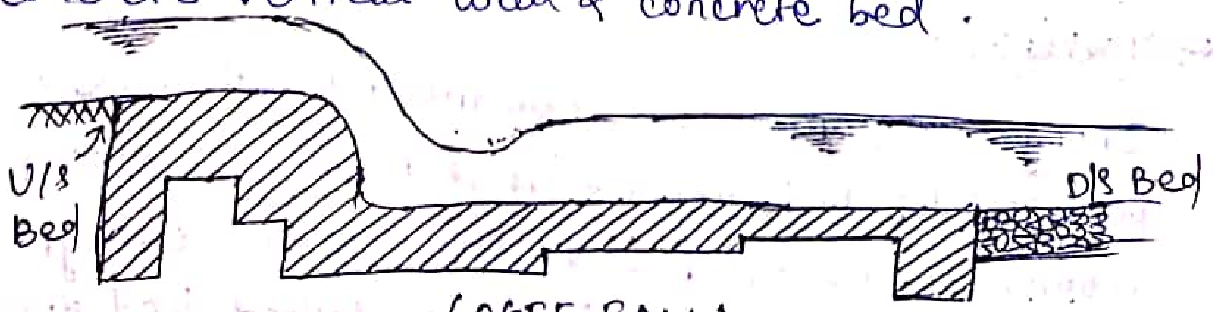
→ In this case "a vertical drop is constructed across a canal to lower down its water level & destroy the surplus energy liberated from the falling water which may otherwise scour the bed & banks of the canal. This is done to avoid unnecessary huge earthwork in filling. Such vertical drops are known as Canal falls or falls simply."

Types of falls :-

The following are the diff. types of canal falls.

(I) Ogee fall :-

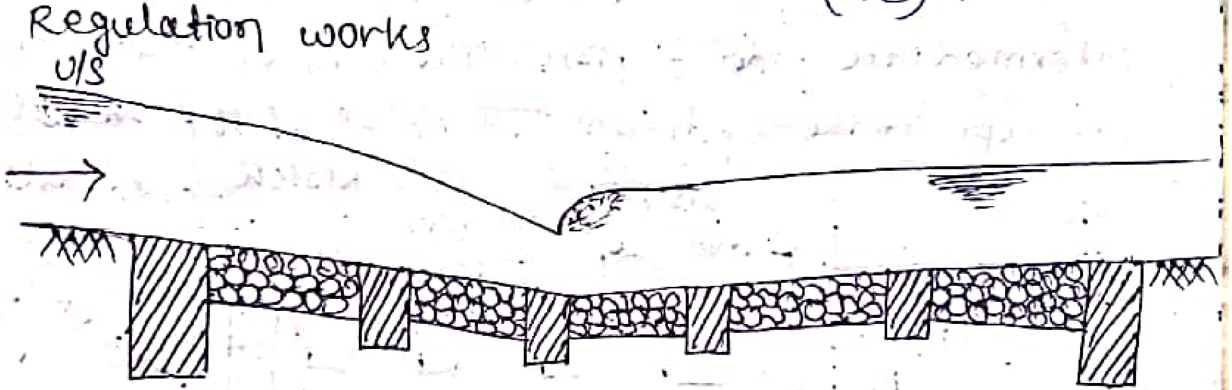
→ In this type of fall, an ogee curve (a combination of convex & concave curve) is provided for carrying the canal water from higher level to lower level. This fall is recommended when the natural ground surface suddenly changes to a steeper slope along the alignment of the canal. The fall consists of a concrete vertical wall & concrete bed.



(OGEE FALL)

(I) Rapid fall :-

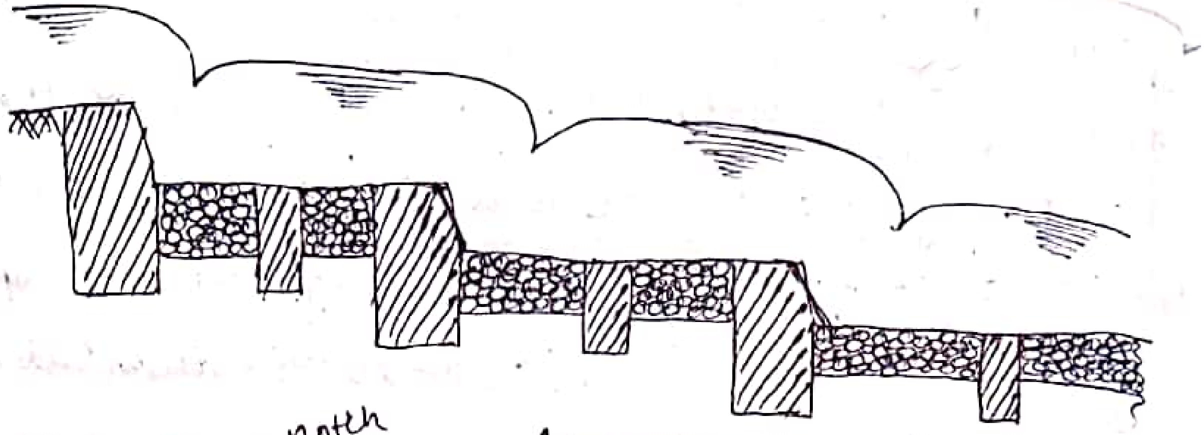
→ The rapid fall is suitable when the slope of the natural ground surface is even & long. It consists of a long slopping glacis with longitudional slope which varies 1 in vertical to 10-20 in horizontal. Curtain walls are provided on the upstream & down stream side of the slopping glacis. The slopping bed is provided with rubble masonry. The masonry surface is finishes with rich cement mortar (1:2).



(RAPID FALL)

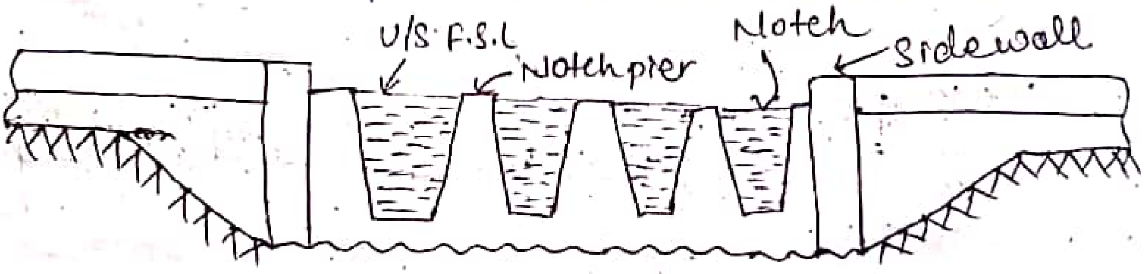
(II) Stepped fall :-

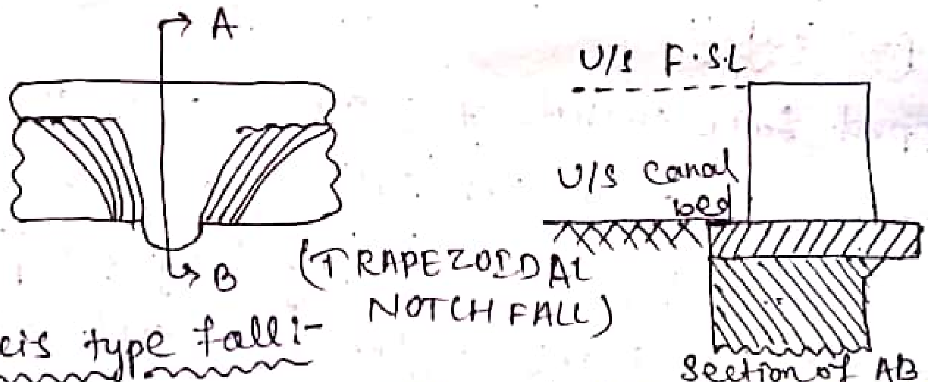
→ Stepped fall consists of a series of vertical drops in the form of steps. This fall is suitable in places where the slopping ground is very long & requires long glacis to connect the heigher bed level with lower bed level. This fall is practically a modification of the rapid fall. The slopping glacis is divided into a no. of drops so that the following water may not cause any damage to the canal bed. ~~Both~~ Brick walls are provided at each of the drops.



(IV) Trapezoidal notch falls :- (STEPPED FALL)

→ In this type of fall a body wall is constructed across the canal. The body wall consists of several trapezoidal notches between the side piers & the intermediate pier or piers. The sills of the notches are kept at the upstream bed level of the canal.





(TRAPEZOIDAL NOTCH FALL)

(V) Glacis type fall :-

→ The glacis type fall utilised the standing wave phenomenon for dissipation of energy. The glacis fall maybe straight glacis or parabolic glacis type.

Energy dissipaters :-

→ The water flowing over the spillway acquires a lot of kinetic energy by the time it reaches near the toe of the spillway. The arrangement is made to dissipate ceed on the downstream side near the toe of the dam. This arrangement is known as energy dissipaters.

Canal outlets:-

An outlet is a small str. which admits water from the distributing channel to a water course or field channel. Thus, an outlet is a sort of head regulator for the field channel delivering water to the irrigation fields.

Types of outlets:-

Outlets may be classified as 3 types.

(1) Non-modular outlet.
(2) Semi module or Flexible Module
(3) Rigid module.

(1) Non modular outlet:-

→ A non-modular outlet is the one in which the discharge depends upon the difference in level between the water levels in the distributing channel & water course. The discharge through such an outlet varies in wide limits with the fluctuations of the water levels in the distributing & field channels. The common examples under this catagory are: submerged pipe outlet, masonry sluice & orifices.

(2) Semi module or Flexible module:-

→ A flexible outlet or semi module outlets the one in which the discharge is affected by the fluctuation in the water level of the discharging channel while the

fluctuations in water levels of the field channel do not have any effect on its discharge.
~~or field channel. Ex - Gibb's Rigid Module.~~

(3) Rigid module :-

→ A rigid module is the one which maintains constant discharge, within limits, irrespective of the fluctuations in water levels in the distributing channel or field channel.

