HYDRAULIC
&
IRRIGATION ENGG

CIVIL ENGINEERING
LECTURE NOTE

CH-1(HYDROSTATICS)

DENSITY

- It is defined as the ratio of the mass of a fluid to its volume.
- It is denoted by ' **ρ'** (rho).

$$\rho = \frac{mass}{volume}$$

WEIGHT DENSITY

- It is the ratio between the weight of fluid to its volume.
- It is denoted as 'w'.

$$W = \frac{weight of fluid}{volume of fluid}$$

SPECIFIC GRAVITY

- It is defined as the ratio between the density of the liquid to the density of the standard fluid.
- It is denoted as 'S'.
- It is unit less.

$$S = \frac{density\ of\ liquid}{density\ of\ standard\ fluid}$$

DYNAMIC VISCOSITY

- It is defined as the property of fluid which offers resistance to the movement of one layer of fluid over another adjacent layer of a fluid.
- Its unit in MKS $\frac{kgf-sec}{m2}$ and in CGS $\frac{dyne-sec}{cm2}$.

KINEMATIC VISCOSITY

- It is defined as the ratio between the dynamic viscosity and density of fluid.
- Its unit in MKS $\frac{m^2}{sec}$ and in CGS $\frac{cm^2}{sec}$.

SURFACE TENSION

- It is defined as the tensile force acting on a 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.

$$P = \frac{4\sigma}{d}$$

P = pressure

σ = surface tension

d = diameter of the droplet

- Capillarity is defined as the phenomenon of rise or fall of a liquid surface in a small tube which held vertically in the liquid.

$$h = \frac{4\sigma \cos \theta}{\rho \times g \times d}$$

where h = height of liquid

σ = surface tension

ρ = density of liquid

d = diameter of the tube

PRESSURE AND ITS MEASUREMENT

Pressure

- The ratio between the force to the area is known as intensity of pressure or pressure .

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

- The unit of pressure are , (i) kgf/m^2 and kgf/cm^2 in MKS units , (ii) Newton/m^2 or N/m^2 and N/mm^2 in SI units .

Pascal's law

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

Absolute pressure

- Absolute pressure is defined as the pressure which is measured above the absolute zero or complete vacuum .

Aauge pressure

- Gauge pressure is defined as the pressure which is measured above the atmospheric pressure and the atmospheric pressure is taken as datum .

Aacuum pressure

- It is defined as the pressure below the atmospheric pressure .
- Vacuum pressure = Atmospheric pressure – Absolute pressure

Manometer

- 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 (i) simple manometer (ii) differential manometer

Piezometer

- It is simplest form of manometer used for measuring gauge pressures .
- One end of this manometer is connected to the point where pressure is to be measured and other end is open to the atmosphere .

Hydrostatic law

- It states that rate of increase of pressure in a vertical direction is equal to weight density of the fluid at the point .

State and prove the Pascal's law

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

Prove –

The fluid element is of very small dimensions i.e. dx ,dy and ds .

Consider an arbitrary fluid element of wedge shape in a fluid mass at rest . Let the width of the element perpendicular to the plane of paper is unity and p_x,p_y and p_z are the pressure or intensity of pressure acting on the face AB , AC and BC.

Let ,<ABC = θ

Force on the face AB = p_x×area of face AB

= p_x×dy×1

Force on the face AC = p_y×dx×1

Force on the face BC=p_z×ds×1

Weight of the element,= mass of element × g

= (volume×ρ) × g=($\frac{AB \times AC}{2}$×1) ×ρ×g

Resolving the force in x- direction

p_x×dy×1- p_z(ds×1)$\sin(90^\circ - \theta)$=0

p_x×dy×1- p_z×ds×1$\cos\theta$=0

p_x×dy×1- p_z×dy×1=0 [where ds$\cos\theta$= AB= dy]

p_x= p_z (I)

similarly resolving the force in y- direction,

p_y×dx×1- p_z×ds×1$\cos(90^\circ - \theta)$-$\frac{d_{x\times d_y}}{2}$ × 1 × ρ× g=0

p_y×dx- p_z×ds$\sin\theta$-$\frac{d_{x\times d_y}}{2}$× ρ× g=0

ds$\sin\theta$= dx

p_y× dx- p_z× dx=0

p_y= p_z (II)

from equation (I) and (II) we get

p_x= p_y= p_z

Hydrostatic force on submerged surface

Total pressure

- **Total pressure** is defined as the force exerted by a static fluid on a surface either plane or curved when the fluid comes in contact with the surface , and this force always acts normal to the surface.

Centre of pressure

- **Centre of pressure** is defined as the point of application of the total pressure on the surface.

CH-2(KINEMATICS OF FLUID FLOW)

Types of fluid flow

(i) steady and unsteady flow

(ii)uniform and non-uniform

(iii)laminar and turbulent flow

(iv)compressible and incompressible

(v)rotational and irrotational flow

(vi)one ,two and three-dimensional flow

Steady flow

- **Steady flow** is defined as that type of flow in which the fluid characteristics like velocity, pressure, density, etc., at a point do not change with time.

Unsteady flow

- **Unsteady flow** is that type of flow, in which the velocity, pressure or density at a point changes with respect to time.

Uniform flow

- **Uniform flow** is defined as that type of flow in which the velocity at any given time does not change with respect to space.

Non-uniform

- **Non-uniform** flow is that type of flow in which the velocity at any given time changes with respect to space.

Laminar flow

- **Laminar flow** is defined as that type of flow in which the fluid particles move along well-defined paths or stream line and all the stream lines are straight and parallel.

Turbulent flow

- **Turbulent flow** is that type of flow in which the fluid particles moves in zig-zagway.Due to the movement of fluid particles in zig-zag way the eddies formation takes place which are responsible for high energy loss.

Compressible flow

- **Compressible flow** is that type of flow in which the density of fluid changes from point to point or in other words the density is not constant for the fluid.

Incompressible flow

- **Incompressible flow** is that type of flow in which the density is constant for the fluid flow.

Euler's equation of motion

- If the flow is assumed to be ideal, viscous force is zero and equation of motion are known as Euler's equation of motion.

NOTCHES AND WEIR

Notch

- Notch is a device used for measuring the rate of flow of a liquid through a small channel or a tank.

Weir

- Weir is a concrete or masonry structure, placed in an open channel over which the flow occurs.

Types of notch

(i) rectangular notch (ii) triangular notch

(iii) trapezoidal notch (v) stepped notch

Advantages of triangular notch or weir over rectangular notch or weir

1- The expression for discharge for a right angled V-notch or weir is very simple.

2- For measuring low discharge, a triangular notch gives more accurate results than rectangular notch.

3- In case of triangular notch, only one reading H is required for the computation of discharge.

4- Ventilation of a triangular notch is not necessary.

Discharge over a rectangular notch or weir

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

Discharge over a triangular notch or weir

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

Discharge over trapizoidal notch or weir

Q=RECTANGULAR NOTCH+TIANGULAR NOTCH

Q. Determine the height of 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 1.8 m and discharge is 2000lit/s. take C_d=0.6 and neglect and contraction.

