GANESH POLYTECHNIC,BHUBANESWAR

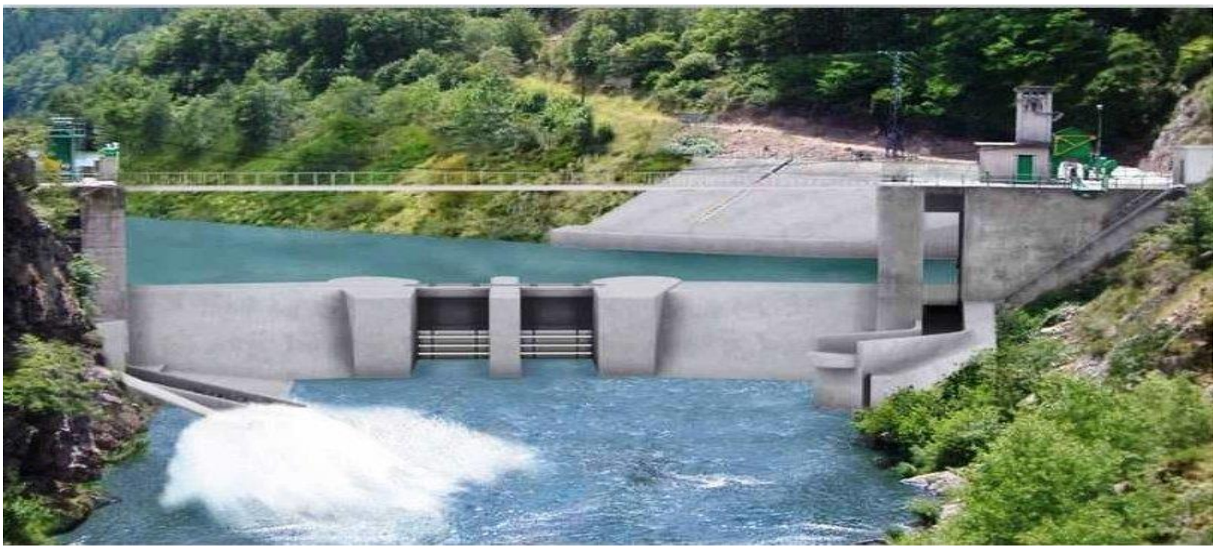
DEPARTMENT OF CIVIL ENGINEERING

LECTURE NOTE ON: HYDRAULICS AND IRRIGATION ENGINEERING (TH-2) 4TH SEMESTER

PREPARED BY: DEBIPRIYA CHINMAYEE JENA

LECTURER IN CIVIL ENGINEERING DEPT

DIVERSION HEAD WORKS AND REGULATORY STRUCTURES



Necessity and objectives of diversion head works, weirs and barrages

General layout, functions of different parts of barrage

Silting and scouring

Functions of regulatory structures

Necessity and objectives of diversion head works, weirs and barrages:

- The main permanent canal, forming the primary part of a direct irrigation scheme, takes off from a diversion weir or a barrage.
- In fact, thesepermanent canals take off from rivers and the arrangements are so well made-at theirheads, that a constant and a continuous water supply is ensured into- the canal, evenduring the periods of low flow.
- The works, which are constructed at the head of the canal, in order to divert the river water towards the canal, so as to ensure a regulated continuous supply of silt-free water with a certain minimum-head into the canal, are known as Diversion Head Works.
- The above purpose can be accomplished by constructing a barrier acrossthe river, so as to raise the water level on the upstream side of the obstruction, and thus,to feed the main canals taking off from its upstream side at one or both of its flanks.
- The ponding of water can be achieved either only by a permanent pucca raised crestacross the river or by a raised crest supplemented by falling counter-balanced gates orshutters, working over the crest.
- If the major part or the entire ponding of water isachieved by a raised crest and a smaller part of it is achieved by the shutters,then this barrier is known as a weir.
- If mostof the ponding is done by gates and a smaller or nil part of it is done by the raised crest hen the barrier is known as a Barrage or River Regulator

DIVERSION HEAD WORK

WEIR

BARRAGE

General layout, functions of different parts of barrage:

A typical layout of a canal head-works consists of:

1. Weir or barrage
2. Undersluices
3. Divide wall
4. Fish ladder
5. Canal head regulator
6. Silt excluders/ Silt prevention devices
7. River training works (Marginal bunds andguide banks)

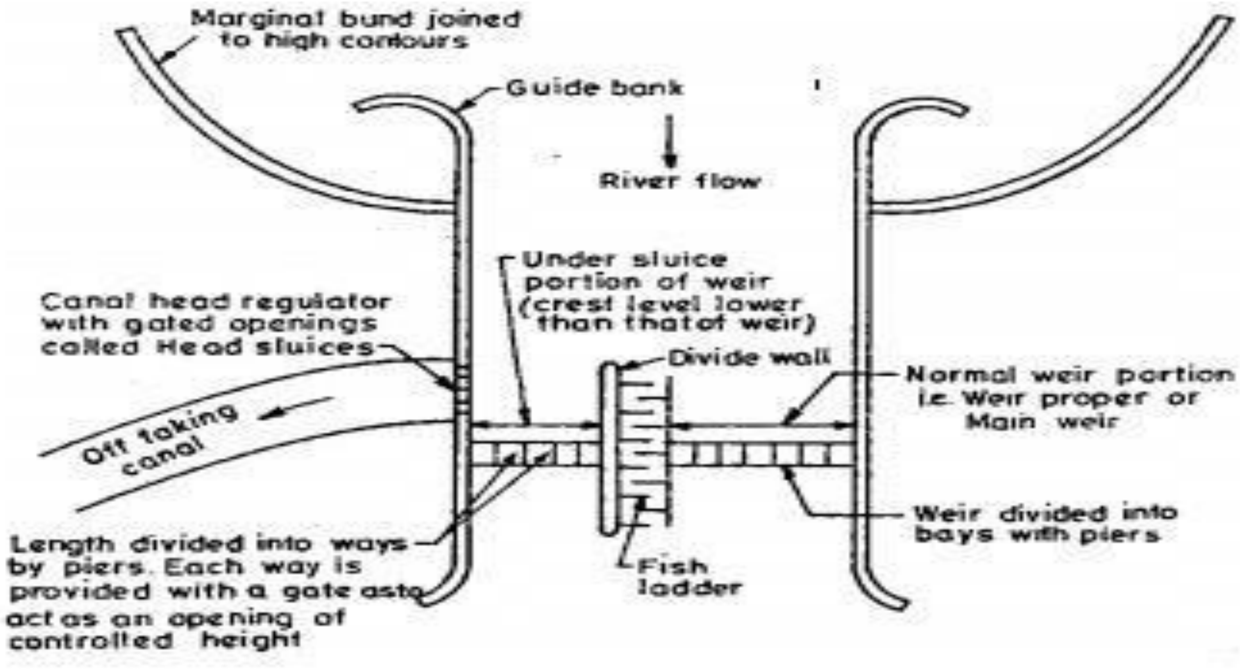
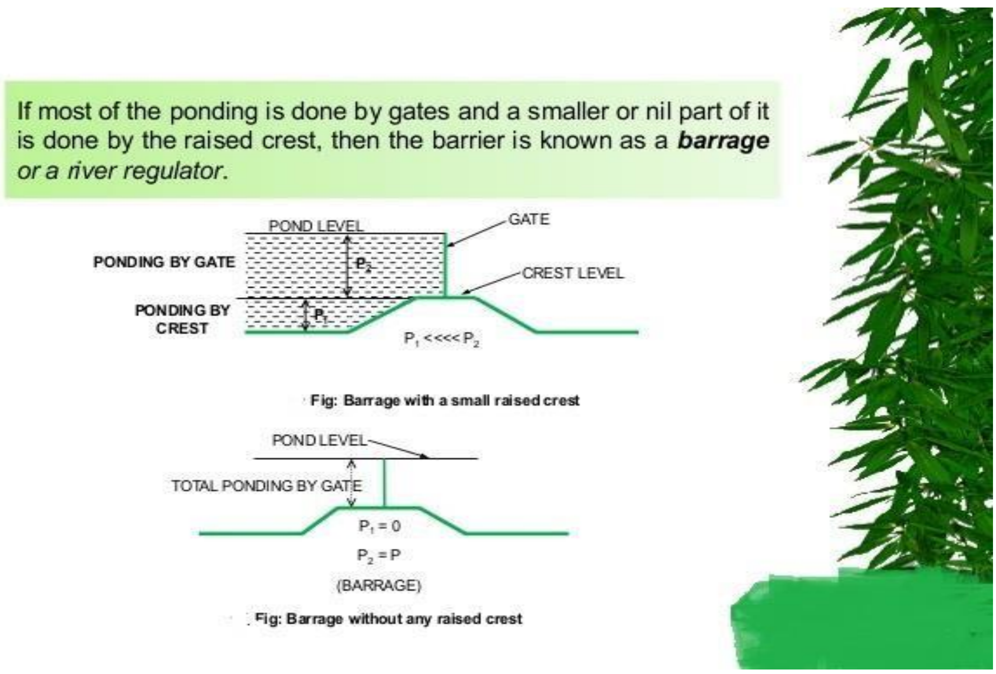


Figure: Typical Layout of Diversion Head-Works

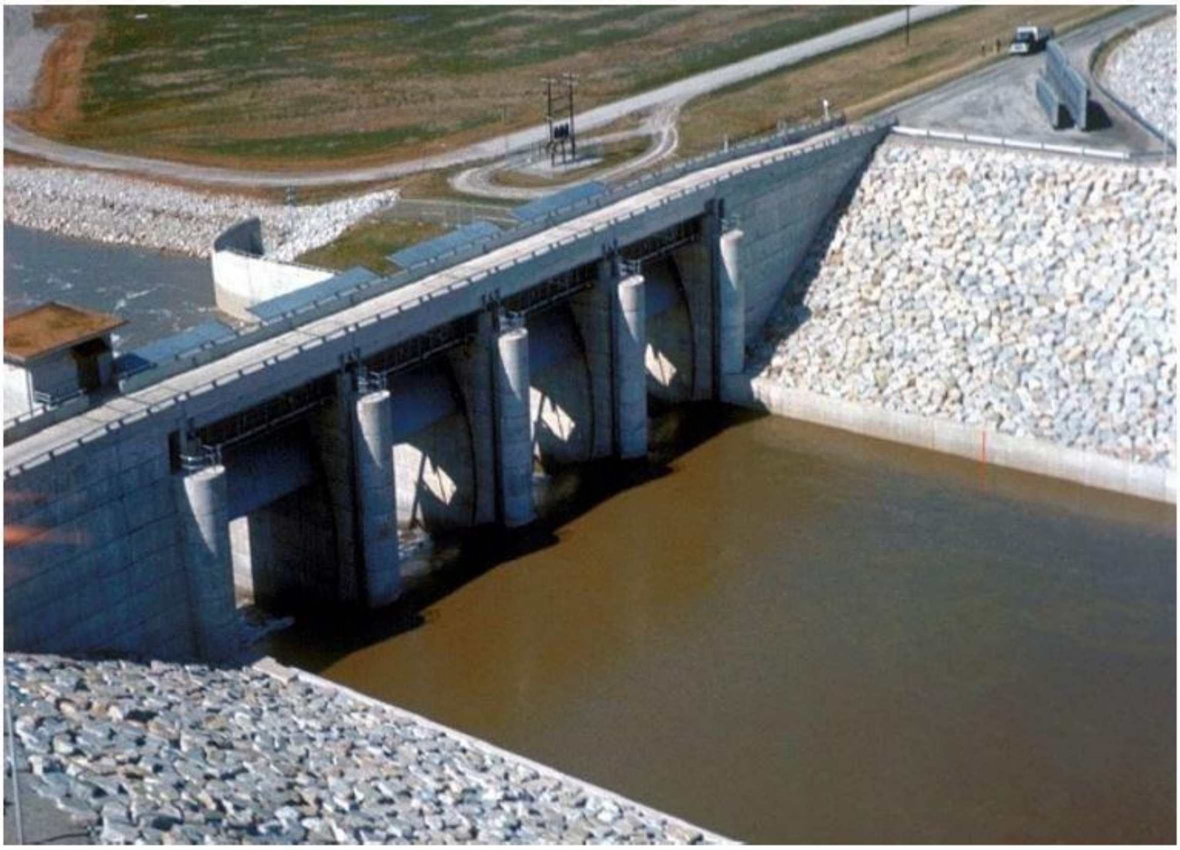
1. **Barrage:**

❖ When the water level on the upstream side of the weir is required to be raised to different levels at different time, barrage is constructed.