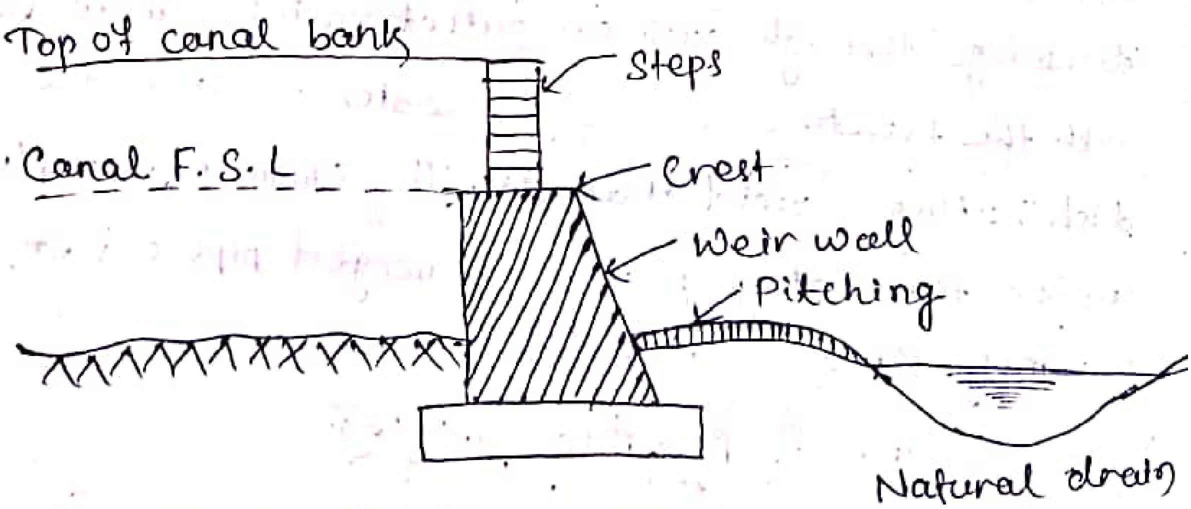
Canal Escapes :-

Canal escapes is defined as an channel meant for the removal of surplus or excess water from the canal into nearby drainage. The function served by canal escape are :-

(i) Safety valve to protect the canal against possible damage by flooding.

(ii) Emptying of the canal reach, below the escape, for silt or weed removal, repairs & maintenance.

(iii) Periodical flushing off the silt prone head of a canal through the escape.



(b) Tail escapes

CANAL ESCAPES

Depending upon the purpose, there can be 3 types of escapes such as :-

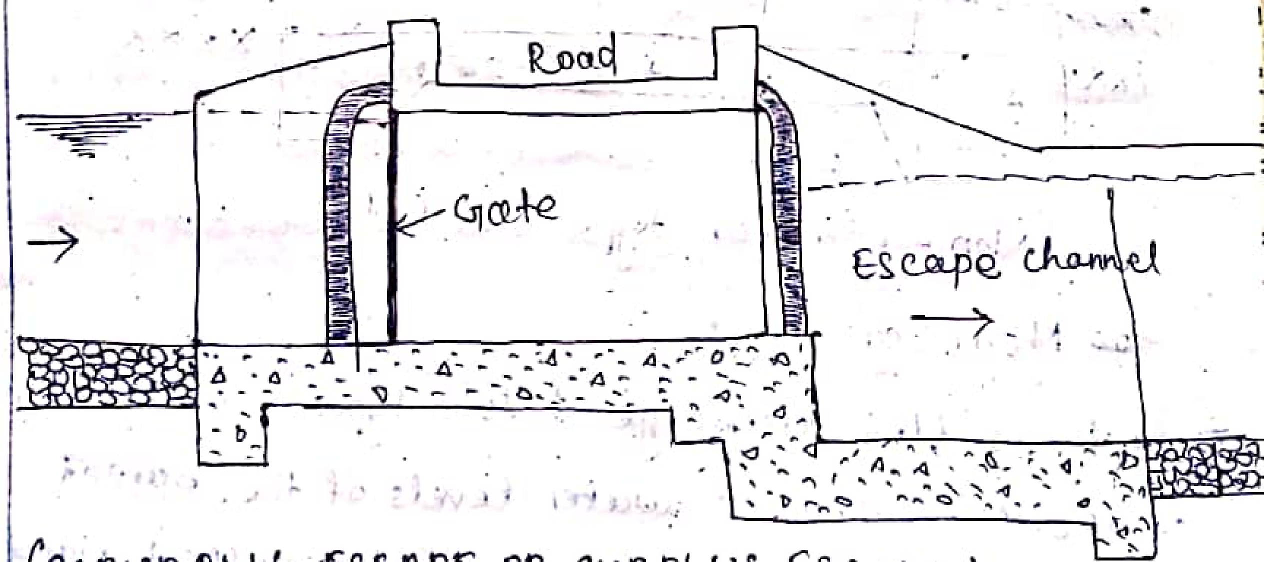
(a) Canal ascouring escapes

(b) Surplus escapes

(c) Tail escapes

(a) Canal scouring escapes :-

→ The scouring escapes is constructed for the purpose of scouring off excess silt from time to time. Escapes are also constructed to dispose off eexcess supplies off the parent channel. Excess supplies in the canal take place either during heavy rains or due to the closure of canal outlet by the farmers. In that case the escapes save the down stream section of the canal from overflow of banks.



(SCOURING ESCAPE OR SURPLUS ESCAPE)

(b) Surplus escapes :- A canal surplus escapes may be weir type, with the crest of weir wall at F.S.L of parent bed level

(c) Tail escapes :- A tail escape is required F.S.L at tail end. The str. is weir type with its crest level at the required F.S.L of canal at its tail end.

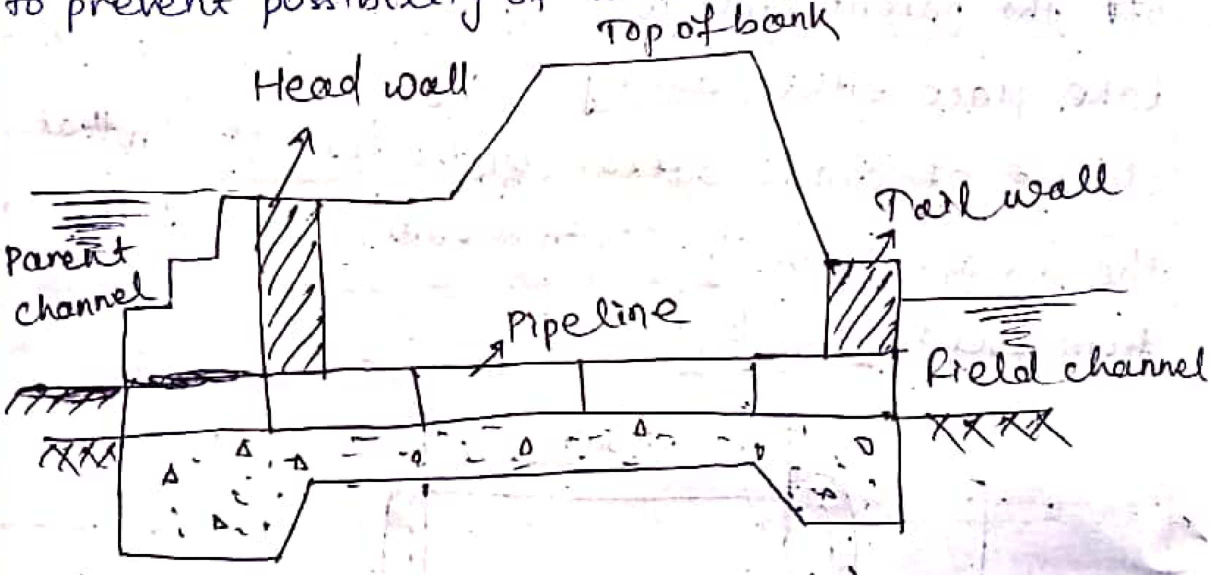
Non-modular outlet :- It is provided in the form of a simple opening made in the canal banks which leads water from the parent channel to the field channel.

→ The opening may be circular or rectangular in shape

→ The rectangular tunnel or barrel may be constructed of masonry.

→ The diameter of the pipe may range from 10 - 30 cm

→ The pipeline is laid on a lime concrete foundation to prevent possibility of settlement.



(Non-modular type outlet)

Modular outlets :-

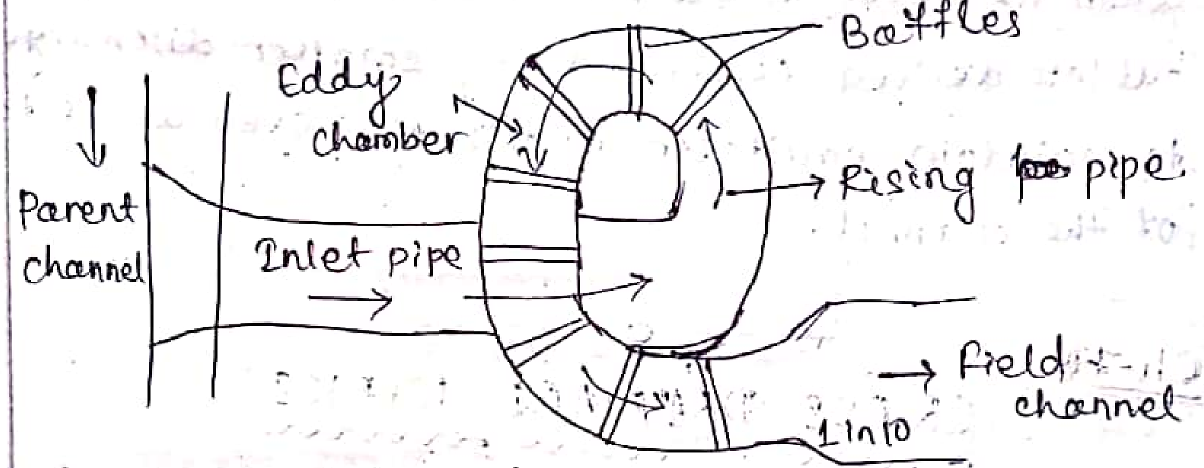
→ As the outlet discharge of this type is independent of the difference of water levels of the parent channel & field channel. It is also called rigid module.