Ans:- given,

Length of weir , L= 6 m

Depth of water, H_1=1.8 m

Discharge , Q= 2000 lit/s =2 m^3/s

C_d=0.6

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

$2.0=(2/3) \times 0.6 \times 0.6 \times \sqrt{2 \times 9.81} \times H^{3/2}$

$H^{3/2}=(2.0/10.623)$

$H = (2.0/10.623)^{3/2}=0.328$ m

Height of weir $H_2 = H_1-H$ =1.8-0.328=1.472 m.

Q. Water flows through a triangular right angled weir first and then over a rectangular weir of 1 m width. The discharge co-efficient of the rectangular and rectangular weirs are 0.6 and 0.7 respectively. If the depth of water over the rectangular weir is 360mm, find depth of water over rectangular weir.

Ans:- given;

For triangular weir θ=90˚, C_d=0.6, H=360mm=0.36m

For rectangular weir L=1m, C_d=0.7, H=?

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

$Q= (8/1) \times 0.6 \times \tan\frac{90}{2} \times \sqrt{2 \times 9.81} \times 0.36^{5/2}$

Q= 0.1102 m^3/s

The same discharge is passing through the rectangular weir.

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

$0.1102=(2/3) \times 0.7 \times 1 \times \sqrt{2 \times 9.81} \times H^{3/2}$

$H^{3/2}=0.0533$

$H=0.0533^{3/2}=0.1415$ m=141.5 mm

FLOW THROUGH PIPES

Chezy's formula.

$$h_f = \frac{Flv^2}{2gd}$$

Where h_f=loss of head due to friction

P= wetted perimeter of pipe

A= area of cross-section of pipe

L= length of pipe

V= mean velocity of flow

Sudden expansion $h_L = \frac{(V_1 - V_2)^2}{2g}$

Sudden contraction $h_L = 0.5\frac{(V_2)^2}{2g}$

Entrance to the pipe $h_L = 0.5\frac{(V)^2}{2g}$

At exit of a pipe $h_L = K\frac{(V)^2}{2g}$

Q. A crude oil of kinematic viscosity 0.4 stoke is flowing through a pipe of diameter 300 mm at the rate of 300 lit/s. find the head lost due to friction for a length of 50 m of the pipe.

Ans:- given;

Kinematic viscosity, v=0.4 stoke=0.4cm^2/s=0.4×10^{-4}m^2/s

Diameter of pipe d=300mm=3m

Discharge Q=300lit/s=0.3 m^3/s

Length of pipe L =50 m

Velocity of flow V=Q/area=0.3/$\frac{\pi}{4}$×0.3^2=4.24 m/s

Reynolds number $R_e = \frac{v \times D}{\gamma} = \frac{4.24 \times 0.30}{0.4 \times 10^{-4}} = 3.18 \times 10^4$

As R_e lies between 4000 and 100000 the value of f is given by,

$F = \frac{0.79}{R_e^{1/4}} = \frac{0.79}{3.18 \times 10^{-4^{1/4}}} = 0.00591$

Head lost due to friction, $h_f = \frac{4 \times f \times l \times v^2}{d \times 2g} = \frac{4 \times 0.00591 \times 50 \times 4.24^2}{2 \times 0.3 \times 9.81} = 3.61$ m.

CH-3(PUMP)

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CENTRIFUGAL PUMPS

Centrifugal pump

- 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 main parts of centrifugal pumps

1- impeller

2- casing

3-suction pipe with a foot valve and a strainer

4- delivery pipe

3. Impeller.

The rotating part of a centrifugal pump is called impeller. It consists of a series of backword curved vane.

4.Suction pipe.

A pipe whose one end is connected to the inlet of the pump and other end dips into water in a sump is called suction pipe.

Suction head.

It is the vertical height of the center line of the centrifugal pump above the water surface in the tank or pump from which water is to be lifted .

Efficiencies of centrifugal pump

The efficiencies of a centrifugal pumps are,

1- manometric efficiencies

2- mechanical efficiencies

3- overall efficiencies

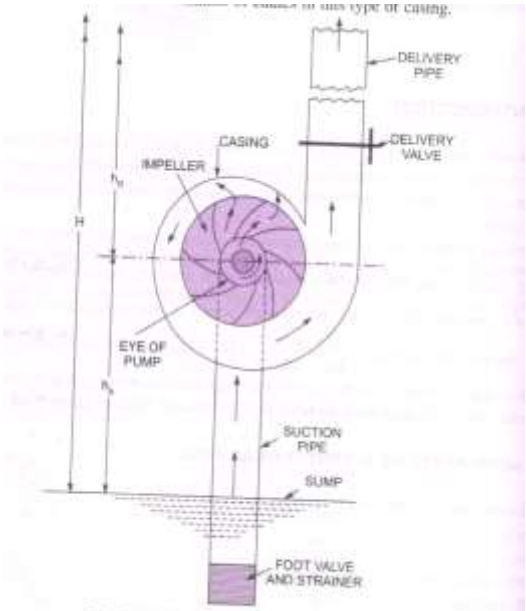

Fig. 19.1 *Main parts of a centrifugal pump.*

RECIPROCATING PUMP

- When the mechanical energy is converted into hydraulic energy or pressure energy by sucking the liquid into a cylinder in which a piston is reciprocating or moving backwards and forwards which exerts the thrust on the liquid and increases its hydraulic energy or pressure energy the pump is known as reciprocating pump.

Slip of reciprocating pump

- Slip of a pump is defined as the difference between the theoretical discharge and actual discharge of the pump
- Slip = Q_{th}-Q_{act}

Negative slip

- If actual discharge is more than the theoretical discharge the slip of the pump will become negative.
- In that case the slip of the pump is known as negative slip.

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

The main parts are

(1) A cylinder with a piston rod, connecting rod, and a crank
(2) Suction pipe
(3) Delivery pipe
(4) Working principle-