❖ Barrage is an arrangement of adjustable gates or shutters at different tires over the weir.



2. **Under sluices:**
    - ❖ Also known as scouring sluices.
    - ❖ The under 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.



3. **Divide wall:**
    - ❖ The divide wall is a long wall constructed at right angles in the weir or barrage, it may be constructed with stone masonry or cement concrete.

- On the upstream side, the wall is extended just to cover the canal head regulator and on the downstream side, it is extended up to the launching apron.

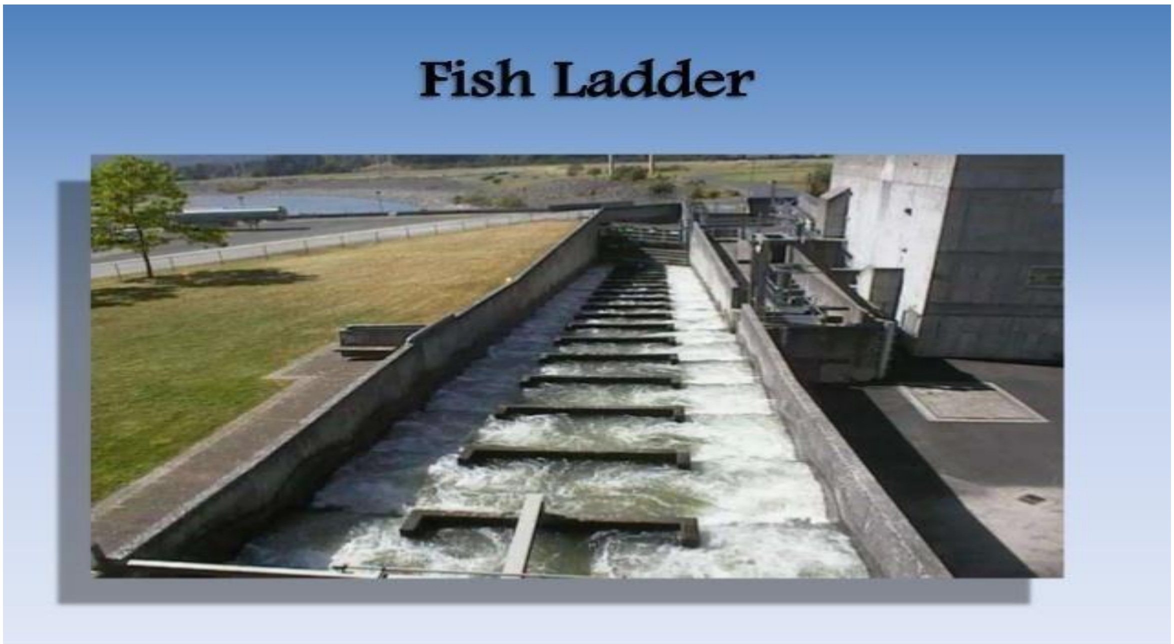
Functions of the divide wall

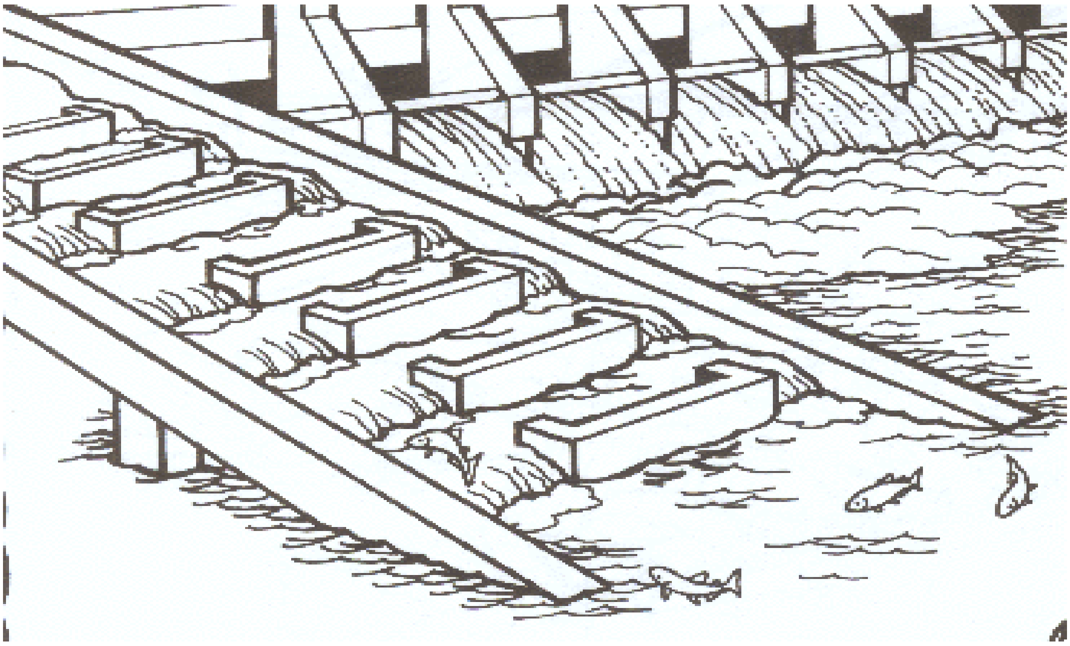
- To form a still water pocket in front of the canal head so that the suspended silt can be settled down which then later be cleaned through the scouring sluices from time to time.
- It controls the eddy current or cross current in front of the canal head.
- It provides a straight approach in front of the canal head.
- It resists the overturning effect on the weir or barrage caused by the pressure of the impounding water.

4. Fish ladder:

- The fish ladder is provided just by the side of the divide wall for the free movement of fishes.
- Rivers are important source of fishes.

- The tendency of fish is to move from upstream to downstream in winters and from downstream to upstream in monsoons.
- This movement is essential for their survival.
- Due to construction of weir or barrage, this movement gets obstructed, and is detrimental to the fishes.
- In the fish ladder, the fable walls are constructed in a zigzag manner so that the velocity of flow within the ladder does not exceed 3 m/sec.
- The width, length and height of the fish ladder depend on the nature of the river and the type of the weir or barrage.





Silting and scouring:

Siltation/Silting can affect navigation channels or irrigation channels. It refers to the undesired accumulation of sediments in channels intended for vessels or for distributing water.

Scouring is the removal of sediment such as silt, sand and gravel from around the base of obstructions to the flow in the sea, rivers and canals. Scour, caused by fast flowing water, can carve out scour holes, compromising the integrity of a structure. It is an interaction between the hydrodynamics and the geotechnical properties of the substrate. It is a notable cause of bridge failure.

Functions of regulatory structures:

<u>Canal head regulator:</u>

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

Functions:

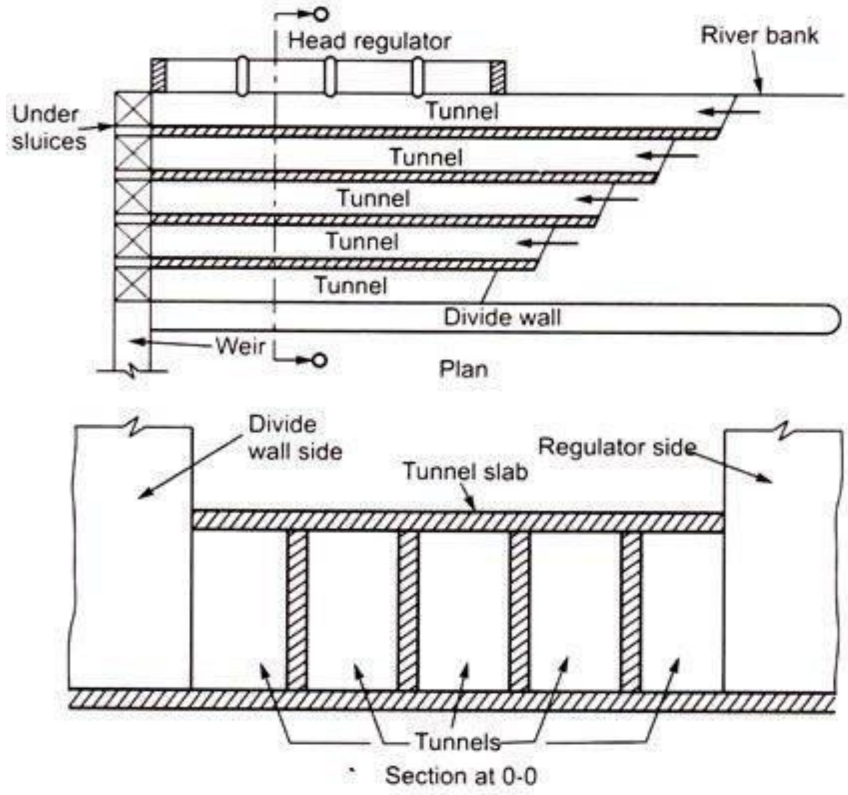
- It regulates the supply of water entering the canal.
- It controls the entry of silt in the canal.
- It prevents the river-floods from entering the canal.

<u>Silt regulation works:</u>

- The entry of silt into a canal, which takes off from a head works, can be reduced by constructed certain special works, called silt control works.
- These works may be classified into the following two types:
  (a) Silt Excluders
  (b) Silt Ejectors

(a) Silt Excluders:

- Silt excluders are those works which are constructed on the bed of the river, upstream of the head regulator.
- The clearer water enters the head regulator and silted water enters the silt excluder.
- In this type of works, the silt is, therefore,, removed from the water before in enters the canal.



SILT EXCLUDER

(b) Silt Ejectors:

- Silt ejectors, also called silt extractors, are those devices which extract the silt from the canal water after the silted water has travelled a certain distance in the off-take canal.
- These works are, therefore, constructed on the bed of the canal, and little distance downstream from the head regulator.

River training works:

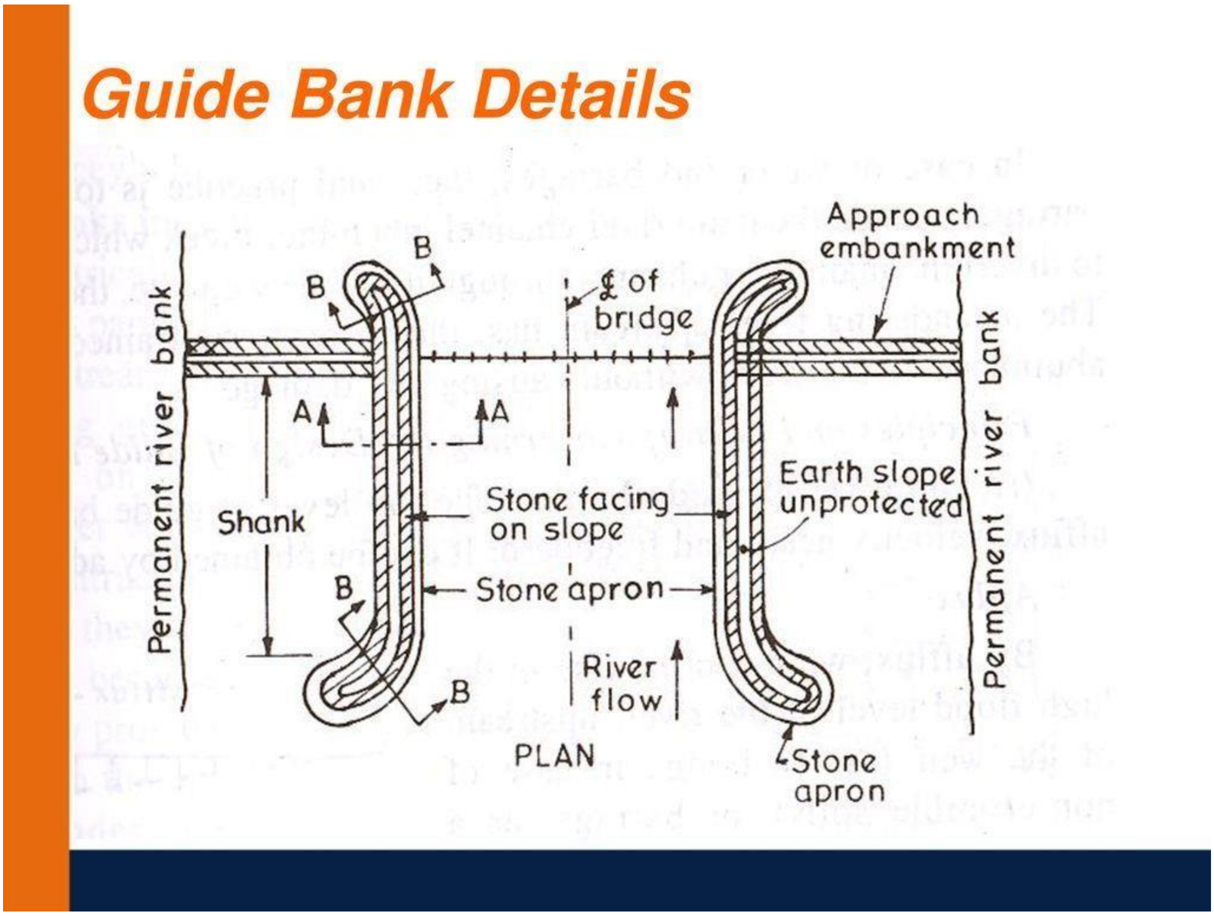
- River training works are required near the weir site in order to ensure a smooth and an axial flow of water, and thus, to prevent the river from outflanking the works due to a change in its course.
- The river training works required on a canal headwork are:
  (a) Guide banks