→ Modular outlets may be constructed with movable parts. But ~~the~~ sometimes the movable parts are liable to be damaged or choked. Hence this type is not use in practice. ex- Gibb's module.

Gibb's module:-

→ It is a modular outlet irrigation water is taken through an inlet pipe to a rising pipe. The raising pipe is in the form of a spiral, generally it is semicircular.

→ The water then flows through it are turned through 180°.



(PLAN)

Eddy chamber → The rising spiral pipe is connected in to eddy chamber. The eddy chamber in circular in plan with horizontal floor.

→ It takes back the water in the original direction of flow. In the eddy chamber the baffles are provided at equal distance to dissipate access energy of flow & to maintain a constant discharge.

→ Modular outlets require complicated arrangement of parts it is quite expensive. The outlet gets choked up with silt. Hence this type is not used in practice.

Semi-modular outlet :-

→ This catagory outlet discharge is independent of the water level in the field channel.

→ When the water level in the parent channel is high all outlets derive proportionately more discharge & protect the channel ~~plumbing~~ being damaged. Also when the level in the parent channel is low all the outlets derived correspondingly smaller discharge to maintain equitable distribution even at the tail of the channel.

Ch-~~7~~8

CROSS DRAINAGE WORKS

→ A cross drainage work is a structure carrying the discharge from a natural stream across a canal intercepting the stream.

→ Canal comes across obstruction like rivers, natural drains & other canals. The various types of structure that are built to carry the canal water across the above mentioned obstructions or viceversa are called cross drainage works.

Necessity of cross drainage work :-

1) At the crossing point the water of the canal & the drainage get intermixed, so for the smooth running of the canal with its design discharge the cross drainage works are required.

11) The site condn of the crossing point may be such

that without any suitable str. the water of the canal & drainage cannot be diverted to their natural dirn. So the cross drainage works must be provided.

Types of cross drainage works :-

1) **By passing the canal over the drainage :-**

→ The str. that fall under this type are

(a) An aqueduct

(b) syphon aqueduct.

(2) **By passing the canal below the drainage :-**

(a) Super passage

(b) Canal syphon / syphon super passage.

3) **By passing the drainage through the canal** - so that the canal water & drainage ware are allowed to interonined with each other.

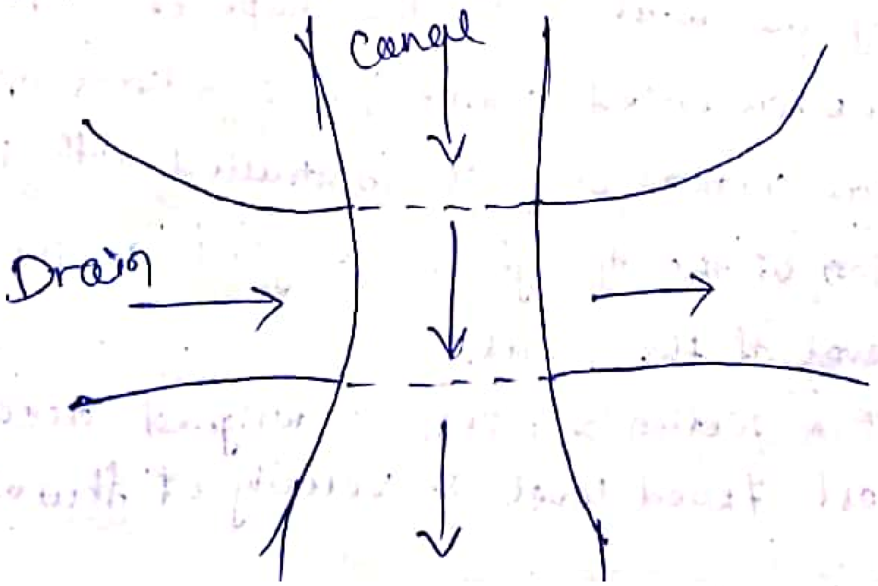
(a) Level crossing

(b) Inlet & Outlet

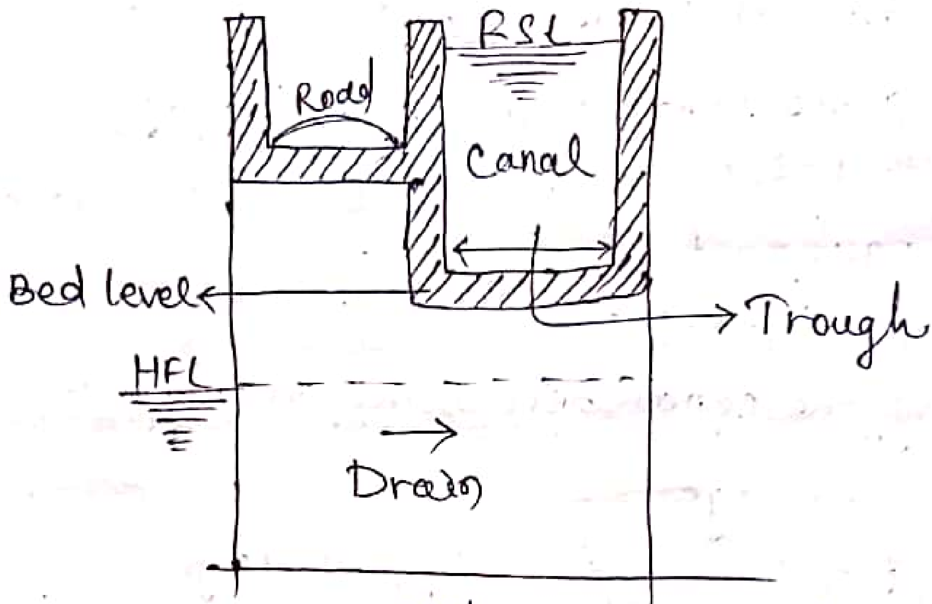
~~Properst~~

(a) **Aqueduct :-**

→ The hydraulic structure in which the irrigation cana is taken over the drainage is known as an aqueduct



→ When the HFL of the drain is sufficiently below the bottom under gravity such type of structure is known as aqueduct.



→ In this type of work the canal water is taken across the drainage in a trough supported on piers.

→ An aqueduct is just like a bridge except that in state of carrying a road or railway it carries a canal on its top.

→ An aqueduct is provided when sufficient level difference is available between the canal & natural drainage & the canal bed level is sufficiently higher than the torrent level.

→ Generally the canal is in the shape of a rectangular trough (narrow filled channel) & sometimes may be trapezoidal section which is constructed with RCC.

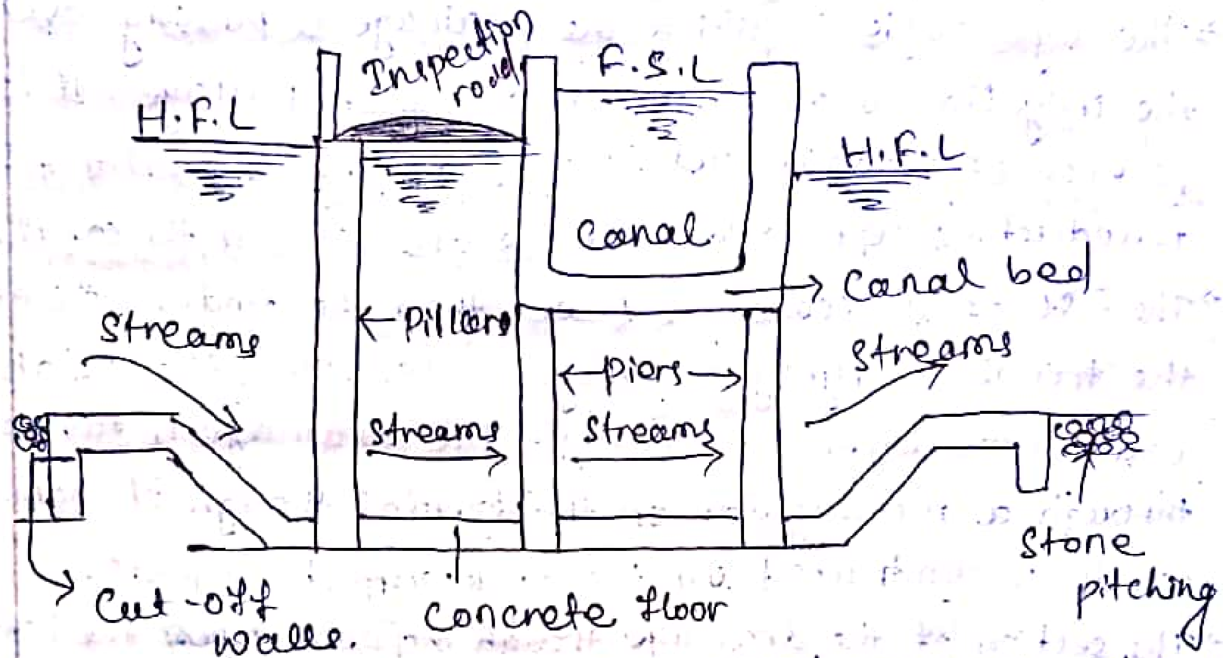
→ The section of the trough is designed as for the full supply level of the canal.

→ The height & section of piers are designed according to the highest flood level & velocity of flow of the drainage.

→ According to the availability of the soil the depth & type of foundation provided.

b) Syphon aqueduct :-

→ In case of the syphon aqueduct the H.F.L of the drain is much higher above the canal bed & water runs under syphonic action through the aqueduct, barrakes or tunnels.