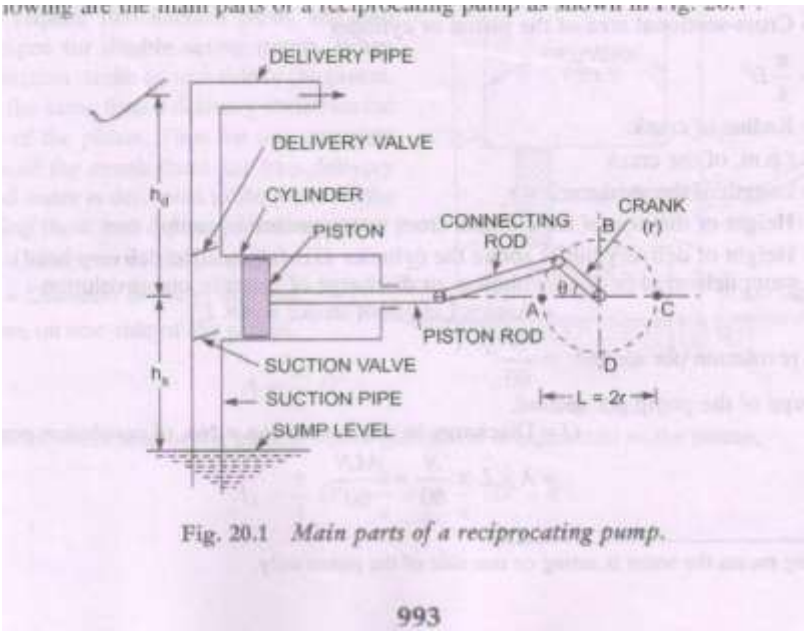

Fig. 20.1 *Main parts of a reciprocating pump.*

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- When crank starts rotating the piston moves to and fro in the cylinder.
- When the crank is at A the piston is at the extreme left position in the cylinder.
- As the crank is rotating from A to C i.e. from ɵ = 0˚ to ɵ = 180˚.
- The piston is moving towards right in the cylinder.
- The movement of the piston towards right creates a partial vacuum in the cylinder.
- But on the surface of a liquid in the sum atmospheric pressure is acting , which is more than the pressure inside the cylinder.
- Thus the liquid is forced in the suction pipe from the sump this liquid opens the suction valve and enters the cylinder.
- When crank is rotating from C to A i.e. from ɵ = 180˚ to ɵ = 360˚, the piston from its extreme right position starts moving towards left in the cylinder.
- The movement of the piston towards left increases the pressure of the liquid inside the cylinder more than atmospheric pressure.
- Hence suction valve closes and delivery valve opens.
- The liquid is forced into the delivery pipe and is raised to a required height .

CH-4(HYDROLOGY)

- The science of studying the different forms of water available above the earth surface or below the earth surface is known as hydrology.
  - It measures the precipitation of rainfall.
  - It study the water loss due to transpiration, evaporation and infiltration.
  - It estimate run-off and peak flow.

Catchment area

- The catchment area of a river means the area from where the surface run off flows to that river through the tributaries, streams, springs etc.
- The area is bounded by water shed line.

Run off

- When it rains, some portion of rain water infiltrates into the soil, some is intercepted by vegetation, some evaporates and the remaining portion flows over the ground surface to join the rivers, streams, lakes etc.
- This portion of water which flows over the ground surface is known as surface run off or run off.

Hydrograph

- The hydrograph is a graphical representation of the discharge of a river against the time.
- The discharge is plotted as ordinate (y-axis) and the time is plotted abscissa (x-axis).
- During the dry season, there is only base flow but no surface run off.
- This may be shown by the line which is approximately straight.
- In rainy season, at the beginning of the rainfall there is only base flow.

Hyetograph

- The graphical representation of rainfall and run-off is known as hyetograph.
- The graph is prepared with intensity of rainfall as ordinate and time as abscissa.
- The infiltration capacity curve is drawn on this graph to show the amount of infiltration loss.

Unit of hydrograph

- It is defined as a hydrograph which is obtained from one cm of effective rainfall for unit duration.
- Here effective rainfall means the rainfall excess which directly flows to the river or stream.
- The unit duration is the period during which the effective rainfall is assumed to be uniformly distributed.

Base flow

- The ground water contribution to the stream is known as the base flow.

- It consists of two portions (i) the ground water directly flows to the stream, (ii) the rain water first infiltrates into the ground and then flows laterally to the stream.

Dicken's formula – $Q=C\times A^{3/4}$

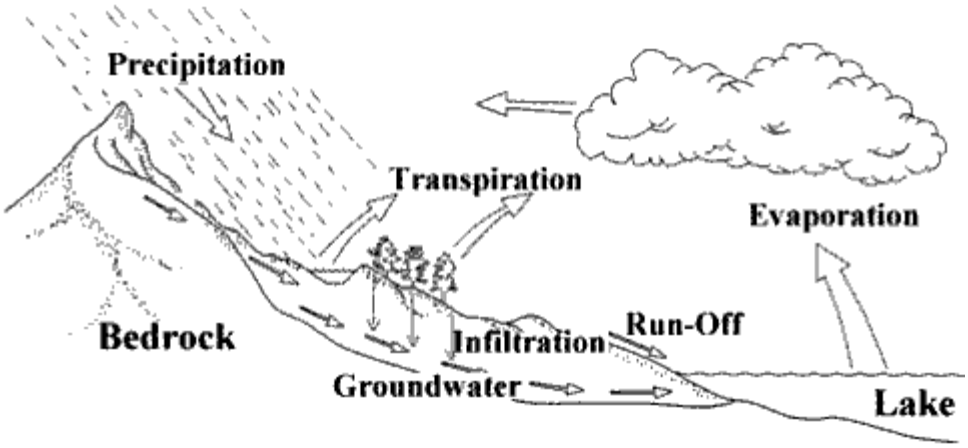
Where Q= discharge, A= catchment area, C= a constant depending upon the factors affecting the flood discharge. Average value of C=11.5

Ryve's formula – **$Q=C\times A^{2/3}$**

Where Q= discharge, A= catchment area, C= a constant. The average value of C= 6.8

Hydrological cycle

- The water of the universe always changes from one state to another state under effect of sun.
- The water from the surface sources like lake, rivers, oceans, etc. converts to vapour by evaporation due to solar heat. The vapour goes on accumulating continuously in the atmosphere.
- This vapour is again condensed due to the sudden fall of temperature and pressure.
- Thus clouds are formed. These clouds again cause the precipitation.
- Some of the vapor is converted to rivers to meet the sea or ocean.
- These processes of evaporation, precipitation and melting of ice go on continuously like an endless chain
- . This phenomenon is known as hydrologic cycle.



[HYDROLOGIC CYCLE]

Factors affecting run-off

- **Intensity of rainfall:-**
- If the intensity of rainfall is more the corresponding run-off will be more.

- Again if the intensity of rainfall is low the corresponding run-off will also be low.
- **Soil characteristics of catchment:-**
- In the catchment area consisting of rocky or clayey soil, the run-off will be more.
- Again if the soil characteristic of the catchment is sandy, the run-off will be low as the loss of infiltration is more.
- **Topography of the catchment:-**
- If the ground slope of the catchment is steep the runoff will be more.
- If the ground slop is flat and consists of depressions, the runoff will be low.
- **Shape and size of catchment:-**
- If the catchment area is large and fan shaped the runoff will be more.
- If the catchment area is small and fern shaped the runoff will be low.
- **Geological condition of catchment:-**
- If the catchment area consists of fissures, cracks, etc. the water losses will be more and the runoff will be low.
- **Cultivation and vegetative cover in catchment area:-**
- If the catchment area consists of more cultivated area and forest areas, the runoff will be low.
- **Weather condition:-**
- If the temperature in the catchment area is high, the evaporation loss will be more and hence runoff will be less and vice versa.

