HYDRAULICS & IRRIGATION

4^{TH} SEMESTER

CIVIL ENGG.

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

ρ = 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.

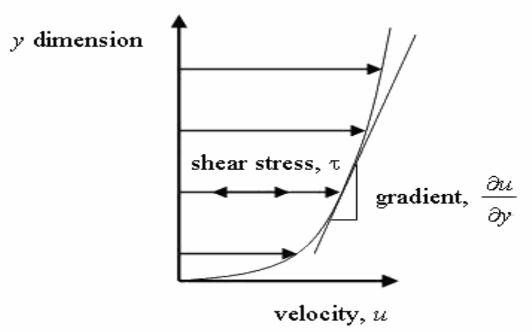


Fig. 1.1

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:-

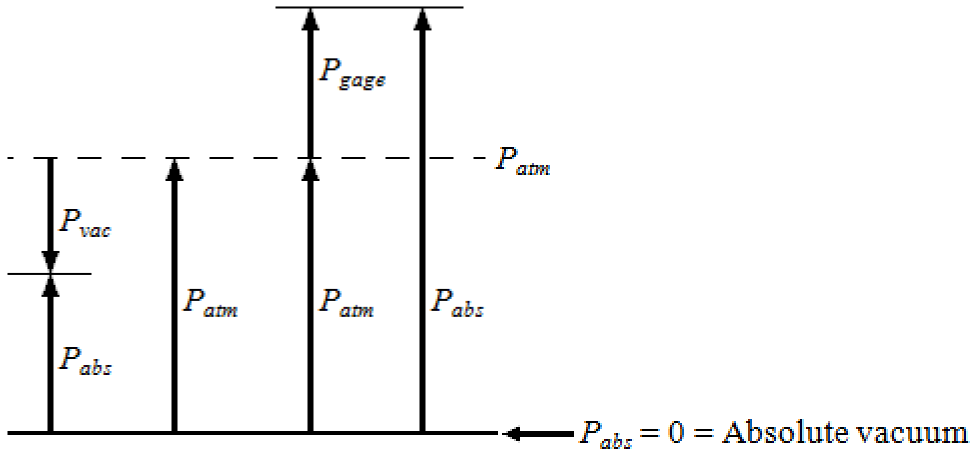


Fig. 1.2

- 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**,

$P = p_1 a_1 + p_2 a_2 + p_3 a_3 \ldots\ldots\ldots$

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.

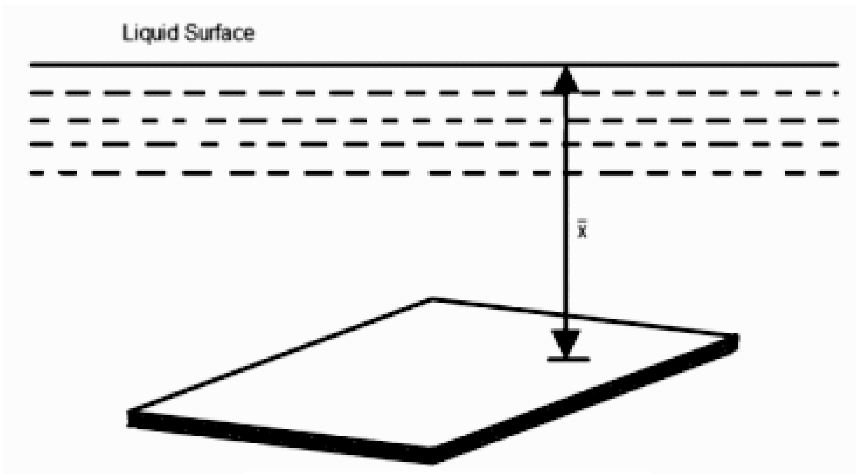


Fig. 1.3

- 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.

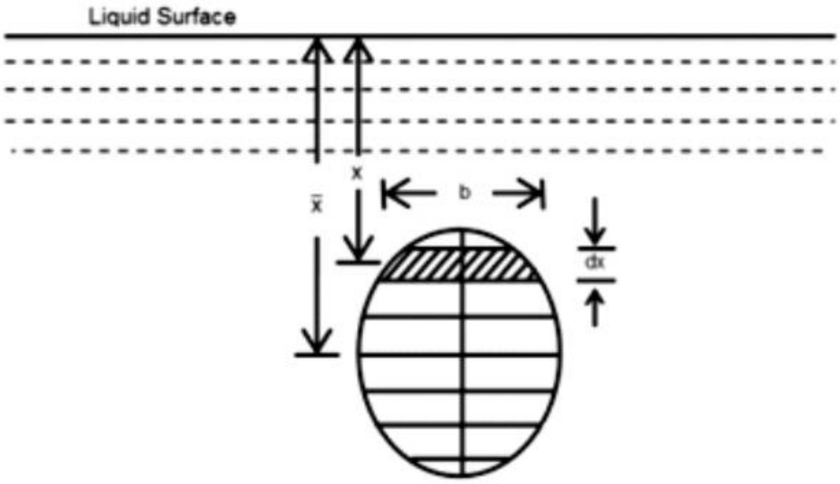


Fig. 1.4

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.

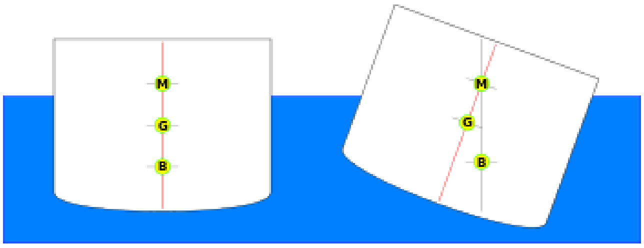


Fig. 1.5

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.

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,

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

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,

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

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,

$Q_1 = a_1.v_1 = (17.67 x l0^{-3}) x 2.5 = 44.2 \times 10^{-3} \; m^3/s$

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

:. 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-

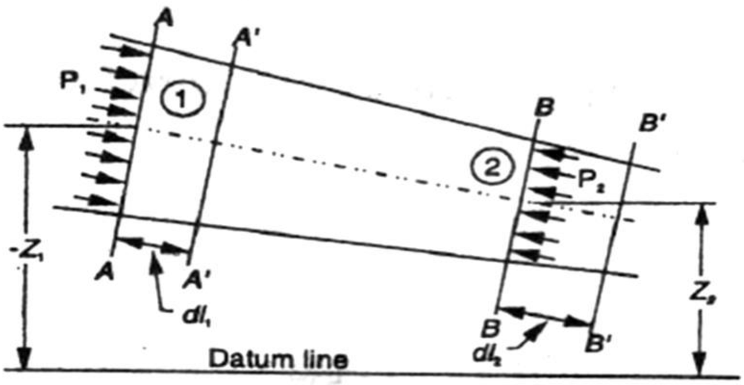


Fig. 2.1

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 $$a_1 \times dl_1 = \frac{W}{w} \quad ...(i)$$

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

$$\therefore a_1 . dL_1 = a_2 dL_2 \quad ...(ii)$$

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'
$=-P_2 a_2 dl_2$
...(Minus sign is taken as the direction of P_2 is opposite to that of P_1)
:. Total work done by the pressure
$= P_1 a1 dl_1 - P_2 a_2 dl_2$
$=P_1 a1 dl_1 - p_{2a} 1 dl_1$ …($a_1 dl_1 = a_2 dl_2$)
$= a_1.dl_1 (P_1 - P_2) = \frac{W}{w} (P_1 - P_2)$ …($a_1.dl_1 = \frac{W}{w}$)
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.

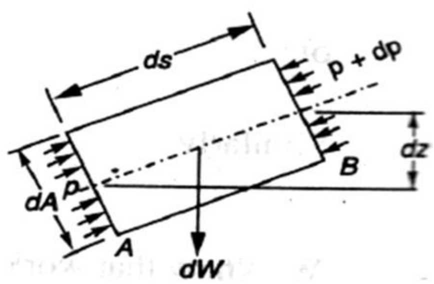


Fig. 2.2

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,
$dW = \rho\, g.\ dA . ds$
From the geometry of the figure, we find that the component of the weight of the fluid element ,in the direction of flow
$= - \rho\, g . dA . ds \cos\theta$
$= - \rho\, g . dA . ds(\frac{dz}{ds})$ …$\cos\theta = \frac{dz}{ds}$
$= - \rho\, g.\ dA.\ dz$
$\therefore$ *mass of the fluid element* $= \rho$ .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 $a_1 . V_1 = a_2 . V_2$

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

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

practical Applications of Bernoulli's Equation

The Bernoulli's theorem or Bernoulli's equation is the basic equation which has the widest applications in Hydraulics and Applied Hydraulics. Since this equation is applied for the derivation .of many formulae, therefore its clear understanding is very essential. Though the Bernoulli's equation has a number of practical applications. yet in this chapter we shall discuss its applications on the following ‘hydraulic devices :

1. Venturi meter.
2. Orifice meter.
3. Pitot tube.

Venturimeter

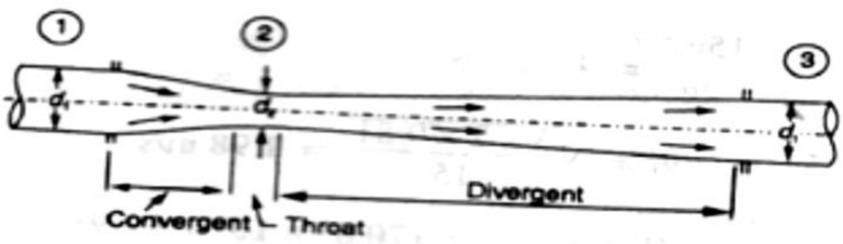


Fig. 2.4

A venturi meter is an apparatus for finding out the discharge of a liquid flowing in a pipe. A- venture meter, in its simplest form, consists of the following three parts:

(a) Convergent cone.
(b) Throat.
(c) Divergent cone.

(a) Convergent cone

It is a short pipe which converges from a diameter d_1 (diameter of the pipe. in which the venture meter is fitted) to a smaller diameter d_2: The convergent cone is also known as inlet of the venturi meter. The slope of the converging sides is between 1 in 4 or 1 in 5 as shown in Fig.

(b) Throat

It is a small portion of circular pipe in which the diameter d_2 is kept constant as shown in Fig.

(c) Divergent cone

It is a pipe, which diverges from a diameter d_2 to a large diameter d_1. The divergent cone is also known as outlet of the venture meter. The length of the divergent cone is about 3 to 4 times than that of the convergent cone as shown in Fig.

A little consideration will show that the liquid, while flowing through the venture meter, is accelerated between the sections 1 and 2 (i.e., while flowing through the convergent cone). As a result of the acceleration, the velocity of liquid at section 2 (i.e., at the throat) becomes higher than that at section 1. This increase in velocity results in considerably decreasing the pressure at section 2.1fthe pressure head at the throat falls below the separation head (which is 2.5 metres of water), then there will be a tendency of separation of the liquid flow, In order to avoid the tendency of separation at throat, there is always a fixed ratio of the diameter of throat and the pipe (i.e., dz/dt). This ratio varies from 1/4 to 3/4, but the most suitable value is 1/3 to 1/2.

The liquid, while flowing through the venture meter, is decelerated (i.e., retarded) between the sections 2 and 3 (i.e., while flowing through the divergent cone). As a result of this retardation, the velocity of liquid decreases which, consequently, increases the pressure. If the pressure is rapidly recovered, then there is every possibility for the stream of liquid to break away from the walls of the metre due to boundary layer effects. In order to avoid the tendency of breaking away the stream of liquid, the divergent cone is made sufficiently longer. Another reason for making the divergent cone longer is to minimise the frictional losses. Due to these reasons, the divergent cone is 3 to 4 times longer than convergent cone as shown in Fig.

Discharge through a Venturi meter

Consider a venture meter through which some liquid is flowing as shown in Fig.

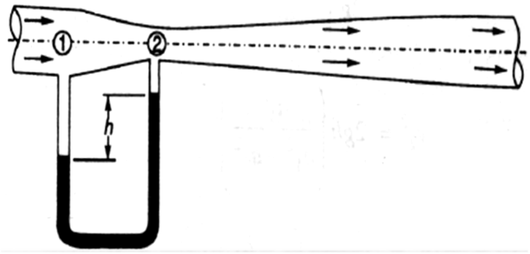


Fig. 2.5

Let

P_1 = Pressure at section 1,

V_1 = Velocity of water at section 1,

Z_1 = Datum head at section 1,

a_1 = Area of the venturi meter at section 1, and

p_2, v_2, z_2, a_2 = Corresponding values at section 2.

Applying Bernoulli's equation at sections 1 and 2. i.e

$Z_1 + v_1^2/2g + (p_1/w) = Z_2 + v_2^2/2g + (p_2/w)$ ....(1)

Let us pass our datum line through the axis of the venture meter as shown in Fig.

Now $Z_1=0$ and $Z_2=0$

$\therefore\ v_1^2/2g + (p_1/w) = v_2^2/2g + (p_2/w)$

Or $(p_1/w) - (p_2/w) = v_2^2/2g - v_1^2/2g$ ....(2)

Since the discharge at sections 1 and 2 is continuous, therefore

$V_1 = a_2 v_2/a_1$ $(a_1 v_1 = a_2 v_2)$

$V_1^2 = a_2^2 v_2^2/a_1^2$ ....(3)

Substituting the above value of v_1^2 in equation (2),

$\frac{p1}{w} - \frac{p2}{w} = v_2^2/2g - (a_2^2/a_1^2 X\ v_2^2/2g)$

$= v_2^2/2g(1 - a_2^2/a_1^2) = v_2^2/2g[(a_1^2 - a_2^2)/a_1^2]$

We know that $\frac{p1}{w} - \frac{p2}{w}$ is the difference between the pressure heads at sections 1 and 2 when the pipe is horizontal, this difference represents the venturi head and is denoted by h.

Or $h = v_2^2/2g[(a_1^2 - a_2^2)/a_1^2]$

Or $v_2^2 = 2gh[a_1^2/(a_1^2 - a_2^2)]$

$\therefore\ v_2 = \sqrt{2gh}[a_1/\sqrt{\square}(a_1^2 - a_2^2)]$

We know that the discharge through a venture meter,

Q = Coefficient of venturi meter x $a_2 v_2$

$=C.a_2v_2=[Ca_1a_2/\sqrt{\square}(a_1^2-a_2^2)]\times\sqrt{2gh}$

Example

A venture meter with a 150 mm diameter at inlet and 100 mm at throat is,laid with its axis horizontal and is used for measuring the flow of oil specific gravity O.9. The oil-mercury differential manometer shows a gauge difference of200 mm. Assume coefficient of the metre as O.9 Calculate the discharge in litres per minute.

Solution. Given: d_1 = 150 mm = 0.15 m; d_2 = 100 mm = 0.1 rn; Specific gravity of oil = 0.9
h = 200 mm = O.2 m of mercury and C = 0.98.

We know that the area at inlet,

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

and the area at throat,

$a_2=\frac{\pi}{4}\times 0.1^2=7.854\times 10^{-3}m^2$

We also know that the difference of pressure head,
H=0.2(13.6-0.9/0.9)=2.82 m of oil
and the discharge through the venturi meter,
$Q=[Ca_1a_2/\sqrt{\square}(a_1^2-a_2^2)]\times\sqrt{2gh}$
$=63.9 \times 10^{-3}m^3/s$=63.9lit/s Ans.

0rifice Metre

An orifice metre is used to measure the discharge in a pipe. An orifice metre, in its simplest form, consists of a plate having a sharp edged circular hole known as an orifice. This plate is fixed inside a pipe as shown in Fig. c A mercury manometer is inserted to know the difference of pressures between the pipe an? the throat (i.e., orifice).

