WATER LOGGING AND WATERSHED MANAGEMENT

18.1 INTRODUCTION

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

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

The height to which the soil water rises above the watertable by capillary action is known as capillary fringe. Generally, the height of capillary fringe varies from 1 m to 1.5 m. When the watertable comes to 1.5 m below the surface of the soil, the land is said to be water logged.

Again, due to heavy rainfall and poor drainage system the water goes on collecting in low lying areas. This stagnant water makes the land marshy. The weeds and aquatic plants gradually cover the whole area and the area becomes unsuitable for cultivation.

18.2 CAUSES OF WATER LOGGING

The following are the main causes of water logging:

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

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

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

(4) Obstruction in Natural Water Course If the bridges or culverts are constructed across a water course with the opening with insufficient discharge capacity, the upstream area gets flooded and this causes water logging.

(5) Obstruction in Sub-soil Drainage If some impermeable stratum exists at a lower depth below the ground surface, then the movement of the subsoil water gets obstructed and causes water logging in the area.

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

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

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

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

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

(11) Topography of the Land If the agricultural land is flat, i.e. with no country slope and consists of depressions or undulations, then this leads to water logging.

(12) 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 causes water logging.

18.3 EFFECTS OF WATER LOGGING

The following are the effects of water logging:

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

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

(3) Fall of Soil Temperature Due to water logging the soil temperature is lowered. At low temperature of the soil the activity of the bacteria becomes very slow and consequently the plants do not get the requisite amount of food in time. Thus, growth of the plants is hampered and the yield also is reduced.

(4) Growth of Weeds and Aquatic Plants Due to water logging, the agricultural land is converted to marshy land and the weeds and aquatic plants are grown in plenty. These plants consume the soil foods in advance and thus the crops are destroyed.

(5) Diseases of Crops Due to low temperature and poor aeration, the crops get some diseases which may destroy the crops or reduce the yield.

(6) Difficulty in Cultivation In water logged area it is very difficult to carry out the operation of cultivation such as tilling, ploughing, etc.

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

18.4 CONTROL OF WATER LOGGING (i.e. ANTI WATER LOGGING MEASURES)

The following measures may be taken to control water logging:

(1) Prevention of Percolation from Canals The irrigation canals should be lined with impervious lining to prevent the percolation of water through the bed and banks of the canals. Thus the water logging may be prevented.

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

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

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

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

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

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

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

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

(9) Construction of Sump Well Sump wells may be constructed within the water logged area and they help to collect the surface water. The water from the sump wells may be pumped to the irrigable lands or may be discharged to any river.

CANAL HEAD WORKS

10.1 INTRODUCTION

The water flows through the irrigation canal under the force of gravity. So, the elevation of the head of the canal must be higher than the command area of the irrigation project. Now, to form a storage reservoir or to raise the water level at the head of the canal, some structures are constructed which are known as canal head works. The canal head works may be of two forms.

1. Storage Head Works When a dam is constructed across a river valley to form a storage reservoir, it is known as storage head work. The water is supplied to the canal from this reservoir through the canal head regulator. Again, this reservoir serves the multipurpose functions such as hydro-electric power generation, flood control, fishery, etc.

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

10.2 OBJECT OF DIVERSION HEAD WORKS

The following are the objects of diversion of head works

(a) To raise the water level at the head of the canal.
(b) To form a storage by constructing dykes on both the banks of the river so that water is available throughout the year.
(c) To control the entry of silt into the canal and to control the deposition of silt at the head of the canal.
(d) To control the fluctuation of water level in the river during different seasons.

10.4 SELECTION OF SITE FOR DIVERSION HEAD WORKS

The following points should be remembered while selecting the site for the diversion head works

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

10.5 COMPONENTS PARTS OF DIVERSION HEAD WORKS

The following are the component parts of the diversion head works (Fig. 10.1)

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

10.6 WEIR OR BARRAGE

(a) Weir Normally, the water level of any perennial river is such that it cannot be diverted to the irrigation canal. The bed level of the canal may be higher than

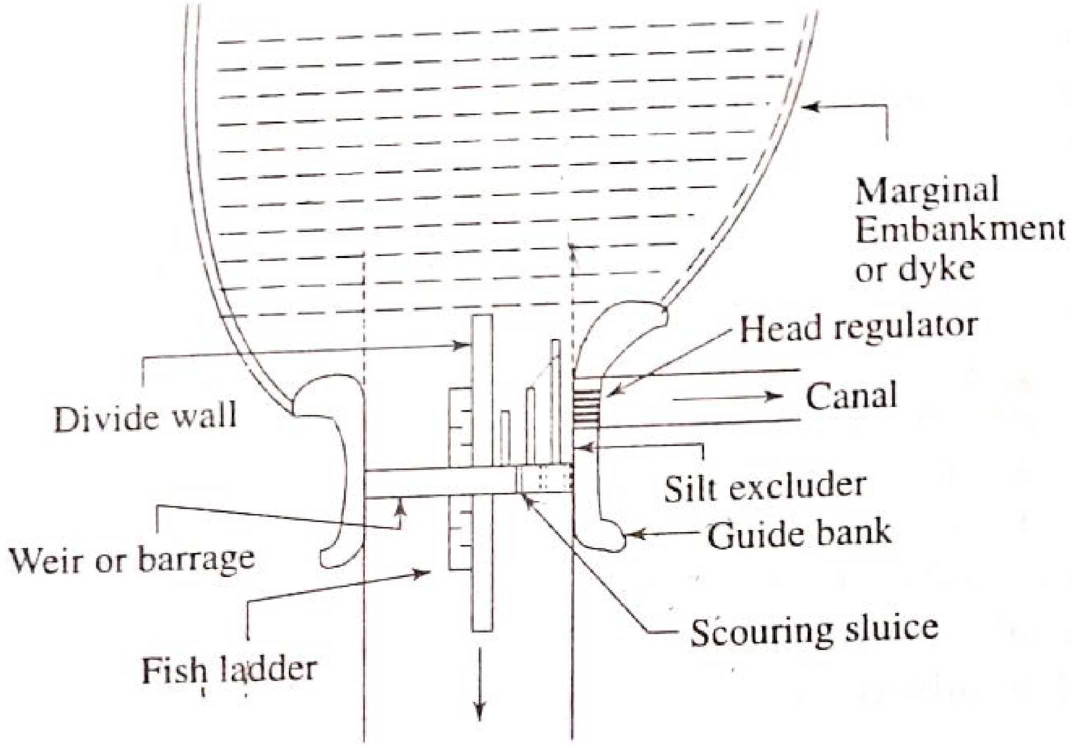


Fig. 10.1 Diversion head works

the existing water level of the river. In such a case, a weir is constructed across the river to raise the water level from H_1 to H_2 (Fig. 10.2). Then, the water can be easily diverted to the canal. The surplus water passes over the crest of the weir. Sometimes, adjustable shutters are provided on the crest to raise the water level to some required height, if necessary. But these shutters are dropped down during the flood. The weir may be constructed with masonry or concrete. The details of weir are given in Chapter 11.

(b) Barrage When the water level on the up stream side of the weir is required to be raised to different levels at different time, then the barrage is constructed. Practically a barrage is an arrangement of adjustable gates or shutters at different tiers over the weir. The water level can be adjusted at H_1, H_2, H_3 ..., etc. by operating the adjustable gates (Fig. 10.3). (The details of barrage are given in Chapter 11).

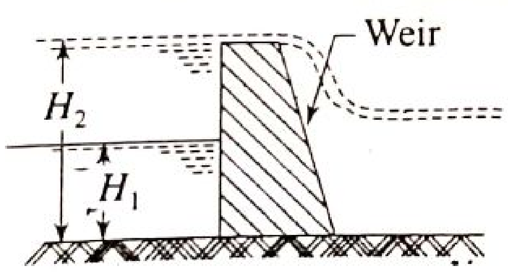


Fig. 10.2 Weir

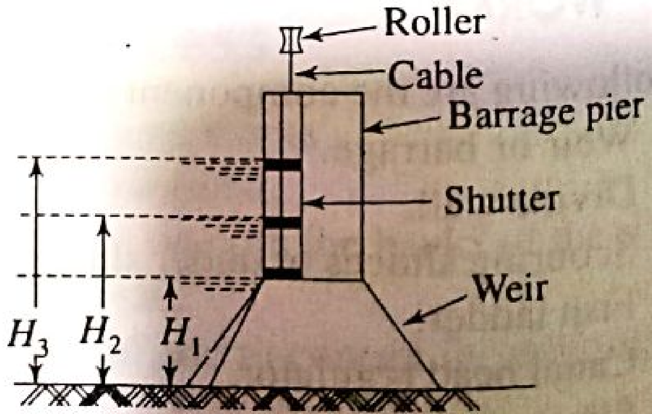


Fig. 10.3 Barrage

10.8 SCOURING SLUICES OR UNDER SLUICES

The scouring sluices are the openings provided at the base of the weir or barrage. These openings are provided with adjustable gates. Normally, the gates are kept closed. The suspended silt goes on depositing in front of the canal head regulator. When the silt deposition becomes appreciable the gates are opened and the deposited silt is loosened with an agitator mounting on a boat. The muddy water flows towards the downstream through the scouring sluices. The gates are then closed. But, at the period of flood, the gates are kept opened (Fig. 10.5).

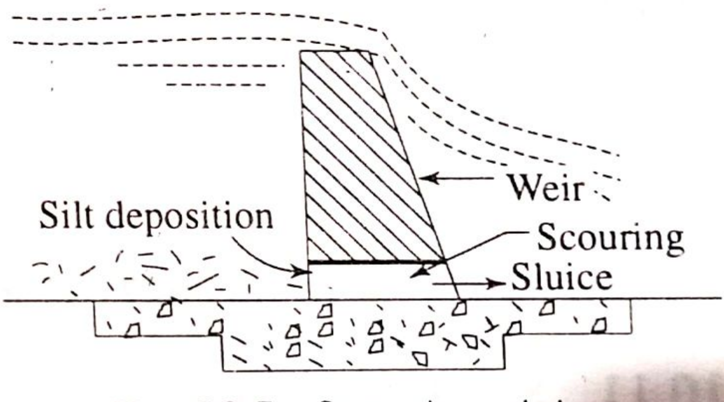


Fig. 10.5 Scouring sluice

11.10 COMPONENT PARTS OF WEIR

The component parts of the weir and their functions are described in the following passages (Fig. 11.7).