There are two types of rain gauge are there ,

(i) Non recording type

(ii) Recording type

(I) NON RECORDING TYPE RAIN GAUGE:-

- It is also called Simon's rain gauge.
- It consists of metal casting of diameter 127 mm which is set on a concrete foundation. A glass bottle of capacity about 100 mm of rainfall is placed within the casing. A funnel with brass rim is placed on the top of the bottle.
- The rainfall is recorded at every 24 hours.
- Generally the measurement is taken at 8.30 am every day.
- In case of every rain fall the measurement should be taken 2 or 3 times daily so that the bottle does not overflows.
- To measure the amount of rainfall the glass bottle is taken off and the collected water is measured in a measuring glass, and recorded in the rain gauge record book.
- When the glass bottle is taken off it is immediately replaced with a new bottle of same capacity.

(i) RECORDING TYPE RAIN GAUGE:-

- In this type of rain gauge the amount of rain fall automatically recorded on a graph paper by some mechanical device.

- Here no person is required for measuring the amount of rain fall from the container in which the rain water is collected.
- It is of three types,

(a) WEIGHING BUCKET RAIN GAUGE:-

- This type of rain gauge consists of a receiving bucket which is placed on pan.
- The pan is again fitted with some weighing mechanism.
- A pencil arm is pivoted with the weighing mechanism in such a way that the movement of the bucket can be traced by a pencil on the moving recording drum.
- So when the water is collected in the bucket the increasing weight of the water is transmitted through the pencil which traces a curve on the recording drum.
- The rain gauge produces a graph of cumulative rain fall versus time and hence it is sometimes called Integrating rain gauge.
- The graph is known as the mass curve of rainfall.

(b) TIPPING BUCKET RAIN GAUGE:-

- It consists of a circular collector of diameter 30 cm in which the rain water is initially collected. The rain water then passes through a funnel fitted to the circular collector and get collected in two compartment tipping buckets pivoted below the funnel.
- When 0.25 mm rain water is collected in one bucket then it tips and discharges the water in a reservoir kept below the bucket. At the same time the other bucket comes below the funnel and the rain water goes on collecting in it.
- When the requisite amount of rain water is collected it also tips and discharges the water in the reservoir.
- In this way a circular motion is generated by the bucket. This circular motion is transmitted to a pen or pencil which traces a wave like curve on the sheet mounted on a revolving drum.
- The total rainfall may be ascertained from the graph.
- There is an opening with stopcock at the bottom of the reservoir for discharging the collected rain water.

(c) FLOAT TYPE RAIN GAUGE:-

- In this type of rain gauge a funnel is provided at one end of a rectangular container and a rotating recording drum is provided at the other end.
- The rain water enters the container through the funnel. A float is provided with in the container which rises up as the rain water gets collected there.
- The float consists of a rod which contains a pen arm for recording the amount of rainfall on the graph paper wrapped on the recording drum.
- It consists of a syphon which starts functioning when the float rises to some de3finite height and the container goes on emptying gradually.

CH-4(WATER REQUIREMENT OF CROPES)

Necessity of irrigation

(a) If there is insufficient rainfall means, when the seasonal rainfall is less than the minimum requirement for the satisfactory growth of crops.

(b) If there is uneven distribution of rainfall means, when the rainfall is not evenly distributed.

(c) If there is improvement of perennial crops means some perennial crops like sugarcane, cotton, etc. require water throughout the major part of the year. But the rainfall may fulfill the water requirement in rainy season only. So irrigation becomes necessary.

(d) If there is development of agriculture in desert area , the rainfall is very scanty , so irrigation is required.

Benefits of irrigation

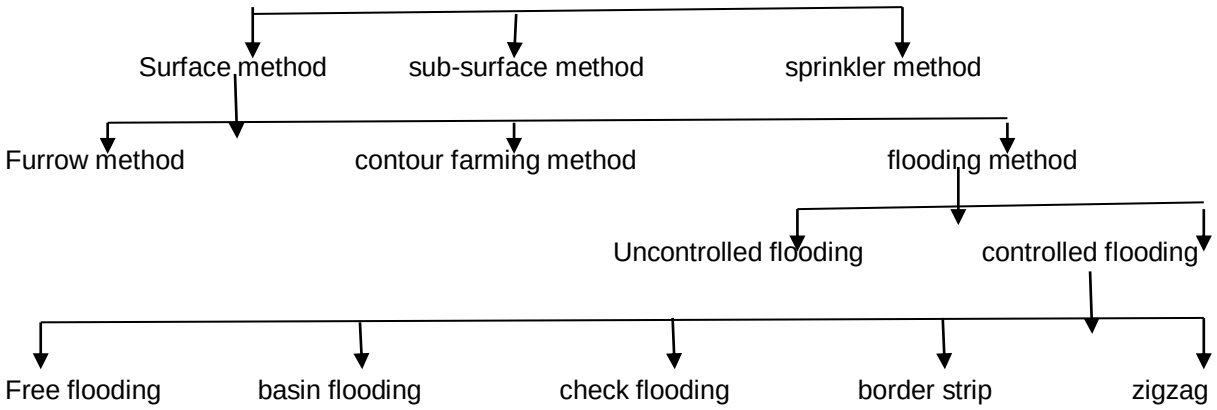
(a) **Yield of crops** – In the period of low rainfall, the yield of crop may be increased by irrigation system.

(b) **Improvement of cash crops** – Irrigation helps to improve the cultivation of cash crops like vegetables, fruit, tobacco, etc.

(c) **Water supply** – The irrigation canals may be source of water supply for domestic and industrial purpose.

(d) **Source of revenue** – When irrigation water is supplied to the cultivators for some taxes, it helps to earn revenue which may be spent on other development schemes.

methods of distribution



SURFACE METHOD-

(a) **Furrow method**:-

- In this method, the irrigation water is supplied to the land by digging narrow channels known as furrows at regular intervals.
- The flows through the furrows and infiltrates into the soil and spreads laterally to saturate the root zone of the crops.
- This method is suitable for the crops.

- The crops are potato, ground nut, tobacco, sugarcane, etc.

(b) **Contour farming**:-

- This method is adopted in hilly areas where the land has steep slope.
- Here, the land is divided into series of horizontal strips which are known as terraces.
- Small bunds are provided at the end of each terrace to hold water upto the required depth. This method serves also the purpose of flood control and soil erosion.

(c) **Flooding method**:- This method is suitable for the agricultural land which exists in flat topography. It is of two types, (1)-uncontrolled flooding, (2) controlled flooding.

(1)- **Uncontrolled flooding**:-

- This method is applicable in inundation irrigation system.
- Here, the land is flooded with water by inundation canal.
- As there is no controlling system this type of distribution of water is known as uncontrolled flooding.
- This method results in wastage of water and over irrigation.

(2)- **Controlled flooding**:-

- This method is applicable in perennial irrigation system. In this method, the agricultural area is flooded with water through the canals which are provided with regulators.
- It is of following types, (a)- free flooding, (b)- basin method, (c)- check flooding, (d)- border flooding, (e)- zigzag method.

(a):- **Free flooding**-

- In this method, the agricultural land is divided into small strip by a series of field channels which are connected to the supply channels.
- The strip of land are flooded with water by opening the field regulators the surplus water flows through the waste water channel and is discharged into the river or drainage.