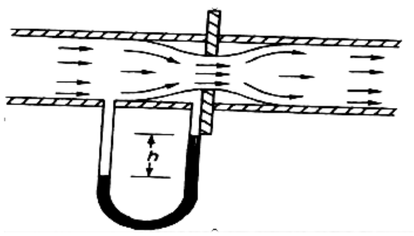


Fig. 2.6

Let
h = Reading of the mercury manometer,
P_1 = Pressure at inlet,
V_1 = Velocity of liquid at inlet,
a_1 = Area of pipe at inlet, and
P_2,v_2,a_2= Corresponding values at the throat.

Now applying Bernoulli's equation for inlet of the pipe and the throat,

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

$(p_1/w)-(p_2/w)=v_2^2/2g-v_1^2/2g$

Or $h= v_2^2/2g-v_1^2/2g=1/2g(v_2^2-v_1^2)$ ....(ii)

Since the discharge is continuous, therefore $a_1.v_1 = a_2v_2$

$V_1=a_2/a_1 \times v_2$ or $v_1^2=a_2^2/a_1^2 \times v_2^2$

Substituting the above value of v_1^2 in equation (ii)

$h = 1/2g(v_2^2-a_2^2/a_1^2 \times v_2^2)= v_2^2/2g \times (1- a_2^2/a_1^2)=v_2^2/2g[(a_1^2-a_2^2)/a_1^2]$

$\therefore v_2^2= 2gh[a_1^2/(a_1^2-a_2^2)]$ or $v_2=\sqrt{\square}2gh[a_1/\sqrt{\square}(a_1^2-a_2^2)]$

We know that the discharge,

Q = Coefficient of orifice metre x $a_2 . v_2$

$=[Ca_1a_2/\sqrt{}(a_1^2-a_2^2)]\times\sqrt{2gh}$

Example. An orifice metre consisting of 100 mm diameter orifice in a 250 mm diameter pipe has coefficient equal to 0•65. The pipe delivers oil (sp. gr. 0•8). The pressure difference on the two sides of the orifice plate is measured by a mercury oil differential inano meter.lfthe differential gauge reads 80 mm of mercury, calculate the rate of flow in litresls.
Solution. Given: d_2 = 100 mm = 0.1 m; d_1 = 250 mm = o.25 m; C = 0.65 ; Specific gravity of oil = 0.8 and h = 0.8 m of mercury.

We know that the area of pipe,

$a_1=\frac{\pi}{4}\times 0.25^2=49.09\times 10^{-3}m^2$

and area of throat

$a_2=\frac{\pi}{4}\times 0.1^2=7.854\times 10^{-3}m^2$

We also know that the pressure difference,

h = 0.8[(13.6-0.8)/0.8]=12.8 m of oil

and rate of flow,

$Q=[Ca_1a_2/\sqrt{}(a_1^2-a_2^2)]\times\sqrt{2gh}$

$=82\times 10^{-3}\ m^3/s=82$ lit/s Ans

Pitot Tube.

A Pitot tube is an instrument to determine the velocity of flow at the required point in a pipe or a stream. In its simplest form, a pitot tube consists of a glass tube bent a through 90° as shown in Fig.
The lower end of the tube faces the direction of the flow as shown in Fig. The liquid rises up in the tube due to the pressure exerted by the flowing liquid. By measuring the rise of liquid in the tube, we can find out the velocity of the liquid flow.
Let h = Height of the liquid in the pitot tube above the surface,

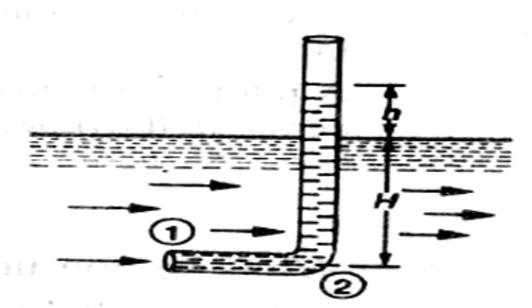


Fig. 2.7

H = Depth of tube in the liquid, and

v = Velocity of the liquid.

Applying Bernoulli's equation for the sections 1 and 2,

$H+v^2/2g=H+h$ .....($z_1=z_2$)

$h=v^2/2g$

$\therefore v=\sqrt{}2gh$

Example .

A pltot tube was inserted in a pipe to measu!e the velocity of water in it. If (

water rises the tube is 200 mm, find the velocity of water.

Solution. Given: h = 200 mm = 0.2 m.

We know that the velocity of water in the pipe,

$v = \sqrt{2gh} = \sqrt{(2 \times 9.81 \times 0.2)} = 1.98$ m/s 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.

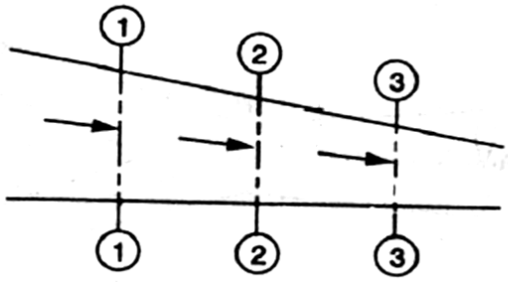


Fig. 2.8

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 = $a_1.v_1$ = (7.854×10^{-3})x 10 = $78.54 \text{ X } 10^{-3}\ m^3/s$

= 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 ,$v_2 = \frac{Q}{a2}$ = $((78.54 \text{ X } 10^{-3})/(31.42x10^{-3}))$=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.

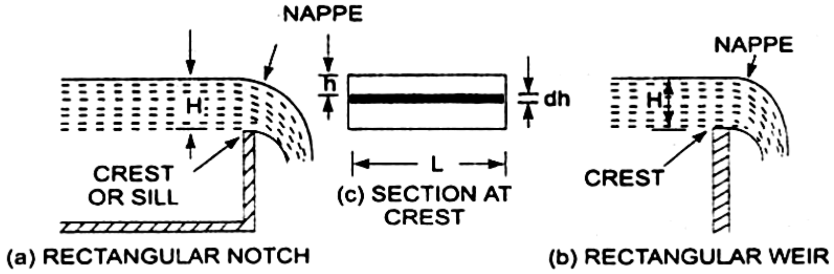


Fig. 2.9

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

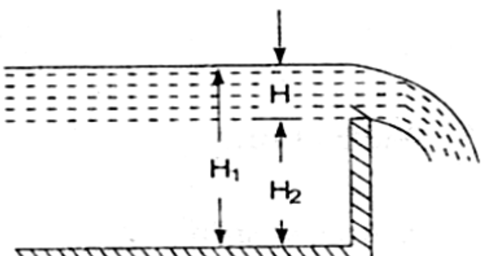
Cd/=0.6

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 .

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

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



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

$= H^{3/2}=\frac{2.0}{10.623}$ Fig. 2.10

$H=\left(\frac{2.0}{10.623}\right)^{2/3}=0.328$ 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, $Q = \frac{8}{15}\times 0.6\times 1\times\sqrt{2\times 9.81}\times H^{5/2}$

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

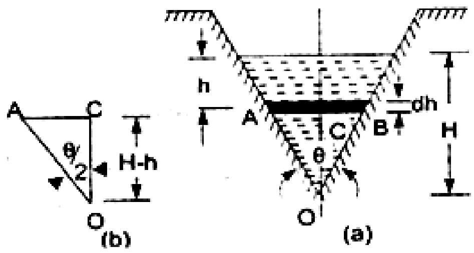


Fig. 2.11

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

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

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

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

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

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

$H_1=(0.07631)^{0.4}=0.3572$ 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:

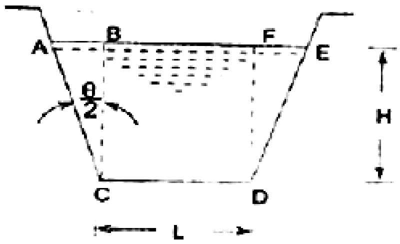
Top width AE=1 m

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



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

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

Fig. 2.12

Discharge through trapezoidal notch is given by equation

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

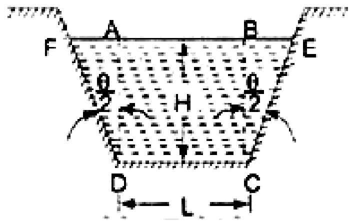
$$= \frac{2}{3} \times 0.62 \times 0.4 \times \sqrt{2\times 9.81} \times (0.2)^{3/2} + \frac{8}{15} \times 60 \times 1 \times \sqrt{2\times 9.81} \times (0.2)^{5/2}$$

= 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.



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

L_1 = Length of notch 1,

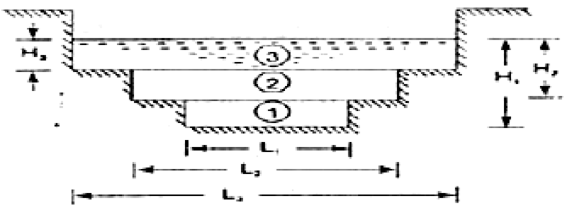
H_2,L_2 and H_3,L_3 are corresponding values for notches 2 and 3 res

C_d=Co-efficient of discharge for all notches

Total discharge $Q=Q_1+Q_2+Q_3$

Fig. 2.12

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



Problem

Fig. 2.13

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,

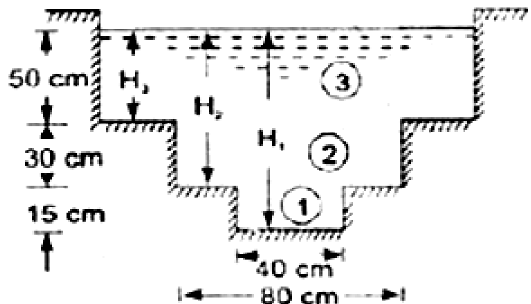
L_3 = 120cm

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

$\therefore Q = Q_1 + Q_2 + Q_3$

$= 154.067 + 530.144 + 776.771$

$= 1460.98$ 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,

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

$$= \frac{2}{3} \text{ x}0.623\text{x}10\sqrt{(2 \times 9.81)} \times (0.4)^{3/2}$$

$$=46.55 \text{ m}^2/\text{s} =4655 \text{ lit/s}$$

Discharge over a Broad-crested Weir :-

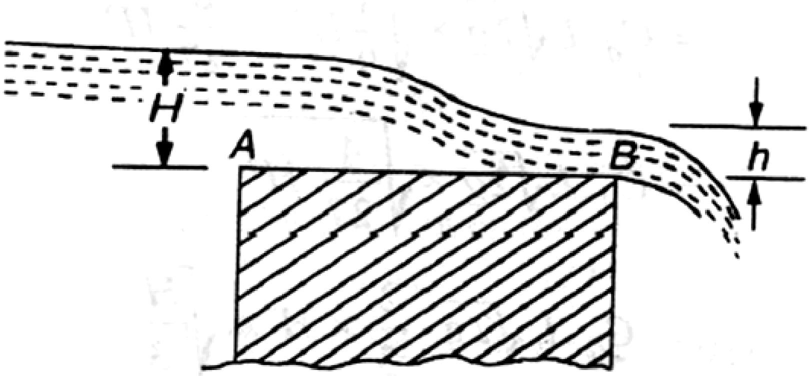


Fig. 2.15

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.

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

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.,

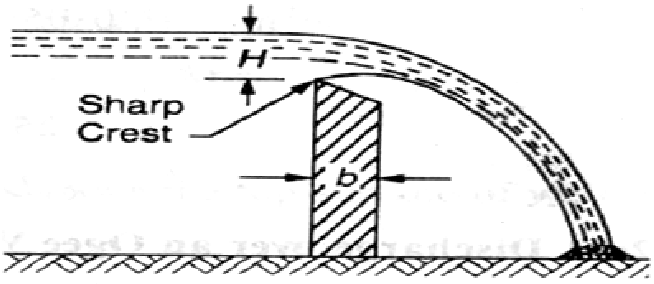


Fig. 2.16

Sharp-crested weir :-

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

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,

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

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

$= 0.0073\ m^3/s$ =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.,

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

Where C_d = Co-efficient of discharge and
L= Length of an ogee weir

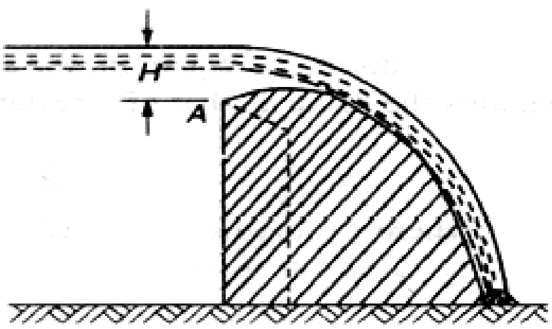


Fig. 2.17

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,

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

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

= 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.

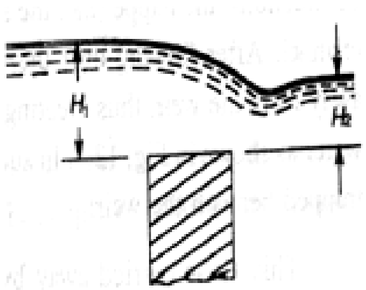


Fig. 2.18

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),

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

Submerged weir :-

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

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

:. 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

$Q_1 = \frac{2}{3} \times C_d . L\sqrt{2g} \times (H1-H2)^{3/2}$

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

= 5.315 x 0.125 = 0.664 m^3/s = 664 liters/s ... (i)

and discharge over the submerged portion of the weir,

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

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

= 0.36 x 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 :-

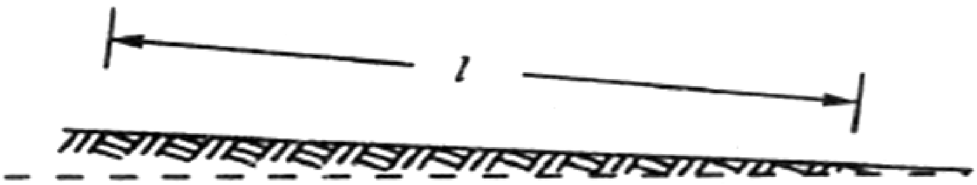


Fig. 2.19

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 x 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$\sqrt{mi}$ = 9x50$\sqrt{(1 X 1/900)}$= 15m^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 X $m^{2/3}$ X $i^{1/2}$

where

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

Now the discharge,

Q = Area x Velocity = A x 1/N x m^2 x$i^{1/2}$

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

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,

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

and wetted perimeter,

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

$\therefore$ hydraulic mean depth m = A/P=4/5.83=0.686 m

We know that the discharge through the channel

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

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

$= 1.945 \ m^3/s$ 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

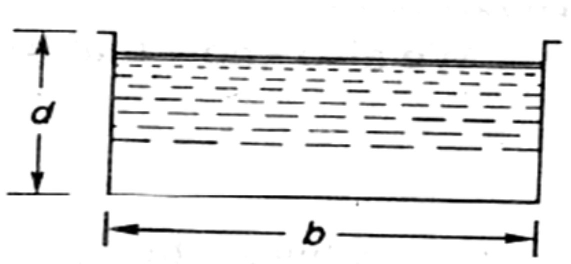


Fig. 2.20

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 x 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.