(b) Marginal bunds

(c) Spurs or groynes

(a) Guide banks:

- When a barrage is constructed across a river which flows through the alluvial soil, the guide banks must be constructed on both the approaches to protect the structure from erosion.



Guide bank serves the following purposes:

- It protects the barrage from the effect of scouring and erosion
- It provides a straight approach towards the barrage.
- It controls the tendency of changing the course of the river.
- It controls the velocity of flow near the structure.

(b) Marginal bunds:

- The marginal bunds are earthen embankments which are constructed parallel to the river bank on one or θboth the banks according to the condition.
- The top width is generally 3 m to 4 m. The side slope on the river side is generally 1.5: 1 and that on the country side is 2:1.

The marginal bunds serve the following purposes:

- It prevents the flood water or storage water from entering the surrounding area which may be submerged or may be water logged.
- It retains the flood water or storage water within a specified section.

- It protects the towns and villages from devastation during the heavy flood.
- It protects valuable agricultural lands.

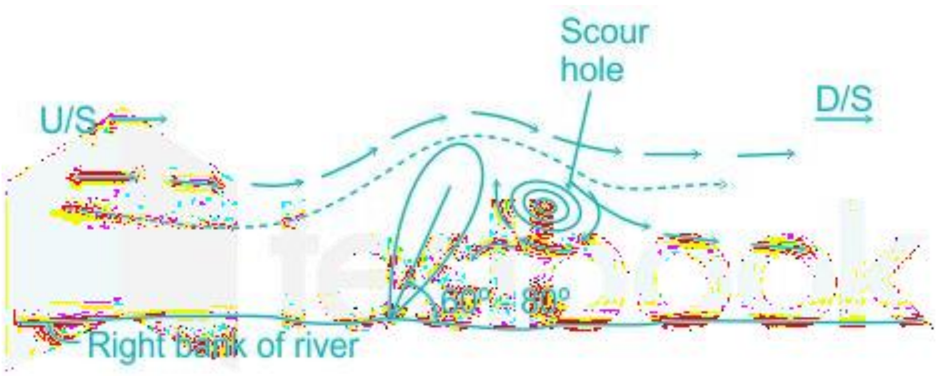
(c) Spurs or groynes:

Spurs:

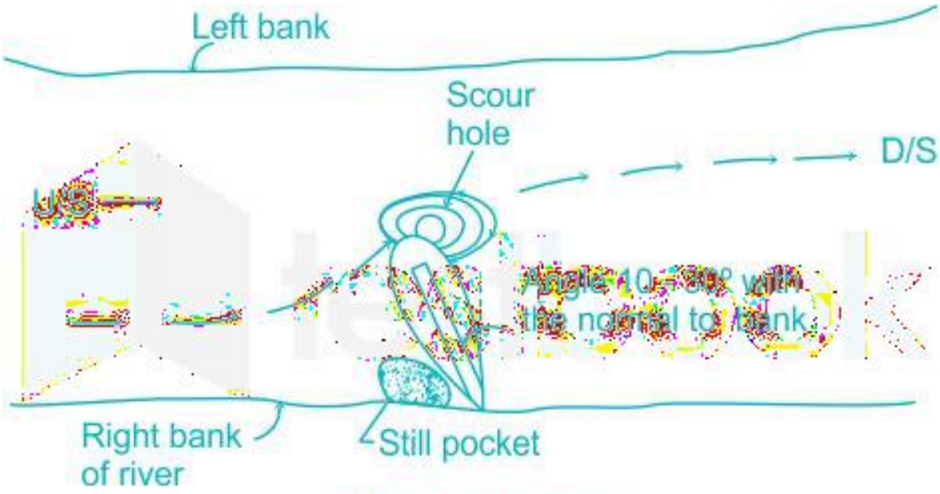
- These are temporary structures permeable in nature provided on the curve of a river to protect the river bank from erosion. These are projected from the river bank towards the bed making angles 60° to 75° with the bank of the river. The length of the spurs depends on the width of the river and the sharpness of the curve.
- Types of Spur
  1. Bamboo spur
  2. Timber spur
  3. Boulder spur

Groynes:

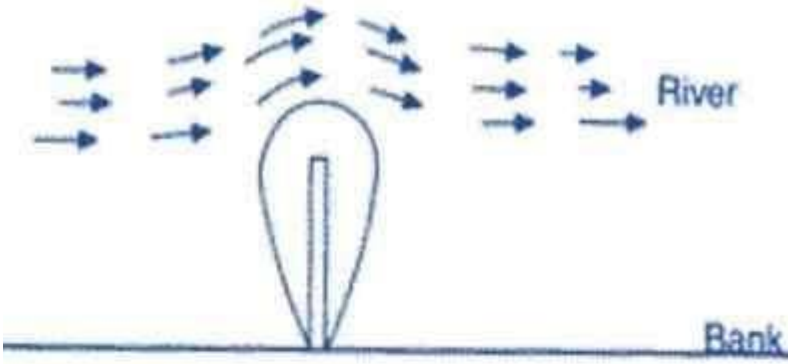
- The function of groynes is similar to that of spur. But these are impervious permanent structures constructed on the curve of a river to protect the river bank from erosion. They extend from the bank towards the bed by making an angle of 60o to 75o with the bank. The angle may be towards the upstream or downstream. Sometimes, it is made perpendicular to the river bank.
- Types of Groyne
  (a) Attracting Groyne
  (b) Repelling Groyne
  (c) Deflecting Groyne



Attracting groyne



Repelling groyne



Deflecting gryone

Chapter-07

DAMS

Necessity of storage reservoirs, types of dams

Earthen dams: types, description, causes of failure and protection measures.

Gravity dam- types, description, Causes of failure and protection measures.

Spillways- Types (With Sketch) and necessity.

Necessity of storage reservoirs, types of dams:

- A dam may be defined as an obstruction or a barrier built acrossa stream or a river. At the back of this barrier, water gets collected, forming a pool ofwater. The side on which water gets collected is called the upstream side, and the otherside of the barrier .is called the downstream side. The lake of water which is formedupstream is often called a ***reservoir***.
- Storage reservoir serve the following purpose :Irrigation, Water supply, Hydroelectric power generation, Flood control, Navigation, Recreation, Development of fish & wild life, Soil conservation etc.
- A city water supply, irrigation watersupply, or a hydroelectric project drawing water directly from a river or a stream mayfail to satisfy the consumer's demands during extremely low flows; while during highflows, it may become difficult to carry out their operations due to devastating floods.
- Astorage or a conservation reservoir can retain such excess supplies during periods of peak flows, and can release them gradually during low flows as and when the needarises.
- In addition to conserving water for later use, the storage of flood watersmay also reduce flood damage below the reservoir. Hence, a reservoir can be used forcontrolling floods either solely or in addition to other purposes.

Types of dams:

Dams can be classified in various ways depending upon the purpose of the classification.

A. *Classification According to the Material used for Dam Construction:* The dams classified according to the material used for construction are: Solid masonry gravity dams, Earthen dams, Rock fill dams, Hollow masonry gravity dams, Timber dams, Steel dams, and R.C.C. Arch dams.

a) **Solid masonry gravity dams:** These big dams are expensive to be built but are more durable and solid than earth and rock dams. They can be constructed on any dam site, where there is a natural foundation strong-enough-to bear the great-weight of the dam. Example: - Aswan dam, Roosevelt dam, Hoover dam, and above all Bhakra dam.
b) **Earthen dams:** Earth dams are made of soil that is pounded down solidly. They are built in areas where the foundation is not strong enough to beat the weight of a concrete dam, and where earth is more easily- available as a building material compared to concrete or stone or rock.Some important earth dams of the world are: Green mountain dam on Colorado River in U.S.A., Swift dam in Washington inU.S.A. ,Side flanks of NagarjunSagar dam in India., Trinity Dam in California in U.S.A., Maithan Dam in India (which is partly Earthen and partly Rockfill).
c) **Rock fill dams:** Rock fill are formed of loose rocks and boulders piled in the river bed. A slab of reinforced concrete is often laid across the upstream face of a rock fill dam to make it water-tight.Some important rock-fill dams of the world are: The Salt Springs Dam in California, The San Gabriel No. 1 Dam U.S.A, Cougar Dam on Mc-Knezie River in Oregon U.S.A.
d) **Hollow masonry gravity dams:** These are essentially designed on the same lines on which the solid masonry gravity dams are designed. But they contain less concrete or masonry about 35 to 40% or so. Generally, the weight of water is carried by a deck of R.C.C. or by arches that share the weight burden. They are difficult to build and are adopted only if very skilled labour is easily available, otherwise the labour cost is-too-high-to-build its-complex structure.
e) **Timber dams:** These are short lived, since in a few years’ time, rotting sets in. Their life is not more than 30 to 40 years and must have regular maintenance during that time. However they are valuable in agricultural areas, where a cattle raiser may need a pool for his live stock to drink from, and for meeting other such low-level needs.
f) **Steel dams:** These are not used for major works. Today, steel dams are used as temporary coffer dams needed for the construction of

permanent dams. Steel coffer dams are usually reinforced with timber or earthfill.

g) **R.C.C. Arch dams:** Arch dams are very complex and complicated. They make use of the horizontal arch action in place of weight to hold back the water. They are best suited at sites where the dam must be extremely high and narrow. Some examples are: *Sautet dam* on the Drac River in France, *The Tignes dam* in France, *Mauvoisin.dam*on the Drause River in Switzerland, *Idduki*dam in Kerala.

B. *Classification According to Use:*

i. Storage Dams: They are constructed in order to store water during the periodsof surplus water supply, to be used later during the periods of deficient supply. Thestored water may be used in different seasons and for different uses. They may be furtherclassified depending upon the specific use of this water, such as navigation, recreation,water supply, fish, electricity, etc.

ii. Diversion Dams: These small dams are used to raise the river water level, inorder to feed an off-taking canal and or some other conveyance systems. They are veryuseful as irrigation development works. A diversion dam is generally called a weir ora barrage.

iii. The Detention Dams: They detain food-waters temporarily so as to retard floodrunoff and thus minimise the bad effects of sudden flood.Detention dams are sometimes constructed to trap sediment .They are often called debris dams.