(b):- Basin method-

- This method is employed for watering orchards.
- In this method, each tree or a group of trees are enclosed by circular channel through which water flows.
- The circular channel is known as basin.
- Each basin is connected to field channel.
- The field channel is again connected to the supply channel.
- When all the basins are filled with water, the supply of water is stopped.

(c):- **Check flooding**-

- In this method the agricultural area is divided into small plots by check bunds.

- The water is supplied to the check basins through the field channels which are connected with the supply channel.
- Each basin is flooded with water to the desired depth and the water is retained for some hours so that it can infiltrate into the soil.

(d):- **Border strips**-

- In this method, the agricultural area is divided into series of long narrow strips by levees, i.e. small country slope so that the water can flow easily throughout the area.
- This method is suitable when the area is at level with gentle country slope.

(e):- **Zigzag method**-

- In this method, the agricultural area is sub-divided into small plots by low bunds in zigzag manner.
- The water is supplied to the plots from the field channel through the openings.
- The water flows in zigzag way to cover the entire area. When the desired depth is attained, the openings are closed.

SUB-SURFACE METHOD-

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

(C)**SPRINKLER METHOD**-

- In this method, the water is applied to the land in the form of spray like rain.
- The spraying of water is achieved by the network of main pipe, sub-main pipes and lateral pipes.

Crop season

- The period during which some particular types of crops can be grown every year on the same land is known as crop season.
- These are the main crop season, (a) kharif season, (b) rabi season.

Gross command area(G.C.A)

- The whole area enclosed between an imaginary boundary line which can be included in an irrigation project for supplying water to agricultural land by the network of canals is known as Gross Command Area.

- It includes both the culturable and unculturable areas.

Culturable command area

- The total area within an irrigation project where the cultivation can be done and crops can be grown is known as Culturable Command Area.

Crop ratio

- It is defined as t5he ratio of the areas of the two main crop seasons, e.g. kharif and rabi.
- The crop ratio should be so selected that the discharge of the canal for supplying water to kharif and Rabi may be nearly equal.

Crop rotation

- The process of changing the type of crop for the cultivation on the same land is known as crop rotation.
- It is found that if the same crop is cultivated on the same land every year, the fertility of the land gets reduced and the yield of crop also gradually reduces.
- It is found by experiment that the principle of crop rotation is practised, the fertility of the soil can be restored.

- Rice – Gram
- Wheat – Millet –Gram
- Rice – Gram – wheat

Base period

- The base is defined as the period from the first to the last watering of the crop just before its maturity.
- It is also known as **base period**.
- It is denoted by B and expressed in number of days

Delta

- Each crop requires certain amount of water per hectare for its maturity.
- If the total amount of water supplied to the crop is stored on the land without any loss, then there will be a thick layer of water standing on that land.
- This depth of water layer is known as **delta** for the crop.
- It is denoted by Δ and expressed in cm.

Duty

- The **duty** of water is defined as number of hectares that can be irrigated by constant supply of water at the rate of one cumec throughout the base period.
- It is expressed in hectare /cumec.
- It is denoted by D.

Welting point

- It is defined as the amount of moisture held by soil which cannot be extracted by the plant root for transpiration.
- At this point the wilting of the plant occurs. It is also expressed in percentage.

Frequency of irrigation

- If the moisture content is dropped below the requisite amount, the growth of the plants gets disturbed.
- So the moisture content requires to be immediately replenished by irrigation and it should be raised to the field capacity.
- The frequency of irrigation should be worked out in advance so that it can be applied in proper intervals.

Relation between base, delta and duty

D= Duty of water in hectares/cumee. B= Base in days. Δ= Delta in m.

B days gives a depth of water Δ over an area D hectares. That is,

1 cumec for B days Δ over D hectares

1 cumec for 1 days gives Δ over D/B hectares.

1 cumec for 1 day= (D/B)× Δ hectare-metre (1)

1 cumec-day=(D/B)× Δ hectare-metre

Again, 1 cumec-day= $1\times24\times60\times60=86400m^3$

= 8.64 hectare-metre (1 hectare=$10000m^2$) (2)

From (1) and (2),

(D/B)× Δ=8.64

Δ=(8.64×B)/D=in m

CH-6(FLOW IRRIGATION)

Classification of canal according to their alignment

(a) Ridge or watershed canal,

(b) Contour canal,

(c) Side slope canal

Inundation canal	Perennial canal
➢ The irrigation water is available in rainy season only. ➢ No hydraulic structure is necessary. ➢ Large area cannot be included under this system. ➢ The silting of the canal bed is a major problem. ➢ Initial cost is low.	➢ The irrigation water is available throughout the year. ➢ Hydraulic structures are necessary. ➢ Large area can be included under this system. ➢ Negligible silting takes place in the canal bed.

➢ Water tax cannot be imposed.	➢ Initial cost is high. ➢ Water tax can be imposed.

Types of canal lining

(a) Cement concrete lining,

(b) Pre-cast concrete lining,

(c) Cement mortar lining,

(d) Lime concrete lining,

(e) Brick lining

,(f) Boulder lining,

(g) Short Crete lining

(i) Asphalt lining,

(j) Bentonite and clay lining

(k) Soil-cement lining.

Advantages and disadvantages of canal lining

Advantages:-

- It reduces the loss of water due to seepage and hence the duty is enhanced.
- It controls the water logging and hence the bad effects of water-logging are eliminated.
- It provides smooth surface and hence the velocity of flow can be increased.
- Due to increased velocity the discharge capacity of a canal is also increased.
- Due to the increased velocity the evaporation loss also be reduced.
- It eliminates the effect of scouring in the canal bed.
- It reduce the maintenance cost for the canal.
- It control the growth of weeds along the canal sides and bed.
- It provides the stable section of the canal.

Disadvantages:-

- It involves many difficulties for repairing the damaged section of lining.
- It takes too much time to complete the project work.
- The initial cost of the canal lining is very high. So it makes the project very expensive.

Different parts of canal section

1- Canal bank

2- Berm

3- Hydraulic gradient

4- Counter berm
5- Free board
6- Side slope
7- Service road or inspection road
8- Dowel or dowlas
9- Borrow pit
10- Spoil bank
11- Land width

1. Canal bank:-

- The canal bank is necessary to retain water in the canal to the full supply level.
- But the section of the canal bank is different for different site conditions.
- In the case of canal fully in cutting, the banks are constructed on the both sides of the canal to provide only a inspection road. Here the hydraulic gradient has no function.
- In case of the canal in partial cutting and banking, the banks are constructed on sides of the canal to retain water. The section of the canal depends on the hydraulic gradient.
- In case of the canal in full banking, the canal and both the canal banks are constructed above the ground level. The height of the bank will be high and its section will be large due to the hydraulic gradient.

2. Berm:-

- The berm is provided to protect the bank from erosion.
- It provides a space for widening the canal section in future if necessary.
- It provided to protect the bank from sliding down towards the canal section.

3. Hydraulic gradient:-

- The sloping line of the canal is known as hydraulic gradient.
- The hydraulic gradient depends on the permeability of the soil.