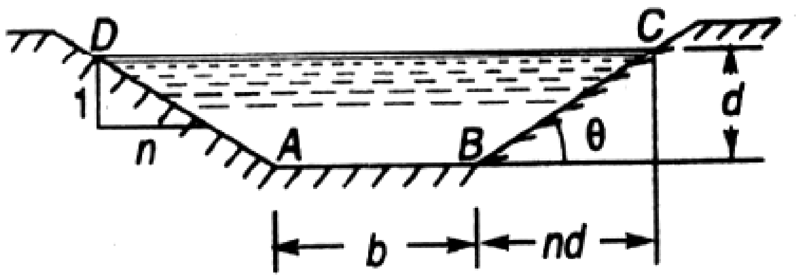


Fig. 2.21

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.$\sqrt{mi}$ =1.866$d^{5/2}$

∴ $d^{5/2}$ =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,

$$P = 2r\theta \qquad ...(i)$$

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

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

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** = $r^2\left(\theta - \frac{\sin 2\theta}{2}\right)$ = 171m^2

And perimeter P = 2rθ = 1.124m

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

And velocity of water v= M X$m^{2/3}$X$i^{1/2}$ = 0.71m/s ANS

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

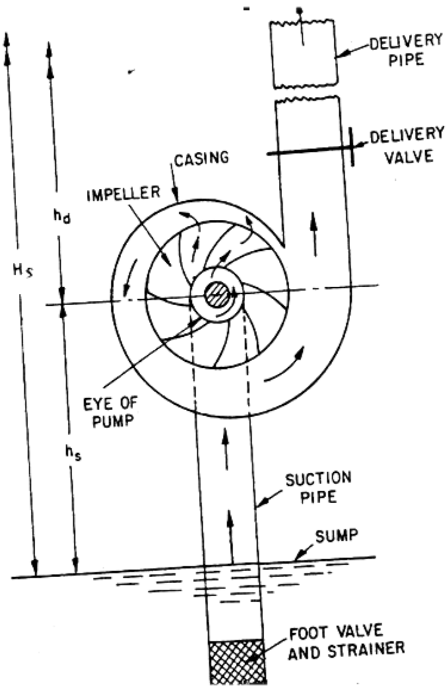
All the main parts of the centrifugal pump are shown in Fig 19.1

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.



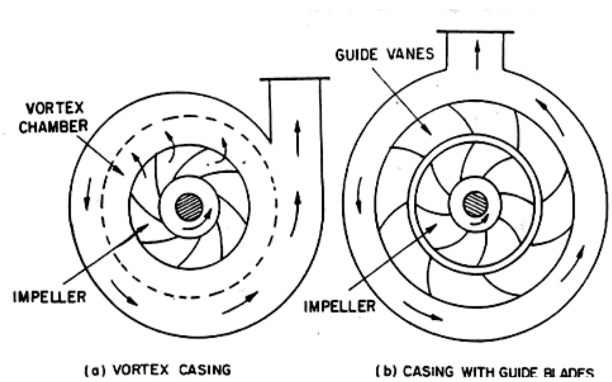
Main parts of a centrifugal pump

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

$\eta_{\max}$ = 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 = $\frac{Work\ done\ by\ impeller\ per\ second}{1000} kW$

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

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

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

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

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

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

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

$$= \eta_{man} \times \eta_m \ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

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, $u_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times .30 \times 1000}{60} = 15.70 m/s$

Now using equation

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

$$0.95 = \frac{9.81\times14.5}{V_{w2}\times15.70}$$

$$V_{w2} = \frac{0.95\times14.5}{0.95\times15.70} = 9.54m/s$$

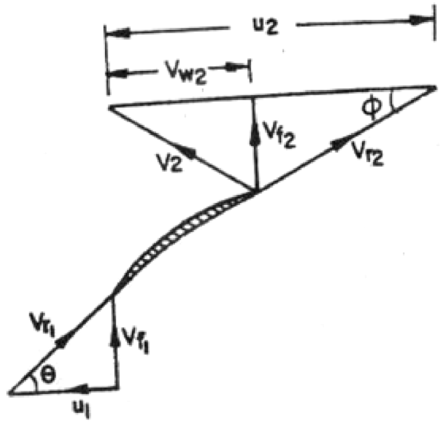


Fig. 3.3

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

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

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

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

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

$$= \pi\times0.30\times0.05\times3.556m^3/s = 0.1675m^3/s$$

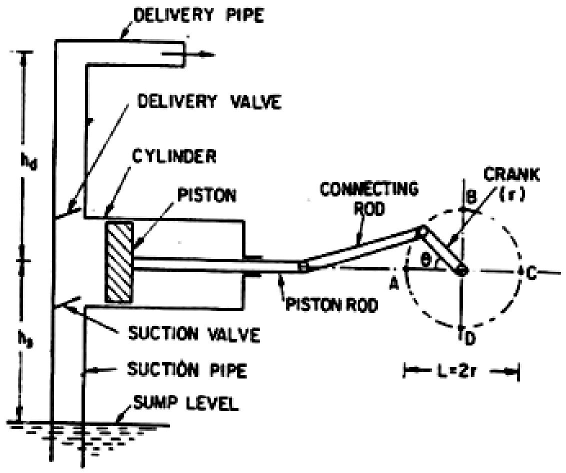
3.2 Reciprocating Pump:-

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

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

Wt. of water delivered per second, W = $\rho g Q = \frac{\rho g ALN}{60}$ ....

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 =

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

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

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

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

IRRIGATION

CROP WATER REQUIREMENT

Need and classification of irrigation- historical development and merits and demerits of irrigation- types of crops-crop season-duty, delta and base period- consumptive use of crops- estimation of Evapotranspiration using experimental and theoretical methods.

Irrigation- Definition

- Irrigation is an artificial application of water to the soil.
- It is usually used to assist the growing of crops in dry areas and during periods of inadequate rainfall.

Need of the Irrigation

- India is basically an agricultural country, and all its resources depend on the agricultural.
- Water is evidently the most vital element in the plant life.
- Water is normally supplied to the plants by nature through rains.
- However, the total rainfall in a particular area may be either insufficient, or ill-timed.
- Systematic irrigation system – Collecting water during the period of excess rainfall & releasing it to the crop when it is needed.

Less rainfall:

- Artificial supply is necessary
- Irrigation work may be constructed at a place where more water is available & than conveythe water where there is less rainfall.

Non uniform rainfall:

- Rainfall may not be uniform over the crop period in the particular area.
- Rains may be available during the starting period of crop but no water may be available atend, with the result yield may be less or crop may be die.
- Collection of water during the excess rainfall & supplied to the crop during the period whenthere may be no rainfall.

Commercial crops with additional water:

- Rainfall may be sufficient to raise the usual crop but more water may be necessary forraising commercial & cash crop . (Sugarcane, Tea, Tobacco, cotton, cardamom, & indigo)

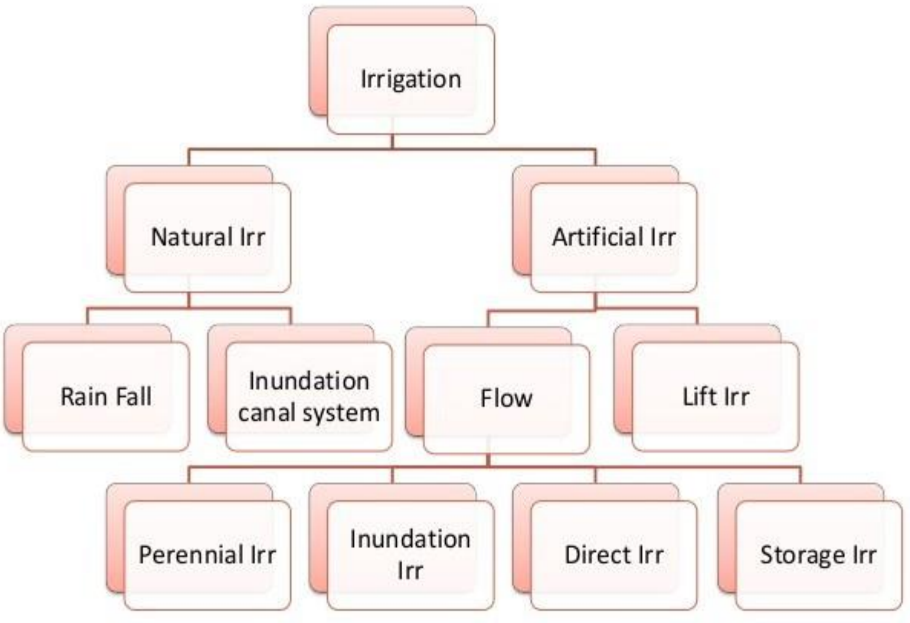
Controlled water supply:

- Yield of the crop may be increased by the construction of proper distribution system

Benefits of Irrigation:

- Increase in food production
- Protection from famine
- Cultivation of cash crop (Sugarcane, Tobacco, & cotton)
- Addition to the wealth of the country
- Increase the prosperity of people
- Generation of hydro-electric power
- Domestic & industrial water supply
- Inland navigation
- Improvement of communication
- Canal plantations
- Improvement in the ground water storage
- General development of the country.

Types of Irrigation OR Classification of Irrigation:



Natural Irrigation

- No engineering structure is constructed.

1) Rainfall Irrigation

- Rainfall is only used for raising crops.

2) Inundation canal system

- Flood water is utilized for Irrigation purpose by properly direction flow of water.

Artificial Irrigation

- Properly designed engineering structure are constructed.

1) Flow irrigation

- Water flows to the irrigated land by gravity.
- Water sources is to be higher level than the irrigated land.

a) Perennial irrigation :

Water is supplied according to the requirements throughout the crop period through storage canal head works & Canal distribution system.

b) Inundation irrigation:

- Lands are submerged & throughly flooded when floods occur in the river.
- Lands are allowed to drain off & the crop are sown.
- Now the soil retains sufficient moisture for the crops to grow.

c) Direct irrigation :

- Water is directly diverted to the canal from the river is called Direct irrigation.
- Discharge in the river shall be higher than the water requirement during the crop period.
- A low diversion weir or a barrage is constructed across the river to rise the water leveland divert the same to the canal.
- Direct irrigation can be adopted only where there is enough flow in the river to providesufficient quantity of water required for irrigation throughout the crop period.

d) Storage Irrigation:

- River flow is not perennial or insufficient during crop period, Storage Irrigation is adopted.
- A dam is construction across the river to store water in the reservoir.
- In some area rain water that run off from a catchment area is stored in tanks and is usedfor irrigation during the crop period.

2) Lift or well Irrigation:

- Water is lifted up by mechanical such as pump etc or manual to supply for irrigation .
- Lift irrigation is adopted when the water source is lower than the level of lands to beirrigated.

Historical development of Irrigation

- Historically, civilizations have been dependent on development of irrigated agriculture.
- Archaeological investigation has identified evidence of irrigation in **Mesopotamia, Ancient Egypt & Ancient Persia** (at present Iran) as far back as the 6th millennium BCE.

- In the **“Zana”** valley of the Andes Mountain in **Peru**, archaeologists found remains of three irrigation canals radiocarbon dated from the 4th millennium BCE, the 3rd Millennium BCE & the 9th century CE, These canals are the earliest record of irrigation in the new world.
- The **Indus valley** civilization in Pakistan & North India (from 2600 BCE) also had an early canal irrigation system. Large scale agriculture was used for the purpose of irrigation.
- There is evidence of **ancient Egyptian** Pharaoh Amenemhet-III in the 12th dynasty (about 1800 BCE) using the natural lake of the Faiyum Oasis as a reservoir to store surpluses of water for use during the dry seasons, the lake swelled annually from flooding of the Nile.
- The irrigation works of **ancient Sri Lanka**, the earliest dating from about 300 BCe, in the reign of King Pandukabhaya & under conditions development for the next thousand years, were one of the most complex irrigation systems of the ancient world.
- In the Szechwan region **ancient China** the Dujiangyan Irrigation System was built in 250 BCE to irrigate a large area & it still supplies water today.
- In the **Americas**, extensive irrigation systems were created by numerous groups in prehistoric times. One example is seen in the recent archaeological excavations near the Santa Cruz River in Tucson, Arizona. They have located a village site dating from 4000 years ago.

Present status of Irrigation:

- In the middle of 20th century, the advent of diesel & electric motors led for the first time to system that could pump groundwater out of major aquifers faster than it was recharged.
- This can lead to permanent loss of aquifer capacity, decreased water quality, ground subsidence & other problems.
- The largest contiguous areas of high irrigation density are found in North India & Pakistan along the rivers Ganges & Indus, in the Hai He, Huang He & Yangtze basins in China, along the Nile River in Egypt & Sudan, in the Mississippi-Missouri river basin & in parts of California.

Developmental Aspects of Irrigation:

Irrigation is practiced to maintain the different developmental parameters. Those are:

1. To make up for the soil moisture deficit.
2. To ensure a proper & sustained growth of crops.
3. To make harvest safe.
4. To colonize the cultivable wasteland for horizontal expansion of cultivation.
5. To shift from seasonal cultivation.
6. To promote more intensive cultivation by multiple cropping.
7. To improve the level of agricultural productivity by acting as an agent for adoption ofmodern technology.

Advantages of irrigation

Advantages of irrigation can be direct as well as indirect.

I. Direct Benefits

- The grower has many choices of crops and varieties and can go for multiple cropping forcultivation
- Crop plants respond to fertilizer and other inputs and there by productivity is high.
- Quality of the crop is improved.
- Higher economic return and employment opportunities. It makes economy drought proof.
- Development of pisciculture and afforestation. Plantation is raised along the banks of canalsand field boundaries.
- Domestic water supply, hydel power generation at dam site and means of transport wherenavigation is possible.
- Prevention of damage through flood.

II. Indirect Benefits

- Increase in gross domestic product of the country, revenue, employment, land value, higherwages to farm labour, agro-based industries and groundwater storage.
- General development of other sectors and development of the country
- Increase of food production.
- Modify soil or climate environment – leaching.
- Lessen risk of catastrophic damage caused by drought.
- Increase income & national cash flow.
- Increase labor employment.
- Increase standard of living.
- Increase value of land.
- National security thus self sufficiency.
- Improve communication and navigation facilities.
- Domestic and industrial water supply.
- Improve ground water storage.
- Generation of hydro-electric power.

Disadvantages of Irrigation

The following are the disadvantages of irrigation.

- Water logging.
- Salinity and alkalinity of land.

- Pollution of underground water.
- Results in colder and damper climate causing outbreak of diseases like malaria.

Types of Crops:

1) **Wet crops**- which lands are irrigated and than crop are cultivation

2) **Dry crops**-which do not need irrigation.

3) **Garden crops**- which need irrigation throughout the year

4) **Summer crop (Kharif)**-which are sown during the south west monsoon & harvested in autumn.

5) **Winter crops(rabi)**-which are sown in autumn & harvested in spring.

6) **Cash crop** – which has to be encased in the market. As it cannot be consumed directly by thecultivators.

S.No	Crop	Sown	Harvested
1	Summer season (Kharif crop)		
	Rice	June -July	Oct-Nov
	Maize	June -July	Sep-Oct
	Bajra	June -Aug	Sep-Oct
	Jowar	June -July	Oct-Nov
	Pulses	June -July	Nov-Dec
2	Winter season (Rabi Crops)		
	Wheat, Barley, peas	Oct-Nov	March - April
	Gram	Sep- Oct	March - April
	Tobacco	Feb-Mar	June
	Potato	Oct	Feb
3	Eight Months Crop cotton	May-June	Dec-Jan
4	Annual crop sugercane	Feb-March	Dec-march

Crop

Seasons:

• In north India the crop season is divided as Rabi & Kharif.

• Rabi crops are called as winter crops and kharif crops are called as summer crops.

• Kharif crops required more water than rabi crops.

• Rabi starts from 1 st oct and ends on 31 march

• In TamilNadu crops are classified as wet and dry crops.

Crops rotation:

Rotation of crops implies the nature of the crop sown in a particular field is changed year after year.

Necessity for rotation

- The necessity for irrigation when the same crop is grown again and again in the same field, the fertility of land gets reduced as the soil becomes deficient in plant foods favorable to that particular crop.
- If different crops were to be raised there would certainly be more balanced fooding and soil deficient in one particular type of nutrient is allowed to recouped.
- Crop diseases and insect pests will multiply at an alarming rate, if the same crop is to be grown continuously. Rotation will check the diseases.
- A leguminous crop (such as gram) if introduced in rotation will increase nitrogen content of soil thus increasing its fertility.
- The deep rooted and shallow rooted crops in rotation draw their food from different depths of soil. The soil will be better utilized.
- Rotation of crops is beneficial to the farmers as there would be rotation of cash crops, fooderand soil renovating crops.