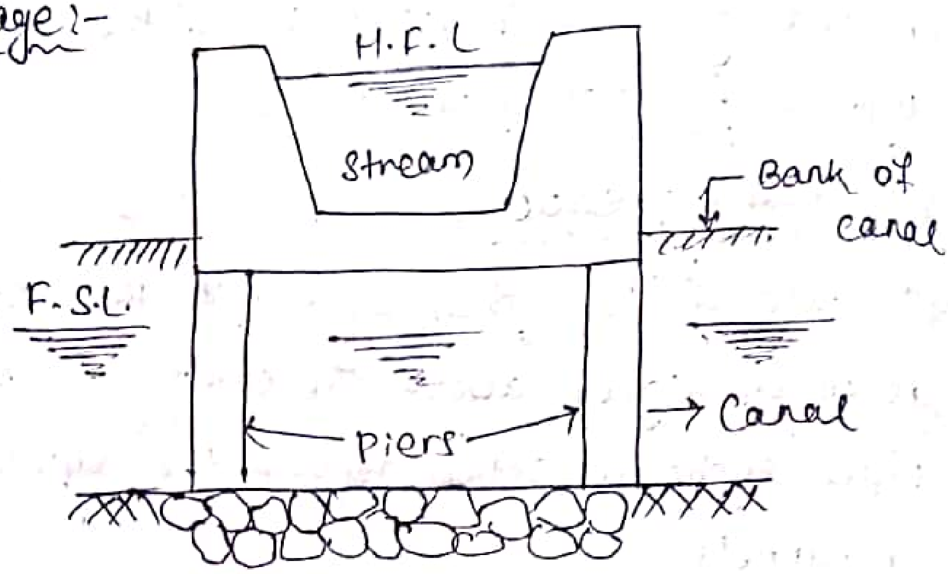
→ Here the slopping apron provided on both sides of the crossing. The apron may be constructed by cement concrete or stone pitching.

→ The section of the drainage below the canal trough is constructed with PCC in the form of tunnels or barrels.

→ These tunnel acts as a syphon.

→ Cut-off walls are provided on the both side of the apron to prevent scouring during heavy flood. also boulder pitching should be provided on the upstream side & down stream side of the cut-off walls.

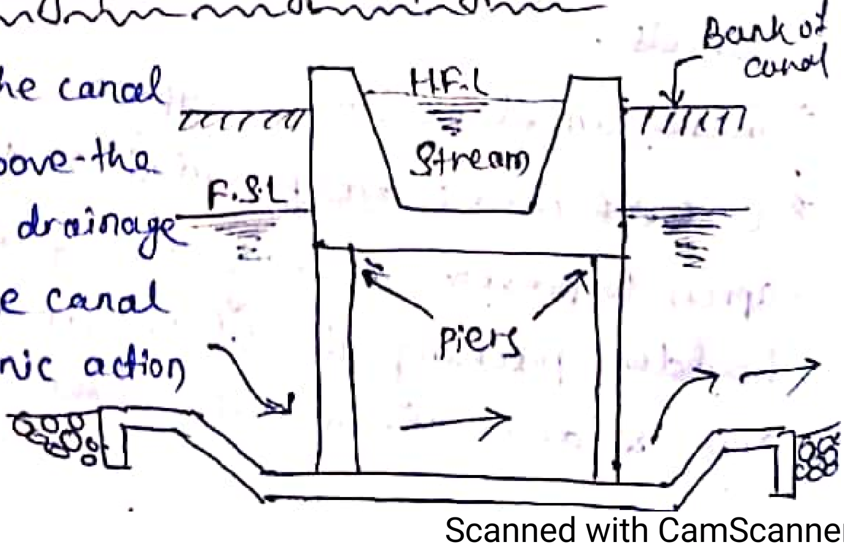
Super passage :-



→ The hydraulic in which the drainage is passing over the irrigation canal is known as super passage. It is reverse of an aqueduct. A super passage is similar to a aqueduct, except in this case the drain is over the canal.
→ The F.S.L of the canal is lower than the under side of the trough carrying drainage water. Thus the canal water runs under the gravity. The drainage is taken through a rectangular or trapezoidal trough of channel which is constructed on the deck support by piers..
→ The section of the drainage trough depends upon the high flood discharge. A free board of about 1.5 m should be provided for safety. The trough should be constructed of R.C.C. The bed & banks of the canal the drainage trough should be protected by boulder pitching or lining with concrete slab.

Syphon super passage / canal syphon / syphon :-

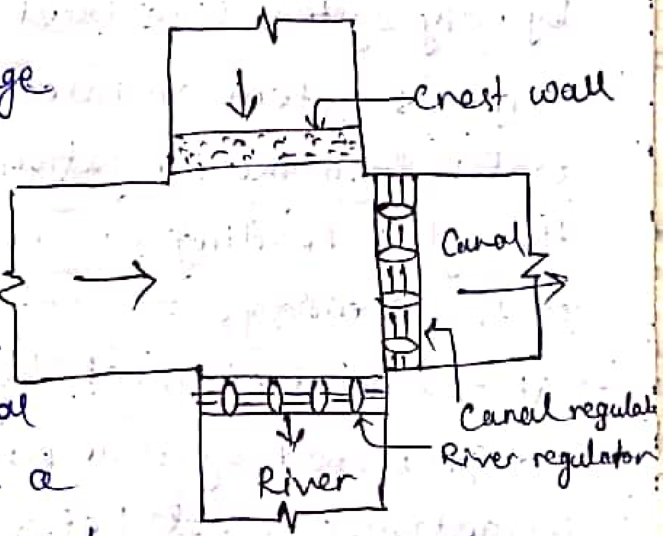
→ If the F.S.L of the canal is sufficiently above the bed level of the drainage trough, so that the canal flows under syphonic action under the trough, the structure is



known as canal syphon / a syphon super passage.

→ This structure is reverse of an syphon aqueduct. The section of the trough is designed according to high flood discharge. The canal bed is lowered & a ramp is provided at the entry & exit. So that the trouble of silting is minimized. The slopping operon 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 an syphon. cut-off walls are provided on U/S & d/s of the slopping operon to minimize scouring affects during high flood.

Level crossing :-



→ In this type of cross drainage work; the canal water & drain water allowed to intermingle with each other.

→ A level crossing is generally provided when a large canal & huge drainage (such as a stream or river) approach each other practically at the same level.

→ In this type of work, the drainage water is pass into the canal & taken out at the opposite bank. The work consists of (I) construction of crest, with its top at the F.S.L of the canal, as the U/S section with canal.

(II) Provision of the head regulator across the drainage at its down stream junction with the canal.

(III) A cross regulator at the end of the incoming canal is also sometimes required.

When the drainage donot carry any water, its regulato is closed while the cross regulator of the canal is kept open so that the canal flows without any interruption. During the floods, however, the drainage regulator is opened so that the flood discharge after spilling over the crest & mixing with the canal water, passes through it to the downstream of the drainage.

Inlet & Outlet :-

→ In case of crossing of a small irrigation channel with small drainage, no hydraulic str. is constructed, because, the discharged of the drainage & the channel are practically low & these can be easily trackled by easy system like inlet & outlet arrangement.

→ In this system an inlet is provided by open cut & the water from the irrigation channel is allowed to flow through a leading channel towards the original coarse of the drainage.

→ At the point of inlet bed & banks of the drainage are protected by stone pitching. The bed & banks of the irrigation channel between inlet & outlet point should also be protected by stone pitching.

→ A dam is a hydraulic structure of fairly impervious material built across a river to creat a reservoir on its upstream side for impounding water for various purposes.

→ It is suitable in hilly resion where a deep gorge section is available for the strange reservoir.

→ The various purposes are irrigation, hydro power, water supply, flood control, navigation, fishing ~~etc.~~ & recreation etc

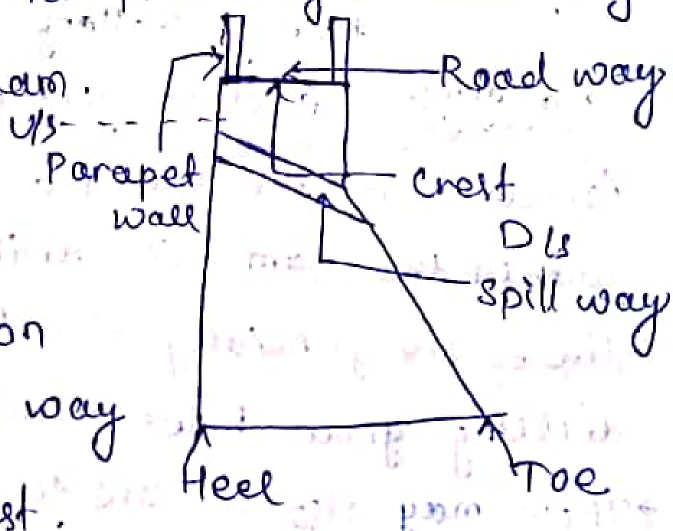
→ Dam can be classified as single purpose dam & multi purpose dam.

Necessity of Dam :-

→ The dam is meant for serving multipurpose concept such as irrigation, hydro electric power, water supply, flood control, navigation, fishing & recreation etc.

Different parts & terminology of dams :-

(1) Crest :- The top of the dam structure. These may in some cases be used for providing a road way or walk way over the dam.



(2) Parapet walls :-

→ Low protective walls on either side of the road way or walk way on the crest.

(3) Heel :-

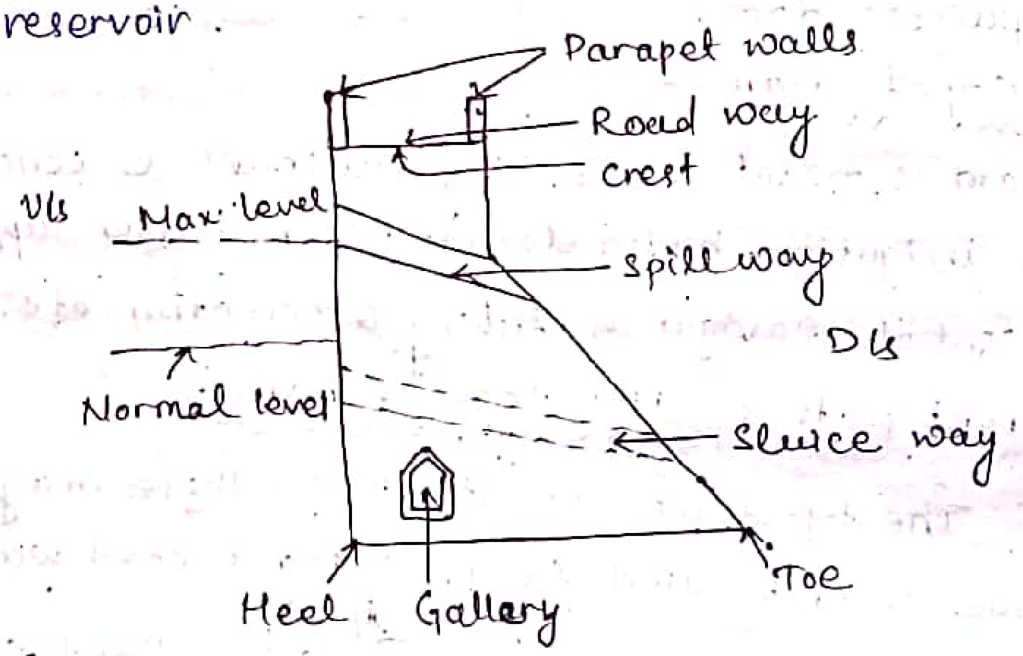
→ The portion of structure in contact with ground or river bed at upstream side is known as heel.