The following are the functions of each component:

(1) Weir Breast It is the main body of the structure. It may be constructed with masonry work or concrete. The height and the section of the breast wall depends on the depth of water to be retained and the nature of the foundation. The function of this component is to raise the water level on the upstream side so that the water can be diverted to the irrigation canal through the head regulator.

(2) Crest Shutters These are adjustable gates or shutters provided on the crest of the weir. The bottom ends of these shutters are hinged with the crest and the top ends are free. The shutters may be raised or dropped by a mechanical device. Struts are provided on the downstream side of the shutters to resist the thrust of the water. The function of these shutters is to raise the water level on the upstream side. If required the shutters are dropped during the flood.

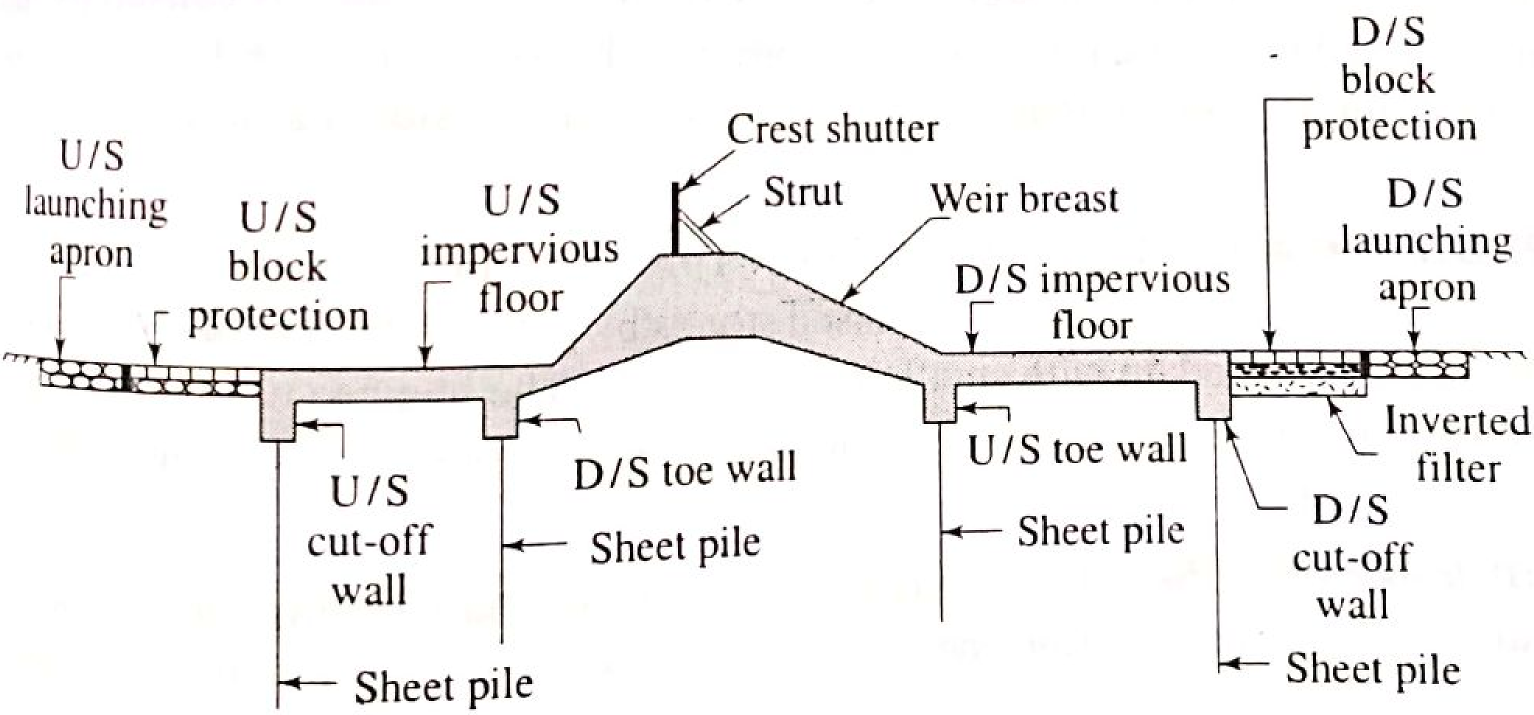


Fig. 11.7 Component parts of weir

(3) Upstream Impervious Floor or Apron Impervious floor or apron is provided to protect the main body of the weir from the scouring effect. The floor is constructed with reinforced cement concrete. In case of masonry weir, this floor covers the total designed length of upstream and downstream apron. It acts as a base plate of the weir but in case of concrete weir, the floor is made monolythic with the main body by providing reinforcement. The floor is made sloping on both sides. So, it is also known as sloping glacis.

(4) Cut-off and Toe Walls The cut-off walls are provided at the upstream end and the downstream end of the impervious floor. Walls are also provided at the upstream and the downstream toe of the weir. The function of the cut-off and toe walls are to provide proper anchorage to the impervious floor and to provide sufficient bearing to the sheet piles.

(5) Upstream Block Protection This block protects the impervious floor from the effect of scouring. This is constructed with concrete blocks or dressed stone blocks over a bed of loose stone packing. The joints are finished with cement morter. The width of this protection work is taken equal to the length of sheet piles.

(6) Upstream Launching Apron This apron is constructed with boulders or stones (not less than 30 kg) arranged in layers without any joint. It protects the impervious floor and the sheet piles from the scour holes which may develop and proceed towards the weir. The size of stones and the depth of apron depend on the velocity of flow and the probable scour depth.

(7) Sheet Piles The sheet piles are provided on the upstream and downstream cut-off walls and on the intermediate toe walls. The function of the sheet piles is to lengthen the path of the seepage flow. Thus the uplift pressure of the seepage water on the foundation is reduced considerably and the scouring effect on the exit gradient is also reduced.

(8) Downstream Impervious Floor or Apron The function of this impervious floor is to protect the weir from the scouring effect which is caused by the formation of hydraulic jump. Again, it protects the weir from the effect of piping or undermining which may occur on the downstream side due to the seepage flow.

(9) Downstream Block Protection This protection block is constructed with cement concrete blocks or dressed stones by placing them with open joints. The joints are filled up with small gravels or bajri. The seepage water can escape through the joints. Below these concrete or stone blocks, the inverted filter is provided.

(10) Inverted Filter It consists of layers of materials having the increasing grade or permeability from the bottom towards the top for example, medium sand—coarse sand—bajri—gravels—ballast are arranged from the bottom to the top, layer by layer. Thus, it is similar to a filter, but in inverted position. The function on this filter is to allow the seepage water to escape without dislocating the soil particles.

(11) Downstream Launching Apron This apron is constructed with loosely packed stones or boulders (weight not less than 30 kg). It covers completely the zone of exit gradient. This apron protects the weir from the effect of piping or undermining which may occur due to seepage of water.

11.11 COMPONENT PARTS OF BARRAGE

The following are the component parts of the barrage and then functions.

1. Barrage Piers

These are the main component parts of the barrage. Depending on the width of the river, the length of the barrage is ascertained. The total length is then divided into a number of compartments by constructing piers. Each compartment is known as a bay. The piers are constructed over the deep foundation like well foundation or pneumatic caisson foundation. On the upstream side of the piers, the adjustable gates or shutters are provided at different tiers according to the water level desired to be raised from time to time. The shutters are operated from the cabin by the cables which pass through the rollers or pulleys. Beams and slabs are constructed over the piers to allow the laying of railway lines and the roads.

2. Adjustable Gates

The gates or shutters are made of steel plates welded on the fabricated steel frame work. The thickness of the plates depend on the water pressure to be resisted.