4. Counter berm:-

- When water is retained by a canal bank the hydraulic gradient line passes through the body of the bank.
- For stability of bank this gradient should not intersect the outer side of the bank. It should pass through the base and a minimum cover of 0.5 m should always be maintained.
- Sometimes it may occur that the hydraulic gradient line intersects the outer side of the bank. In that case a projection is provided on the bank to obtain minimum cover.
- This projection is known as counter berm.

5. Free board:-

- It is the distance between the full supply level and the top of the bank.
- The amount of free board varies from 0.6 m to 0.75 m.
- It is provided to keep the saturation gradient much below the top of the bank.

6. **Side slope:-**
   - The side slopes of the canal bank and canal section depends on the angle of repose of the soil existing on the site.
7. **Service road or inspection road:-**
   - The road way which is provided on the top of the canal bank for inspection and maintenance work is known as service road.
8. **Dowel or dowla:-**
   - The protective small embankment which is provided on the canal side of the service road for the safety of the vehicles plying is known as Dowel or dowlas.
9. **Borrow pit:-**
   - When the canal is constructed in partial cutting and partial banking, the excavated earth may not be sufficient for forming the required bank.
   - In such case, the extra earth required for the construction of banks is taken from some pits which are known as borrow pit.
   - The borrow pits may be inside or outside of the earth.
10. **Spoil bank:-**
    - When the canal is constructed in full cutting, the excavated earth may not be completely required for forming the bank.
    - In such a case, the extra earth is deposited in the form of small banks which are known as spoil bank.
    - The spoil banks are provided on one side or both sides of the canal bank depending on the quantity of excess earth and the available space.
11. **Land width:-**
    - The total land width required for the construction of a canal depends on the nature of the site condition, such as fully in cutting or fully in banking or partly in cutting and partly in banking.
    - These conditions arise according to the designed bed level of the canal and the natural ground surface.
    - Total land width differs with the site condition.

CH-7(WATER LOGGING AND DRAINAGE)

Main cause of water logging are,

(i) **Over irrigation:-**

- In inundation irrigation since there is no controlling system of water supply , it may cause over irrigation.
- The excess water percolates and remains stored within the root zone of the crops.
- This excessive water is responsible for the water logging.

(ii) **Seepage from canal`s:-**

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

(iii) **Inadequate surface drainage:-**

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

(iv) **Obstruction in natural water course:-**

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

(v) **Obstruction in sub-soil drainage:-**

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

(vi) **Nature of soil:-**

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

(vii) **Seepage from reservoir:-**

- If the reservoir basin consists of permeable zone, cracks and fissures which are not detected during the construction of dam, these may cause seepage of water.

(viii) **Excessive rainfall:-**

- If the rainfall is excessive and the water gets no time to get drained off completely, then a pool of stagnant water is formed which might head to water logging.

(ix) **Topography of the land:-**

- If the agricultural land is flat i.e with no country slope and consists of depressions or undulations, then this load to water logging.

(x) **Occasional flood:-**

- If an area gets affected by flood every year and there is no proper drainage system, the water table gets raised and this cause water logging.

CH-8(DIVERTION HEAD WORK)

Necessities and objectives of diversion head work?

Necessity:-

- Canal draw supplies from river.
- But river don't have constant flow, the maximum flow in monsoon month and the minimum a the winter.
- But the canal requires continuous flow for irrigating the command area.
- So that a perennial canal is provided with permanent head.

Objectives:-

- To raise the water level at the head of the canal.
- To form storage by constructing decks on both the banks of the river, so that water is available throughout the year.
- To control the entry of silt into the canal and to control the deposition of silt at the head of the canal.
- To control the fluctuation of water level in the river during different season.

Difference between the weir and barrage

Barrage	Weir
➢ It has low set crest.	➢ It has high set crest.
➢ Ponding is done by means of gate.	➢ Ponding is done against the raised crest or partly against crest.
➢ Gated over entire length.	➢ Shutters in part length.
➢ Gates re greater heights.	➢ Shutters are of smaller heights.
➢ Perfect control on river flow.	➢ No control of river in low flood.
➢ High flood can be passed within minimum afflux.	➢ Excessive afflux in high flood.
➢ Less silting upstream due to low set crest.	➢ Raised crest causes silting upstream.
➢ Longer construction period.	➢ Shorter construction period.
➢ Silt removal is done through under sluice.	➢ No means for silt disposal.
➢ Road and/or rail can be constructed at low cost.	➢ No possible to provide road- rail.
➢ It is a costly structure.	➢ It is relatively cheaper structure.

Function and different part of barrage

Components of barrage are,

1- Barrage pears.
2- Adjustable gate.
3- Upstream glacis.
4- Upstream impervious apron.
5- Upstream block protection.
6- Upstream lunching apron.
7- Cut-off and toe walls.
8- Sheet piles.
9- Downstream glacis.
10- Downstream impervious apron.
11- Downstream block protection.
12- Downstream lunching.
13- Inverted filter.
14- Deep foundation.

1. Barrage pears.

- It is the main component part of the barrage.
- The length of the barrage decides according to the width of the river.
- The total length is then divided into number of compartment which is called bay.
- The piers are constructed over the deep foundation.

2. Adjustable gate.

- The adjustable gate / shutter are made of steel plate.
- The thickness of plate depends on the water pressure to be resisted.
- Each shutter consists of roller on both sides.
- Rubber bearing are provided at the bottom and at the edge of the shutter to prevent leakage of water.

3. Upstream glacis.

- The sloping concrete apron on the upstream side is called glacis.
- The slope of the glacis is generally 3 :1
- Glacis is provided to protect the base of the barrage from scoring.

4. Upstream impervious apron.

- Impervious floor or apron is provided to protect the main body of the barrage from the scouring effect
- The floor is constructed with R.C.C.
- In case of masonry barrage the floor covered by upstream and downstream apron.
- It acts as a base plate of the barrage.

5. Upstream block protection

- The block protects the impervious floor from the effect of scouring.
- This is constructed with concrete block or dressed stone block over a bed of loose stone packing.
- The joints are finished with cement mortar.

6. **Upstream lunching apron**
   - This apron is constructed with boulders or stones not less than 30kg arranged in layers without any joint.
   - It protects the impervious floor and the sheet poles from the scour holes.
   - The size of stones and the depth of apron depend on the velocity of flow and probable scour depth.
7. **Cut-off and toe walls.**
   - The cut off walls are provided at the upstream and the downstream end of the impervious floor
   - Walls are also provided at the upstream and the downstream toe.
   - The function of this wall is to provide proper anchorage to the impervious floor and provide sufficient bearing to the sheet piles.
8. **Sheet piles.**
   - The Sheet piles are provided on the upstream and downstream cut off walls and on the intermediate toe walls
   - The function of this is to lengthen the path of seepage flow.
9. **Downstream glacis.**
   - The sloping concrete apron on the downstream side is called downstream glacis.
   - It protects the barrage from scouring.
10. **Downstream impervious apron.**
    - The function of this apron is to protect the barrage from the scouring which is caused by formation of hydraulic jump.
11. **Downstream block protection.**
    - This protection block is constructed with cement concrete block or dressed stones by placing them with open joint.
12. **Downstream lunching.**
    - This apron is constructed with loosely packed stones or boulders
    - This apron protects the barrage from effect of piping.
13. **Inverted filter.**
    - It consists of layers of materials having the increasing grade or permeability from the bottom towards the top,

- Medium stand – Coarse stand – Gravels – Ballast are arranges bottom to top layer by layer.