(4) Toe :- The portion of structure in contact with the ground at down stream side is known as toe.

(5) Spill-way :- It is the arrangement made (kind of passage) near the top of structure for the passage of surplus or excessive water from the reservoir.

(6) Abutments :- The valley slope on either side of the dam wall to which the left & right end of the dam are fixed.

(7) Sluice way :- Opening in the structure near the base provided to clear the silt accumulation in the reservoir.



Gallery :- Level or gently slopping tunnel like passage (small room like space) at transverse or longitudional within the dam with drain on floor for seepage water. These are generally provided for having space for drilling grout holes & drainage holes.

→ These may also be use to accomodate the instrumendation for studying the performance of dam.

Selection of site of dam :-

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

(i) 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.

(ii) The river valley should be narrow & well defined so that the length of the dam may be short as far as possible.

(iii) Site should be in deep gorge section of the valley so that large capacity storage can be formed with minimum surface area & minimum length of dam.

(iv) Valuable property & valuable land should not be submerged due to the construction of dam.

(v) The site should be easily accessible by road or railway for the transport of construction materials, equipment's etc

(vi) The construction materials should be available in the vicinity of the dam site.

(vii) Sufficient space should be available near the site for the construction of labour colony, godowns & staff quarters for the personnel associated with the constructional activities.

(viii) The basin should be free from cracks, fissures etc. to avoid percolation loss. It is done by physical verification & other observations. If unavoidable, the area should be located & necessary measures that should be recommended to make the area leak-proof.

Investigation works for dam site :-

→ The following investigation works should be done before final selection of dam site & the preparation of the project report.

1. Preliminary Survey :- The preliminary survey involves the following steps.

(a) Reconnaissance survey :- The reconnaissance survey should be conducted for the dam site & surrounding area to gather information regarding the natural features of the area, nature of dam site, location of labour colony & staff quarters, stock yard, godowns etc. The nature of the land & the localities in the basin area should also be recorded. And index map should be prepared.

(b) Topographical survey :- A topographical map is to be prepared for the proposed project area by traverse surveying. The traverse survey may be conducted any suitable method depending on the nature of the area.

(c) Contour survey :- A contour map should be prepared for the basin area to determine the capacity of the reservoir.

→ Longitudional levelling & cross sectional levelling should be done at the dam site at least one km upstream & downstream of the proposed centreline of the dam. This is done to select the most suitable dam site.

(2) Geological survey :- The geological survey involves the following steps.

(a) Soil survey :- To work the nature of the foundation at the dam site. Soil exploration should be done by suita method. The sub-soil formation should be thoroughly studied to determine the type of foundation for the da

(b)

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b) **Study of formation in basin area:-** Soil exploration should be done at different spot in the basin area to ascertain the nature of sub-soil. This is done to calculate the probable percolation loss.

c) **Study of source of sediment:-** The sources of sediments carried by the river or its tributaries should be studies & located. If slips or areas of loose soil with mica particles are found, then the stabilization of those areas should be done.

3) **Hydrological survey:-** It involves the following steps.

(a) **Gauge & discharge site:-** The gauge & discharge stations should be established near the dam site to record the discharge of the river throughout the year.

(b) **Site analysis:-** In rainy season the river carries heavy silt or sediment. The analysis of the silt should be carried out throughout the season for some specific period to determine grade of silt. This is done to ascertain the possible sedimentation in the reservoir & thus suitable methods can be employed to reduce the sedimentation.

(4) **Communication Survey:-** The route survey for the possible communication of the dam site the nearest highway or railway station should be done. It involves the preparation of longitudional section & cross-sectional along the proposed alignment. It is done to estimate the cost of construction of this connecting road or railway line. The possible route or telephone communication & electric connections should also be located.

(5) Construction Materials Survey :- The availability of construction materials like stone, sand etc. should be located in the topographical map of the concerned district or state. The possible route for carrying these materials should also be located in the map.

(6) Compensation report :- A detailed report should be prepared for the compensation which is likely to be paid by the govt during the implementation of the project. This will include the damsite, area of labour colony & staff quarters, area required for stack yards & godowns, valuable lands & properties that may be submerged by the reservoir etc.

(7) Project report :- The project involves the following steps.

a. Design & estimate of dam & other allied structures.

b. Detailed drawings of dam section with foundation & other buildings or structures.

c. Detailed estimate for the road or railway communication

d. comprehensive report for compensation.

e. The project is forwarded to the higher authority with recommendation for approval.

f. The project is forward to the higher authority with recommendation for approval.

Classification of dams :-

Based on the functions of dams :-

1. storage dams :- They are constructed to store water during the rainy season when there is a large flow

in the river. Many small dams impound the spring runoff for later use in dry summers. Storage dams may also provide a water supply, or improved habitat for fish & wildlife. They may store water for hydroelectric power generation, irrigation or for flood control project. Storage dams are the most common type of dams & in general the dam means a storage dam unless qualified otherwise.

2. <u>Diversion dams</u>:-

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• Based on structure & design, dams can be classified as follows :-

1. Gravity dams :-

→ A gravity dam is a massive sized dam fabricated from concrete or stone masonry.

→ They are designed to hold back large volumes of water. By using concrete, the weight of the dam is actually able to resist the horizontal thrust of water pushing against it.

→ This is why it is called a gravity dam. Gravity essentially holds the dam down to the ground, stopping water from toppling it over.

Types of dam :-

→ Gravity dams are well suited for blocking rivers in wide valleys or narrow gorge ways. Since gravity dams must realy on their own weight to hold back water, it is necessary that they are built on a solid foundation bed rock.

Examples of Gravity dam :- Grand coulee dam (USA) Nagarjuna sagar (India).

2. Earth Dams :-

→ An earth dam is made of earth (or soil) built up by compacting successive layers of earth, using the most impervious materials to form a core & placing more permeable substances on the upstream & down stream sides. A facing of crushed stone prevents erosion by wind or rain, & an ample spillway, usually of concrete, protects against catastrophic washout should be water overtop the dam.

- Earth dam resist the forces exerted upon it mainly due to shear strength of the soil.
- They can be built on all types of foundations. However, the height of the dam will depend upon the strength of the foundation material.

Examples :- Rongunksky dam (Russia) & New cornelia dam (USA).

(3) Rockfill dams :-

- A rockfill dam is built of rock fragments & boulder of large size.
- An impervious membrane is placed on the rockfill on the upstream side to reduce the seepage through the dam.
- The membrane is usually made of cement concrete or asphaltic concrete.
- Sometimes, the rockfill dams have an impervious earth core in the middle to check the seepage instead of an impervious upstream membrane.
- The earth core is placed against a dumped rockfill. It is necessary to provide adequate filters between the earth core & the rockfill on the u/s & d/s sides of the core so that the soil particles are not carried by water & piping does not occurs.
- Rock fill dams require foundation stronger than those for earth dams.

Ex Mica Dam (Candda) & Chicoasen dam (Mexico)

(4) Arch dam :-

→ An arch dam is curved in plan, with its convexity towards the upstream side. They transfer the water pressure & other forces mainly to the abutments by arch actions.

→ An arch dam is quite suitable for narrow canyons with strong flanks which are capable of resisting the thrust produced by the arch action.

→ The section of an arch dam is approximately triangular like a gravity dam but the section is comparatively thinner.

Example - Hoover Dam (USA) & Idukki Dam (India)

(5) Buttress Dams :-

→ Buttress dams are of three types : (i) Deck type, (ii) Multiple-arch-type & (iii) Massive-head type

→ A deck type buttress dam consists of a slopping deck supported by buttress.

→ Buttress are triangular concrete walls which transmit the water pressure from the deck slab to foundation

→ Buttress are compositions members. Butteress are tropically spaced across the dam site every 6 to 30 metre depending upon the size & design of the dam.

→ Buttress dams are sometimes called hollow dams because the buttress do not form a solid wall stretching across a river valley.

(ii) Multiarch type :-

→ In a multiple-arch type buttress dam the deck slab is replaced by horizontal arches supported by buttresses.

→ The arches are usually of small span & made of concrete.

(iii) Massive head type:-

→ In a massive head type buttress dam, there is no deck slab. Instead of the deck, the upstream edge of the buttresses are flared to form massive heads which span the distance between the buttresses.

(8) Steel Dams :-

→ A steel dam consists of a steel frame work, with a steel skin plate on its upstream face.

→ Steel dams are generally of two types.

(i) Direct-strutted ~~to~~

(ii) Cantilever type.

(i) Direct-strutted :- In direct strutted steel dams, the water pressure is transmitted directly to the foundation through inclined struts.

(ii) Cantilever type :- In a cantilever type steel dams, there is a bent supporting the upper part of the deck which is formed into a cantilever truss.

→ However, it would requier havier sections struts for Another alternative to reduce tension is to frame together the entire bent rigidly so that the moment due to the weight of the water on the lower part of the deck is utilized to offset the moment induced in the cantilever.

→ This arrangement would, however, require bracing & this will increase the cost. These are quite costly & are subjected to corosion.

Expo - Redridge steel Dam (USA).

(7) Timber Dams :-

→ Main load carrying structural elements of timber dam are made of wood, primarily coniferous varieties such as pine & fir.