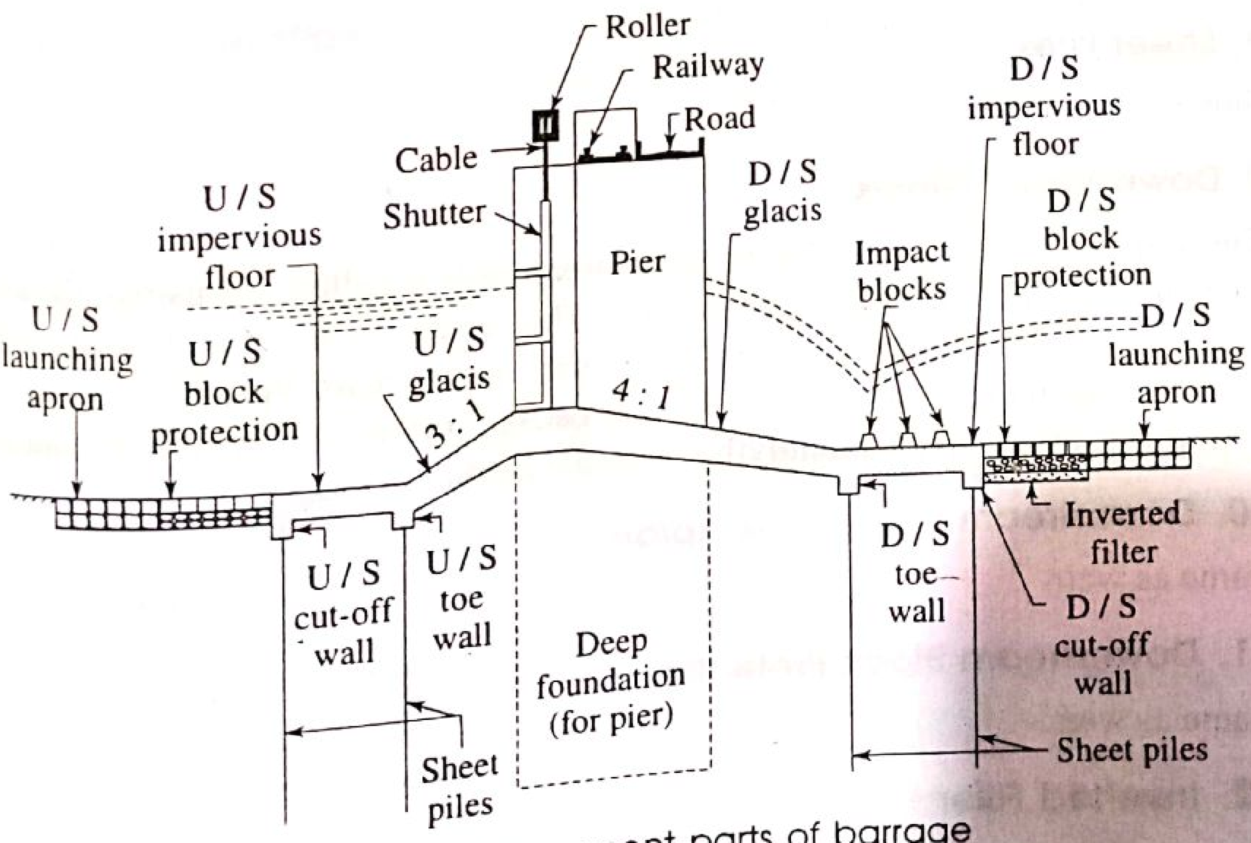


Fig. 11.8 Component parts of barrage

Each shutter consists of rollers on both sides which can move within the grooves in the piers. Rubber bearings are provided at the bottom and the edges of the shutter to prevent the leakage of water. The shutters are suspended by cables at both ends..The cables pass through the rollers or pulleys and are connected to the operating mechanism in the cabin. The shutters may be raised or lowered from the cabin according to the requirement.

3. Upstream Glacis

The sloping concrete apron on the upstream side is called upstream glacis. The slope of the glacis is generally 3:1. This is provided to protect the base of the barrage from scouring. On the top of the barrage, the railway line and roads can cause vibration on the piers and any eccentric load may lead to cracks on the base of piers. Due to the formation of cracks the subsoil water may get entry to the foundation which may endanger the stability of the structure. So, the sloping glacis is made monolythic with the pier for the stability of the barrage.

4. Upstream Impervious Apron

Same as weir.

5. Upstream Block Protection

Same as weir

6. Upstream Launching Apron

Same as weir.

7. Cut-off and Toe Walls

Same as weir.

8. Sheet Piles

Same as weir.

9. Downstream Glacis

The sloping concrete apron on the downstream side is called downstream glacis. The slope of this glacis is generally 4:1. This glacis protects the barrage from scouring. It also imparts stability to the barrage by resisting the formation of cracks at the base of the pier which may cause vibrations or eccentric loading. This glacis also is made monolythic with the pier.

10. Downstream Impervious Apron

Same as weir.

11. Downstream Block Protection

Same as weir.

12. Inverted Filter

Same as weir.

13

CROSS-DRAINAGE WORKS

13.1 INTRODUCTION

In an irrigation project, when the network of main canals, branch canals, distributories, etc are provided, then these canals may have to cross the natural drainages like rivers, streams, nallahs, etc at different points within the command area of the project. The crossing of the canals with such obstacles cannot be avoided. So, suitable structures must be constructed at the crossing point for the easy flow of water of the canal and drainage in the respective directions. These structures are known as cross drainage works. But the nature of cross drainage works may be different at different places. Sometimes, the bed level of canal may be below the bed level of drainage and sometimes, it may be higher than that of the drainage. The bed levels of canal and drainage may be nearly same also. So the structures are different at different places and the designation of the structures also are different. The details of these various structures will be dealt with later on.

13.2 NECESSITY OF CROSS-DRAINAGE WORKS

The following factors justify the necessity of cross drainage works,

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

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

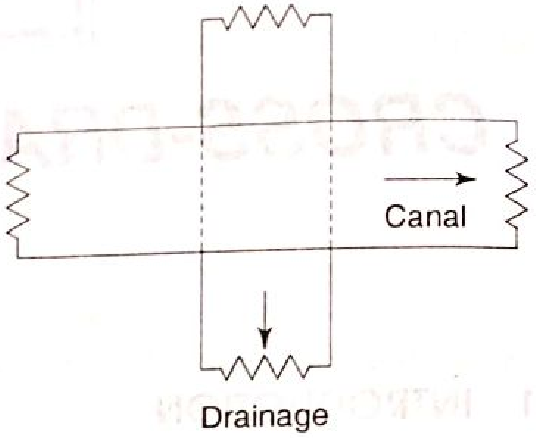
(c) The site condition of the crossing point may be such that without any suitable structure, the water of the canal and drainage cannot be diverted to their natural directions. So, the cross drainage works must be provided to maintain their natural direction of flow.

13.3 TYPES OF CROSS-DRAINAGE WORKS

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

Type–I Irrigation Canal Passes Over the Drainage This condition involves the construction of following:

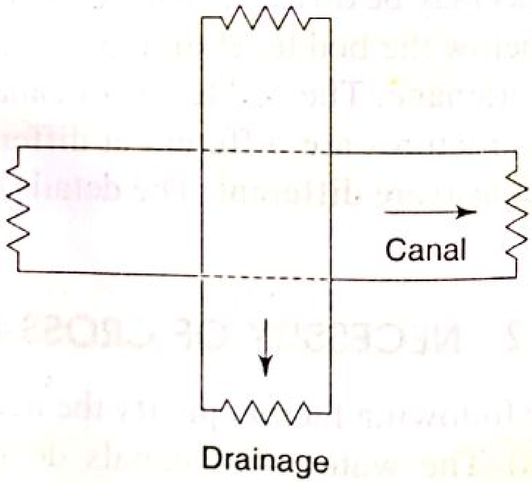
(a) Aqueduct The hydraulic structure in which the irrigation canal is taken over the drainage (such river, stream, etc.) is known as aqueduct. This structure is suitable when bed level of canal is above the highest flood level of drainage. In this case, the drainage water passes clearly below the canal.



(b) Siphon Aqueduct In a hydraulic structure where the canal is taken over the drainage, but the drainage water cannot pass clearly below the canal. It flows under siphonic action. So, it is known as siphon aqueduct. This structure is suitable when the bed level of canal is below the highest flood level of the drainage.

Type–II Drainage Passes Over the Irrigation Canal This condition involves the construction of the following:

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

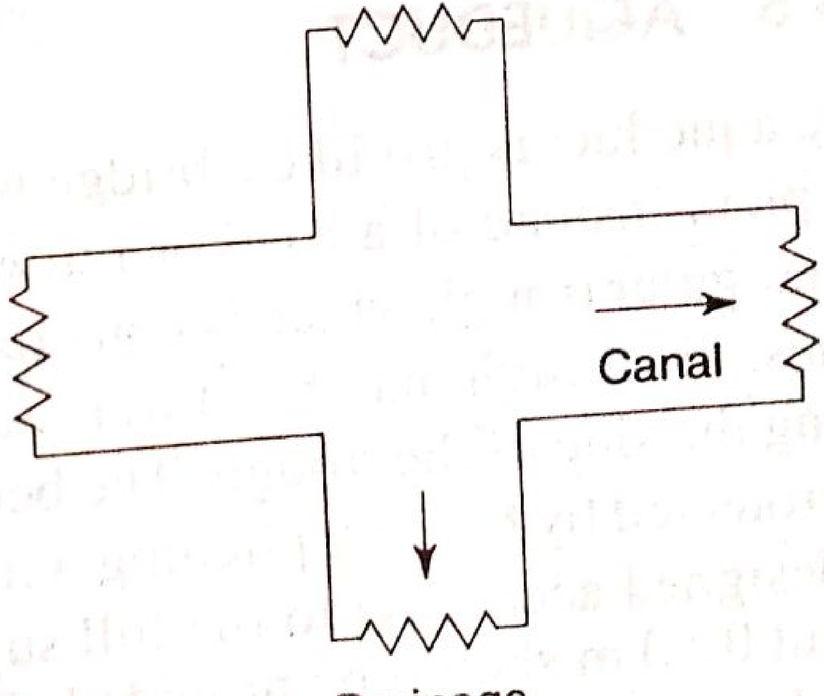


(b) Siphon Super Passage The hydraulic structure in which the drainage is taken over the irrigation canal, but the canal water passes below the drainage under siphonic action is known as siphon super passage. This structure is suitable when the bed level of drainage is below the full supply level of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

Type–III Drainage and Canal Intersection Each Other at the Same Level This condition involves the construction of the following:

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

(b) Inlet and Outlet In the crossing of small drainage with small channel no hydraulic structure is constructed. Simple openings are provided for the flow of water in their respective directions. This arrangement is known as inlet and outlet.



... OF TYPE OF

Types of Cross-Drainage Works.

Type-1: Irrigation Canal Passes Over the Drainage.

* 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 is in the shape of a rectangle trough or trapezoidal trough constructed with R.C.C.

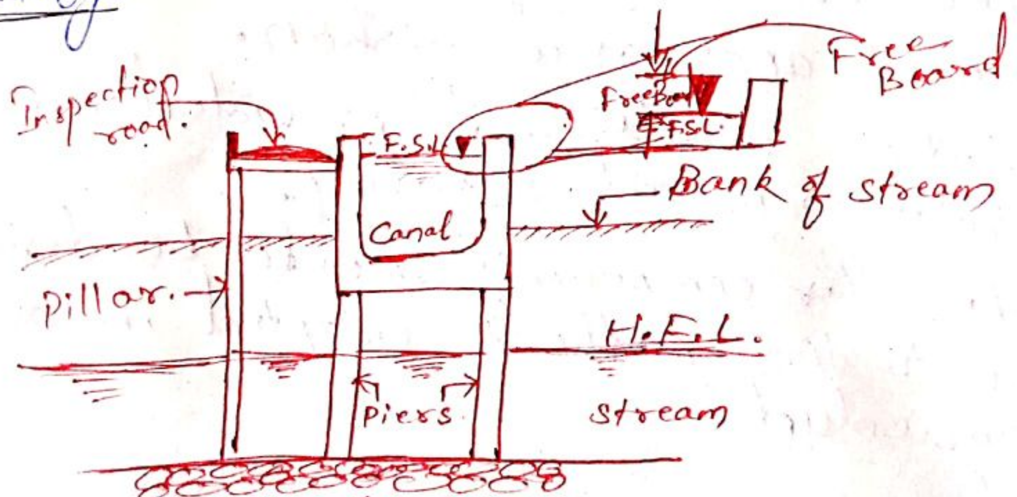
→ The bed and banks of the drainage below the trough is protected by boulder pitching with cement grouting.