14. Deep foundation.

- Deep foundation for the pier may be of two types,
  - Well foundation
  - Pneumatic foundation.

REGULATORY WORKS

Types of outlets

Types of Outlets:-

Outlets are clarified into three types.

(a) Non-modular outlet

(b) Semi modular / flexible outlet.

(c) Rigid module or modular outlet.

canal escape

An escape is a side channel constructed to remove surplus water from an irrigation channel is to natural drain.

Difference between cross regulator and head regulator

Cross Regulator[2010]	**Head Regulator**
It controls the supply of parent channel	Head regulator control the supply of off-taking channel
Cross regulator requires in the main parent channel downstream of the off taking channel, and is operated	Head regulator provided of the head of the off-taking channel control the flow of water entering this new channel
Function – To effectively control the entire canal irrigation	Function – To

Types of canal fall

Type of canal fall :-

1. Ogee fall
2. Trapezoidal Notch fall
3. Rapid fall

4. Stepped fall
5. Vertical drop fall or Sarda fall
6. Glacis fall

1. Ogee fall

- Ogee curve means a combination of convex curve and concave curve.
- This fall is recommended when the natural ground surface suddenly changes to a stepper slope along the alignment of the canal.

2. Trapezoidal Notch fall

- It this type of fall a body wall is constructed across the canal.
- The body wall consists of several trapezoidal notches between the side piers and the intermediate pier or pier
- The sills of the notches are kept at the upstream bed level of the canal.
- The body wall is constructed with masonry or concrete.

3. Rapid fall

- The rapid fall is of the natural ground is even and long
- The sloping bed is provided on the upstream and downstream side of the sloping glass.

4. Stepped fall

- Stepped fall consists of a series of vertical drops in the form of steps
- This fall is suitable is places where the sloping ground is very long and requires long glass

5. Vertical drop fall or sarda fall :

- It consist of a vertical drop wall which is constructed with masonry work
- The water flows over the crest of the wall
- A water cistern is provided

6. Glacis fall

- It consists of a straight sloping glacis provided with concrete bed a crest.
- A water cushion is provided on the D/s side to dissipate the energy of flowing water.
- The sloping glacis is constituted with cement concret

CH-9(CROSS DRAINAGE WORKS)

Necessity of cross drainage works

- The water shed canals do not cross natural drainage. The cross drainage works must be provided for running the irrigation system.
- At the crossing point the water of the canal and the drainage get intermixed. So the smooth running of the canal with its design discharge the cross drainage works are required.

- The water of the canal and drainage cannot be diverted to their natural directions. So the cross drainage works must be provided to maintain their natural direction of flow.

Types of cross drainage works

Cross drainage works may be of following types,

AQUEDUCT:-

- The aqueduct is just like a bridge where a canal is taken over the deck supported by piers instead of road or railway.
- The canal in the shape of a rectangular trough which is constructed with Rcc. Some time the through may be trapezoidal section.
- An inspection road is provided along the side of the trough.
- The bed and bank of the drainage below the trough is protected by boulder pitching with cement grouting.
- The section of the trough is designed according to the full supply discharge of the canal.
- A free board of about 0.50 m should be provided.
- The piers may be brick masonry, stone masonry or Rcc.
- Deep foundation is not necessary for the piers.

SIPHON AQUEDUCT:-[2013]

- The siphon aqueduct, the bed of the drainage is depressed below the bottom level of the canal trough by providing sloping apron on both sides of the crossing.
- The sloping apron may be constructed by stone pitching or cement concrete.
- The section of the drainage below the canal trough is constructed with cement concrete in the form of tunnel.
- This tunnel acts as a siphon.
- Cut off walls are provided on the both sides of the apron to prevent scouring.
- Boulder pitching should be provided on the upstream and downstream of the cut off walls.

SUPER PASSAGE:-

- The super passage is the just opposite of aqueduct.
- In this case the bed level of the drainage is above the full supply level of the canal.
- The drainage is taken through a rectangular or trapezoidal trough of channel which is constructed on the deck support by the piers.
- The section of the drainage trough depends on the high flood discharge.
- A free board of about 1.5 m should be provided for safety.
- The trough should be constructed of Rcc.
- The bed and bank of the canal below the drainage trough should be protected by boulder pitching or lining with concrete slab.

SIPHON SUPER PASSAGE:-

- It is just opposite siphon aqueduct.
- In this case the canal passes below the drainage trough.
- The section of the trough is designed according to high flood discharge.
- The bed of the canal is depressed below the bottom level of the drainage trough by providing sloping apron on both sides of the crossing.
- The sloping apron may be constructed with stone pitching or concrete slab.
- Cut off wall are provided on upstream and downstream of the sloping apron.

LEVEL CROSSING:-

- The level crossing is an arrangement provided to regulate the flow of water through the drainage and the canal when they cross each other approximately at the same bed level.
- The level crossing consists of crest wall, drainage regulator, and canal regulator.
- The crest wall is provided across the drainage just at the upstream side of the crossing point. The top level of the crest wall is kept at the full supply level of the canal.
- The drainage regulator is provided across the drainage just at the downstream side of the crossing point. The regulator consists of adjustable shutter at different tiers.
- The canal regulator is provided across the canal just at the downstream side of the crossing point. This regulator also consists of adjustable shutters at different tiers.
- In rainy season when the discharge regulator is very low the drainage regulator is kept closed and the canal water is allowed to flow as usual.

INLET AND OUTLET:-

- In case of crossing of a small irrigation channel with a small drainage no hydraulic structure is constructed.
- Because the discharges of drainage and the channel are practically low and these can be easily tackled by easy system like inlet and outlet arrangement.
- In this system an inlet is preceded in the channel bank simply by open cut and the drainage water is allowed to join the channel.
- A suitable point on the downstream side of the channel an outlet is provided by open cut and the water from the irrigation channel is allowed to flow through a leading channel towards the original course of the drainage.
-

CH-10(DAM)

Necessitie

- Water collected in this reservoir can be supplied for irrigating farm lands through a system of canal network.
- It also helps for supplying water for drinking purpose.
- It also helps in navigation.

- In times of flood the dams can serve as protections for the town and cities.
- The energy of this collected water can be used to turn the blade of turbine to generate electrical power.

Ttypes of dam

1- **Earth dam:-** This dam are made of soil that is pounded down solidly. They are built in areas where the foundation is not strong.

2- **Rock fill dam:-** This dam are formed to loose rocks and boulder piled in the river bed.

3- **Gravity dam:-** This dam is soil then earth and rock fill dam.