→ Timber dams are made for small heads (2-4 m or rarely, 4-8 m) & usually have sluices, according to the design of the ~~span~~ apron they are divided into pile, crib, pile-crib, & buttressed dams.

→ The openings of timber dams are restricted by abutments; where the sluice is very long it is divided into several openings by intermediate supports; piers, buttresses & posts.

→ The openings are covered by wooden shields, usually several in a row one above the other.

(8) Rubber Dams :-

→ A symbol of sophistication & simple & efficient design, this most recent type of dam uses huge cylindrical shells made of special synthetic rubber & inflated by either compressed air or pressurized water.

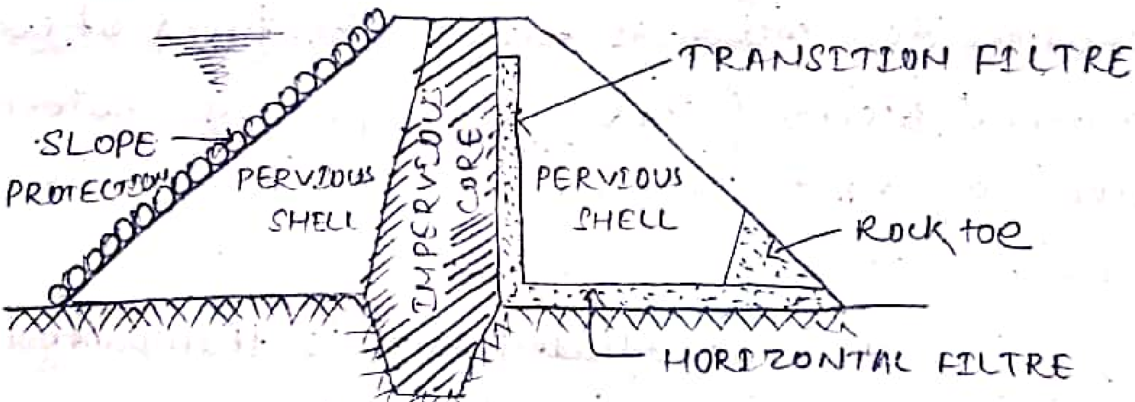
→ Rubber dams offers ease of construction, operation & decommissioning in tight schedule.

→ These can be deflated when pressure is released & hence, even the crest level can be controlled to some extend.

→ Surplus waters would simply overflow the inflated shell. They need extreme care in design & erosion & are limited to small projects.

EARTHEN DAM :-

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



(EARTH DAM)

Based on methods of construction:-

(i) Rolled fill dam:-

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

→ The selected soil is transported from borrow pits & laid on the dam section, to layers of about 45 cm.

→ The layers are thoroughly compacted by rollers of recommended weight & type.

→ When the compaction of one layer is fully achieved, the next layer is laid & compacted in the usual way. The designed dam section hence is completed layer by layer.

(ii) Hydraulic Dam :-

→ In this method, the dam section is constructed with the help of water.

→ Sufficient water is poured in the borrowpit & by plugging thoroughly, slurry is formed. This slurry is transported to the dam site by pipe line & discharged near the upstream & downstream faces of the dam.

→ The coarser material gets deposited near the face & the finer material move towards the centre & gets deposited there.

→ Thus the dam section is formed with faces of coarse material & central core is of impervious materials like clay & silt. In this case, compaction is not necessary.

(iii) Semi-hydraulic Fill dam :-

→ In this method, the selected earth is transported from the borrowpit & dumped within the section of the dam, as done in the case of rolled fill dam.

→ While dumping no water is used. But after dumping the water jet is forced on the dumped earth. Due to the action of water, the finer material move towards the centre of the dam & 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.

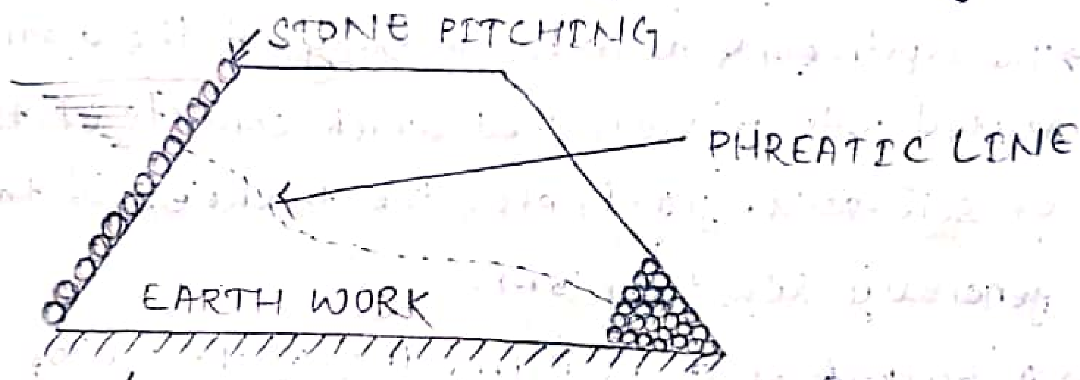
(iv) Homogeneous type dam:-

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

→ The top width & height depends on the depth of water to be retained & the gradient of the seepage line.

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

→ This type of dam is completely pervious. The upstream face of the dam is protected by stone pitching.



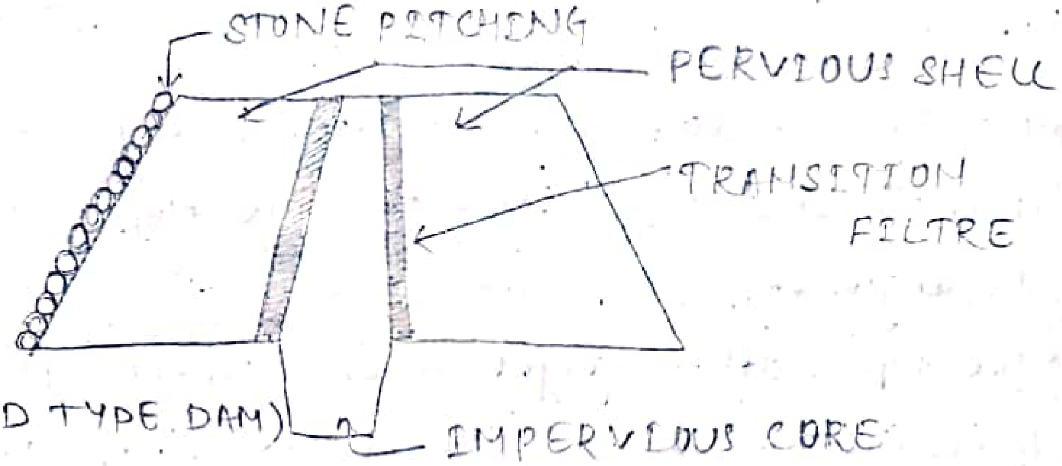
(HOMOGENEOUS TYPE DAM)

(v) Zoned type dam:-

→ This type of dam consist of several materials. The impervious core is made of puddle clay & the outer pervious shell is constructed with the mixture of earth, sand, gravel, etc. the core is trapezoidal in section & its width depends on the seepage characteristics of the soil mixture on the upstream side.

→ The core is extended below the both side of the impervious core to control the seepage.

→ The transition filtre is made of gravel & coarse sand. The upstream face of the dam is protected by stone pitching.



(ZONED TYPE DAM)

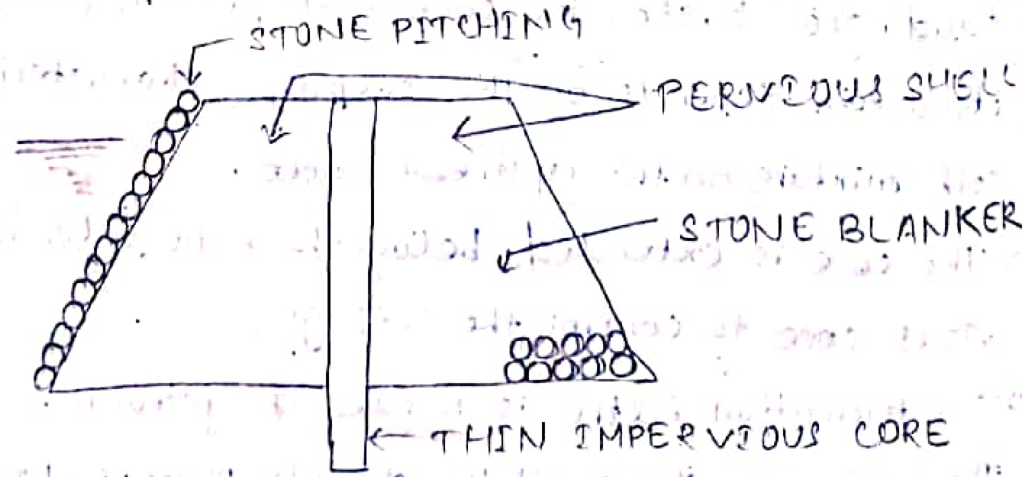
(vi) Diaphragm type Dam :-

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

→ The upstream & downstream body of the dam is constructed with pervious shell which consists of the mixture of soil, sand, gravel, etc. the thickness of the core is generally less than 3 m.

→ A bucket 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. the side slope of the dam should be decided according to the 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 reasons.

1. **Hydraulic failure** :- This type of failure may be cause by.

a) **Overtopping** :- If the actual flood discharge is much is much more than the estimated flood discharge or the fee board is kept insufficient or there is settlement of the dam or the capacity of spill way is insufficient, then it results in the overtopping of the dam.

→ During the overtopping the crest of the dam may be washed out & the dam may collapse.

b) **Erosion** :- If the stone of the upstream side is insufficient, then the upstream face may be damaged by erosion due to wave action.

→ The down stream side also may be damaged by tail water, rainwater, etc.

→ The toe of the dam may also get damaged by the water flowing through the spill ways.

2. **Seepage failure** :- This type of failure may caused by.

a) **Piping of undermining** :- Due to the continuous seepage flow through the body of the dam & through the sub-soil below the dam, the downstream side gets eroded or washed out & 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 weakness the dam & ultimately causes failure of the dam.