→ An inspection road is provided along the side of the trough.

→ The section of the trough is designed acc. to the Full Supply discharge of the canal.

→ A Free board of about 0.50 m should be provided.

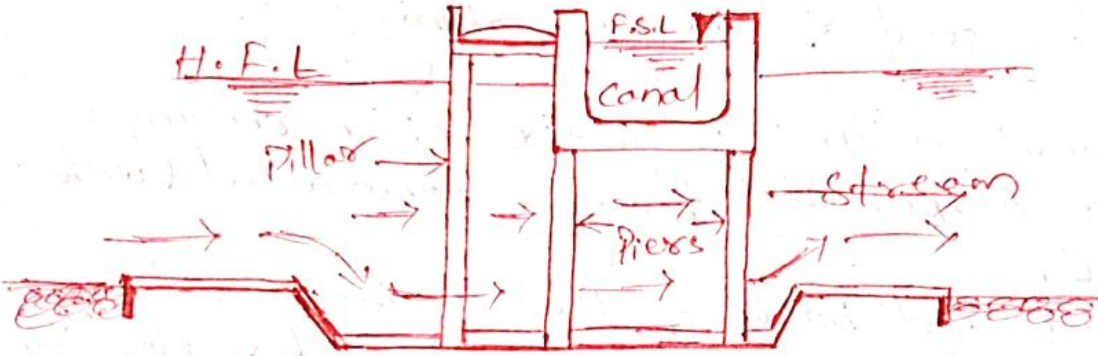
→ The height of the piers are designed acc. to the Highest Flood Level (HFL) & velocity of flow of the drainage.



(Aqueduct)

→ The piers may be of brick masonry, stone masonry or R.C.C.
→ The concrete foundation may be done by providing the depth of foundation according to the availability of hard soil. (Deep foundation is not necessary.)

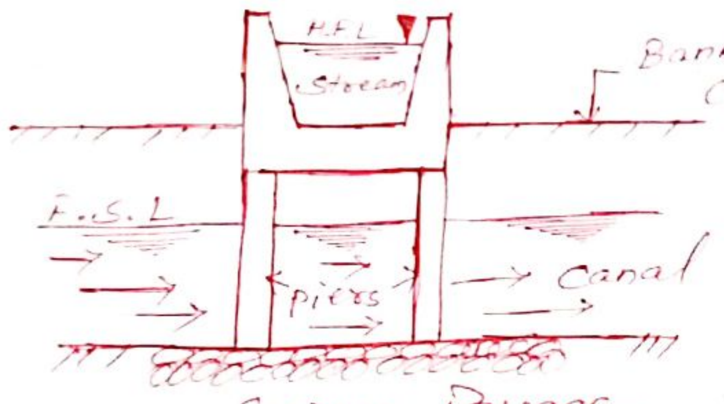
* Siphon Aqueduct.



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 section of the drainage below the canal trough is constructed with cement concrete in the form of tunnel, this tunnel acts as a siphon.
→ Cut off walls are provided on both sides to prevent scouring.
→ The other components should be designed acc to the methods adopted in case of aqueduct.

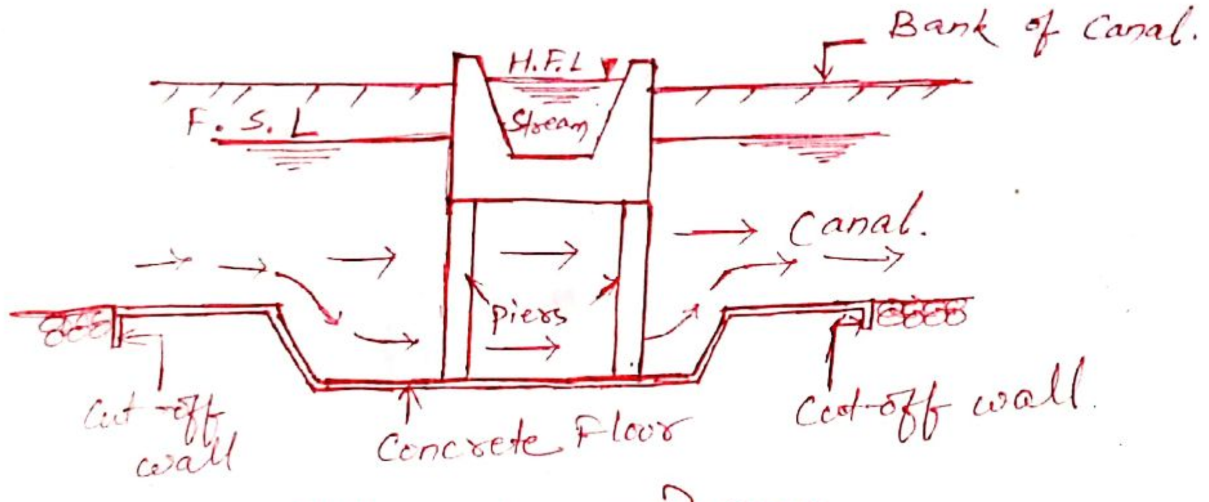
Super Passage



Super Passage

- It is just opposite of aqueduct. Here the bed level of the drainage is above the F.S.L. of the Canal.
- The drainage is taken through a rectangular or trapezoidal trough of channel which is constructed on the deck supported by piers.
- The section of the drainage trough depends on the H.F.L. or High Flood Discharge.
- A Free Board of about 1.5 m should be provided.
- The trough should be constructed of R.C.C. and the foundation of piers will be same as in case of aqueduct.
- The ~~troug~~ bed and banks of the canal below the drainage trough should be protected by boulder pitching or lining with concrete slabs.

Siphon Super Passage

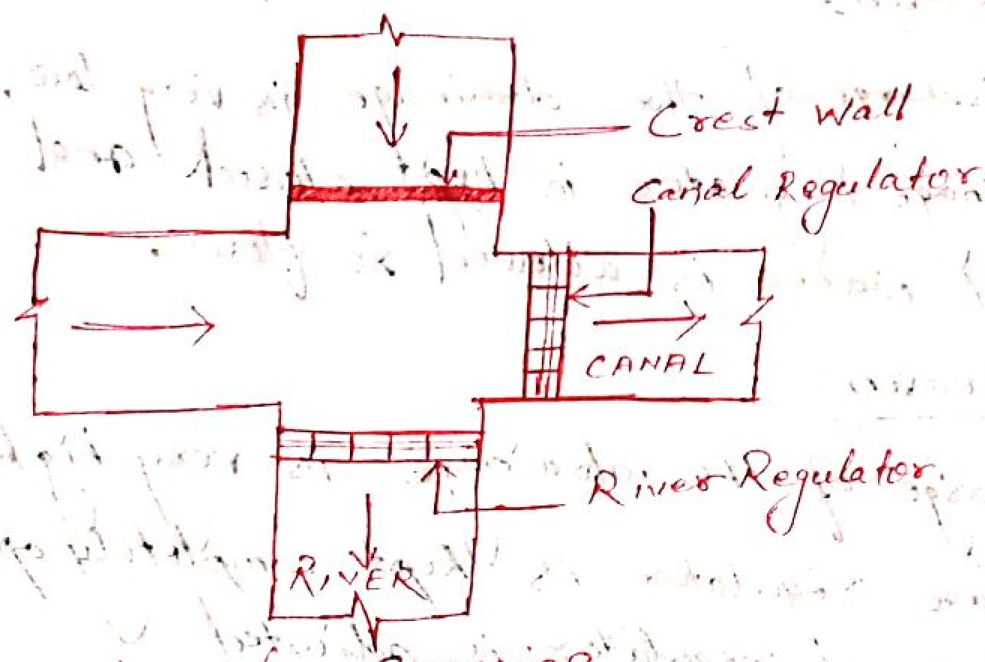


Siphon Super Passage

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

LEVEL CROSSING

[Natural Drainage & canal beds cross eachother at same bed level.]



Level Crossing

* Important Components.

1. **Crest wall** :- It is provided accross the drainage just at the upstream side of the crossing point. The top level of the crest wall is kept at the F.S.L. of the Canal.

2. **Drainage Regulator** :- Provided accross the drainage just at the downstream side of the crossing point. The regulator consists of adjustible shutters at different tiers.

3. **Canal Regulator** :- Provided accross the Canal just at the downstream side of the crossing point. It consists of adjustible shutters at different tiers.

→ <u>Operation</u>

<u>In Dry Season:-</u>

The discharge of the drainage is very low, the Drainage Regulator is kept closed and the canal water is allowed to flow.

<u>In Rainy Season:-</u>

The discharge of the drainage is very high. The drainage regulator is kept completely open and the canal regulator is adjusted according to requirement.

**
[Imp: The level crossing is recommended for the crossing of main canal with Large Drainage.]

DAM

16.1 INTRODUCTION

An impervious high barrier which is constructed across a river valley to form a deep storage reservoir is known as dam. It is suitable in hilly region where a deep gorge section is available for the storage reservoir. The dam is meant for serving multipurpose functions such as, (a) Irrigation, (b) Hydroelectric power generation, (c) Flood control, (d) Water supply, (e) Fishery, (f) Recreation.

Weir and Barrage are also impervious barriers across the river. Which are suitable in plain terrain but not in hilly region. The purpose of weir is only to raise the water level to some desired height and the purpose of barrage is to adjust the water level at different levels when required. These two hydraulic structures are suitable for irrigation only.

16.4 CLASSIFICATION OF DAM

Dams may be classified on the following basis,

A. Based on Materials of Construction

1. Rigid dam It is constructed with rigid materials like masonry, concrete, steel or timber. It is designated as, (a) masonry dam, (b) concrete dam, (c) steel dam, (d) timber dam.