General rotation of crops can be summarized as:

1. Wheat – great millet – gram.
2. Rice – gram
3. Cotton – wheat – gram.
4. Cotton – wheat – sugarcane
5. Cotton – great millet – gram.

Consumptive Use of Water

- Considerable part of water applied for irrigation is lost by evaporation & transpiration.
- This two processes being difficult to separate are taken as one and called Vapor-transpiration or Consumptive use of water.

Duty :

Duty- Area of the crop irrigated/ Volume of water required.

Delta:

- The depth of water required every time, generally varies depending upon the type of thecrop.

- The total depth of water required a crop to nature is called delta.
- Crop period-the time from the instant of its sowing to the instant of harvesting.
- Base Period-time b/w the first supply of water to the land and the last watering beforeharvesting.

Factor affecting the duty:

1) Soil Moisture

- In clayey soil less water is required since its retentive capacity is more.
- Pervious soil it will be more.

2) Topography

- Uniform distribution depends on topography.
- If the area is sloping the lower portion will get more water than the flat portion, & henceWater requirement is increase.

3) Nature of rainfall

- If rainfall is high over the crop period water requirement becomes less, otherwise it will bemore.

4) Nature of crop irrigated

- Dry crop required less water where as wed crop required more water.

5) Method of cultivation:

- If the fields are properly ploughed it will have high retentive capacity & the number ofwatering are reduced.

6) Season of crop

- Less irrigation water is required for rainy season crop and the duty increased.
- If the crop grown in summer, more irrigation water is required & the duty gets decreased

7) System of Irrigation

- In perennial irrigation, continuous supply of water is given & hence water table is kept high& percolation losses is minimized
- In inundation type wastage is more by deep percolation.

8) Canal Condition

- Well maintained canal will have more duty as the losses is less.

Improving Duty

1. The water losses can be reduced by having the irrigated area nearer to the head of thecanal.
2. Evaporation losses can be minimized by using the water as quickly as possible.

3. Water losses can be minimized by lining the canals.

4. The cultivators should be trained to use water economically without wasting.

5. The soil properties should be studied by establishing research stations in villages.

Crop Period or Base Period:

- The time period that elapses from the instant of its sowing to the instant of its harvesting iscalled the **crop period**.
- The time between the first watering of a crop at the time of its sowing to its last watering before harvesting is called the **base period**.

Duty and Delta of a Crop Delta:

The total quantity of water required by the crop for its full growth may be expressed in hectare-meter or simply as depth to which water would stand on the irrigated area if the total quantity supplied were to stand above the surface without percolation or evaporation. This total depth of water is called delta (Δ).

Problem –1**:** If rice requires about 10 cm depth of water at an average interval of about 10 days, and the crop period for rice is 120 days, find out the delta for rice.

Solution:

No. of watering required = 120/10 = 12

Total depth of water required in 120 days = 10 × 12 = 120 cm

Δ for rice = 120 cm

Problem –2**:** If wheat requires about 7.5 cm of water after every 28 days, and the base period for wheat is 140 days, find out the value of delta for wheat.

Solution:

No. of watering required = 140/28 = 5

Total depth of water required in 140 days = 7.5 × 5 = 37.5 cm

Δ for wheat = 37.5 cm

Duty:

- It may be defined as the number of hectares of land irrigated for full growth of a given cropby supply of 1 m^3/s of water continuously during the entire base of that crop.
- Simply we can say that, the area (in hectares) of land can be irrigated for a crop period, B (indays) using one cubic meter of water.

Factors on which duty depends:

1. Type of crop

2. Climate and season
3. Useful rainfall
4. Type of soil
5. Efficiency of cultivation method

Importance of Duty

- It helps us in designing an efficient canal irrigation system.
- Knowing the total available water at the head of a main canal, and the overall duty for all the crops required to be irrigated in different seasons of the year, the area which can be irrigatedcan be worked out.
- *Inversely, if we know the crops area required to be irrigated and their duties, we can work out the discharge required for designing the channel.*

Measures for improving duty of water:

The duty of canal water can certainly be improved by effecting economy in the use of water by resorting to the following precautions and practices:

(1) Proper Ploughing:

Ploughing should be done properly and deeply so that the moisture retaining capacity of soil is increased.

(2) Methods of supplying water:

The method of supplying water to the agriculture land should be decided according to the field and soil conditions. For example,

- Furrow method For crops sown ion rows
- Contour method For hilly areas
- Basin For orchards
- Flooding For plain lands

(3) Canal Lining:

It is provided to reduce percolation loss and evaporation loss due to high velocity.

(4) Minimum idle length of irrigation Canals:

The canal should be nearest to the command area so that idle length of the canal is minimum and hence reduced transmission losses.

(5) Quality of water:

Good quality of water should be used for irrigation. Pollution en route the canal should be avoided.

(6) Crop rotation:

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

Consumptive use of cropsDefinition:

- It is the quantity of water used by the vegetation growth of a given area.
- It is the amount of water required by a crop for its vegetated growth to evapotranspiration and building of plant tissues plus evaporation from soils and intercepted precipitation.
- It is expressed in terms of depth of water. Consumptive use varies with temperature, humidity, wind speed, topography, sunlight hours, method of irrigation, moisture availability.

  Mathematically,

  Consumptive Use = Evapotranspiration = Evaporation + transpiration

- It is expressed in terms of depth of water.

Factors Affecting the Consumptive Use of Water

Consumptive use of water varies with:

1. Evaporation which depends on humidity
2. Mean Monthly temperature
3. Growing season of crops and cropping pattern
4. Monthly precipitation in area
5. Wind velocity in locality
6. Soil and topography
7. Irrigation practices and method of irrigation
8. Sunlight hours

Types of Consumptive Water Use

Following are the types of consumptive use,

1. Optimum Consumptive Use
2. Potential Consumptive Use
3. Seasonal Consumptive Use

1. Optimum Consumptive Use:

It is the consumptive use which produces a maximum crop yield.

2. Potential Consumptive Use:

If sufficient moisture is always available to completely meet the needs of vegetation fully covering the entire area then resulting evapotranspiration is known as Potential Consumptive Use.

3. Seasonal Consumptive Use:

The total amount of water used in the evapo-transpiration by a cropped area during the entire growing season.

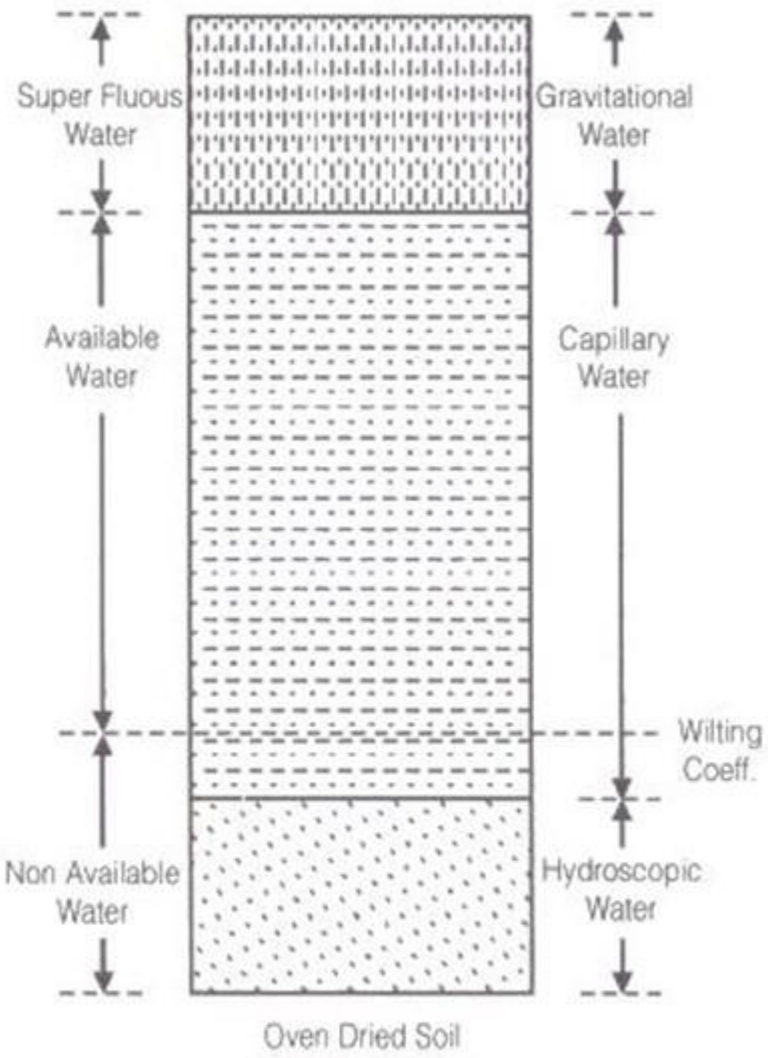
Crop Water Requirements

Soil moisture

Classes and availability of soil water

Water present in the soil may be to classified under three heads

1. Hygroscopic water
2. Capillary water
3. Gravitational water



Hygroscopic water

Water attached to soil particles through loose chemical bonds is termed hygroscopic water. This water can be removed by heat only. But the plant roots can use a very small fraction of this soil moisture under drought conditions.

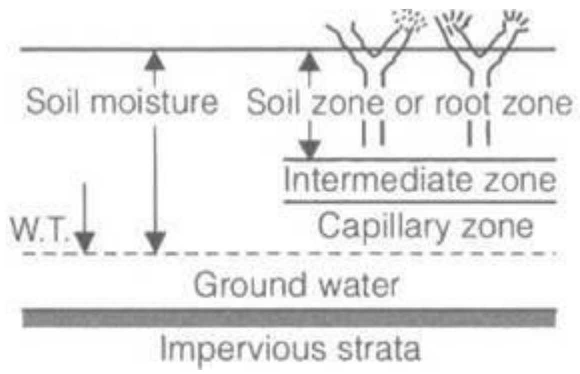
Capillary water

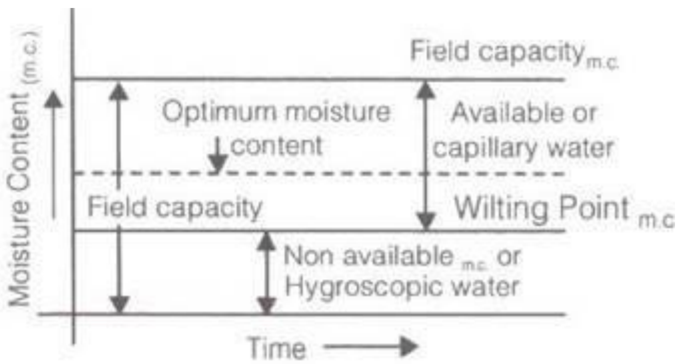
The capillary water is held within soil pores due to the surface tension forces (against gravity) which act at the liquid-vapour (or water-air) interface.

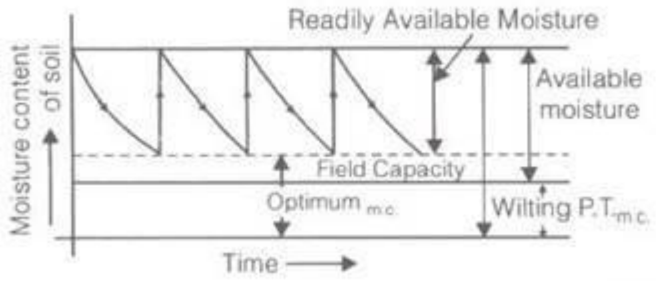
Gravitational water

Gravity water is that water which drains away under the influence of gravity. Soon after irrigation (or rainfall), this water remains in the soil and saturates the soil, thus, preventing circulation of air in the void spaces.

(1) Available moisture for the plant $= F_C - \phi$







(2) Readily available moisture for the plant = FC - Mo

Here FC= field capacity

φ = wilting point or wilting coefficient below plant can’t survive.

Mo= Readily available moisture content

(3) Frequency of Irrigation $= \dfrac{weight\ /\ readily\ available\ moisture\ depth}{consumptive\ use\ rate}$

(4) $F_C = \dfrac{weight\ of\ water\ stored\ in\ soil\ of\ unit\ area}{weight\ of\ same\ soil\ of\ unit\ area}$

where, weight of water stored in soil of unit area $= \gamma_w \cdot d_w \cdot 1 \cdot$

Weight of some soil of unit area $= \gamma \cdot d \cdot l$

dw= depth of water stored in root zone.

(5) $d_w = \dfrac{\gamma \cdot d}{\gamma_w} \cdot F_C$ $\gamma \rightarrow$ dry unit wt. of soil

(6) Available moisture depth to plant $d_w^{'} = \dfrac{\gamma . d}{\gamma_w}(F_C - \phi)$

(7) Readily available moisture depth to plant $d_w^{'} = \dfrac{\gamma . d}{\gamma_w}(F_C - m_o)$

(8) $F_C = n / G$ where, G = specific gravity and n = porosity

Duty and delta

Duty:

- The duty of water is the relationship between the volume of water and the area of the crop itmatures.
- It is defined as the area irrigated per cumec of discharge running for base period B.
- The duty is generally represent by D.

Delta:

- It is the total depth of water required by a crop during the entire base period and isrepresented by the symbol Δ.

Relation between duty and delta

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

Where,

- Δ=Delta in meter
- D = Duty in Ha/cumec
- B = Base period in days

Also $$\Delta = \frac{2B}{D}$$

Where,

- Δ=Delta in meter
- B = Base period in days
- D = Duty in acre/cures

Irrigation Requirements of crops

(1) Consumptive Irrigation Requirement (CIR)

$$CIR = Cu - P_{eff}$$

Where, Cu= total consumptive use requirement

P_{eff}= Effective rainfall.