C. *Classification According to Hydraulic Designs:*

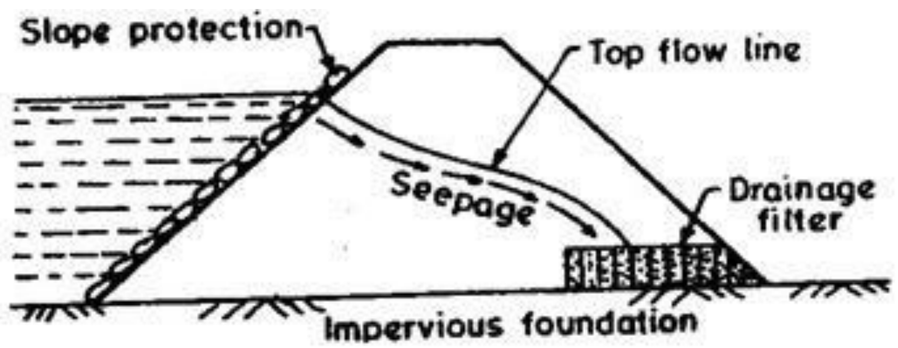
a. **Overflow Dams**. They are designed to pass the surplus water over their crest.They are often called Spillways. They should be made of materials which will not be eroded by such discharges.
b. **Non-overflow Dams:** They are those which are not designed to be overtopped.This type of design gives us wider choice of materials including earthfill and rockfilldams.
c. **Rigid Dams and Non-rigid Dams:** Rigid dams are those which are constructedof rigid materials like· masonry, concrete, steel, timber, etc.; while non-rigid dams areconstructed of earth and rock-fill.

Earthen dams: types, description, causes of failure and protection measures

- Earthen dams and earthen levees are the most ancient type of embankments, as they can be built with the natural materials with a minimum of processing and primitiveequipment.
- Earthen dams are cheaper as they can utilise the locallyavailable materials, and less skilled labour is required for them.
- Gravity dams and arch dams require sound rock foundations, but earthen dams can be easily constructed on earth foundations. However, earth dams are more susceptibleto failure as compared to rigid gravity dams or arch dams.

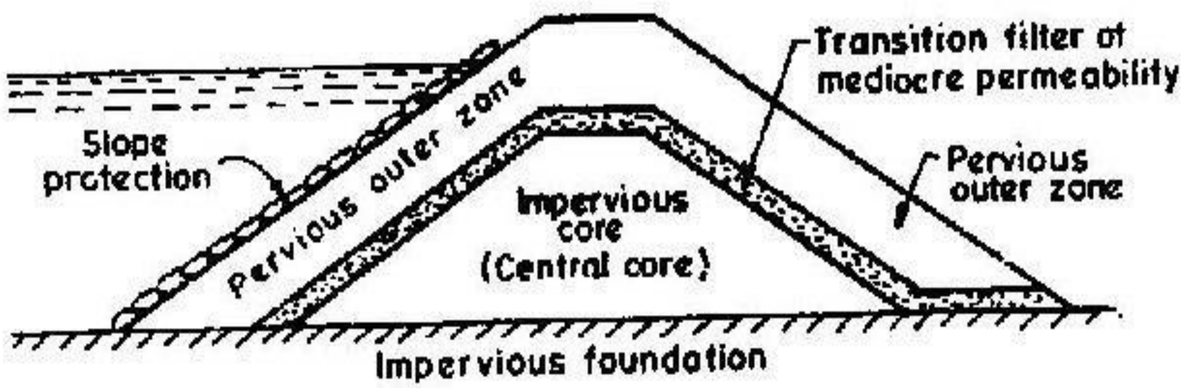
Types of Earthen Dams: The earthen dam can· be of the following three types:

- Homogeneous Embankment type
- Zoned Embankment type
- Diaphragm type.
- **Homogeneous Embankment type:** The simplest type of an earthen embankment consists of a single material and is homogeneous throughout. Sometimes a blanket of relatively impervious material may be placed on the upstream face. A purely homogeneous section is used, when only one type of material is locally available. Large dams are seldom designed as homogeneous embankments. A purely homogeneous section poses the problems of seepage, and huge sections are required to make it safe against piping, stability, etc. Due to this, a homogeneous section is generally added with an internal drainage system such as a horizontal drainage filter.

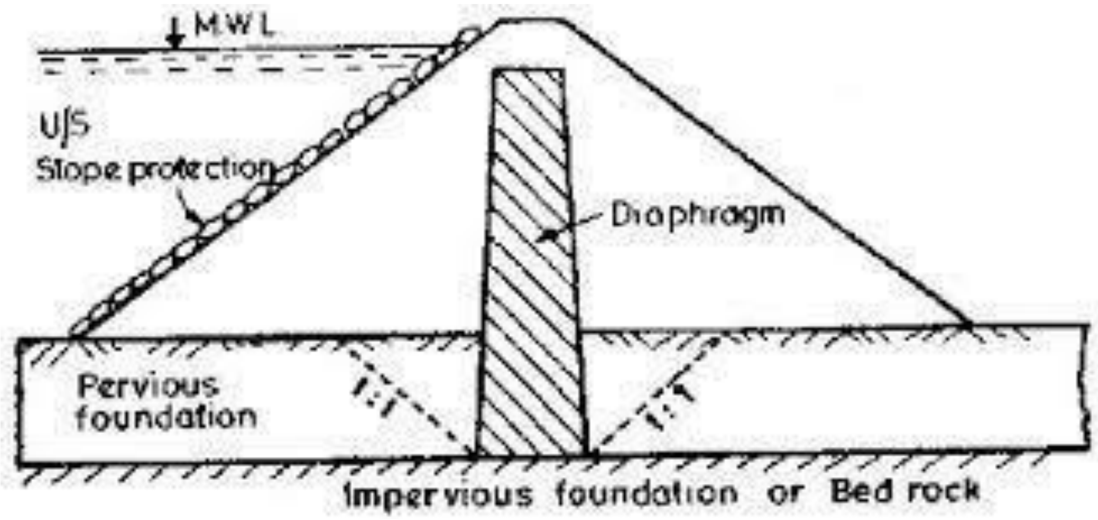


Homogeneous embankment provided with a drainage filter.

- **Zoned Embankment type:** Zoned embankments are usually provided with a central impervious core, covered by a comparatively pervious transition zone, which is finally surrounded by a much more pervious outer zone.The central core checks the seepage. The transition zone prevents piping through cracks which may develop in the core. The outer zone gives stability to the central impervious fill and also distribute the load over a large area of foundations.This type of embankments are widely constructed and the materials of the zones are selected depending upon their availabilities. Clay, inspite of it being highly impervious, may not make the best core, if it shrinks and swells too much. Due to this reason, clay is sometimes mixed with fine sand or fine gravel, so as to use it as the most suitable material for the central impervious core. Silts or silty clays may be used as the satisfactory central core materials. Freely draining materials, such as coarse sands and gravels, are used in the outer shell.

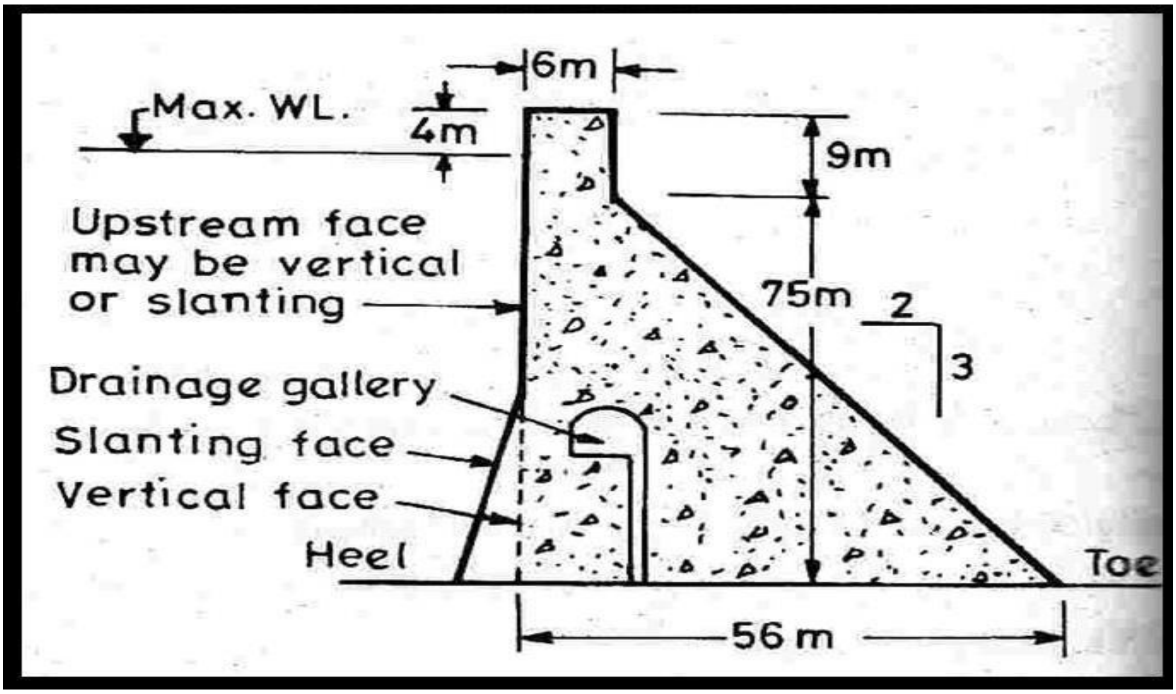


- **Diaphragm type:** Diaphragm type embankments have a thin impervious core, which is surrounded by earth or rock fill. The impervious core, called diaphragm, is made of impervious soils, concrete, steel, timber or any other material. It acts as a water barrier to prevent seepage throughout the dam. The diaphragm, may be placed either at the centre as a central vertical core or at the upstream face as a blanket. The diaphragm must also be tied to the bed rock or to a very impervious foundation material, if excessive under-seepage through the existing previous foundations has to be avoided.The diaphragm typeof embankments are differentiatedfrom zonedembankments, depending upon the thickness of thecore. If the thickness ofthe diaphragm at anyelevation is less than 10 metres or less than theheight of the embankment above the corresponding elevation, the dam embankment is considered to be of'Diaphragm Type'.



Gravity dam- types, description, Causes of failure and protectionmeasures:

- A gravity dam has been defined as a structure which is designed in such a way thatits own weight resists the external forces. This type of a structure is most durable andsolid, and requires very little maintenance. Such a dam may be constructed of masonryor concrete.
- The line of theupstream face of the dam, or the line of the crown of the dam if the upstream face insloping, is taken as the reference line for layout purposes, etc. and is known as the Base line of the dam or the 'Axis of the Dam'.
- When suitable conditions are available, suchdams can be constructed up to great heights. The highest gravity dam in the world isGrand Dixence Dam in Switzerland (284m), followed by ·Bhakta dam in India(226 m); both are of concrete gravitytype. The ratio of base width to height ofall these structures is less than 1: 1.