2. Non rigid dam It is constructed with non-rigid materials such as earth, clay, rock materials, etc. It is designated as, (a) earthen dam, (b) rock-fill dam, (c) composite dam.

B. Based on Structural Behaviour

1. Solid gravity dam It is constructed with masonry or concrete. It resists the forces acting on it by its own weight. It is approximately triangular in section.

2. Arch dam It is a curved masonry or concrete dam which resists the forces acting on it by the principle of arch action.

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

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

C. Based on Functions

1. Storage dam It is constructed to form a reservoir in which the water is stored during the period of rainy season or flood and utilised for the irrigation in the period of draught. The water is also utilised for the generation of hydroelectric power, water supply, etc.

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

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

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

D. Based on Hydraulic Behaviour

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

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

16.5 SOLID GRAVITY DAM

The solid gravity dam may be constructed with rubble masonry or concrete. The rubble masonry is done according to the shape of the dam with rich cement mortar. The upstream and downstream faces are finished with rich cement mortar. Now-a-days, concrete gravity dams are preferred, because they can be easily constructed by laying concrete, layer by layer with construction joints. But good rocky foundation must be available to bear the enormous weight of the dam. The distance between the heel and toe is considered as the base width. It depends, on the height of the dam. Again, the height depends on the nature of foundation. If good rocky foundation is available, the height may be above 200 m. If hard foundation is not available, the height of the dam should be limited to about 20 m. The upstream and downstream base of the dam is made sloping. The horizontal trace (or line) passing through the upstream top edge is known as axis of the dam or the base line. The layout of the dam is done corresponding to this base line. Drainage gallery is provided at the base of the dam. Spill ways are provided at the full reservoir level to allow the surplus water to flow to the downstream. The solid gravity dam resists all the forces acting on it by its self weight (Fig. 16.1).

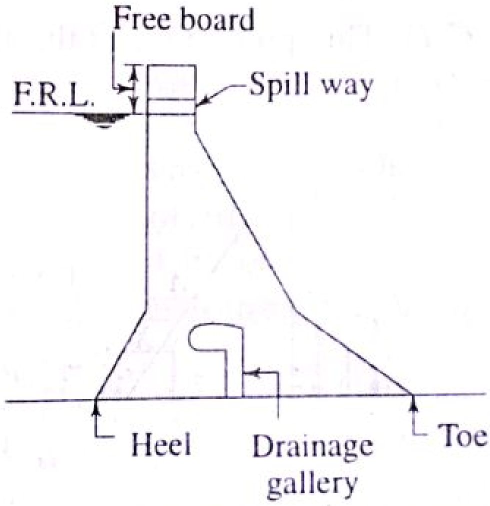


Fig. 16.1 Solid gravity dam

16.6 FORCES ACTING ON GRAVITY DAM

The following forces act on a gravity dam:

1. Weight of the Dam

The weight of the dam is the main stabilising force which counter balances all the external forces acting on the dam. So, the dam should be constructed with heavy materials of high specific gravity. For the construction of dam the specific weight of concrete and stone masonry should not be less than 2400 kg/m^3 and 2300 kg/m^3 respectively. The weight of the dam acts through its centre of gravity. For design purpose, the weight per unit length should be calculated. The centre of gravity of the dam is calculated with respect to the vertical upstream face or with some reference line.

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 pressure is exerted by the tail water. Again, the upstream face of the dam may be completely vertical or partly vertical and partly inclined. But the downstream face is always inclined.

(a) Water pressure on U/S face (when completely vertical)

Total pressure, $P = \frac{W H^2}{2}$, Where H = height of water (F.R.L.)

This pressure acts horizontally at a height $H/3$ from base (Fig. 16.2).

(b) Water pressure on U/S face (when partly vertical and partly inclined) In this case, the water pressure is calculated as horizontal component and vertical component.

Horizontal component, $P_H = \frac{WH^2}{2}$

This pressure acts on the vertical plane ED and at a height $H/3$ from base. The vertical component P_v is the weight of water per unit length contained in the area $E\,F\,G\,D$. This pressure acts through the centre of gravity ($\bar{X}$ from line ED), (Fig. 16.3).

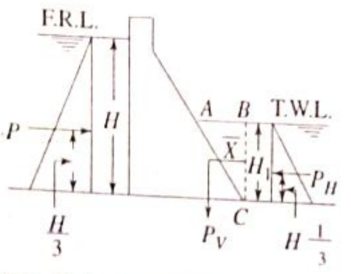


Fig. 16.2 When U/S face vertical

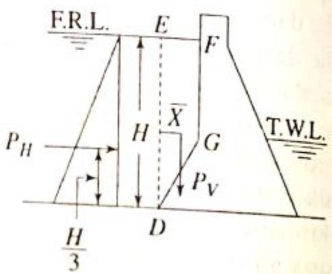


Fig. 16.3 When U/S face inclined

(c) Water pressure on D/S face As the downstream face is inclined, the water pressure is calculated in terms of horizontal component and vertical component.

Horizontal component, $P_H = \frac{WH_1^2}{2}$, This acts horizontally at a height $\frac{H_1}{3}$ from base. The vertical component of pressure P_v is the weight of water per unit length contained in the area $A\,B\,C$, and acts at $\bar{x}$ from BC (Fig. 16.2).

3. Uplift Pressure The stored water on the upstream side of the dam has a tendency to seep through the soil below the foundation. While seeping, the flowing water exerts uplift pressure on the base of the dam which depends on the head of water.

This uplift pressure reduces the self weight of the dam. If the depth of water on the upstream side be H and that on the downstream side be H_1, then the intensity of pressure on U/S base is WH and on the D/S, base is WH_1 (Fig. 16.4).

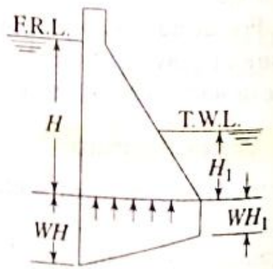


Fig. 16.4 Uplift pressure

From the pressure diagram the total uplift pressure may be computed. To reduce this 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. The vertical and horizontal components of the earthquake waves are considered for the design of a dam coming in seismic zone. In India several zones are marked according to the intensity of earthquake recorded by seismic recorder. The acceleration of earthquake waves consist of two components vertical acceleration f_v and horizontal acceleration (f_h). Again, these accelerations depend on the coefficient (C_v or C_h) which is expressed as the percentage of acceleration due to gravity g i.e. as 0.1 g, 0.2 g ..., etc.

(a) Effect of vertical component The vertical component may act upwards or downwards.

1. When the vertical component of earthquake waves act upwards, the foundation of the dam will be lifted up and thus the stress on the dam will be increased momentarily. Due to this increase of stress, if the permissible stress in the dam exceeds, the dam may fail by crushing. So. while designing the dam, the effect of sudden increase of stress should be taken into account.
2. When the vertical component act downwards. the foundation of the dam has a tendency to move downwards and thus a gap may be formed instantaneously between the base of the dam and the foundation soil. Thus, there is a tendency of the dam to settle down and cracks may be formed within foundation or on the body of the dam. The vertical acceleration (f_v) exerts a downward force on the dam which is given by $\frac{W}{g} \times f_v$.

This force reduces the effective weight of the dam. So, the net effective weight of dam, $W_f = W - \frac{W}{g} f_v$.

again, $f_v = C_v \times g$

$$W_f = W - \frac{W}{g} \times C_v \times g$$

$$= W(1 - C_v).$$

Where, W_f = net effective weight of dam, W = total weight of dam, C_v = a coefficient adopted for vertical acceleration its value varies from 0.1 g to 0.3 g, g = acceleration due to gravity.

(b) Effect of horizontal component The horizontal component imparts following two forces:

(1) Hydrodynamic force Due to horizontal acceleration (f_h), the water pressure is increased momentarily. This extra pressure caused by the earthquake waves is known as hydrodynamic pressure. The expression given by Von-Karman for the hydrodynamic force is as follows (Fig. 16.5):

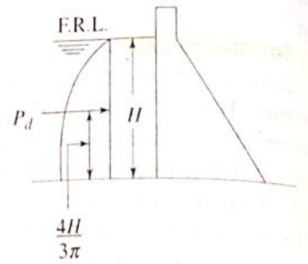


Fig. 16.5 Hydrodynamic force

$$P_d = 0.555 \times f_h \times W \times H^2$$

Where, P_d = hydrodynamic force, f_h = horizontal acceleration, W = sp. wt. of water, H = depth of water in reservoir.

This force acts at a height $\frac{4H}{3\pi}$ from the base of dam.

The moment of this force $= P_d \times \left(\frac{4H}{3\pi}\right) = 0.424 \times P_d \times H$.

(2) Inertia force Due to the horizontal acceleration 'f_h' an inertia force will be developed on the body of the dam. This force is given by, $I = \left(\frac{W}{g}\right) \times f_h$.

but $\quad f_h = C_h \times g$

or $\quad I = \frac{W}{g} \times C_h \times g = W \times C_h$

Where, I = inertia force, W = total weight of dam, g = acceleration due to gravity, f_h = horizontal acceleration, C_h = a coefficient adopted for horizontal acceleration 0.1 g to 0.3 g.

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 resist this silt pressure. The upstream face of the dam may be completely vertical or partly vertical and partly sloping. So, the pressure of silt will differ accordingly.

(a) When the upstream face is completely vertical, the silt pressure is given by Rankine's formula,

$$P = \frac{W_s h^2}{2} \times \frac{(1 - \sin \phi)}{(1 + \sin \phi)}$$

Where, W_s = submerged sp.wt of silt, h = depth of silt deposit, ϕ = angle of internal friction

This force acts at a distance 2h/3 below the surface of silt deposit (Fig. 16.6).

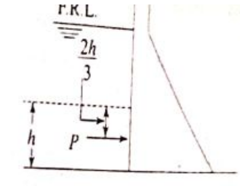


Fig. 16.6 Silt pressure when U/S face vertical

(b) When the upstream face is partly vertical and partly sloping, the silt pressure gets resolved in two components—horizontal and vertical. The horizontal component (P_H) is given by,

$$P_H = \frac{W_s h^2}{2} \times \frac{(1 - \sin \phi)}{(1 + \sin \phi)}$$

It acts at a distance $\frac{2h}{3}$ from the surface of silt deposit.