(2) Net Irrigation Requirement (NIR)

NIR = CIR + Leaching requirement

(3) Field irrigation requirement (FIR)

$$FIR = \frac{NIR}{\eta_a}$$

(4) Gross irrigation requirement, (GIR)

$$GIR = \frac{FIR}{\eta_c}$$

Methods of Determination of Evapotranspiration

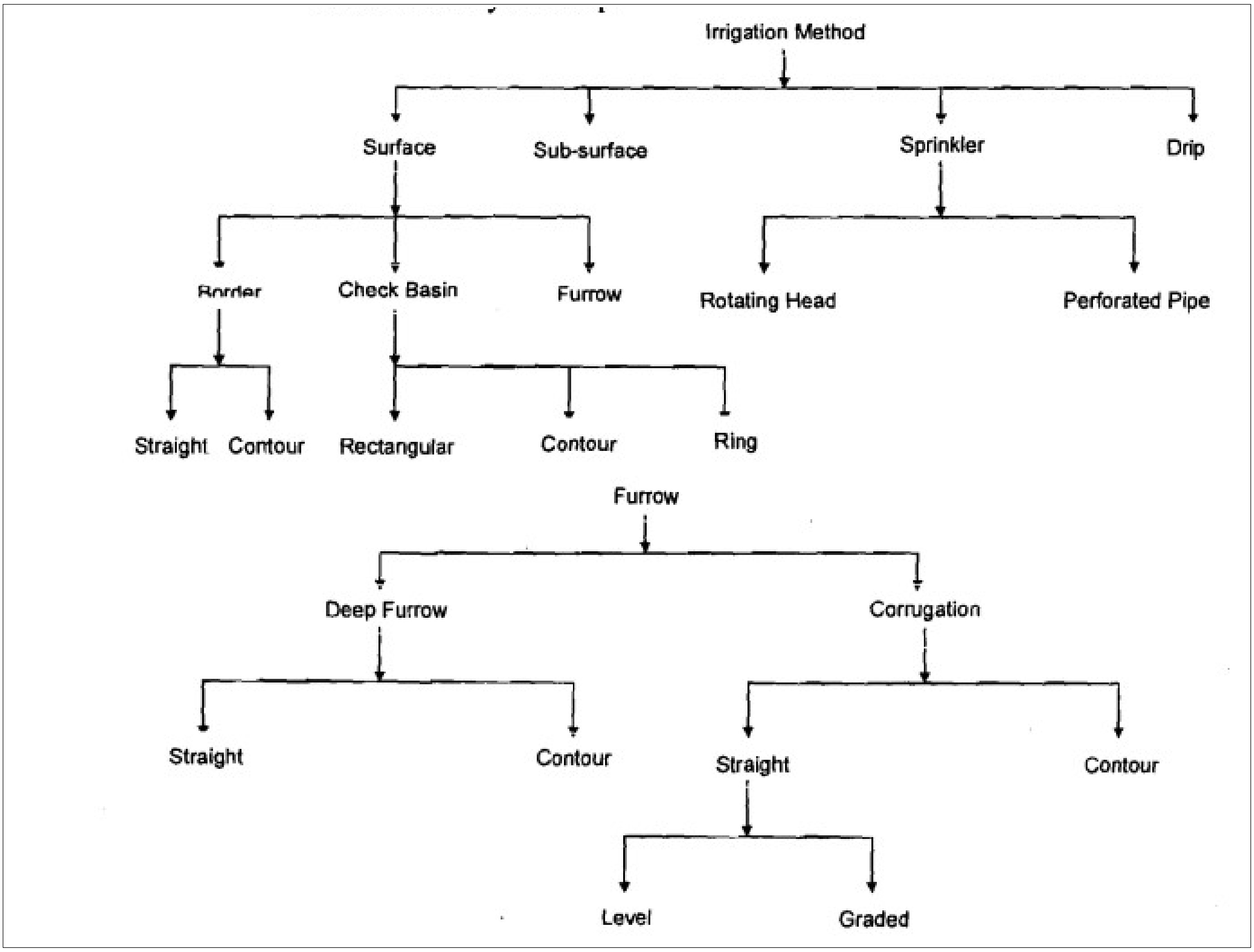
To measure or estimation the consumptive use there are three main methods:

1. Direct Methods/Field Methods
2. Empirical Methods
3. Pan evaporation method

1. Direct Methods:

In this method field observations are made and physical model is used for this purpose. This includes,

i. Vapour Transfer Method/Soil Moisture Studies
ii. Field Plot Method
iii. Tanks and Lysimeter
iv. Integration Method/Summation Method
v. Irrigation Method
vi. Inflow Outflow Method



SURFACE IRRIGATION:

- Surface irrigation is defined as the group of application techniques where water is appliedand distributed over the soil surface by gravity.
- It is by far the most common form of irrigation throughout the world and has been practicedin many areas virtually unchanged for thousands of years.

Surface irrigation:

There are four variations under this method viz.

1. Flooding,
2. Bed or border method (Saras and flat beds
3. Basin method (ring and basin) and
4. Furrow method (rides and furrows, broad ridges or raised beds)

Flooding:

- It consist of opening a water channel in a plot or field so that water can flow freely in alldirections and cover the surface of the land in a continuous sheet.

- It is the most inefficient method of irrigation as only about 20 percent of the water isactually used by plants. The rest being lost as a runoff, seepage and evaporation.
- Water distribution is very uneven and crop growth is not uniform. It is suitable for uneven land where the cost of leveling is high and where a cheap and abundant supply of water is available.
- It is unsuitable for crops that are sensitive to water logging the method suitable where broadcast crops, particularly pastures, alfalfa, peas and small grains are produced.

Adaptations:

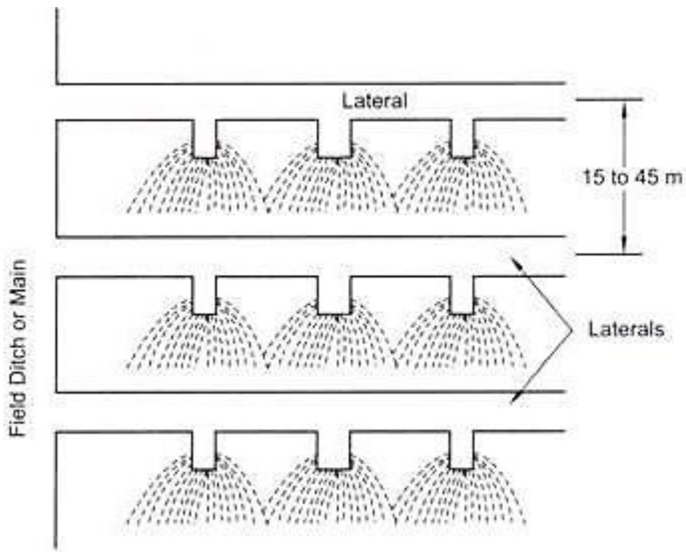
1. An abundant supply of water
2. Close growing crops
3. Soils that do not erode easily
4. Soils that is permeable
5. Irregular topography
6. Areas where water is cheap.

Advantages:

1. Can be used on shallow soils
2. Can be employed where expense of leveling is great
3. Installation and operation costs are low
4. System is not damaged by livestock and does not interfere with use of farm implements.

Disadvantages:

1. Excessive loss of water by run of and deep percolation
2. Excessive soil erosion on step land.
3. Fertilizer and FYM are eroded from the soil.



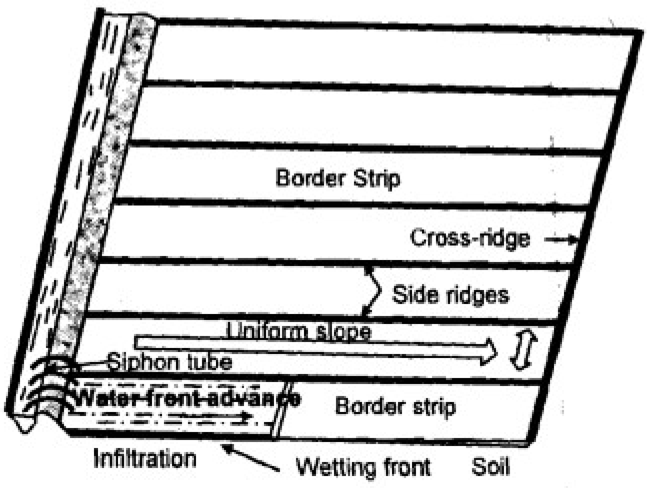
Bed or border method (Sara and Flat beds or check basin):

- In this method the field is leveled and divided into small beds surrounded by bunds of 15 to 30 cm high. Small irrigation channels are provided between two adjacent rows of beds.
- The length of the bed varies from 30 meters for loamy soils to 90 meters for clayey soils.
- The width is so adjusted as to permit the water to flow evenly and wet the land uniformly.
- For high value crops, the beds may be still smaller especially where water is costly and not very abundant.
- This method is adaptable to most soil textures except sandy soils and is suitable for high value crops. It requires leveled land.
- It is more efficient in the use of water and ensures its uniform application. It is suitable for crops plant in lines or sown by broadcast. Through the initial cost is high requires less labourand low maintenance cost.
- This may also be called a sort of sara method followed locally in Maharashtra but the saras to be formed in this method are much longer than broader.

Types of Border Irrigation

Two types of borders are formed :

- Straight Border
- These border are formed along the general slope of the field. These are preferred when fieldscan be levelled or be given a gentle slope economically.



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Contour Border

- These are formed across the general slope of the field and are preferred when land slopeexceeds the safe limits.

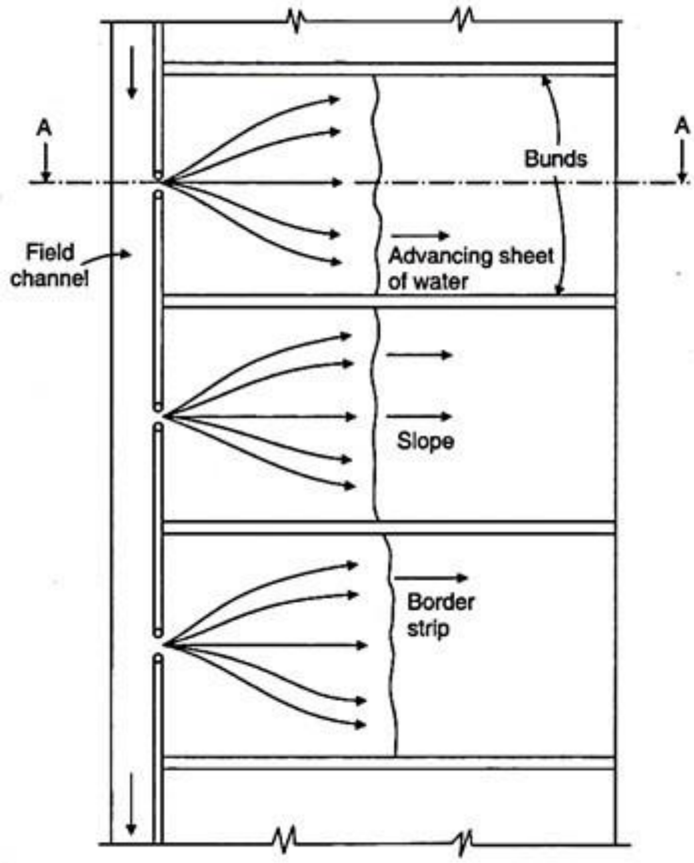
- As fields are undulating and require a lot of earth work to level, economical levelling is not possible. Design criteria for both are not different.

Adaptations:

1. A large supply of water
2. Most soil textures including sandy Loam, loams and clays
3. Soil at least 90 cm deep
4. Suitable for close growing crops.

Advantages:

1. Fairly large supply of water is needed.
2. Land must be leveled
3. Suited only to soils that do not readily disperse.
4. Drainage must be provided



Basin irrigation:

- This method is suitable for orchids and other high value crops where the size of the plot tobe irrigated is very small.

- The basin may be square, rectangular or circular shape. A variation in this method viz. ring and basin is commonly used for irrigating fruit trees.
- A small bund of 15 to 22 cm high is formed around the stump of the tree at a distance of about 30 to 60 cm to keep soil dry.
- The height of the outer bund varies depending upon the depth of water proposed to retain. Basin irrigation also requires leveled land and not suitable for all types of soil. It is also efficient in the use of water but its initial cost is high.
- There are many variations in its use, but all involve dividing the field into smaller unit areas so that each has a nearly level surface. Bunds or ridges are constructed around the areas forming basins within which the irrigation water can be controlled. Check basin types may be rectangular, contour and ring basin.

Types of Check Basins

Based on Size and Shape

The size of check basins may vary from one meters square, used for growing vegetables and other intensive cultivation, to as large as one or two hectares or more, used for growing rice under wet land conditions. While the following points need to be considered :

Rectangular

The basins are rectangular in shape when the land can be graded economically into nearly level fields.

Contour

- The ridges follow the contours of the land surface and the contour ridges are connected by cross ridges at intervals when there is rolling topography.
- The vertical interval between contour ridges usually varies fkom 6 to 12 cm in case of upland irrigated crops like wheat and 15 to 30 cm in case of low land irrigated crops like rice.

Adaptations:

1. Most soil texture
2. High value crops
3. Smooth topography.
4. High water value/ha

Advantages:

1. Varying supply of water

2. No water loss by run off

3. Rapid irrigation possible

4. No loss of fertilizers and organic manures

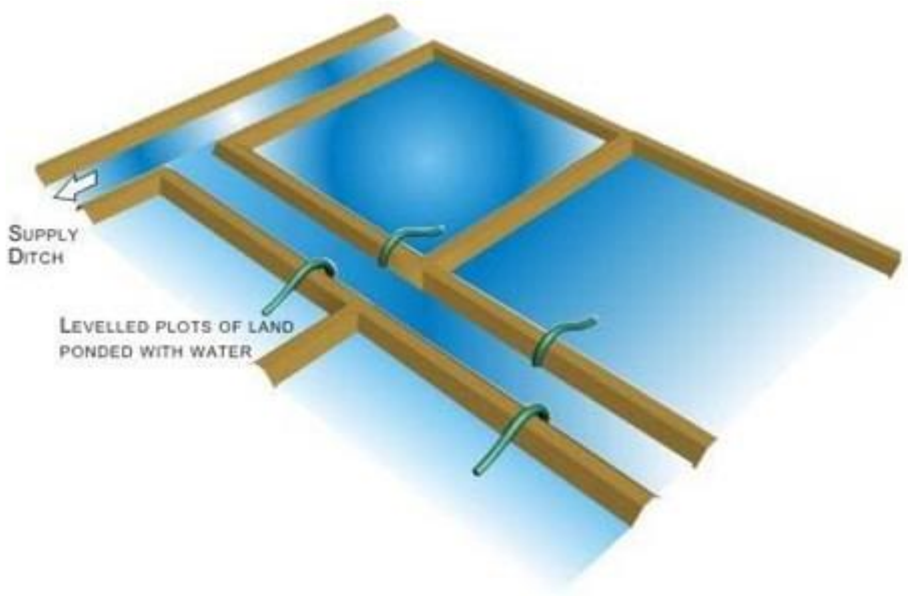
5. Satisfactory

Disadvantages:

1. If land is not leveled initial cost may be high

2. Suitable mainly for orchids, rice, jute, etc.

3. Except rice, not suitable for soils that disperse easily and readily from a crust.



Furrow Method

- In this method, irrigation water is useful for row crops. Narrow channels are dug at regularintervals. Water from the main supply is allowed to enter these small channels or furrows.

- Water from the furrows infiltrates into soil and spread laterally to saturate the root zone ofthe crops.

- It is suitable for row crops like potatoes, sugarcane, tobacco, maize, groundnut, cotton,jowar, etc.

- Row crops such as potatoes, cotton, sugarcane, vegetable etc. can be irrigated by furrowmethod. Water is allowed to flow in furrow opened in crop rows.

- It is suitable for sloppy lands where the furrows are made along contours. The length offurrow is determined mostly by soil permeability.

- It varies from 3 to 6 meters. In sandy and clay loams, the length is shorter than in clay and clay loams. Water does not come in contact with the plant stems.
- There is a great economy in use of water. Some times, even in furrow irrigation the field is divided into beds having alternate rides and furrows. On slopes of 1 to 3 percent, furrow irrigation with straight furrows is quite successful.
- But on steeper slopes contour furrows, not only check erosion but ensure uniform water penetration.

Irrigation furrows may be classified into two general types based on their alignment. They are :

(a) straight furrows, and

(b) contour furrows.

Straight Furrows

- They are best suited to sites where the land slope does not exceed 0.75 per cent. In areas of intense rainfall, however, the furrow grade should not exceed 0.5 per cent so as to minimise the erosion hazard.
- The range in furrow slopes for efficient irrigation in different soil types are the same as thoserecommended for borders.

Contour Furrows

- Contour furrows carry water across a slopping field rather than the slope. Contour furrows are curved to fitthe topography of the land.
- Contour furrow method can be successfully used in nearly all irrigable soils. The limitations of straight furrow are overcome by contouring to include slopping lands. Light soils can be irrigated successfully across slopes up to 5 per cent.