Types of Gravity Dams:

I. **Based on construction material used**
- Concrete dam
- Composite dam

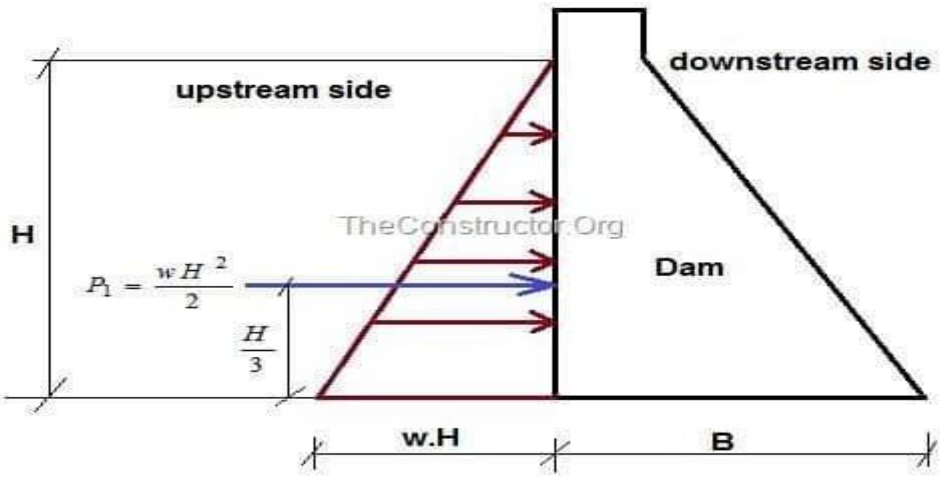
II. **Based on shape or plan**
- Straight dam
- Curved dam

III. **Based on the structural height**
- Low dam (up to 100 feet)
- Medium dam (100 feet to 300 feet)
- High dam (over 300 feet)

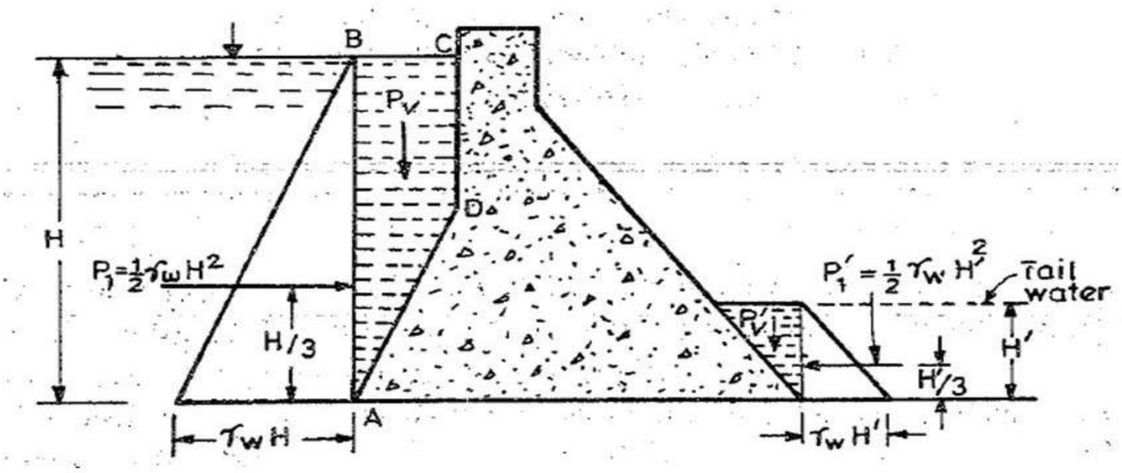
Forces Acting on Gravity Dam: The various external forces acting on a gravity dam may be

1. **Water Pressure**
2. **Uplift pressure**
3. **Pressure due to earthquake forces**
4. **Silt Pressure**
5. **Wave Pressure**
6. **Ice Pressure**
7. **The stabilising force is the weight of the dam itself.**

1. **Water Pressure:** Water pressure (P) is the most major external force acting on such a dam. The horizontal water pressure, exerted by the weight of the water stored on the upstream side on the dam can be estimated from rule of hydrostatic pressure distribution which is triangular in shape.When the upstream face is vertical,the intensity is zero at the water surface andequal to ϒw×H at the base; where ϒw is the unit weightof water and His the depth of water.The resultant force due to this external water= $1/2 \times \Upsilon w \times H^2$acting at H/3 from base.



:Water pressure due to water on upstream side only:



:Water pressure due to water on upstream side and downstream side:

2. **Uplift pressure:**

Water seeping through the pores, cracks and fissures of the foundation material, and water seeping through dam body and then to the bottom through the joints between the body of the dam and its foundation at the base exert an uplift pressure on the base of the dam. It is the second major external force and must be accounted for in all calculations. When drainage galleries are provided to relieve the uplift, the recommended uplift at the face of the gallery is equal to the hydrostatic pressure at toeϒw×H’ plus 1/3rd the difference of hydrostatic pressure between heel and toe. It is also assumed that the uplift pressures are not affected by the earthquake forces. The uplift pressures can be controlled by constructing cut-off walls under the upstream face, by constructing drainage channels between the darn and its foundation, and by pressure grouting the foundation.

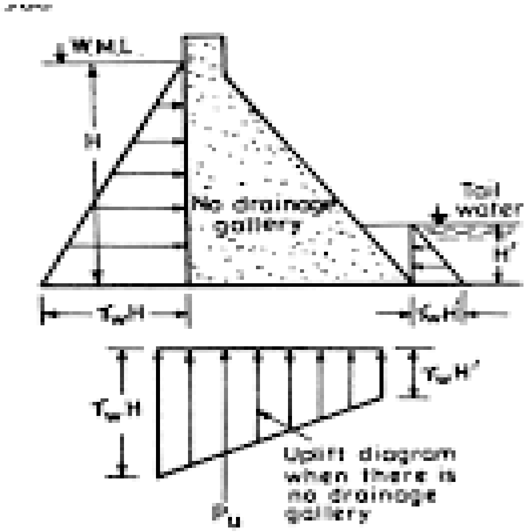


Fig. 19.3 (a) Uplift pressure (U) diagram, when no drainage gallery is provided.

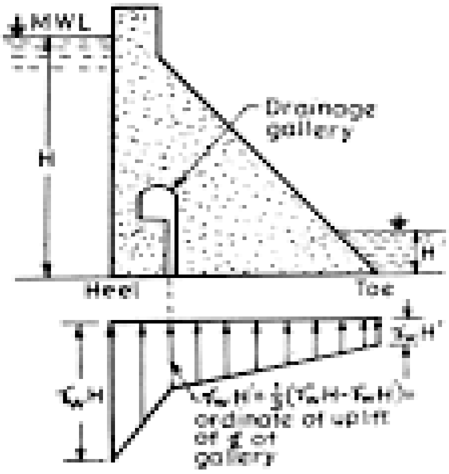


Fig. 19.3 (b) Uplift pressure (U) diagram, when drainage gallery is provided.

3. Pressure due to earthquake forces:

If the dam to be design is located in a region which is susceptible to earthquake, allowance must be made for the stress generated by the earthquake. An earthquake produces waves which are capable of shaking the Earth upon which the dam is resting, in every possible direction. The effect of an earthquake is, therefore, equivalent to imparting an acceleration to the foundations of the dam in the direction in which the wave is travelling at the moment. Earthquake wave may move in any direction, and for design purposes, it has to be resolved in vertical and horizontal components. Hence, two accelerations, i.e. one horizontal acceleration (α_h) and one vertical acceleration (α_v) are induced by an earthquake. The values of these accelerations are generally expressed as percentage of the acceleration due to gravity (g), i:e. α= 0.1g or 0.2 g, etc.

Effect of vertical acceleration (αv): A vertical acceleration may either act downward or upward. When it is acting in the upward direction, then the foundation of the dam will be lifted upward and becomes closer to the body of the dam, and thus the effective weight of the dam will increase and hence, the stress developed will increase. When the vertical acceleration is acting downward, the foundation shall try to move downward away from the dam body; thus reducing the effective weight and the stability of the dam, and hence is the worst case for designs.

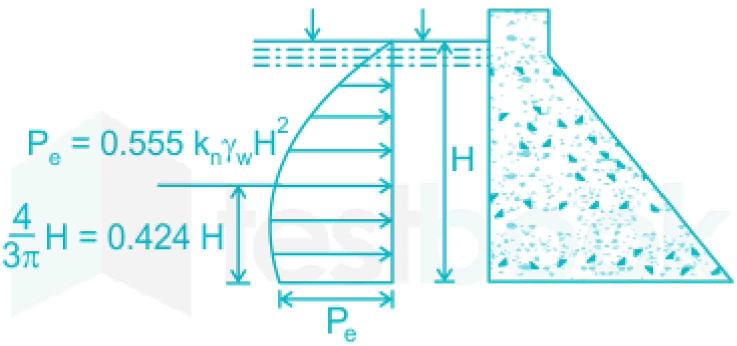
Such acceleration will, therefore, exert an inertia force given by $\mathbf{W/g \times \alpha_v}$ (Inertia Force= Mass ×Acceleration)

The net effective weight of the dam= $\mathbf{W - W/g \times \alpha_v}$

Effects of horizontal acceleration (α_h): Horizontal acceleration may cause the following two forces :

1) Hydrodynamic pressure
2) Horizontal inertia force.

1) Hydrodynamic pressure: Horizontal acceleration acting towards the reservoircauses a momentary increase in the waterpressure, as the foundation and dam accelerate towards the reservoir and the water resists the movement owing to its inertia.The extra pressure exerted by this process is known as hydrodynamic pressure.



Hydrodynamic pressure distribution

2) Horizontal inertia force: In addition to exerting the hydrodynamic pressure, the horizontal acceleration produces an inertia force into the body of the dam. This force is generated in order to keep the body and the foundation of the dam together as one piece. The direction of the produced force will be opposite to the acceleration imparted by the

earthquake. The amount of horizontal inertia force is equal to the product of the mass of the dam and the acceleration.

Horizontal inertia force= **$W/g \times \alpha_h$**

4. Silt Pressure:

Silts gets deposited against the upstream face of the dam. If h is the height of silt deposited, then the force exerted by this silt in addition to external water pressure, can be represented by Rankine's formula as: $P_{silt} = ½ \Upsilon_{sub} H^2$ Ka and it acts at H/3 from base.

Where, Ka is The Coefficient Of Active Earth Pressure of silt

Ka = (1 - sin Θ)/(1+ sin Θ)• Where Θ is the angle of internal friction of Soil, and cohesion is neglected. • ϒsub= Submerged unit weight of silt material • H= height of silt deposited.

5. Wave Pressure:

Waves are generated on the surface of the reservoir by the blowing winds, which causes a pressure towards the downstream side. Wave pressure depends upon the wave height.

Wave height may be given by the equation

Hw= 0.032 √ V.F + 0.763 – 0.271 (F) ¾ for F < 32 Km And

Hw= 0.032 √V.F for F > 32 Km.

Where Hw= height of water from top of crest and bottom of trough in metre. • V= Wind velocity in Km/ hr

F= Fetch or Straight length of water expanse in Km.

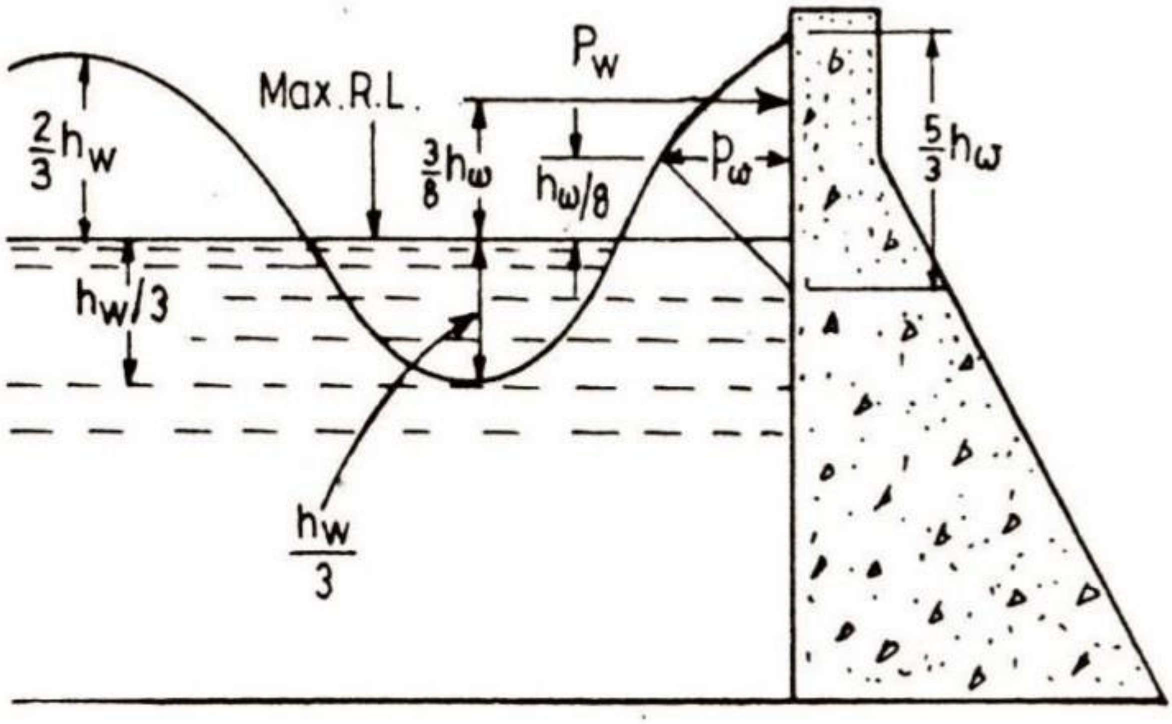
The maximum Pressure Intensity due to wave action may be given by **$P_w = 2.4 \gamma_w h_w$** and acts at h_w /2 metres above the still water surface.