The vertical component P_v is equal to the submerged weight of the silt deposit contained in the area *abcd* for unit length. This force acts at a distance $\bar{x}$ from the line *ab* (Fig. 16.7).

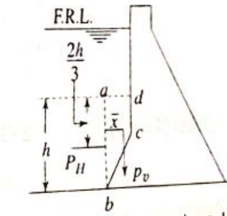


Fig. 16.7 Silt pressure when U/S face inclined

6. Wave Pressure When very 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. The wave pressure is calculated by Moliter's formula as follows (Fig. 16.8):

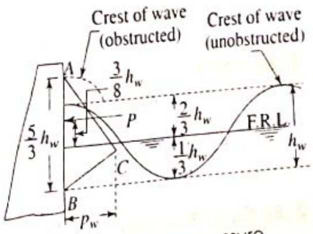


Fig. 16.8 Wave pressure

(i) *Height of wave,*

$$h_w = 0.032\sqrt{VF} + 0.763 - 0.271.(F)^{1/4} \text{ (when } F \text{ is less than 32 km)}$$

$$h_w = 0.032\sqrt{VF} \text{ (when } F \text{ is greater than 32 km)}$$

Where, H_w = height of wave, v = velocity of wind km/hr, F = straight length of water surface in km.

(ii) Maximum intensity of pressure, $P_w = 2400 \times h_w$ km/m^2.

(iii) Wave pressure diagram is represented by the area of triangle *ABC*. Total pressure is given by the area of triangle per unit length of dam.

$$P = 1/2 \times p_w \times 5/3\, h_w = 2000\, (h_w)^2 \text{ kg/m}$$

This force acts at a height 3/8 h_w above F.R.L.

7. Ice Pressure This pressure should be counted only in places 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.

In India, ice pressure is generally not required to be considered. However, if required, the intensity of ice pressure may be assumed as 25,000 kg/m^2 which is applicable for the contact area between the ice and the face of dam.

8. Wind Pressure The top exposed portion of the dam is not much and the wind pressure on the 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 faces.

16.7 CAUSES OF FAILURE OF GRAVITY DAM

The solid gravity dam may fail because of the following reasons,

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

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

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

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

16.8 PRECAUTIONS AGAINST FAILURE

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

1. To avoid overturning, the resultant of all forces acting on the dam should remain within the middle-third of the base width of the dam. This condition should be achieved in both the cases, when the reservoir is full and also when it is empty.

2. In the dam, the sliding should be fully resisted when the condition for no sliding exists in the dam section.

The condition for no sliding is given by.

$$\text{Tan } \theta = \frac{\Sigma p}{\Sigma W}$$

and $\tan \theta < \mu$.

Where, Σ p, sum of horizontal forces, ΣW = sum of vertical forces, μ = coefficient of friction of the materials of dam.

3. In the dam section, the compressive stresses of concrete or masonry should not exceed the permissible working stresses to avoid failure due to crushing.
4. There should be no tension in the dam section to avoid the formation of cracks. This condition may be achieved by maintaining the middle-third rule.
5. The factor of safety should be taken 4 to 5.

16.21 EARTHEN DAM

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

Based on Method of Construction

Rolled Fill Dam In this method, the dam is constructed in successive layers of earth by mechanical compaction. The selected soil is transported from borrowpits and laid on the dam section, to layers of about 45 cm. The layers are thoroughly compacted by rollers of recommended weight and type. When the compaction of one layer is fully achieved, the next layer is laid and compacted in the usual way. The designed dam saction hence is completed layer by layer.

Hydraulic Fill Dam In this method, the dam section is constructed with the help of water. Sufficient water is poured in the borrowpit and by pugging thoroughly, slurry is formed. This slurry is transported to the dam site by pipe line and discharged near the upstream and downstream faces of the dam. The coarser material gets deposited near the face and the finer material move towards the centre and get deposited there. Thus the dam section is formed with faces of coarse material and central core is of impervious materials like clay and silt. In this case, compaction is not necessary.

Semi-Hydraulic Fill Dam In this method the selected earth is transported from the borrowpit and dumped within the section of the dam, as done in the case of rolled fill dam. While dumping no water is used. But, after dumping the water jet is forced on the dumped earth. Due to the action of water the finer materials move towards the centre of the dam and an impervious core is formed with fine materials like clay. The outside body is formed by coarse material, In this case also compaction is not necessary.

Homogeneous Type Dam This type of dam is constructed purely with earth in trapezoidal section having the side slopes according to the angle of repose of the soil. The top width and height depends on the depth of water to be retained and the gradient of the seepage line. The phreatic line (top level of seepage line) should pass well within the body of the dam. This type of dam is completely pervious. The upstream face of the dam is protected by stone pitching. Now-a-days, the earthen dam is modified by providing horizontal drainage blanket or rock toe (Fig. 16.24).

Zoned Type Dam This type of dam consists of several materials. the impervious core is made of puddle clay and the outer previous shell is constructed with the mixture of earth, sand, gravel, etc. The core is trapezoidal in section and its width depends on the seepage characteristics of the soil mixture on the upstream side. The core is extended below the base of the dam to control the sub-soil seepage. Transition filters are provided on both sides of the impervious core to control the seepage. The transition filter is made of gravel and coarse sand. The upstream face of the dam is protected by stone pitching (Fig. 16.25).

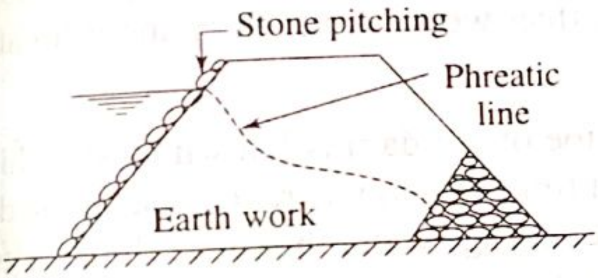


Fig. 16.24 Homogeneous type dam

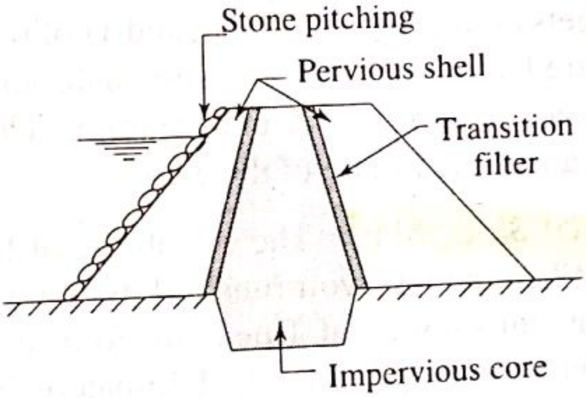


Fig. 16.25 Zoned type dam

Diaphragm Type Dam In this type of dam, a thin impervious core or diaphragm is provided which may consist of puddle clay or cement concrete or bituminous concrete. The upstream and downstream body of the dam is constructed with pervious shell which consists of the mixture of soil, sand, gravel, etc. The thickness of the core is generally less than 3m. A blanket of stones is provided on the toe of the dam for the drainage of the seepage water without damaging the base of the dam. the upstream face is protected by stone pitching. The side slope of the dam should be decided according to the angle of repose of the soil mixture (Fig. 16.26).

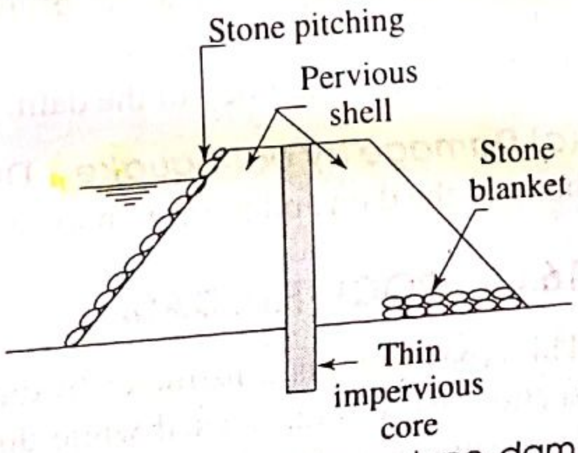


Fig. 16.26 Diaphragm type dam

16.22 CAUSES OF FAILURE OF EARTHEN DAM

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

(1) Hydraulic Failure This type of failure may be caused by:

(a) Overtopping If the actual flood discharge is much more than the estimated flood discharge or the free board is kept insufficient or there is settlement of the dam or the capacity of spill way is insufficient, then it results in the overtopping of the dam. During the overtopping the crest of the dam may be washed out and the dam may collapse.

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

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

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

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

(3) Structural Failure This type of failure may be caused by

(a) Sliding of the side slopes Sometimes, it is found that the side slope of the dam slides down to form some steeper slope. The dam goes on depressing gradually and then overtopping occurs which leads to the failure of the dam.

(b) Damage by burrowing animals Some burrowing animals like craw-fish, snakes, squirrel, rats, etc cause damage to the dam by digging holes through the foundation and body of the dam.

(c) Damage by earthquake Due to earthquake cracks may develop on the body of the dam and the dam may eventually collapse.

CENTRIFUGAL PUMPS

19.1 INTRODUCTION

The hydraulic machines which convert the mechanical energy into 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 acts as a reverse of an inward radial flow reaction turbine. This means that the flow in centrifugal pumps is in the radial outward directions. 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 $\left(i.e., \text{ rise in pressure head } = \frac{V^2}{2g} \text{ or } \frac{\omega^2 r^2}{2g}\right)$. Thus at the outlet of the impeller, where radius is more, the rise in pressure head will be more and 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.