Adaptations:

1. Medium and fine textured soils.
2. Variable water supply
3. Farms with only small amount of equipment.

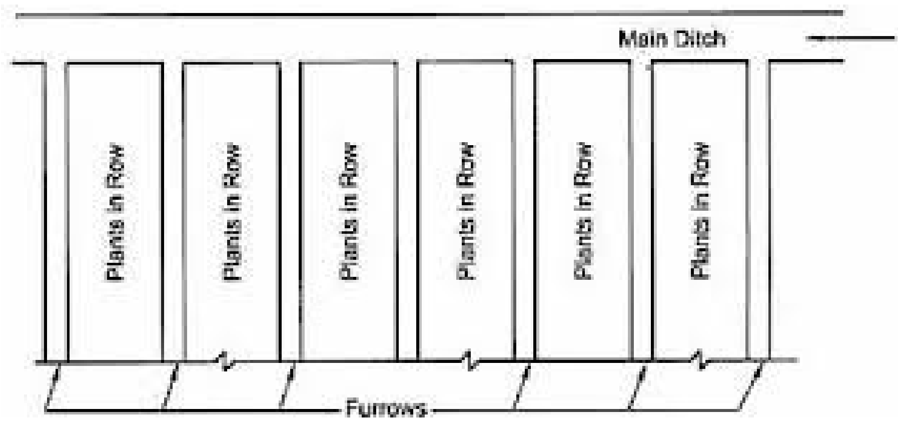
Advantages:

1. High water efficiency
2. Can be used in any row crop
3. Relatively easy in stall

4. Not expensive to maintain
5. Adapted to most soils.

Disadvantages:

1. Requirement of skilled labour is more
2. A hazard to operation of machinery
3. Drainage must be provided.



Contour farming

- Contour farming involves ploughing, planting and weeding along the contour, i.e, across theslope rather than up and down.
- Contour lines are lines that run across a (hill) slope such that the line stays at the sameheight and does not run uphill or downhill.
- As contour lines travel across a hillside, they will be close together on the steeper parts ofthe hill and further apart on the gentle parts of the slope.
- Experiments show that contour farming alone can reduce soil erosion by as much as 50% onmoderate slopes.
- However, for slopes steeper than 10%, other measures should be combined with contourfarming to enhance its effectiveness.

Benefits :

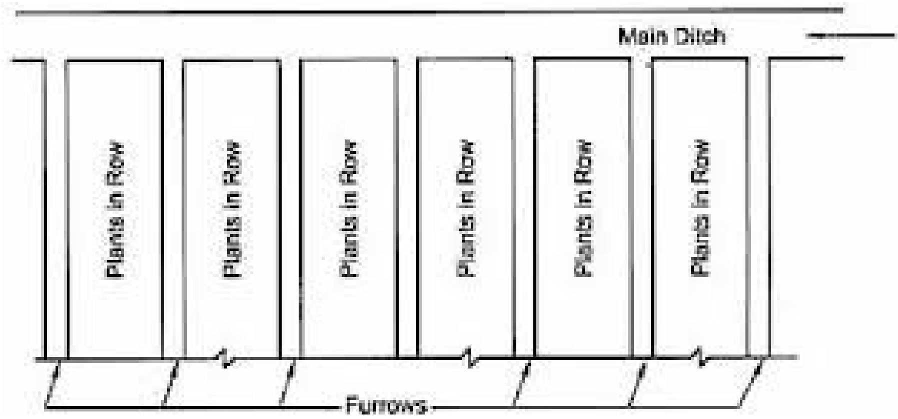
1. Contouring can reduce soil erosion by as much as 50% from up and down hill farming
2. By reducing sediment and run off and increasing water infiltration
3. Contouring promotes better water quality
4. It gives 10-15% additional yield.

Criteria for Surface Irrigation Method Selection

6. Adapted to most soils.

Disadvantages:

4. Requirement of skilled labour is more
5. A hazard to operation of machinery
6. Drainage must be provided.



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Criteria for Surface Irrigation Method Selection

- The deciding factors for the suitability of any surface irrigation method are natural conditions (slope, soil type), type of crop, required depth of application, level of technology,previous experiences with irrigation, required labour input.
- Moreover the irrigation system for a field must be compatible with the existing farming operations, such as land preparation, cultivation, and harvesting practices.
- The following outline lists a number of factors of the environment which will have a bearing on the evaluation of irrigation system alternates and the selection of a particular system.
- Not all points will be equally significant in each case, but the outline can serve as a useful checklist to prevent overlooking important factors.

Physical Factors

- Crops and cultural practices are of prime importance while selecting an irrigation system.
- Hence, proper knowledge of agronomic practices and irrigation intervals is necessary for proper use of irrigation water and to increase water use efficiency.
- The following physical factors need to be given due consideration.

Crop Parameters

- Tolerance of the crop to soil salinity during development and maturation.
- Magnitude and temporal distribution of water necessary for maximum production.
- Economic value of crop.

Soils Parameters

- Texture and structure;infiltration rate and erosion potential;salinity and internal drainage, bearing strength.
- Sandy soils have a low water storage capacity and a high infiltration rate. Under these circumstances, sprinkler or drip irrigation are more suitable than surface irrigation. Clay soils with low infiltration rates are ideally suited to surface irrigation.
- High intake characteristicrequire higher flow rate to achieve the same uniformity and efficiency.
- Crusting of soil and its effects on infiltration
- Reclamation and salt leaching- basin irrigation
- Spatial variability

- Location and relative elevation of water source – water diversion, pumping
- Acreage in each field
- Location of roads, natural gas lines, electricity lines, water lines and other obstructions.
- Shape of field – non rectangular shapes are more difficult to design for
- Field slope – steepness & regularity
- Furrow&borders 2-6% maximum

Climate and Weather Conditions

- Under very windy conditions, drip or surface irrigation methods are preferred.
- Scalding (the disruption of oxygen-carbon dioxide exchange between the atmosphere andthe root)& the effect of water temperature on the crop at different stages of growth - risk in basin irrigation.
- Irrigation with cold water early in the spring can delay growth, whereas in the hot periods of the summer, it can cool the environment— both of which can be beneficial or detrimental in somecases.

Water Supply

The following parameters are important:

1. Source and delivery schedule
2. Water quantity available and its reliability
3. Water quality
4. Water table in case of ground water source.
5. Availability and Reliability of Electricity
6. Availability and reliability of energy for pumping of water is of muchimportance.

Economic Considerations

The following points need to be considered while selecting irrigation alternatives.

1. Capital investment required and recurring cost.
2. Credit availability and interest rate.
3. Life of irrigation system, efficiency and cost economics.

Social Considerations

- The education and skill of common farmers and labours available for handling the irrigation system
- Social understanding of handling of cooperative activities and sharing of water resources
- Legal and political considerations, local cooperation and support, availability and skill of labour and level of automatic control

Suitability and Limitations of Surface Irrigation Methods

- Some form of surface irrigation is adaptable to almost any vegetable crop. Basin and border strip irrigation have been successfully used on a wide variety of crops.
- Furrow irrigation is less well adapted to field crops if cultural practices require travel across the furrows. However, it is widely used in vegetables like potato.
- Basin and border strip irrigations flood the soil surface, and will cause some soils to form a crust, which may inhibit the sprouting of seeds.
- Surface irrigation systems perform better when soils are uniform, since the soil controls the intake of water. For basin irrigation, basin size should be appropriate for soil texture and infiltration rate.
- Basin lengths should be limited to 100 m on very coarse textured soils, but may reach 400 mon other soils. Furrow irrigation is possible with all types of soils, but extremely high or low intake rate soils require excessive labor or capital cost adjustments that are seldom economical.
- A major cost in surface irrigation is that of land grading or leveling. The cost is directly related to the volume of earth that must be moved, the area to be finished, and the length andsize of farm canals.

MICRO IRRIGATION METHOD

- Micro irrigation methods are precision irrigation methods of irrigation with very high irrigation water efficiency.
- In many parts of the country there is decline of irrigation water and conventional methods are having low water use efficiency.
- To surmount the problem, micro irrigation methods h8s recently been introduced in Indian agriculture.
- These methods save a substantial amount of water and helps increasing crop productivity particularly valuable cash crops like vegetables.

- The research results have confirmed a substantial saving of water ranging between 40 to80% and there are reports of two times yield increase for different crops crops by using micro irrigation.

Two main micro irrigation systems are :

Advantages of Micro Irrigation

(a) Water saving, possibility of using saline water.

(b) Efficient and economic use of fertilizers.

(c) Easy installation, flexibility in operation.

(d) Suitable to all types of land terrain also suitable to waste lands.

(e) Enhanced plant growth and yield and uniform and better quality of produce.

(f) Less weed growth.

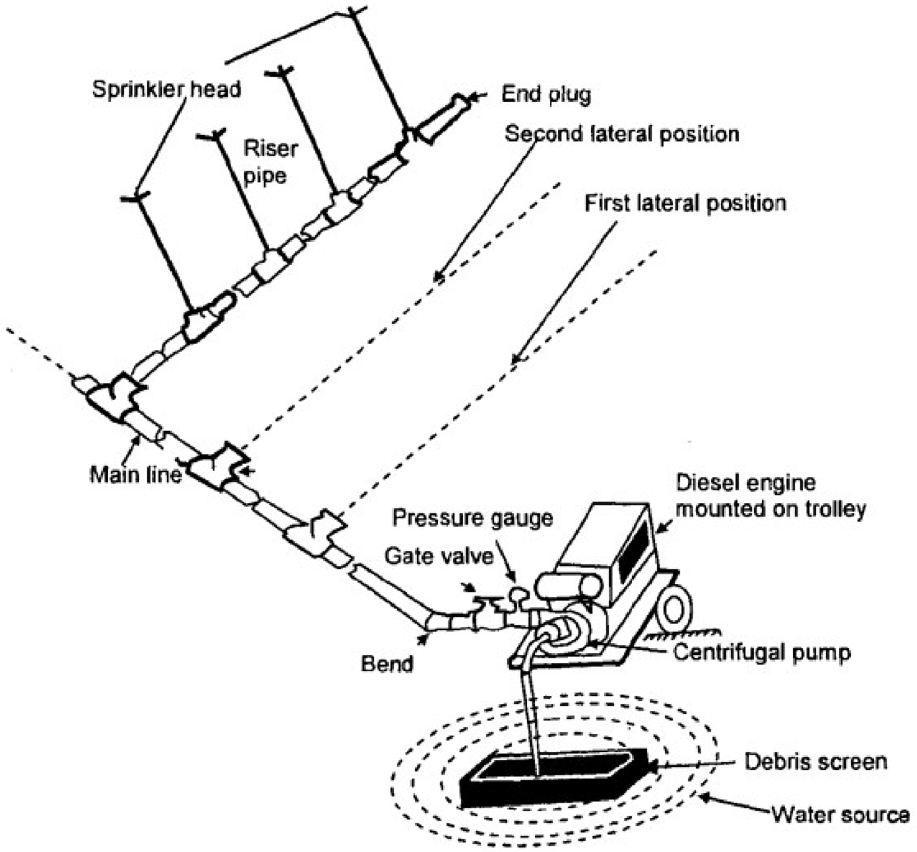
(g) Labour saving.

(h) No soil erosion, saves land as no bunds, etc. are required.

(i) Minimum diseases and pest infestation.

SPRINKLER IRRIGATION

- In sprinkler irrigation, water is delivered through a pressurized pipe network to sprinklers nozzles or jets which spray the water into the air.
- To fall to the soil in an artificial "rain". The basic components of any sprinkler systems are : a water source. a pump to pressurize the water.
- A pipe network to distribute the water throughout the field. sprinklers to spray the water over the ground, and valves to control the flow of water.
- The sprinklers when properly spaced give a relatively uniform application of water over the irrigated area.



Components of

Sprinkler irrigation System

- Sprinkler systems are usually fthere are some exceptions) designed to apply water at a lowerrate than the soil infiltration rate so that the amount of water infiltrated at any point depends upon the application rate and time of application but not the soil infiltration rate.

General Classification of Sprinkler Systems

Sprinkler systems are classified into the following two major types on the basis of the arrangement for spraying irrigation water.

(a) Rotating head or revolving sprinkler system.

(b) Perforated pipe system.

Components of Sprinkler Irrigation System

Sprinkler system usually consists of the following components :

(a) A pump unit

(b) Tubings-main/sub-mains and laterals

(c) Couplers

(d) Sprinker head

(e) Other accessories such as valves, bends, plugs and risers.

Suitability and Limitations

With regards to crops, soils, and topography nearly all crops can be irrigated with some type of sprinkler system though the characteristics of the crop especially the height, must be considered in system selection.

Sprinklers are sometimes used to germinate seed and establish ground cover for crops like lettuce alfalfa and sod.

The light frequent applications that are desirable for this purpose are easily achieved with some sprinkler systems.

Sprinklers are applicable to soils that are too shallow to permit surface shaping or too variable for efficient surface irrigation.

In general, sprinklers can be used on any topography that can be formed. Land leveling is not normally required.

With regards to labour and energy considerations, it has been observed that labour requirements vary depending on the degree of automation and mechanization of the equipment used.

Hand-move systems require the least degree of skill, but the greatest amount of labor.

Advantages of Sprinkler Irrigation

The followings are the advantages of sprinkler irrigation :

(a) Elimination of the channels for conveyance, therefore no conveyance loss.

(b) Suitable to all types of soil except heavy clay, suitable for irrigating crops where the plant population per unit area is very high. It is most suitable for oil seeds and other cereal and vegetable crops.

(c) Water saving, closer control of water application convenient for giving light and frequentirrigation and higher water application efficiency.

(d) Increase in yield.

(e) Mobility of system.

(f) May also be used for undulating area, saves land as no bunds etc. are required, areas located at a higher elevation than the source can be irrigated.

(g) Influences greater conducive micro-climate.

(h) Possibility of using soluble fertilizers and chemicals.

(i) Less problem of clogging of sprinkler nozzles due to sediment laden water

Capacity of Sprinkler System

The capacity of the sprinkler system may be calculated by the formula :

$$Q = 2780 \times \frac{A \times d}{F \times H \times E}$$

Where,

Q = Discharge capacity of the pump, liter/second,

A = Area to be irrigated, hectares,

d = Net depth of water application, cm,

F = Number of days allowed for the completion of one irrigation,

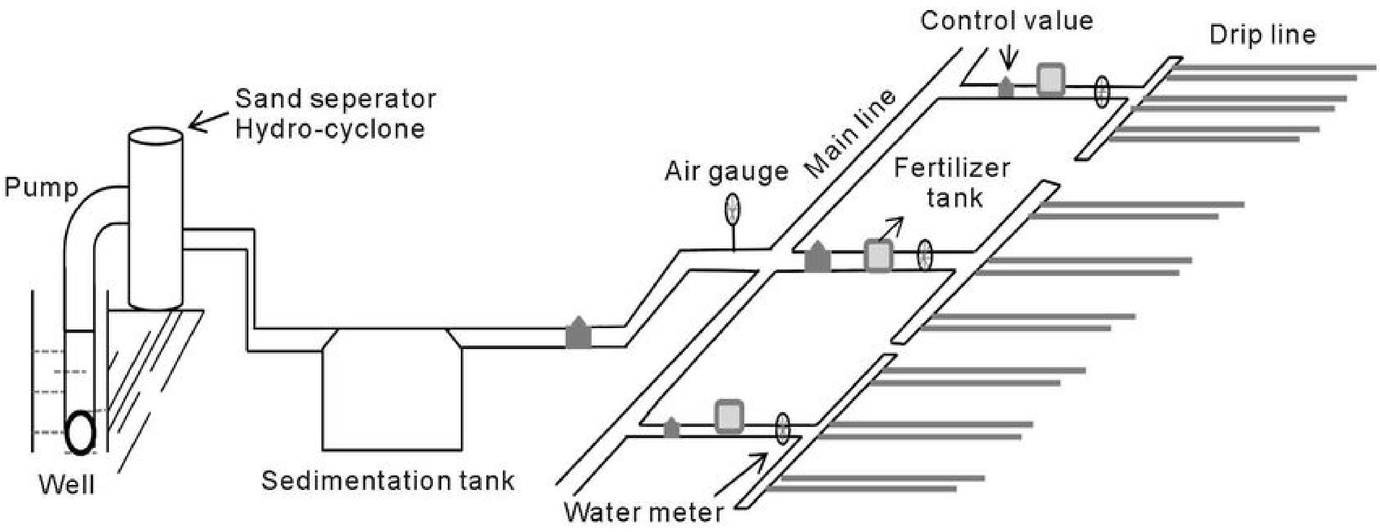
H = Number of actual operation hours per day, and

E = Water Application Efficiency in %

DRIP IRFUGATION

- Drip irrigation, also known as trickle irrigation or microirrigation is an irrigation method which minimizes the use of water and fertilizer by allowing water to drip slowly to the roots of plants, either onto the soil surface or directly onto the root zone, through a network of valves, pipes, tubing, and emitters.
- It is becoming popular for row crop irrigation. This system is used in place of water scarcity as it minimizes conventional losses such as deep percolation, evaporation and run-off or recycled water is used for irrigation.
- Small diameter plastic pipes fitted with emitters or drippers at selected spacing to deliver the required quantity of water are used. Drip irrigation may also use devices called micro-spray heads, which spray water in a small area, instead of dripping emitters.
- Subsurface drip irrigation (SDI) uses permanently or temporarily buried drip per line or drip tape located at or below the plant roots.
- Pump and valves may be manually or automatically operated by a controller Drip irrigation is the slow, frequent application of water to the soil though emitters placed along a water delivery line.
- The term drip irrigation is general, and includes several more specific methods. Drip irrigation applies the water through small emitters to the soil surface, usually at or near the plant to be irrigated.