The Pressure distribution may be assumed to be Triangle, of height 5 hw/3. Hence, the total force due to wave action (P_w)

$P_w = ½ (2.4 \gamma_w h_w) \times 5 h_w/3$

Or

$P_w = 2 \times \gamma_w \times h_w^2 = 2 \times 9.81 h_w^2$ KN/m = $19.62 h_w^2$ KN/m , This force acts at a distance of 3/8 h_w above the reservoir surface.



6. Ice Pressure:

The Ice Pressure which may be formed on the surface of the reservoir in cold countries, may sometimes melt and expand. The dam face has then to resist the thrust exerted by the expanding Ice. This force acts linearly along the length of the dam and at the reservoir level. The magnitude of this force varies from 250 to 1500 KN/ m2 depending upon the temperature variations. On an average, a value of 500 KN/ m2 may be allowed under ordinary conditions.

7. The stabilising force is the weight of the dam itself:

The weight of the dam body and its foundation is the major resisting force. In two dimensional analysis of a gravity dam, a unit length of the dam is considered. The Cross-Section can be divided into rectangles and triangles. The weight of each along with their C.Gs can be determined. The resultant of all these downward forces will represent the total weight of the dam acting at the C.Gs of the dam.

Modes of Failure and Criteria for Structural Stability of Gravity Dams:

A gravity dam may fail in the following ways:-

- (i) By overturning (or rotation) about the toe.
- (ii) By Crushing

(iii) By development of tension, causing ultimate failure by crushing.
(iv) By shear failure called sliding.

The failure may occur at the foundation plane (i.e. at the base of the dam) or at any other plane at higher level.

(I) **By overturning about the toe**: If the resultant of all the forces acting on a dam at any of its sections, passes the toe, the dam shall rotate and overturn about the toe. • Practically, such a condition shall not arise, as the dam will fail much earlier by compression. The ratio of the righting moments about toe to the overturning moments about toe is called the factor of safety against overturning. Its value generally varies between 2 and 3.

(II) **By Compression or Crushing:** A dam may fail by the failure of its material, i.e. the compressive stresses produced may exceed the allowable stresses, and the dam material may get crushed. The vertical direct stress distribution at the base is given by the equation

P= Direct Stress + Bending Stress

$$\mathbf{P_{max/min}} = \frac{\sum V}{B} \times \left[1 \pm \frac{6e}{B}\right].$$

Where, • E= Eccentricity of the resultant force from the centre of the base. • ∑ V=Total Vertical force • B= Base Width

(III) **By development of tension:** Masonry and Concrete gravity dams are usually designed in such a way that no tension is developed anywhere, because these materials cannot withstand sustained tensile stresses, If subjected to such stresses, these materials may finally crack. However, for achieving economy in designs of very high gravity dams, certain amount of tension may be permitted under severest loading conditions. This may be permitted because of the fact that such worst loading conditions shall occur only momentarily for a little time and would neither last long nor occur frequently. The maximum permissible tensile stress for high concrete gravity dams, under worst loading may be taken as 500 KN/ m2. In a dam, when such a tension crack develops, say at heel, crack width loses contact with the bottom foundation, and thus, becomes ineffective.

Hence, the effective width B of the dam base will be reduced. This will increase p_{max} at the toe. • Hence, a tension crack by itself does not fail the structure, but it leads to the failure of the structure by producing excessive compressive stresses.

In order to ensure that no tension is developed anywhere, we must ensure that p_{min} is at the most equal to Zero.

(IV) By sliding: Sliding (or Shear failure) will occur when the net horizontal force above any plane in the dam or at the base of the dam exceeds the frictional resistance developed at that level.

The friction developed between the two surfaces is equal to $\mu \sum V$.

In order that no sliding takes place, the external horizontal forces $\sum H$ must be less than the shear resistance $\mu \sum V$.

$$\sum \mathbf{H} < \mu \sum \mathbf{V}$$

OR

$$\frac{\mu \sum V}{\sum H} > 1$$

($\mu \sum V$) /($\sum H$)represents nothing but the factor of safety against sliding, which must be greater than unity.

Protection measures in Gravity Dam:

i. The material underlying the base of a dam i.e. the foundations of the dam, must be strong enough and capable to withstand the foundation pressure exerted on it under various conditions of loading and in dry as well as wet conditions.

ii. The surface preparation consist in removing the entire loose soil till a sound bed rock is exposed. The excavation should be carried out in such a way that the underlying rock is not damaged. The final surface obtained above is stepped, so as to increase the frictional resistance of the dam against sliding.

iii. The shear key may sometimes be provided in the centre but is generally provided at the heel .If faults seams, or shattered rock zones are detected in the exploratory geological investigations, special steps and remedies must be taken to ensure their removal.

iv. The foundation grouting can be done by (a) Consolidation Grouting and (b) Curtain Grouting. The entire foundation of the dam is consolidated by grouting. For this purpose, shallow holes are drilled through the foundation rock. The depths of these holes generally vary between 10 to 15 m. They are situated at about 5 to 20 m apart, in general area of the heel of the dam. After the holes have been drilled, mixture of cement and water called grout is forced into the holes at low pressure of about 30 to 40 N/ cm^2 .

Spillways- Types (With Sketch) and necessity:

A spillway is a structure constructed at a dam site, for effectively disposing of the surplus water from upstream to downstream. Just after the reservoir gets filled up, upto the normal pool level, water starts flowing over the top of the spillway crest (which is generally kept at normal pool level).Depending upon the inflow rate, water will start rising above the normal pool level, and at the same time, it will be let off over the spillway. Spillway, will dispose of the surplus water and will not let the water rise above the maximum reservoir level. So it act as a safety valve for a dam. It must be properly designed and must have adequate capacity to dispose of the entire surplus water at the time of the arrival of the worst design flood.

Types of Spillways: Depending upon the type of the structure constructed for disposing of the surplus water, the spillways can be of the following major types:-

a) Straight Drop Spillway.
b) Overflow Spillway generally called Ogee Spillway.
c) Trough Spillway or Open channel Spillway
d) Side Channel Spillway.
e) Shaft Spillway.
f) Syphon Spillway.

a) Straight Drop Spillway. This is the simplest type of spillway and may be constructed on small bunds or on thin arch dams, etc. It is a low weir and simple vertical fall type structure. The downstream face of the structure may be kept vertical or slightly inclined. The crest is sometimes extended in the form of an overhanging lip, which keeps small discharges away from the face of the overfall section. The water falls freely from the crest under the action of gravity.The design of such a spillway is done as that of a weir. Sometimes, a secondary dam of low height is constructed on the downstream side to create an artificial pool of water so as to dissipate the energy of the falling water.

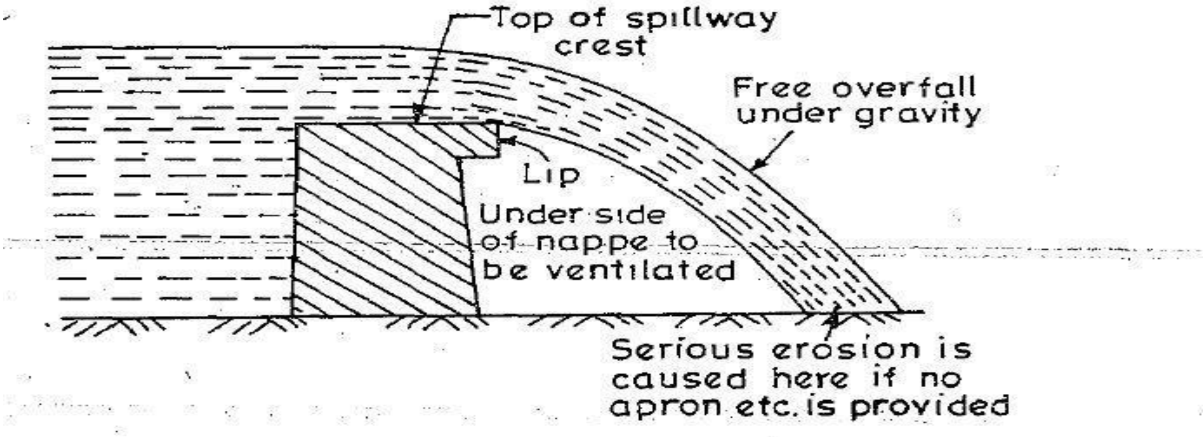


Fig. 21.3. (*a*) Straight drop spillway without d/s protection.

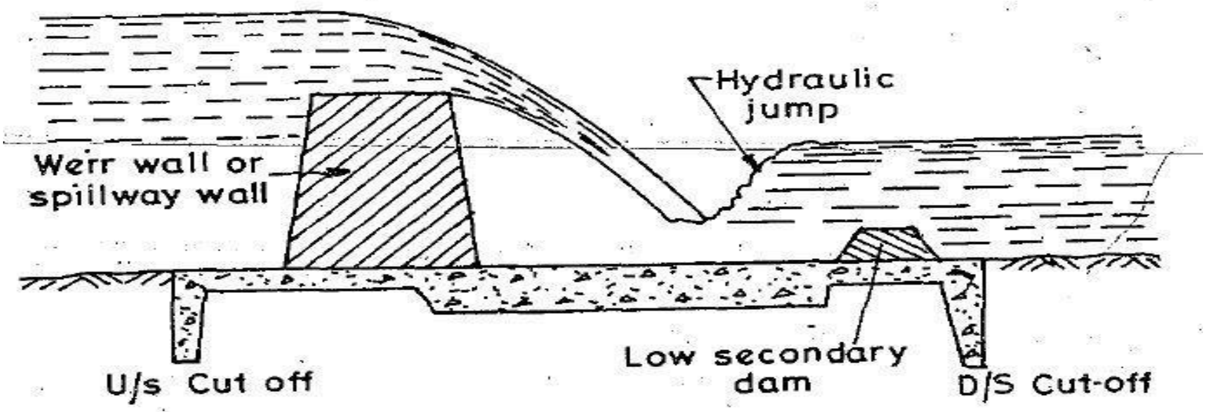
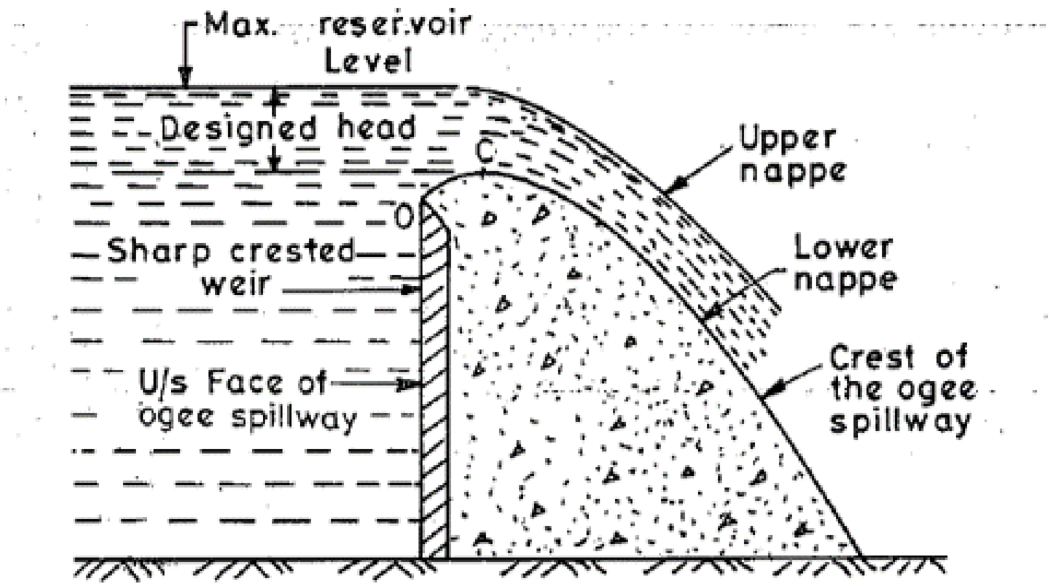
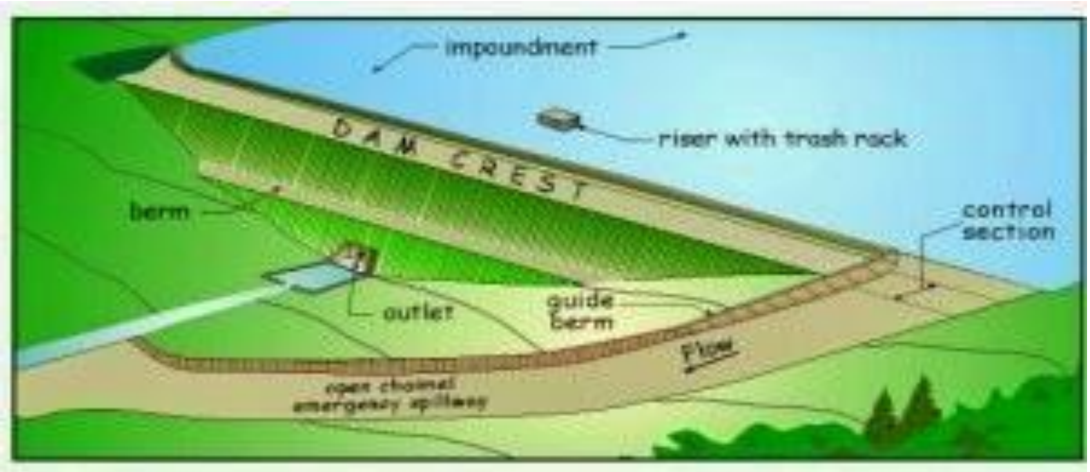