19.2 MAIN PARTS OF A CENTRIFUGAL PUMP

The following are the main parts of a centrifugal pump :

1. Impeller.
2. Casing.
3. Suction pipe with a foot valve and 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 and 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 and enters the delivery pipe. The following three types of the casings are commonly adopted :

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

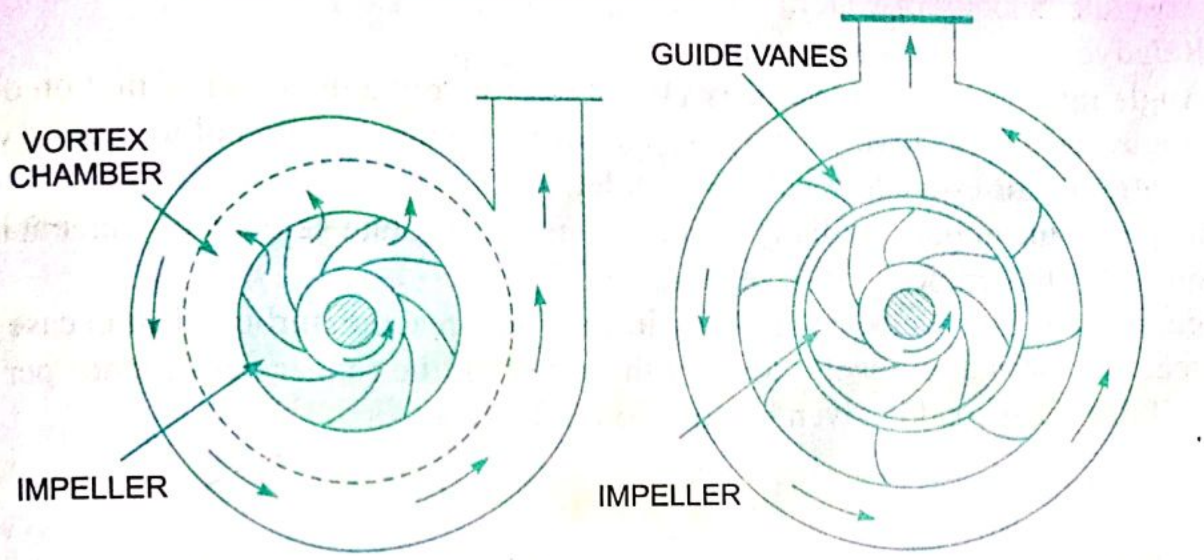


Fig. 19.2 *Different types of casing.*

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

19.3 WORK DONE BY THE CENTRIFUGAL PUMP (OR BY IMPFLLER) ON WATER

In case of the centrifugal pump, work is done by the impeller on the water. The expression for the work done by the impeller on the water is obtained by drawing velocity triangles at inlet and outlet of the impeller in the same way as for a turbine. The water enters the impeller radially at inlet for best efficiency of the pump, which means the absolute velocity of water at inlet makes an angle of 90° with the direction of motion of the impeller at inlet. Hence angle $\alpha = 90°$ and $V_{w_1} = 0$. For drawing the velocity triangles, the same notations are used as that for turbines. Fig. 19.3 shows the velocity triangles at the inlet and outlet tips of the vanes fixed to an impeller.

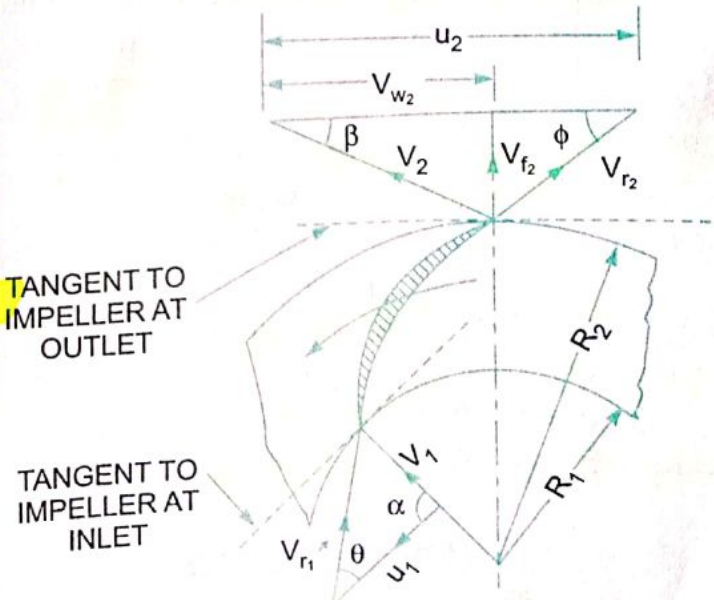


Fig. 19.3 *Velocity triangles at inlet and outlet.*

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

D_1 = Diameter of impeller at inlet,

u_1 = Tangential velocity of impeller at inlet,

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

D_2 = Diameter of impeller at outlet,

u_2 = Tangential velocity of impeller at outlet

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

V_1 = Absolute velocity of water at inlet,

V_{r_1} = Relative velocity of water at inlet,

α = Angle made by absolute velocity (V_1) at inlet with the direction of motion of vane,

θ = Angle made by relative velocity (V_{r_1}) at inlet with the direction of motion of vane, and V_2, V_{r_2}, β and ϕ are the corresponding values at outlet.

As the water enters the impeller radially which means the absolute velocity of water at inlet is in the radial direction and hence angle $\alpha = 90°$ and $V_{w_1} = 0$.

A centrifugal pump is the reverse of a radially inward flow reaction turbine. But in case of a radially inward flow reaction turbine, the work done by the water on the runner per second per unit weight of the water striking per second is given by equation (18.19) as

$$= \frac{1}{g}[V_{w_1}u_1 - V_{w_2}u_2]$$

$\therefore$ Work done by the impeller on the water per second per unit weight of water striking per second

$$= -\text{[Work done in case of turbine]}$$

$$= -\left[\frac{1}{g}\left(V_{w_1}u_1 - V_{w_2}u_2\right)\right] = \frac{1}{g}\left[V_{w_2}u_2 - V_{w_1}u_1\right]$$

$$= \frac{1}{g}V_{w_2}u_2 \qquad (\because \; V_{w_1} = 0 \text{ here}) \quad ...(19.1)$$

Work done by impeller on water per second

$$= \frac{W}{g}.V_{w_2}u_2 \quad ...(19.2)$$

where W = Weight of water = $\rho \times g \times Q$

where Q = Volume of water

and Q = Area $\times$ Velocity of flow = $\pi D_1 B_1 \times V_{f_1}$

$= \pi D_2 B_2 \times V_{f_2}$ ...(19.2A)

where B_1 and B_2 are width of impeller at inlet and outlet and V_{f_1} and V_{f_2} are velocities of flow at inlet and outlet.

Equation (19.1) gives the head imparted to the water by the impeller or energy given by impeller to water per unit weight per second.

19.4 DEFINITIONS OF HEADS AND EFFICIENCIES OF A CENTRIFUGAL PUMP

1. Suction Head (h_s). It is the vertical height of the centre line of the centrifugal pump above the water surface in the tank or pump from which water is to be lifted as shown in Fig. 19.1. This height is also called suction lift and is denoted by 'h_s'.

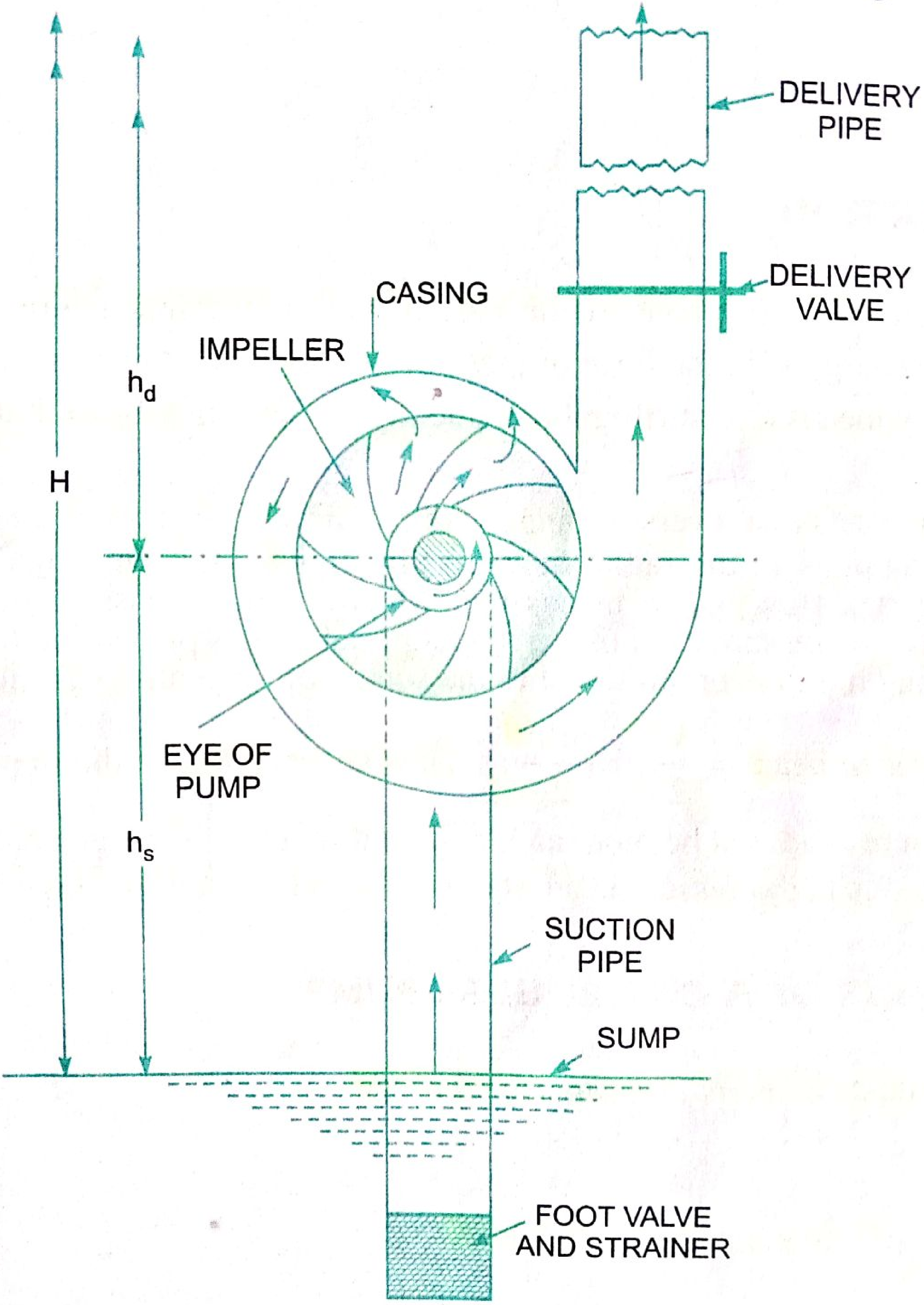


Fig. 19.1 *Main parts of a centrifugal pump.*

2. Delivery Head (h_d). The vertical distance between the centre line of the pump and the water surface in the tank to which water is delivered is known as delivery head. This is denoted by 'h_d'.