- Subsurface irrigation is the application of water below the soil surface. Emitter dischargerates for drip and subsurface irrigation are generally less than 12 liters per hour.



Components of Drip Irrigation System (Listed in Order from Water Source)

(a) Pump or pressurised water source.

(b) Water Filter(s) - Filtration Systems : Sand Separator, Cyclone, Screen Filter, Media Filters.

(c) Fertigation Systems (Venturi injector).

(d) Backwash Controller.

(e) Main Line (larger diameter Pipe and Pipe Fittings).

(f) Hand-operated, electronic, or hydraulic Contvl Valves and Safety Valves.

(g) Smaller diameter polytube (often referred to as "laterals").

(h) Poly fittings and Accessories (to make connections).

(i) Emitting Devices at plants (Example : Emitter or Drippers, micro spray heads, inline drippers, trickle rings).

Suitabi1ity:and Limitation

(a) From stand point of crops, soil, and topography, drip irrigation is best suited for tree, vine, and row crops. A lot of research work has been conducted to establish the suitability of drip irrigation for different vegetable crops. Drip irrigation has been found suitable both for field vegetable crops and also under covered cultivation practices.

(b) With respect to water quantity and quality, drip irrigation uses a slower rate of water application over a longer period of time than other irrigation methods. The most economical design would have water flowing into the farm area throughout most of the day, every day, during peak use periods. If water is not available on a continuous basis, on-farm water storage may be necessary.

(c) Though a form of pressurized irrigation, drip is a low pressure, low flow rate method. These conditions require small flow channel openings in the emission devices, which are prone to plugging.

(d) High efficiencies are USP of drip irrigation system. Properly designed and maintained drip systems are capable of high efficiencies. Design efficiencies should be on the order of 90 to 95%.

(e) Labour and energy considerations are very important consideration in drip irrigation system. Due to their low flow characteristics, drip irrigation systems usually have few sub-units, and are designed for long irrigation times.

(f) Drip irrigation systems generally use less energy than other forms of pressurized irrigation systems. The emission devices usually operate at pressures ranging from 5 to 25 PSI. Additional pressure is required to compensate for pressure losses through the control head (filters and control valves) and the pipe network.

(g) Economic factors need special attention in case drip irrigation system as initial cost and operational cost is reasonably high. Drip systems costs can vary greatly. Depending on crop (plant. and therefore. emitter and hose spacings) and type of hose employed (permanent or "disposable" thin-walled tubing).

Advantages

The advantages of drip irrigation are :

1. Minimised fertilizerlnutrient loss due to localized application and reduced leaching, allowssafe use of recycled water.
2. High water distribution efficiency. Moisture within the root zone can be maintained at fieldcapacity.
3. Leveling of the field not necessary. Soil type plays less important role in frequency of irrigation, minimised soil erosion.
4. Highly uniform distribution of water, i.e. controlled by output of each nozzle.
5. Lower labour cost.
6. Early maturity and good harvest.
7. Foliage remains dry thus reducing the risk of disease.

Performance Indicator	Conventional Irrigation Methods	Drip Irrigation
Water saving	Waste lot of water. Losses occur due to percolation, runoff and evaporation	40-70% of water can be saved over conventional irrigation methods. Runoff and deep percolation losses are nil or

		negligible.
Water use efficiency	30-50%, because losses are very high	80-95%
Saving in labour	Labour engaged per irrigation is higher than drip	Labour required only for operation and periodic maintenance of the system
Weed infestation	Weed infestation is very high	Less wetting of soil, weed infestation is very less or almost nil.
Use of saline water	Concentration of salts increases and adversely affects the plant growth. Saline water cannot be used for irrigation	Frequent irrigation keeps the salt concentration within root zone below harmful level
Diseases and pest problems	High	Relatively less because of less atmospheric humidity
Suitability in different soil Type	Deep percolation is more in light soil and with limited soil depths. Runoff loss is more in heavy soils	Suitable for all soil types as flow rate can be controlled
Water control	Inadequate	Very precise and easy
Efficiency of fertilizer use	Efficiency is low because of heavy losses due to leaching and runoff	Very high due to reduced loss of nutrients through leaching and runoff water
Soil erosion	Soil erosion is high because of large stream sizes used for irrigation.	Partial wetting of soil surface and slow application rates eliminate any possibility of soil erosion
Increase in crop yield	Non-uniformity in available moisture reducing the crop yield	Frequent watering eliminates moisture stress and yield can be increased up to 15- 150% as compared to conventional methods of irrigation.

Extent of Water Saving and Increase in Yield with Drip Irrigation Systems

Crops	Water Saving (%)	Increase in Yield (%)
Sugarcane	50	99
Tomato	42	60
Watermelon	66	19
Cucumber	56	45
Chili	68	28
Cauliflower	68	70
Okra	37	33
Ground nut	40	152
Mulberry	22	23
Banana	45	52
Grapes	48	23
Sweet lime	61	50
Pomegranate	45	45

Source : INCID 1994 Drip irrigation in India, New Delhi.

Check Basin Irrigation : In this irrigation system, water is applied to a completely level or dead level area enclosed by dikes or boarders.

Furrow Irrigation : Furrows are sloping channels formed in the soil. Infiltration occurs laterally and vertically through the wetted perimeter of the furrow and plants get water in its root zone.

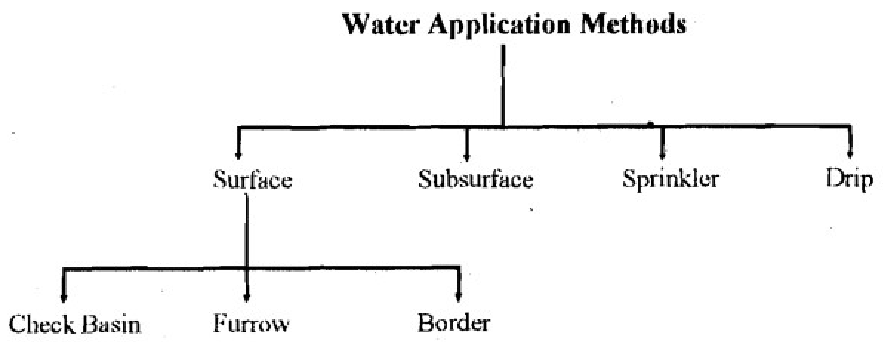
Sprinkler Irrigation : In this system of irrigation, water is delivered through a pressurised pipe network to sprinklers nozzle or jets which spray water into the air.

Drip Irrigation : It minimises the use of water and fertilizer by allowing water to drip slowly to the roots of plants.

Fertigation : It is the process of application of water soluble solid fertilizer or liquid fertilizer through drip irrigation system.

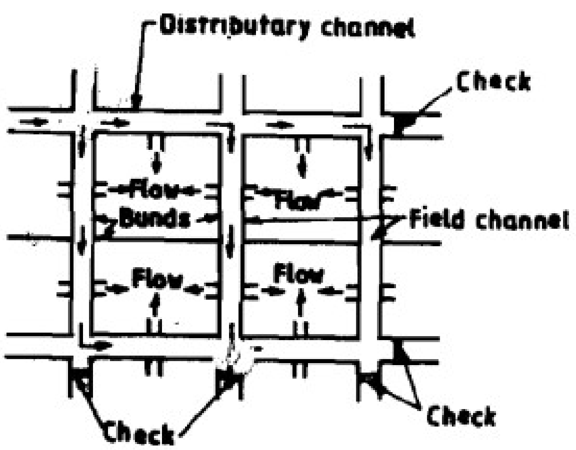
Water distribution system

Irrigation water inay be applied to crops either by flooding the field. by applying water beneath the soil surface, by spraying it under pressure. or by applying it in drops. Selection of the suitable method, from among these methods, depends on topography. soil condition, land preparation, type of crop and its value. available water supply and other factors

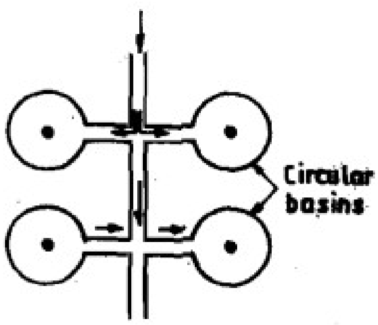


CHECK BASIN IRRIGATION

Check basin irrigation or simply basin irrigation is the simplest available mode of irrigation and commonly practised in India end other countries. The principle underlying this system involves dividing tile field or fanil into smaller unit areas such that each has a nearly level surface.



(a) Check basins

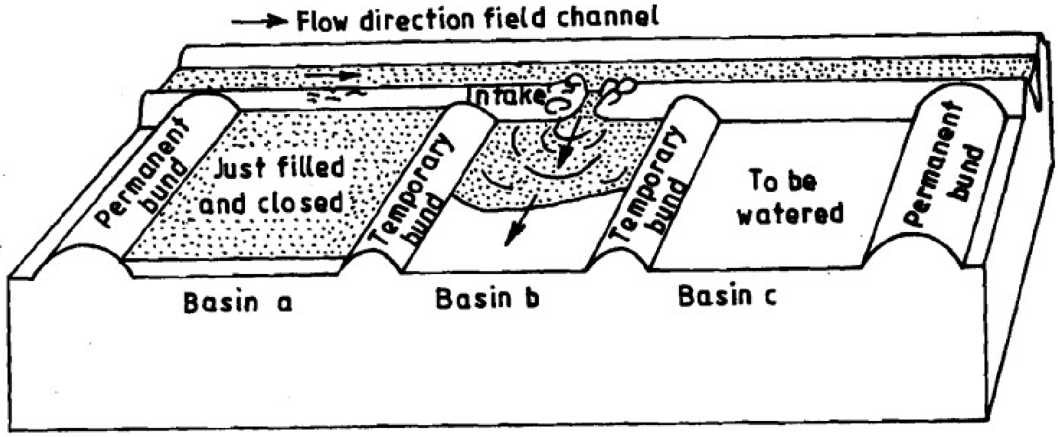


(b) Ring or circular basins

Methods to Apply Irrigation Water to check Basins

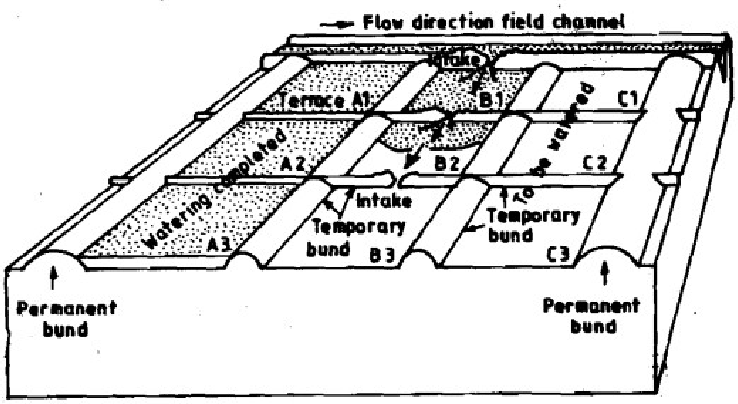
There are two methods to supply imgation water to check basins, namely, direct method, and cascade inetliod.

In the direct method. irrigation water is led dircctly from thc field channel into the basins through siphons. or bund breaks, basin A is irrigated first and then basin B and so on. This method can bc used for most crop types. and is also suitable for nlost type of soil.



Direct Method

The other method. namely, the cascade method is suitable for sloping land where terraces are used. In this method, the irrigation water is supplied to the highest terrace, and then allowed to flow to a lower terrace and so on. In Figure water is supplied to tlie tcrrace A1 until tlie lowest terrace A3 is fillcd. Tlie supply to A1 is tlien closed and irrigation water is diverted to terrace B1 until B I, B2 and B3 are filled, and so on.



Cascade Method

- About 5% of sand by volume is added to the dug up soil and mixed well.
- The pit is then filled back with the mixture and while filling up every 15 cm layer is well compacted, so that the soil in the pit retains the original bulk density as that of surrounding soil.
- Crop is sown normally and is allowed to grow as usual with the rest of the field.
- As and when the plants in the mini-plot show wilting symptoms it is taken as a warning of impending water need and cropped field is irrigated.

Plant population

- Increase in plant population by 1.5 to 2.0 times that of optimum
- This happens because when more plants are there per unit area, the available water withinthat zone is depleted rapidly as compared to other area
- This result in drooping or wilting of plants earlier, which can be taken as an indication of water deficits and accordingly irrigations are scheduled to crops.

Rate of growth

- Growth of a plant is dependent on turgor, which in turn is dependent on a favourable soilwater balance.
- So fluctuations in the water balance are reflected by parallel fluctuations in the growth rateof expanding organs.
- Stem elongation is markedly reduced when the available soil moisture level approaches thecritical level, but accelerates again after irrigation.

Canopy temperatureIndicator plants

- In wheat, scheduling irrigations on the basis of wilting symptoms in maize and sunflowergave the highest grain yields.

Critical growth stages

- The crop plants in their life cycle pass through various phases of growth, some of which arecritical for water supply.
- The most critical stage of crop growth is the one at which a high degree of water stresswould cause maximum loss in yield.

Irrigation Efficiencies

• Efficiency is the ratio of the water output to the water input, and is usually expressed aspercentage.

• Input minus output is nothing but losses, and hence, if Losses are more, output is less and,therefore, efficiency is less. Hence, efficiency is inversely proportional to the losses.

• Water is lost in irrigation during various processes and, therefore, there are different kinds ofirrigation efficiencies, as given below

- Efficiency of Water-conveyance

- Efficiency of Water Application
- Efficiency of Water Use
- Efficiency of water storage
- Water Distribution Efficiency

Efficiency of Water-conveyance (η_c)

• It is the ratio of the water delivered into the fields from the outlet point of the channel, to the water entering into the channel at its starting point. It may be represented by η_c. It takes the conveyance or transit losses into consideration.

$$\eta_c = (W_f/W_r) \text{ X } 100$$

Where

- η_c= Water conveyance efficiency,
- W_f = Water delivered to the irrigated plot at field supply Channel,
- W_r = Water diverted from the source (river or reservoir)

Efficiency of Water Application (η_a)

• It is ratio of water stored into the root zone of the crop to the quantity of water delivered at thefield (Farm).

$$\eta_a = W_s/W_f \text{ X } 100$$

Where,

- η_a = Water application efficiency,
- W_s = Water stored at the root zone during the irrigation
- W_f = Water delivered to the farm.