(b) Sloughing :- The crumbling of toe of the dam is known as sloughing. When the reservoir runs full, for a longer time, the downstream base 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 caused by

(a) Sliding of the side slope :- Sometimes it is found that the side slope of the dam slides down to form some steeper slope.

→ The dam goes on depressing gradually & then over-topping occurs which leads to the failure of the dam.

(b) Damage by burrowing animals :-

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

~~CAUSES OF FAILURE OF EARTHEN DAM~~ :-

SPILLWAYS :-

→ Spill ways are structures constructed to provide safe release of flood waters from a dam to a downstream are, normally the river on which the dam has been constructed.

→ Every reservoir has a certain capacity to store water. If the reservoir is full & flood water enters the same the reservoir level will go up & may eventually result in overtopping of the dam. To avoid this situation, the flood has to be passed to the downstream & this is done by providing a spillway which draws water from the top of the reservoir. A spill way can be a part of the dam or separate from it.

→ spillways can be controlled or uncontrolled. A controlled spillway is provided with gates which can be raised or lowered.

Parameters considered in Designing spill ways:-

→ Thees controlled spillways allow more storage for the same height of the dam. Many parameters need consi~~deration~~ deration in designing a spillway. These include:-

1. The inflow design flood hydro-graph.
2. The type of spill-way to be provided & its capacity.
3. The hydraulic & structural design of various components.
4. The energy dissipation down stream of the spillway.

Types of spillways:-

→ There are diff types of spillways that can be provided depending on the suitability of site & other parameters. Generally a spill way consists of a control structure, a conveyance channel & a terminal structure, but the former two may be combined in the same for certain types. The more common types are briefly described below.

1. Ogee Spillway:-

→ The ogee spillway is generally provided in rigid dams & forms a part of the main dam itself if sufficient length is available.

→ The crest of the spillway is shaped to conform to the lower nappe of a water sheet flowing over an aerated sharp crested weir.

2. Chute (Trough) Spillway :-

→ In this type of spillway, the water, after flowing over a short crest or other kind of control structure, is carried by an open channel (called the 'chute' or 'trough') to the downstream side of the river.

→ The control str is generally normal to the conveyance channel

→ The channel is constructed in excavation with stable side slopes & invariably lined.

3. Side channel spillway :-

→ Side channel spillways are located just upstream & to the side of the dam.

→ The water after flowing over a crest enters a side channel which is nearly parallel to the crest. This is then carried by a chute to the downstream side.

→ Sometimes a tunnel may be used instead of a chute

4. Shaft (Morning Glory or Glory hole) Spillway :-

→ This type of spillway utilizes a crest circular in plan the flow over which is carried by a vertical or sloping tunnel on to horizontal tunnel nearly at the stream bed level & eventually to the downstream side.

→ The diversion tunnels constructed during the dam construction can be used as the horizontal conduit in many cases.

Siphon spillway :-

→ As the name indicates, the spillway works on the principle of a siphon. A hood provided over a conventional spillway from a conduit.

→ With the rise in reservoir level water starts flowing over the crest as in an "ogee" spillway. The flowing water however, entrance air & once all the air in the crest area is removed, siphon action starts.

→ Under this condition, the discharge takes place at a much larger head. The spill way thus has a larger discharging capacity.

→ The inlet end of the hood is generally kept below the reservoir level to prevent floating debris from entering the conduit.

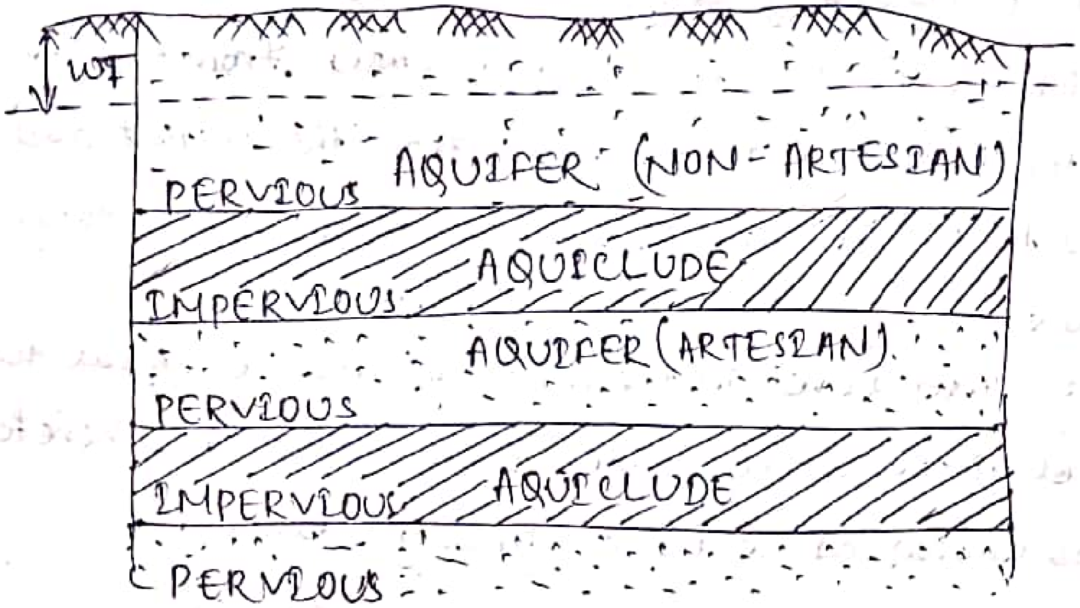
→ This may cause the reservoir to be drawn down below the normal level before the siphon action breaks & therefore arrangement for de-priming the siphon at the normal reservoir level is provided.

→ A permeable stratum or a geological formation of permeable material, which is capable of yielding appreciable quantities of ground water under gravity, is known as aquifer.

→ The term 'appreciable quantity' is relative, depending upon the availability of the ground water.

→ In the regions, where ground-water is available with great difficult, even fine-grained materials containing very less quantities of water may be classified as principal aquifers.

→ When an aquifer is obtained by a confined bed of impervious material, then this confined bed of overburden is called as aquifer.



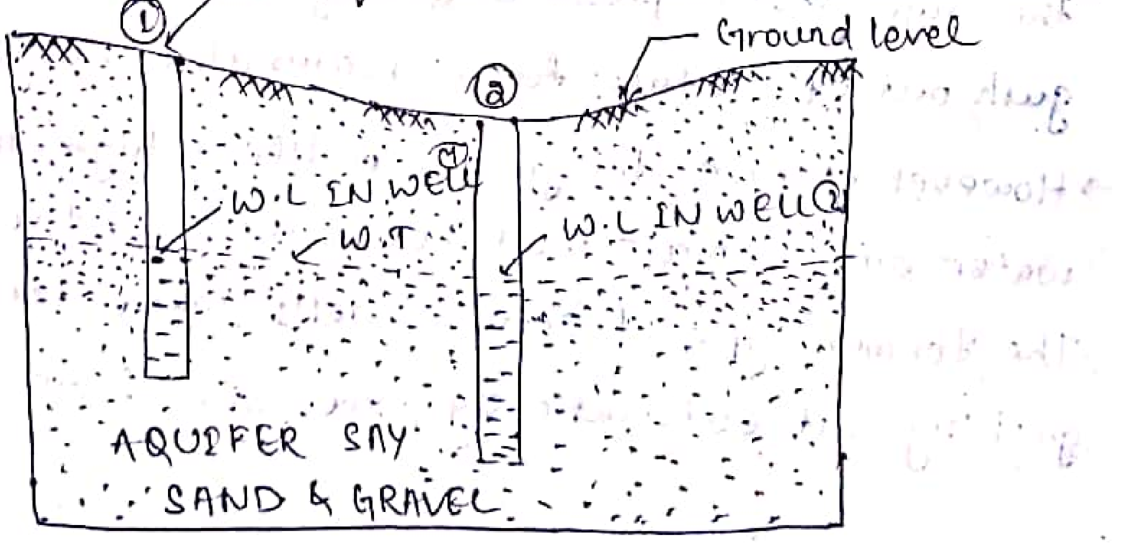
Aquifer vary in depth, lateral extend, & thickness but in general, all aquifer fall into one of the two catagories. i.e-

(1) Unconfined or Non-artesian aquifers

(2) Confined or Artesian aquifers.

(1) Unconfined or Non-artesian aquifers :-

→ The top most water bearing stratum having no confine impermeable over burden (i.e- aquiclude) lying over it is known as an unconfined aquifer or non-artesian aquifer.



→ The ordinary gravity wells of 2 to 5 m diameter, which are constructed to gap water from the top most water bearing strata, i.e. from the unconfined aquifers, are known as unconfined or non-artesian wells.

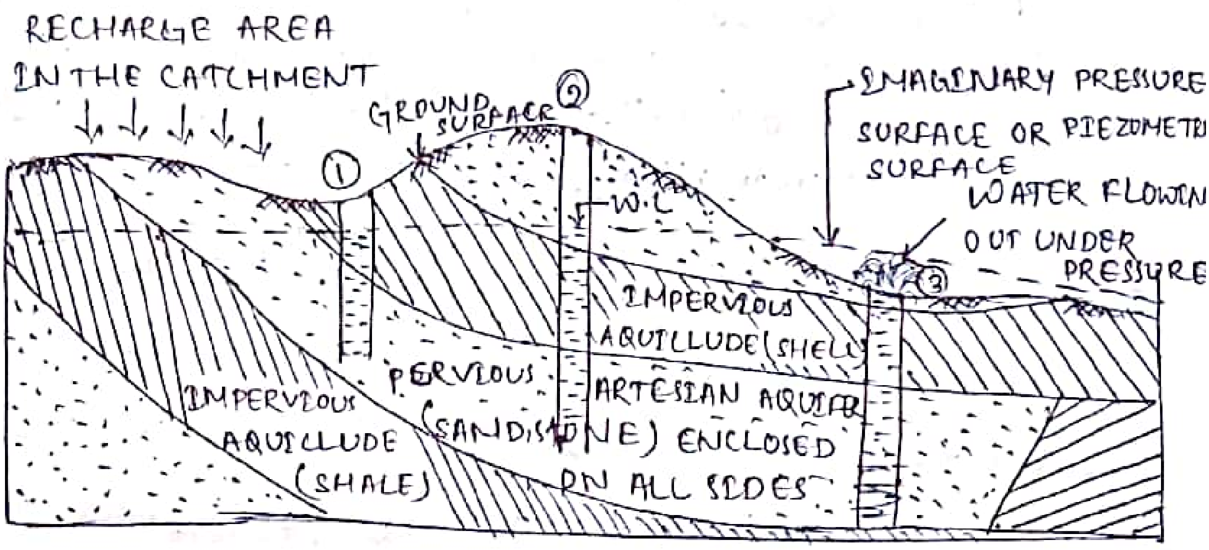
→ The water level in these wells will be equal to the level of the water table. Such well are, therefore, also known as wells or gravity wells.