3. Static Head (H_s). The sum of suction head and delivery head is known as static head. This is represented by 'H_s' and is written as

$$H_s = h_s + h_d. \qquad ...(19.3)$$

4. Manometric Head (H_m). The manometric head is defined as the head against which a centrifugal pump has to work. It is denoted by 'H_m'. It is given by the following expressions :

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

$$= \frac{V_{w_2} u_2}{g} - \text{Loss of head in impeller and casing} \qquad ...(19.4)$$

$$= \frac{V_{w_2} u_2}{g} \text{ ...if loss of pump is zero} \qquad ...(19.5)$$

(b) H_m = Total head at outlet of the pump – Total head at the inlet of the pump

$$= \left(\frac{P_o}{\rho g} + \frac{V_o^2}{2g} + Z_o\right) - \left(\frac{p_i}{\rho g} + \frac{V_i^2}{2g} + Z_i\right) \qquad ...(19.6)$$

where $\frac{p_o}{\rho g}$ = Pressure head at outlet of the pump = h_d

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

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

Z_o = Vertical height of the outlet of the pump from datum line, and

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

i.e., h_s, $\frac{V_s^2}{2g}$ and Z_s respectively.

(c) $$H_m = h_s + h_d + h_{f_s} + h_{f_d} + \frac{V_d^2}{2g} \qquad ...(19.7)$$

where h_s = Suction head, h_d = Delivery head,
h_{f_s} = Frictional head loss in suction pipe, h_{f_d} = Frictional head loss in delivery pipe, and
V_d = Velocity of water in delivery pipe.

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

(a) Manometric efficiency, η_{man} (b) Mechanical efficiency, η_m and
(c) Overall efficiency, η_o.

(a) Manometric Efficiency (η_{man}). The ratio of the manometric head to the head imparted by the impeller to the water is known as manometric efficiency. Mathematically, it is written as

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

$$= \frac{H_m}{\left(\frac{V_{w_2} u_2}{g}\right)} = \frac{gH_m}{V_{w_2} u_2} \quad ...(19.8)$$

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

$$= \frac{W}{g} \times \frac{V_{w_2} \times u_2}{1000} \text{kW}$$

$$\eta_{man} = \frac{\frac{W \times H_m}{1000}}{\frac{W}{g} \times \frac{V_{w_2} \times u_2}{1000}} = \frac{g \times H_m}{V_{w_2} \times u_2}.$$

(*b*) **Mechanical Efficiency (η_m).** 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

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

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

$$= \frac{W}{g} \times \frac{V_{w_2} u_2}{1000} \quad \text{[Using equation (19.2)]}$$

$$\eta_m = \frac{\frac{W}{g}\left(\frac{V_{w_2} u_2}{1000}\right)}{\text{S.P.}} \quad ...(19.9)$$

where S.P. = Shaft power.

(*c*) **Overall Efficiency (η_o).** It is defined as ratio of power output of the pump to the power input to the pump. The power output of the pump in kW

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

Power input to the pump = Power supplied by the electric motor
= S.P. of the pump.

$$\therefore \quad \eta_o = \frac{\left(\frac{WH_m}{1000}\right)}{\text{S.P.}} \quad ...(19.10)$$

Also $\eta_o = \eta_{man} \times \eta_m$. ...(19.11)

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RECIPROCATING PUMPS

APTER

20.1 INTRODUCTION

In the last chapter, we have defined the pumps as the hydraulic machines which convert the mechanical energy into hydraulic energy which is mainly in the form of pressure energy. If the mechanical energy is converted into hydraulic energy, by means of centrifugal force acting on the liquid, the pump is known as centrifugal pump. But 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 and increases its hydraulic energy (pressure energy), the pump is known as reciprocating pump.

20.2 MAIN PARTS OF A RECIPROCATING PUMP

The following are the main parts of a reciprocating pump as shown in Fig. 20.1 :

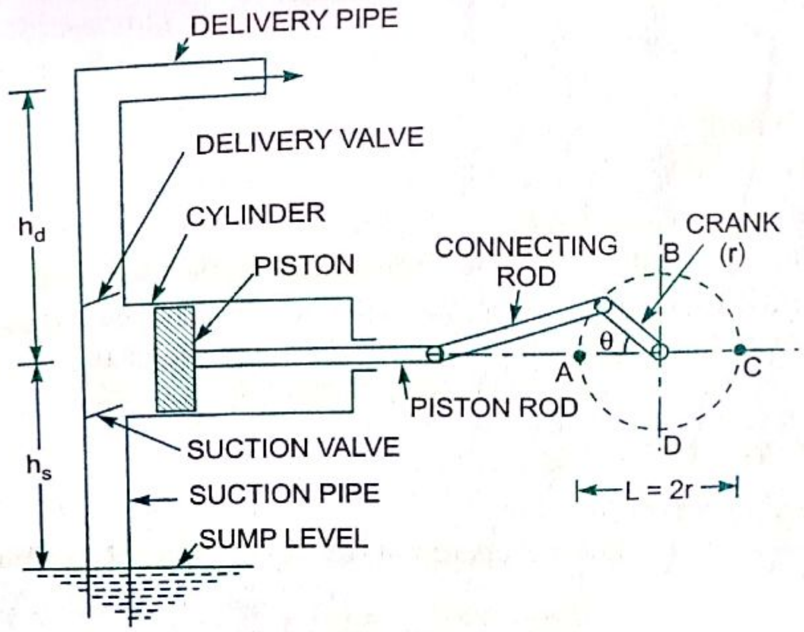

Fig. 20.1 *Main parts of a reciprocating pump.*

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.

▶ 20.3 WORKING OF A RECIPROCATING PUMP

Fig. 20.1 shows a single acting reciprocating pump, which consists of a piston which moves forwards and backwards in a close fitting cylinder. The movement of the piston is obtained by connecting the piston rod to crank by means of a connecting rod. The crank is rotated by means of an electric motor. Suction and delivery pipes with suction valve and delivery valve are connected to the cylinder. The suction and delivery valves are one way valves or non-return valves, which allow the water to flow in one direction only. Suction valve allows water from suction pipe to the cylinder which delivery valve allows water from cylinder to delivery pipe only.

When crank starts rotating, the piston moves to and fro in the cylinder. When 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 $\theta = 0°$ to $\theta = 180°$), 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 the liquid in the sump 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 $\theta = 180°$ to $\theta = 360°$), 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.

20.3.1 Discharge Through a Reciprocating Pump.

Consider a single* acting reciprocating pump as shown in Fig. 20.1.

Let D = Diameter of the cylinder

A = Cross-sectional area of the piston or cylinder

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

r = Radius of crank

N = r.p.m. of the crank

L = Length of the stroke = $2 \times r$

h_s = Height of the axis of the cylinder from water surface in sump.

h_d = Height of delivery outlet above the cylinder axis (also called delivery head)

Volume of water delivered in one revolution or discharge of water in one revolution

$$= \text{Area} \times \text{Length of stroke} = A \times L$$

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

∴ Discharge of the pump per second,

$$Q = \text{Discharge in one revolution} \times \text{No. of revolution per second} \quad ...(20.1)$$

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

---

* Single acting means the water is acting on one side of the piston only.

Weight of water delivered per second,

$$W = \rho \times g \times Q = \frac{\rho g A L N}{60}. \quad \text{...(20.2)}$$

20.3.2 Work done by Reciprocating Pump. Work done by the reciprocating pump per second is given by the reaction as

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

$$= W \times (h_s + h_d) \quad \text{...}(i)$$

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

From equation (20.2), Weight, W, is given by

$$W = \frac{\rho g \times A L N}{60}.$$

Substituting the value of W in equation (i), we get

$$\text{Work done per second} = \frac{\rho g \times A L N}{60} \times (h_s + h_d) \quad \text{...(20.3)}$$

∴ Power required to drive the pump, in kW

$$P = \frac{\text{Work done per second}}{1000} = \frac{\rho g \times A L N \times (h_s + h_d)}{60 \times 1000}$$

$$= \frac{\rho g \times A L N \times (h_s + h_d)}{60{,}000} \text{ kW} \quad \text{...(20.4)}$$

20.5 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, and (*ii*) Double-acting pump.

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

(*i*) Single cylinder pump, (*ii*) Double cylinder pump, and

(*iii*) Triple cylinder pump.

20.10 COMPARISON BETWEEN CENTRIFUGAL PUMPS AND RECIPROCATING PUMPS

Centrifugal pumps	*Reciprocating pumps*
1. The discharge is continuous and smooth.	1. The discharge is fluctuating and pulsating.
2. It can handle large quantity of liquid.	2. It handles small quantity of liquid only.
3. It can be used for lifting highly viscous liquids.	3. It is used only for lifting pure water or less viscous liquids.
4. It is used for large discharge through smaller heads.	4. It is meant for small discharge and high heads.
5. Cost of centrifugal pump is less as compared to reciprocating pump.	5. Cost of reciprocating pump is approximately four times the cost of centrifugal pump.
6. Centrifugal pump runs at high speed. They can be coupled to electric motor.	6. Reciprocating pump runs at low speed. Speed is limited due to consideration of separation and cavitation.
7. The operation of centrifugal pump is smooth and without much noise. The maintenance cost is low.	7. The operation of reciprocating pump is complicated and with much noise. The maintenance cost is high.
8. Centrifugal pump needs smaller floor area and installation cost is low.	8. Reciprocating pump requires large floor area and installation cost is high.
9. Efficiency is high.	9. Efficiency is low.