Fig. 21.3. (*b*) Straight drop spillway with d/s protection works.

b) Ogee Spillway: Ogee spillway is an improvement upon the 'free overfall spillway, and is widely used with concrete, masonry, arch and buttress dams.Such a spillway can be easily used on valleys where the width of the river is sufficient to provide the required crest lengthand the river bed below can be protected from scour at moderate costs.The profile of this spillway is made in accordance with the shape of the lower nappe of a free falling jet, over a duly ventilated sharp crested weir.The shape of the lower nappe of freely falling jet over a sharp crested weir can be determined by the principle of projectile. It generally rises slightly (to point C) as it originates from the crest (O) of a sharp crested weir and then falls to make a parabolic form.Now, if the space between the sharp crested weir and the lower nappe is filled with concrete or masonry, the weir so formed will have a profile similar to an 'ogee' (S-shaped curve in section), and hence called an 'ogee weir' or an 'ogee spillway'.This lower nappe, will then become the crest of the spillway. Since the lower nappe of the free falling jet will be different for different heads over the crest of the sharp crested .weir, the profile of the ogee weir is generally confined to the lower nappe that would be obtained for maximum head over the spillway.

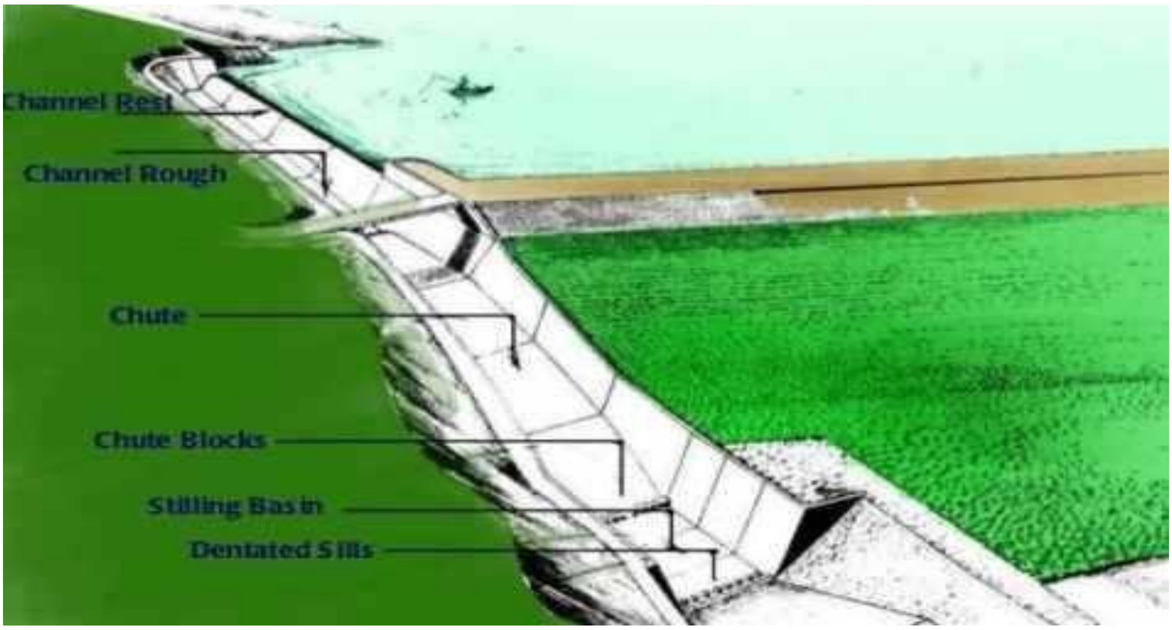


c) **Open channel Spillway:** Open channel or Trough spillway is a type of spillway in which surplus water from upstream is disposed to the downstream through a steeply sloped open channel. It is generally constructed at one end of the dam or separately away from the dam in a natural saddle in a bank of the river. It is suitable for gravity dams, earthen dams, rockfill dams, etc. But it is preferred when the width of the river valley is very narrow. The water flows along the steeply sloped chute or trough or open channel and reaches the downstream of the river. The slope of spillway is designed in such a way that the flow should be always in supercritical condition. To dissipate energy from the falling water, energy dissipators can be provided on the bed of open channelspillway.It is also called chute spillway.

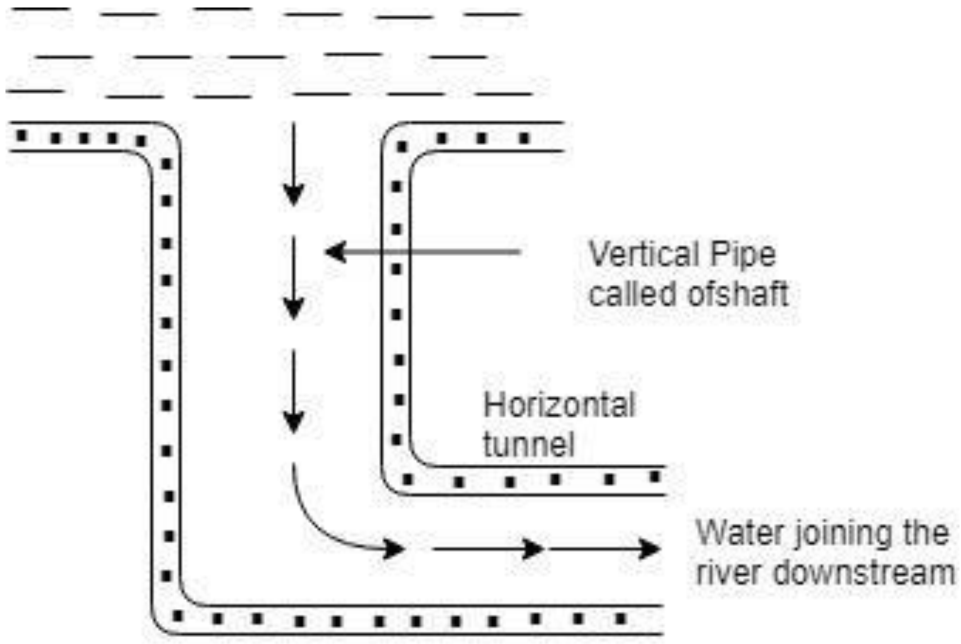


d) Side Channel Spillway: Side channel spillway is similar to Open channel spillway but the only difference is the crest of side channel spillway is located on one of its sides whereas crest of chute spillway is located between the side walls. In other words, the water spilling from the crest is turned to 90 degrees and flows parallel to the crest of side channel spillway unlike in chute spillway.

Side channel spillways are located just upstream and to the side of the dam. The water after flowing over a crest enters a side channel which is nearly parallel to the crest. This is then carried by a chute to the downstream side. Sometimes a tunnel may be used instead of a chute.

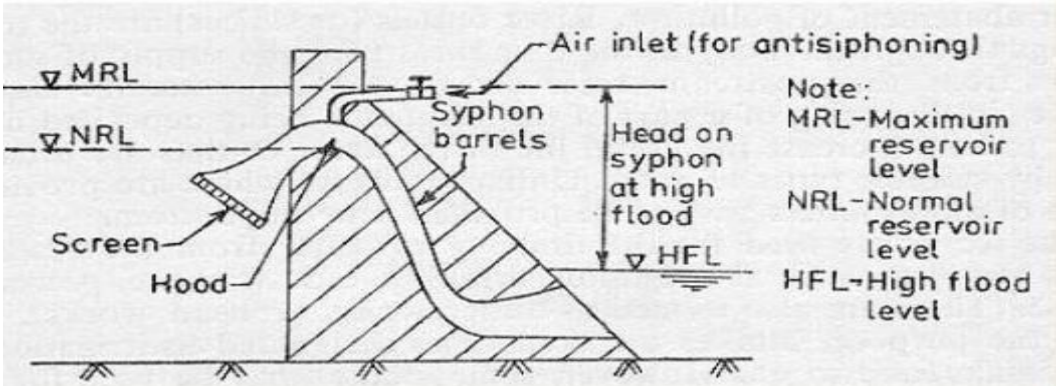


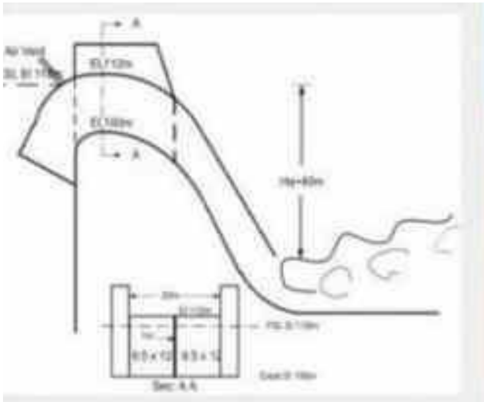
e) **Shaft Spillway:**A Shaft spillway is a type of spillway which consists of a vertical shaft followed by a horizontal conduit. The surplus water enters into the vertical shaft and then to the horizontal conduit and finally reaches the downstream of the channel.The shaft constructed is either artificial or natural. Excavation for the natural shaft is possible only when the hard rocky layer is present on the upstream side. The horizontal conduit either passes through the dam body or through the foundation of the dam.In the case of large projects, the inlet hole of the vertical shaft is specially shaped which is called as morning glory or glory hole of the spillway. Hence, shaft spillway is also called as Morning glory spillway or Bell Mouth spillway. Shaft spillway is recommended when there is no space to provide for other types of spillways such as ogee spillway, straight drop spillway, etc.



SHAFT SPILLWAY

f) **Syphon Spillway:** A siphon spillway is a type of spillway in which surplus water is disposed to downstream through an inverted U shaped conduit. It is generally arranged inside the body or over the crest of the dam.In both types of siphon spillways, air vents are provided at the bent portion of the upper passageway to prevent the entrance of water when the water level is below the normal poll level. Whenever the level rises above normal pool level, water enters into the conduit and is discharged to the downstream of the channel by siphonic action.





Necessity of Spillways:

a. The height of the dam is always fixed according to the maximum reservoir capacity. The normal pool level indicates the maximum capacity of the reservoir. The water is never stored in the reservoir above this level. The dam may fail by overturning so, for the safety of the dam the spillways are essential.
b. The top of the dam is generally utilized by making road. The surplus water is not be allowed to over top the dam, so to stop the over topping by the surplus water, the spillways become extremely essential.
c. To protect the downstream base and floor of the dam from the effect of scouring and erosion, the spillways are provided so that the excess water flows smoothly.