Four other types of dams are,

1- **Hollow masonry gravity dam:-** It contains less concrete or masonry about 35 to 40 %. It is difficult to build.

2- **Steel dam:-** It is used for temporary work. It is usually reinforced with timber or earth fills.

3- **Timber dam:-** These are short lived. Their life is not more than 30 to 40 years. It is used in agricultural area.

4- **Arch dam:-** It is very complex and complicated.

Spillway

The spillways are openings provided at the body of the dam to discharge safely the excess water or flood water or surplus water when the water level rise above the normal pool level. The spillway is constructed for effectively depositing of surplus water from upstream to downstream.

Types of earth dam,

(a) Homogeneous embankment type:-

- This type of dam is purely constructed with earth.
- The top width and height depends on the depth of water and gradient of seepage line.
- The top level of seepage line is called phreatic line.
- It should pass well within the body of the dam.
- This toe of dram is completely pervious.
- The upstream of the dam is protected by stone pitching.

(b) Zoned type dam:-

- This type of dam is consists of several materials.
- The impervious core is made of puddle clay and the outer pervious shell is constructed with the mixture of earth, sand and gravel.
- The central core checks k the seepage.
- Transition filter are provided on both side of the impervious core to control the seepage.
- The upstream of the dam is protected by stone pitching.
- These types of embankment are widely used.

(c) Diaphragm type dam:-

- These type embankments have a thin impervious core which is surrounded by earth or rock fill.
- The impervious core is called diaphragm which is made of impervious soil, concrete, steel, timber or any other material.
- It acts as a water barrier to prevent seepage through the dam.
- The upstream and downstream body of the dam is constructed with pervious shell which consists of the mixture of soil, sand, gravel.
- The thickness of core is generally less than 3 m.
- The blanket is made of stone.
- The upstream of the dam is protected by stone pitching.

Causes of failure of earthen dam

(a) Hydraulic failure:-

- This type of failure may be caused by over topping and erosion.
- In over topping the actual flood discharge is much more than the estimated flood discharge or the free board is kept insufficient or there is settlement of the dam capacity of spillway is insufficient then it results in the over topping of the dam.
- If the stone protection of the upstream side is insufficient then the upstream face may be damaged by erosion due to wave action and it is called wave erosion.
- The downstream side also may be damaged by tail water rainwater.

(b) Seepage failure:-

- This type of failure may be caused by piping or under mining and sloughing.
- Due to the continuous seepage flow through the body of the dam and through the sub-soil below the dam, the downstream side get eroded or washed out and a hollow pipe like groove is termed which extent gradually at the base of the dam. This phenomenon is known as piping.
- The crumbling of the toe of the dam is known as sloughing.

(c) Structural failure:-

- This type of failure may be caused by sliding of the side slope, damage by borrowing animals and damage by earth quack.
- Sometimes it is found that the side slope of the dam slides down to form some steeper slope.
- Some borrowing animals like crow fish, snake, squirrel, rats etc cause damage to the dam by digging holes through the foundation and body of dam.
- Due to earthquake cracks may develop on the body of the dam and the dam may eventually collapse.

Forces acting on gravity dam

1- Weight of the dam

2- Water pressure
3- Uplift pressure
4- Seismic force
5- Silt pressure
6- Wave pressure
7- Ice pressure
8- Wind pressure

1- Weight of the dam:-

- The weight of the dam is the main stabilizing forces which counter balance all the external forces acting on the dam.
- The dam should be constructed with heavy material of specific gravity.
- The weight of the dam acts through its centre of gravity.

2- Water pressure:-

- On the upstream face the pressure is exerted by the water stored up to full reservoir level and on the downstream face .
- The upstream face of the dam may be completely vertical or partly vertical or partly inclined.

3- Uplift pressure:-

- The stored water on the upstream side of the dam has a tendency to seep through the soil bellow the foundation.
- The uplift pressure reduces the self weight of the dam.
- To reduce the uplift pressure the drainage galleries are provided on the base of the dam.

4- Seismic force:-

- When the selected dam site comes under the seismic zone the effect of earthquake waves should be taken into account as it endangers the structure.

5- Silt pressure:-

- The silt carried by the river and its tributaries gets deposited against the upstream base of the dam year after year.
- After considerable deposition of silt, it exerts pressure on the dam.
- So provisions should be made to resists this silt pressure.

6- Wave pressure:-

- When every high wind or Tornado flows over the water surface of the reservoir waves are formed which exert pressure on the upper part of the dam.
- The magnitude of the wave depends on the velocity of wind, depth of reservoir and the area of water surface.

7- Ice pressure:-

- The pressure should be counted only in place where the formation of ice is expected on the reservoir surface.

- When the sheet of ice is formed on the entire water surface of the reservoir, then it exerts pressure on the dam at the point of contact during the process of contraction and expansion with the change of temperature.

8- Wind pressure:-

- The top exposed portion of the dam is not much and the wind pressure on the surface area of the upstream and downstream surface area of this portion 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 and downstream surface.

Causes of failure of gravity dam

1- By overturning:-

- The solid gravity dam may fail by overturning at its toe when the total horizontal forces acting on the dam are greater than the total vertical forces.
- In such case the resultant force passes through a point outside the middle third of the base of the dam.

2- By sliding:-

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

3- By over stressing:-

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

4- By cracking:-

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

Types of spillway

(a) Straight and drop spillway

(b) Over flow spillway/ ogee spillway

(c) Chute spillway/ trough spillway

(d) Side channel spillway

(e) Shaft spillway

(f) Siphon spillway

(a) Straight and drop spillway:-

- This is the simplest type of spillway.
- This type of spillway is suitable for weirs or low dams.
- The drop spillway is not suitable for a high dam.

- High impact on the downstream apron may cause vibration in the structure which may create cracks in the foundation.

(b) Over flow spillway/ ogee spillway:-

- This type of spillway is used on valley and where the width of the river is sufficient to provide the required crest length
- It is a modified form of drop spillway.
- The spillway takes the shape of the letter ‘ S ‘.
- It differs from the head of water.

(c) Chute spillway/ trough spillway:-

- This spillway is simply a rectangular open channel or trough provided on the dam to discharge the surplus water from the reservoir to the same river on the downstream side.
- The spillway may be provided along the abutment of the dam or along the edge of reservoir at the full supply level.
- The channels are supported on pillars.

(d) Side chnnel spillway:-

- The side channel spillway is completely separate from the main body of the dam.
- The spillways are constructed at right angle of the dam at any sides according to the site condition.
- This type of spillway is recommended for the site where other types of spillway are found unsuitable.

(e) Shaft spillway:-

- It consists of a vertical shaft which is constructed with which is constructed with masonry work or plain cement concrete or reinforced cement concrete on the bed of the reservoir just at the upstream side of the dam.
- The inlet mouth of the vertical shaft is conical shaped.

(f) Siphon spillway:-

- There are two types of siphon spillway.
- If the available space is limited and discharge is not large, siphon spillway is often superior to other forms.
- Usually siphon spillway is provided in concrete gravity dam.
- Steps are joggle are provided to seal the outlet end.