Efficiency of Water Use (η_u)

- It is the ratio of the water beneficially used including leaching water, to the Quantity ofwater delivered. It may be represented by η_u

$$\eta_u = (Wu/Wd) \text{ X } 100$$

Where,

- η_u = Water use efficiency,
- Wu = Beneficial use of water or consumptive.

- Wa = Water delivered to the field.

Efficiency of water storage: (η_s)

- The concept of water storage efficiency gives an insight to how completely the requiredwater has been stored in the root zone during irrigation.

$$\eta_s = (Ws/Wn) X 100$$

Where,

- η_s= Water storage efficiency,
- Ws = water stored in the root zone during irrigation.
- Wn = Water need in the root zone prior to irrigation.

Water Distribution Efficiency (η_d)

Water distribution efficiency evaluates the degree to which water is uniformly distributed throughout the root zone. Uneven distribution has many undesirable results. The more uniformly the water is distributed , the better will be crop response.

$$\eta_d = 100 (1-y/d)$$

Where,

- η_d= Water distribution efficiency,
- y= avg numerical deviation in depth of water stored from avg depth stored in the rootzone during irrigation
- d = Avg depth of water stored during irrigation..

Consumptive use Efficiency (η_{cu})

It is the ratio of consumptive use of water to the water depleted from the root zone.

$$\eta_{cu} = (W_{cu}/W_d) X 100$$

Where,

- η_{cu}= Consumptive use efficiency,
- W_{cu}= Nominal consumptive use of water
- W_d = Net amount of water depleted from the root zone soil.

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UNIT -3

DIVERSION AND IMPOUNDING STRUCTURES

Types of Impounding structures - Gravity dam – Forces on a dam -Design of Gravity dams; Earth dams, Arch dams- Diversion Head works - Weirs and Barrages.

Impounding structure

- Impounding structure or dam means a man-made device structure, whether a dam across a watercourse or other structure outside a watercourse, used or to be used to retain or store waters or other materials.
- The term includes: (i) all dams that are 25 feet or greater in height and that create an impoundment capacity of 15 acre-feet or greater, and (ii) all dams that are six feet or greater in height and that create an impoundment capacity of 50 acre-feet or greater.

Diversion headwork.

- Any hydraulic structure, which supplies water to the off-taking canal, is called a headwork.
- A diversion headwork serves to divert the required supply in to the canal from the river.

The purposes of diversion headwork.

1. It raises the water level in the river so that the commanded area can be increased.
2. It regulates the intake of water in to the canal.
3. It controls the silt entry in to the canal.
4. It reduces fluctuations in the level of supply in the river.
5. It stores water for tiding over small periods of short supplies.

Weir

The weir is a solid obstruction put across the river to raise its water level and divert the water in to the canal. If a weir also stores water for tiding over small periods of short supplies, it is called a storage weir.

The component parts of diversion headwork

- Weir or barrage
- Divide wall or divide groyne
- Fish ladder
- Head sluice or canal head regulator
- Canal off-takes
- Flood banks
- River training works.

Dam

A dam is a hydraulic structure constructed across a river to store the suppliy for a longer duration and release it through designed outlets.

Types of Dams

Based on Materials of Construction

- Rigid.
- Non-Rigid.

Based on Structural Behaviour

- Gravity Dam.
- Arch Dam.
- Buttress Dam.
- Embankment Dam.

Based on Functions

- Storage Dam.
- Detention Dam.
- Diversion Dam.
- Coffer dam.

Based on Hydraulic Behaviour

- Over Flow Dam.
- Non Over Flow Dam.

General Types

- Solid gravity dam (masonry, concrete, steel and timber)
- Arch dams
- Buttress dams
- Earth dams
- Rockfill dams
- Combination of rockfill and earth dams

Gravity dam

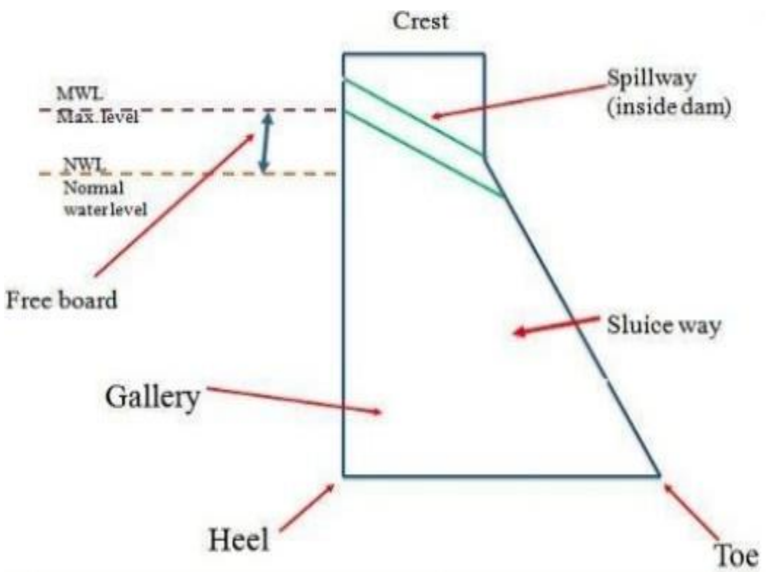
- A gravity dam is a structure so proportioned that its own weight resists the forces exertedupon it. It requires little maintenance and it is most commonly used.
- A Gravity dam has been defined as a "structure which is designed in such a way that its ownweight resist the external forces".
- This type of a structure is most durable and solid and requires very less maintenance.
- Such dams are constructed of masonry or Concrete.
- However, concrete gravity dams are preferred these days and mostly constructed.
- The line of the upstream face or the line of the crown of the dam if the upstream face

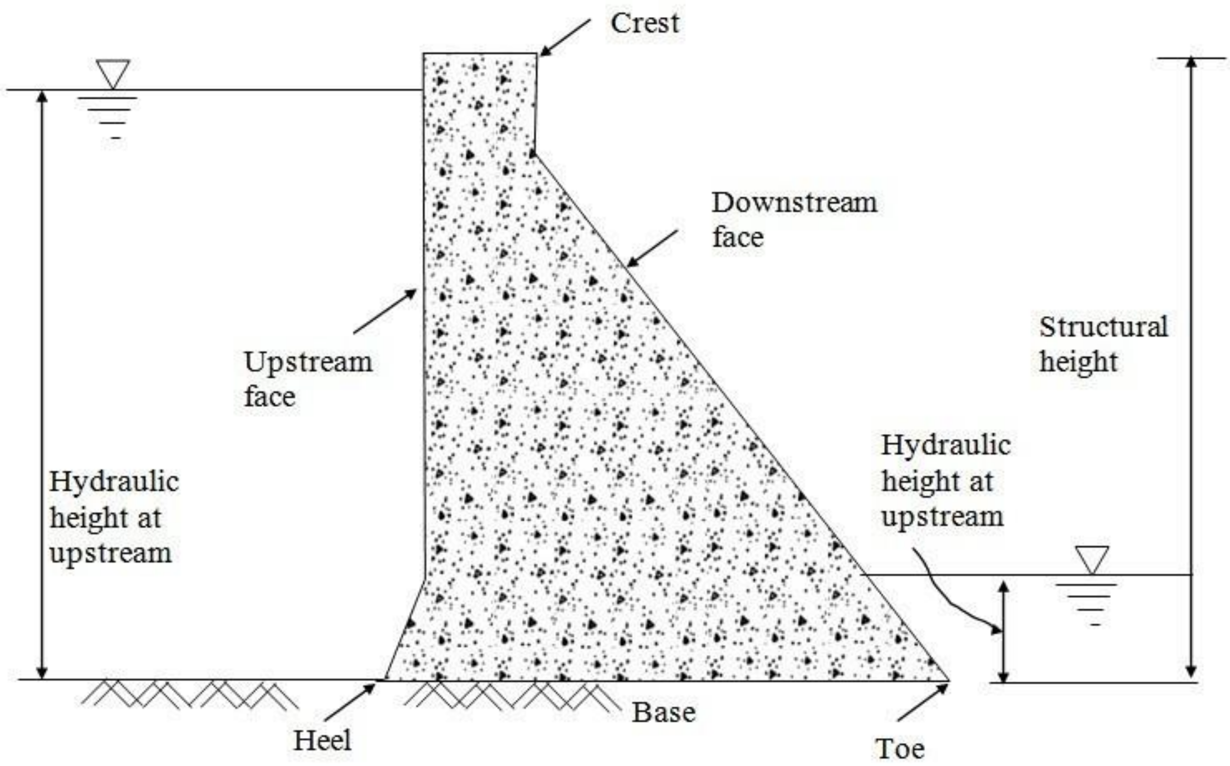
issloping, is taken as the reference line for layout purpose etc. and is known as the Base line of the dam or the "Axis of The Dam" When suitable conditions are available such dams can be constructed up to great heights.

The different components of a solid gravity dam are

- Crest.
- Free Board.
- Heel.
- Toe.
- Sluice Way.
- Drainage Gallery.

Typical cross section of gravity Dam:





Heel: contact with the ground on the upstream side

Toe: contact on the downstream side

Abutment: Sides of the valley on which the structure of the dam rest

Galleries: small rooms like structure left within the dam for checking operations.

Diversion tunnel: Tunnels are constructed for diverting water before the construction of dam. This helps in keeping the river bed dry.

Spillways: It is the arrangement near the top to release the excess water of the reservoir to downstream side

Sluice way: An opening in the dam near the ground level, which is used to clear the silt accumulation in the reservoir side.

Forces Acting on Gravity Dam

The Various external forces acting on Gravity dam may be:

- Water Pressure
- Uplift Pressure
- Pressure due to Earthquake forces
- Silt Pressure
- Wave Pressure
- Ice Pressure
- The stabilizing force is the weight of the dam itself

Self weight of the Dam

Self weight of a gravity dam is main stabilizing force which counter balances all the external forces acting on it.

For construction of gravity dams the specific weight of concrete & stone masonry shouldn't be less than 2400 kg/m^3 & 2300 kg/m^3 respectively.

The self weight of the gravity dam acts through the centre of gravity of the.

Its calculated by the following formula – $W = \gamma_m \, X \, Volume$

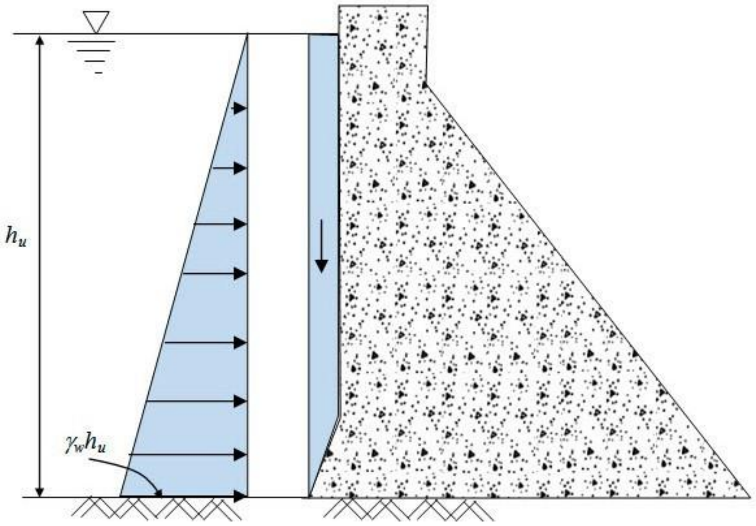
Where γ_m is the specific weight of the dam's material.

Water pressure

- Water pressure on the upstream side is the main destabilizing force in gravity dam.
- Downstream side may also have water pressure.
- Though downstream water pressure produces counter overturning moment, its magnitude is much smaller as compared to the upstream water pressure and therefore generally not considered in stability analysis.

- Water Pressure is the most major external force acting on a gravity dam.
- On upstream face pressure exerted by water is stored upto the full reservoir level. Theupstream face may either be vertical or inclined.
- On downstream face the pressure is exerted by tail water. The downstream face is always inclined. It is calculated by the following formula – $P = \frac{1}{2}\gamma_w \, x \, h^2$

Where γ_w is the unit weight of water & h is the height of water.



Uplift water pressure

- The uplift pressure is the upward pressure of water at the base of the dam as shown in Figure 29.3. It also exists within any cracks in the dam.
- The water stored on the upstream side of the dam has a tendency to seep through the soilbelow foundation.
- While seeping, the water exerts a uplift force on the base of the dam depending upon thehead of water.
- This uplift pressure reduces the self weight of the dam.
- To reduce the uplift pressure, drainage galleries are provided on the base of the dams.
- It is calculated by the following formula – $U = \frac{1}{2}\gamma_w \, x \, h \, x \, B$

Where 'B' is the width of the base of the dam.

Wave Pressure

When very high wind flows over the water surface of the reservoir, waves are formed which exert pressure on the upstream part of the dam.

The magnitude of waves depend upon –

- The velocity of wind.
- Depth of Reservoir.

- Area of Water Surface.

It is calculated by the following formula - $P_v = 2.4\, \gamma_w x h_w$

Where 'h_w ' is the wave height.

WIND PRESSURE :

- The top exposed portion on the dam is small & hence the wind pressure on this portion ofdam is negligible.
- But still an allowance should be made for the wind pressure at the rate of about 150 kg/m^2 for the exposed surface area of the upstream & downstream faces.

SEISMIC FORCES :

- Dams are subjected to vibration during earthquakes.
- Vibration affects both the body of the dam as well as the water in the reservoir behind thedam.
- The most danger effect occurs when the vibration is perpendicular to the face of the dam.
- Body Forces: Body force acts horizontally at the center of gravity and is calculated as: $P_{em} = a\, x\, W$
- Water Force: Water vibration produces a force on the dam acting horizontally & calculated by: $P_{ew} = \frac{2}{3} C_e\, a\, h^2$

ELEMENTRY PROFILE

- When water is stored against any vertical face, then it exerts pressure perpendicular to theface which is zero at top & maximum at bottom.
- The required top thickness is thus zero & bottom thickness is maximum forming a rightangled triangle with the apex at top, one face vertical & some base width.
- Two conditions should be satisfied to achieve stability
  - **When empty -** The external force is zero & its self weight passes through C.G. of the triangle.
  - **When Full -** The resultant force should pass through the extreme right end of themiddlethird.

The limiting condition is – $h = \frac{\sigma_c}{\gamma (1+S)}$

- where, σc=allowable compressive stress

Practical Profile

- Various parameters in fixing the parameters of the dam section are,
- Free Board –IS 6512, 1972 specifies that the free board will be 1.5 times the wave heightabove normal pool level.

- Top Width – The top width of the dam is generally fixed according to requirements of theroadway to be provided. The most economical top width of the dam is 14 % of its height.

- Base Width – The base width of the dam shall be safe against overturning, sliding & no tension in dam body.

For elementary profile –

- When uplift is considered, $B = \frac{h}{\sqrt{S}}$
- When uplift isn't considered $B = \frac{h}{\sqrt{S - 1}}$

Low Gravity Dam

- A low gravity dam is designed on the basis if of elementary profile, where the resultant forcepasses through the middle-third of its base.
- The principal stress is given by – [illegible] = γ H (S – C + 1) Where, [illegible]=principal stress, γ=unit weight, S=Specific Gravity and C=A constant.
- The principal stress varies with 'H' as all other terms are constant. To avoid failure of the dam the value of '[illegible]' shouldn't exceed allowable working stress(f). F = γ H (S – C + 1)

High Gravity Dam

- The high gravity is a complicated structure, where the resultant force may pass through apoint outside the middle-third of the base.
- The section of the dam is modified by providing extra slope on the upstream and downstream side.
- The condition for the high gravity dam are $H > \frac{f}{w(S+1)}$ – Where, f=allowable working

stress.

Failure of Gravity Dam

Failure of gravity dams are caused due to,

Sliding – It may take place on a horizontal joint above formation, on