(2) Confined Aquifers or Artesian Aquifers :-

→ when an aquifer is confined on its upper & under surface, by impervious rock formations (i.e. aquicludes) & is also broadly inclined so as to expose the aquifer somewhere to the catchments area at a higher level for the creation of sufficient ~~day~~ hydraulic head, it is called a confined aquifer or an artesian aquifer.

→ A well excavated through such an aquifer, yields water than often flows out automatically, under the hydrostatic pressure, & may thus, even rise on gush out of surface for a reasonable height.

→ However, where the ground profile is high, the water may remain well below the ground level. The former type of artesian wells, where after is gushing out automatically, are called flowing well



WELL NO 1 & 2 ARE NON-FLOWING ARTESIAN WELLS AND WELL 3 IS A FLOWING ARTESIAN WELL.

Perched Aquifers :-

→ Perched aquifer is a special case which is sometimes found to occur within an unconfined aquifer.

→ If within the zone of saturation, an impervious deposit below a pervious deposit is found to support a body of saturated material, then this body of saturated materials which is a kind of aquifer is known as perched aquifer.

→ The top surface of the water held in the perched aquifer is known as perched water table.

Wells :-

→ A water well is a hole usually vertical, excavated in the earth for bringing ground water to the surface. The wells may be classified into two types.

(1) Open wells (2) Tube wells

(1) Open wells or Dug wells :-

→ Smaller amount of ground water has been utilized from ancient times by open wells.

→ Open wells are generally open masonry wells having comparatively bigger diameters, & are suitable for low discharges of the order of 18 cubic metre per hour. The diame of than 20 m in depth. The walls of an open well maybe buil of precast concrete rings or in brick or stone masonry, the thic generally varies from 0.5 to 0.75 m, according to the depth of the we

→ The yield of an open well is limited because suc wells can be excavated only to a limited depth where the ground water storage is also limited.

→ One of the recent methods used to improve the yiel of an open well is to put in a 8 to 10 cm diameter bore hole in the centre of the well, so as to tap the additional water from an aquifer or from fissures in the rock.

→ If a clay or kankar layer is available at a smaller depth so as to support the open masonry well, a bore hole can be made in its centre so as to reach the sand strata.

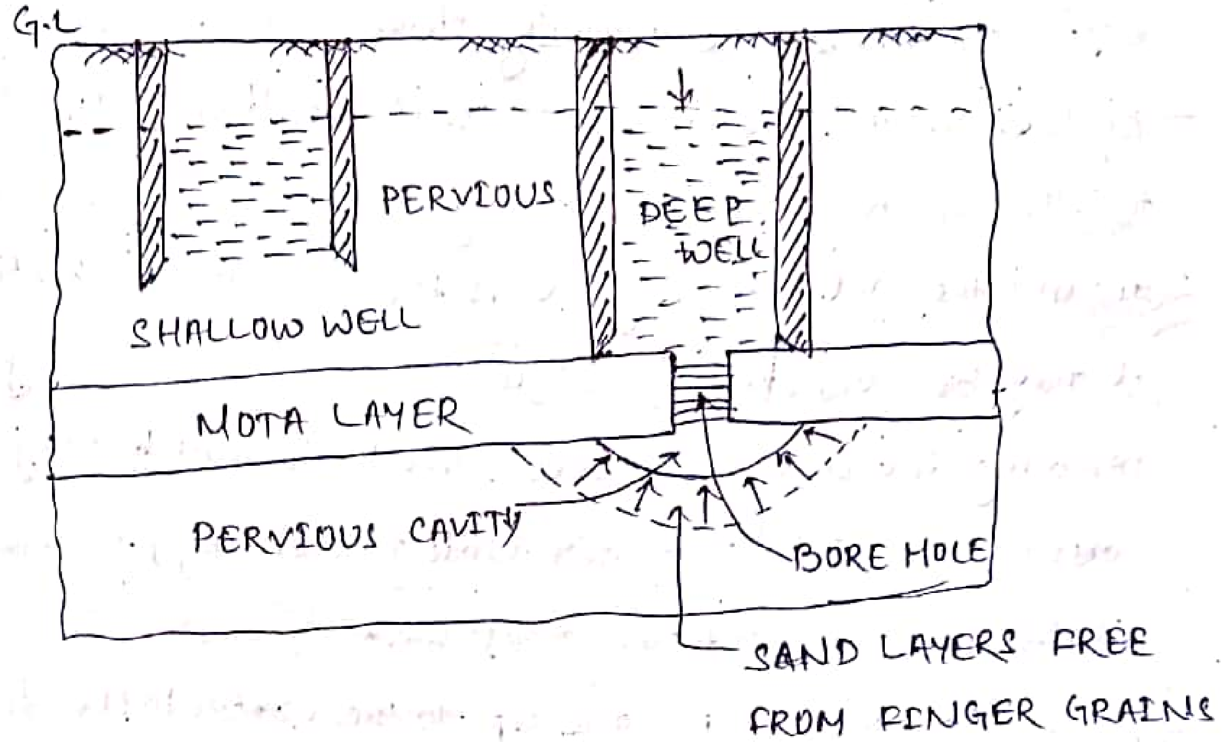
→ Such an arrangement will not only give a structural support to the open well but will also considerably increase its yield. Depending upon the availability of such a provision, the open wells may be classified into the following two types.

(a) Shallow wells

(b) Deep wells

→ Shallow wells are those which rest in a pervious stratum & draw their supplies from the surronding material.

→ On the other hand, a deep well is one which rests on an impervious 'mota' layer & draws its supply from the pervious formation lying below the mota layer, through a bore hole made into the 'mota layer'.



Constructions of open wells :-

→ From the construction point of view, the open wells may be classified into the following three types.

Type-I → Wells with an impervious lining, such as masonry lining, & generally resting on a mota layer.

Type-II → Wells with a pervious lining, such as dry brick or stone lining, & fed through the pores in the lining.

Type-III → No lining at all, ie-a kachha well.

Type-I → Wells with impervious lining. They provide the most stable & useful wells for obtaining water supplies. For constructiong such a well, a pit is first of all excavated generally by hand tools, up to the soft moist soil. Masonry lining is then built up on a kerb upto a few metres above the ground level. A 'kerb' is a circular ring of R.C.C, timber or steel having a cutting edge at the bottom & a ~~top~~ flat top, wide enough to support the thickness of a well lining called 'steining'.

→ The kerb is then descended into the pit by loading the masonry by sand bags, etc. As excavation proceeds below the kerb; the masonry sinks down.

→ As the masonry sinks down, it is further built up at top. To ensure vertical sinking, plum bobs are suspended around the well steining, & if the well starts tilting, it may be corroded by adjusting the loads or by removing the soil from below the kerb which may be causing the tilt. The well lining (steining) is generally reinforced with vertical steel bars.

→ After the well has gone up to the water table, further excavation & sinking may be done either by continuously removing the water through pumps etc or the excavation may be carried out from top by Jharns.

→ ~~When~~ A the Jham is self-closing bucket which is tied to a rope & worked up & down over a pulley.

→ when the Jham is thrown into the well, its jaws strike the bottom of the well, dislodging some of the soil materials.

→ As the Jham is pulled up, the soil cuttings get retained but the water oozes out. The sinking is continued till the mota layer is reached.

Type-II -

→ wells with pervious lining. In this type of wells, dry brick or stone lining is used on the sides of the well. No mortar or binding material is used.

→ The water, thus enters from the sides, through the pores in the lining. The flow is, therefore, radial. Such well are generally plugged at the bottom by means of concrete.

→ If the bottom is not plugged, the flow pattern will be combination of radial flow & a spherical flow. Such

→ well are generally suitable in strata as of gravel or coarse sand

→ The pervious lining may have to be surrounded by gravel, etc, when such a well is constructed in finer soils, so as to prevent the entry of sand into the well along with the seeping water.

Type - III :- Kachha well :-

→ These are temporary well of very shallow depth & are generally constructed by cultivators or irrigation supplies in their fields.

→ Such well can be constructed in hard soils, where the well walls can stand vertically without any support.

→ They can therefore, be constructed only where the water table is very near to the ground. Though they they are very cheap & useful, yet they collapse after sometime, & may sometimes prove to be dangerous.

Yield of an open well :-

→ The yield of an open well can be determined with the help of theoritical methods, with practical methods, or by carrying out a practical test & then calculating it from the observations.

→ This third method is useful for calculating the yields of open wells as well as that of tube-wells penetrating through confined aquifers.

Theoritical method:-

→ If a well is penetrated through the aquifer, water will rush into it with a velocity V. If A is the area of the aquifer opening into the well, then

$Q = AV$

Where, $V = vK$, where v is the actual flow velocity & V is the velocity with which water rushes into the well & is constant.

$Q = K \cdot A \cdot V$

Where K is a constant depending upon ~~the soil~~ & is known as permeability constant.

In the above equation, the velocity of ground water flow (v) can be found by using Slichter's or Hazen's formula or by actual measurements by chemical or electrical methods.

A = Area of the aquifer, & can be found by knowing the diameter of the well & the depth of porous strata.

K = Constant can be found by studying the sample of the soil in the laboratory.

Knowing v, A & K, the discharge can be easily calculated.

Tube wells :-

→ It is a type of water well in which a long 100-200' wideless stainless steel tube or pipe is bored into an underground aquifer. The lower end is fitted with a stainer. & a pump lifts water for irrigation.

→ The required depth of the well depends upon the depth of the water tables.