Chapter-06

CROSS DRAINAGE WORKS

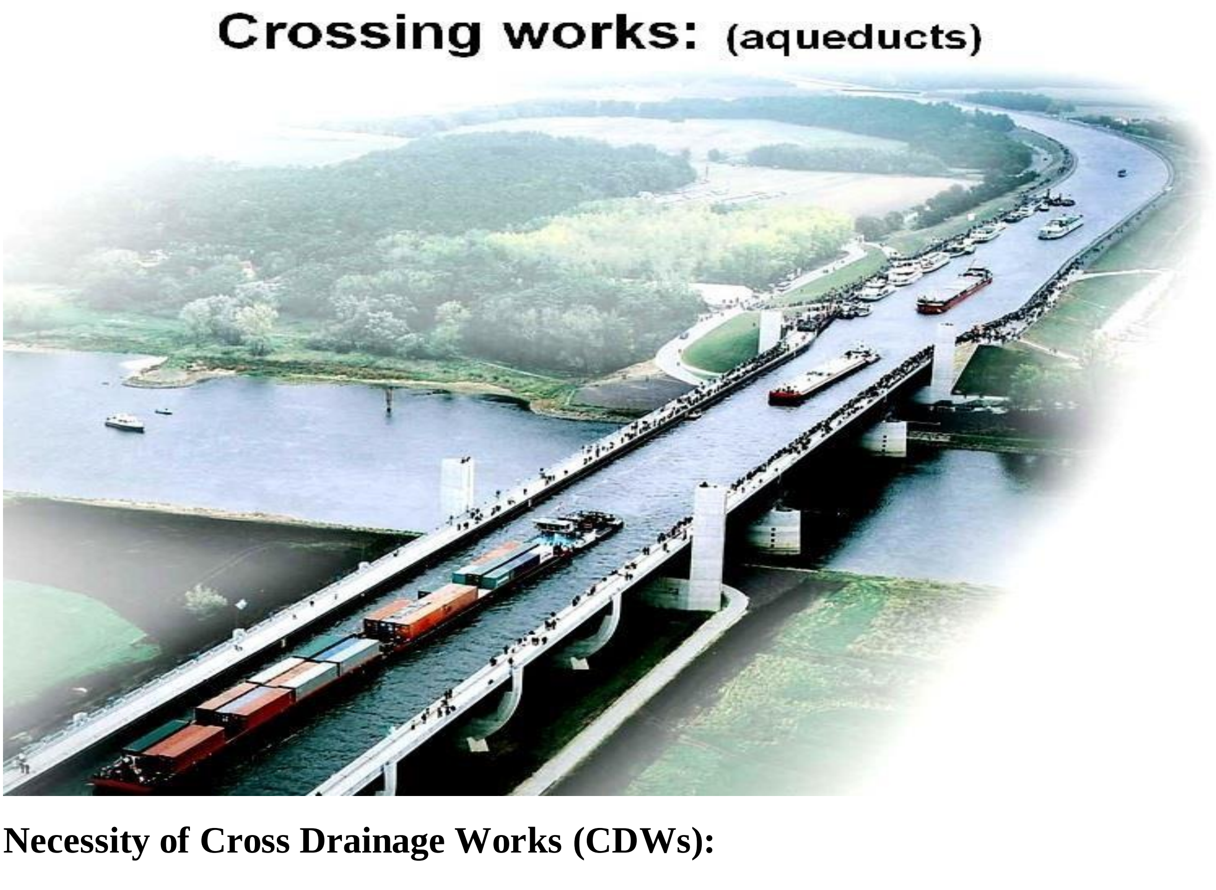
By: C.H

Functions and necessity of Cross drainage works - aqueduct, siphon, super-passage, level crossing

Concept of each with help of neat sketch

Functions and necessity of Cross drainage works - aqueduct, siphon,Super-passage, level crossing:

- In an Irrigation project, when the network of main canals, branch canals, distributaries, etc. are provided, then these canals may have to cross the natural drainages like rivers, streams, nallahs, etc. at different points within the command area of the project. The crossing of the canals with such obstacle 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 (CDWs).
- At the meeting point of canals and drainages, bed levels may not be same. Depending on their bed levels, different structures are constructed and accordingly they are designated by different names.



Necessity of Cross Drainage Works (CDWs):

i. 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.

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

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

Types of Cross Drainage Works:

A. Type I (Irrigation canal passes over the drainage)

- Aqueduct
- Siphon Aqueduct

B. Type II (Drainage passes over the irrigation canal)

- Super passage
- Siphon super passage

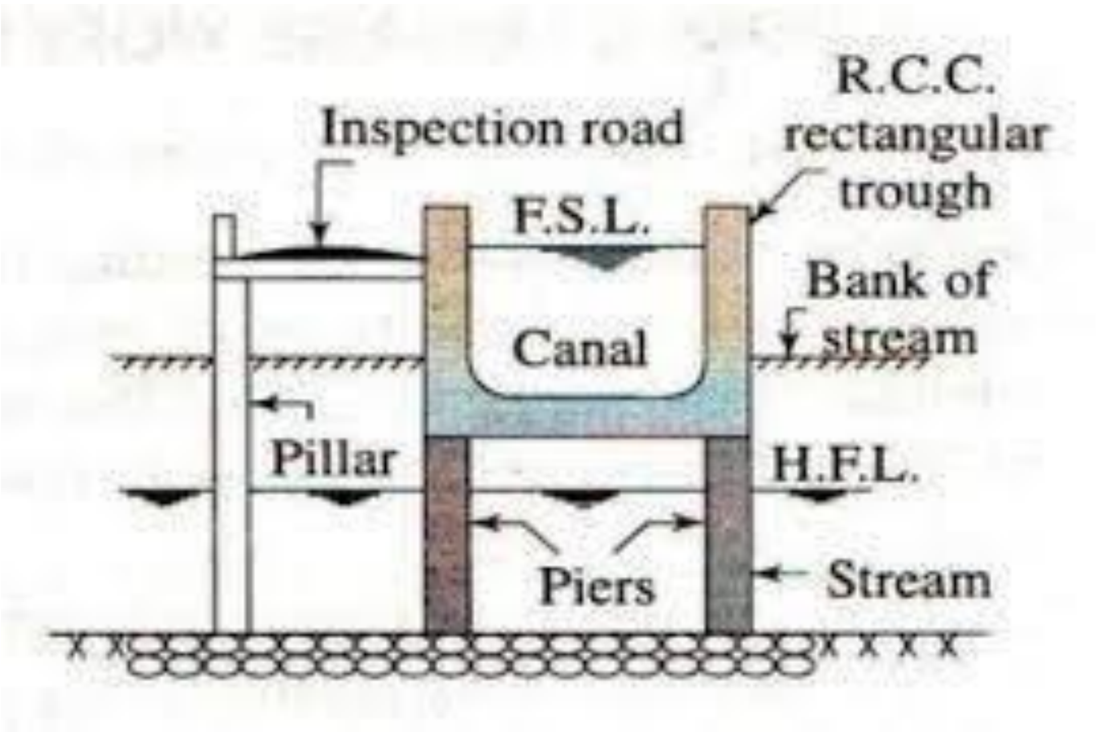
C. Type III (Drainage and canal intersection each other of the same level)

- Level crossing
- Inlet and outlet

Concept of each with help of neat sketch:

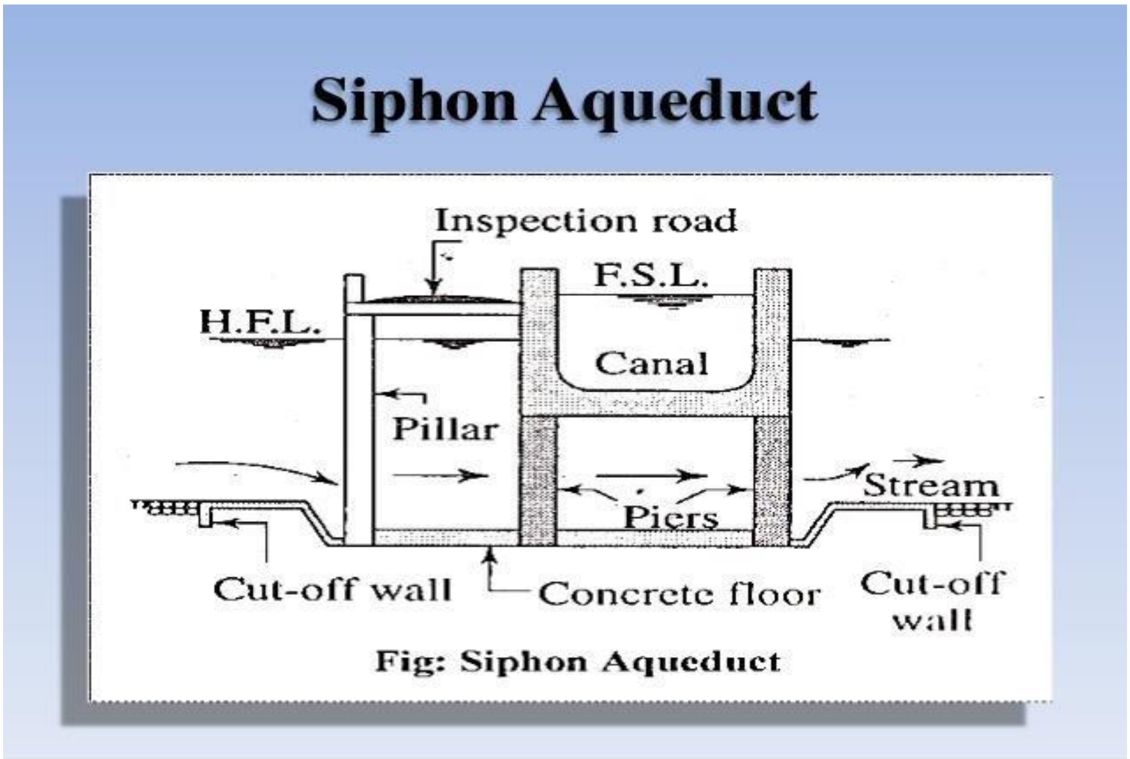
I. **<u>Type-I (Irrigation canal Passes over the Drainage):</u>** This condition involves the construction of following:

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



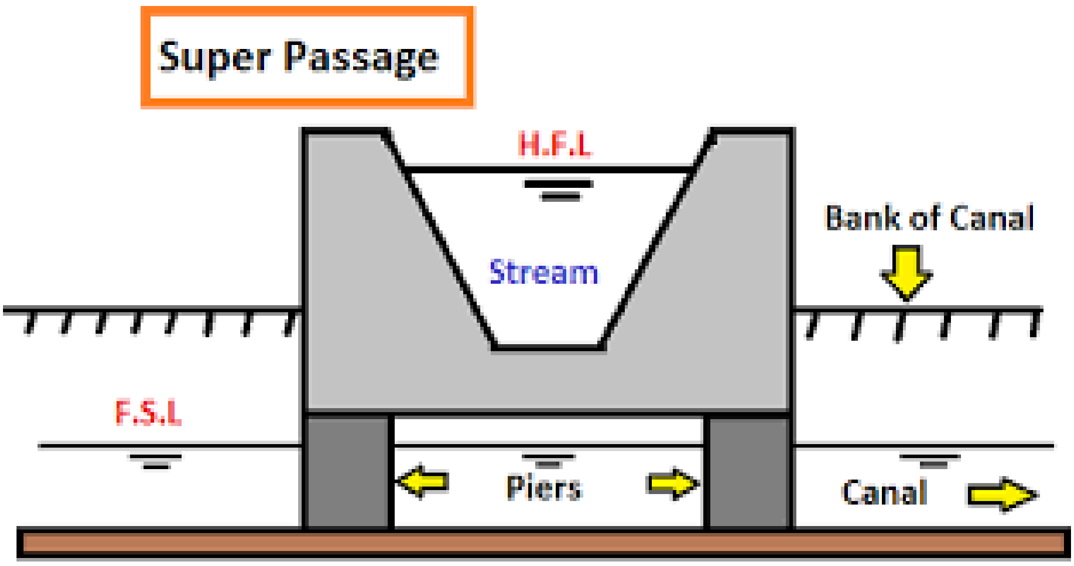
2. Syphon Aqueduct: In a hydraulic structure where the canal is taken over the drainage, but the drainage water cannot pass clearly below the canal. It flows under syphonic action. So, it is

known as siphon aqueduct. This structure is suitable when the bed level of canal is below the highest flood level.

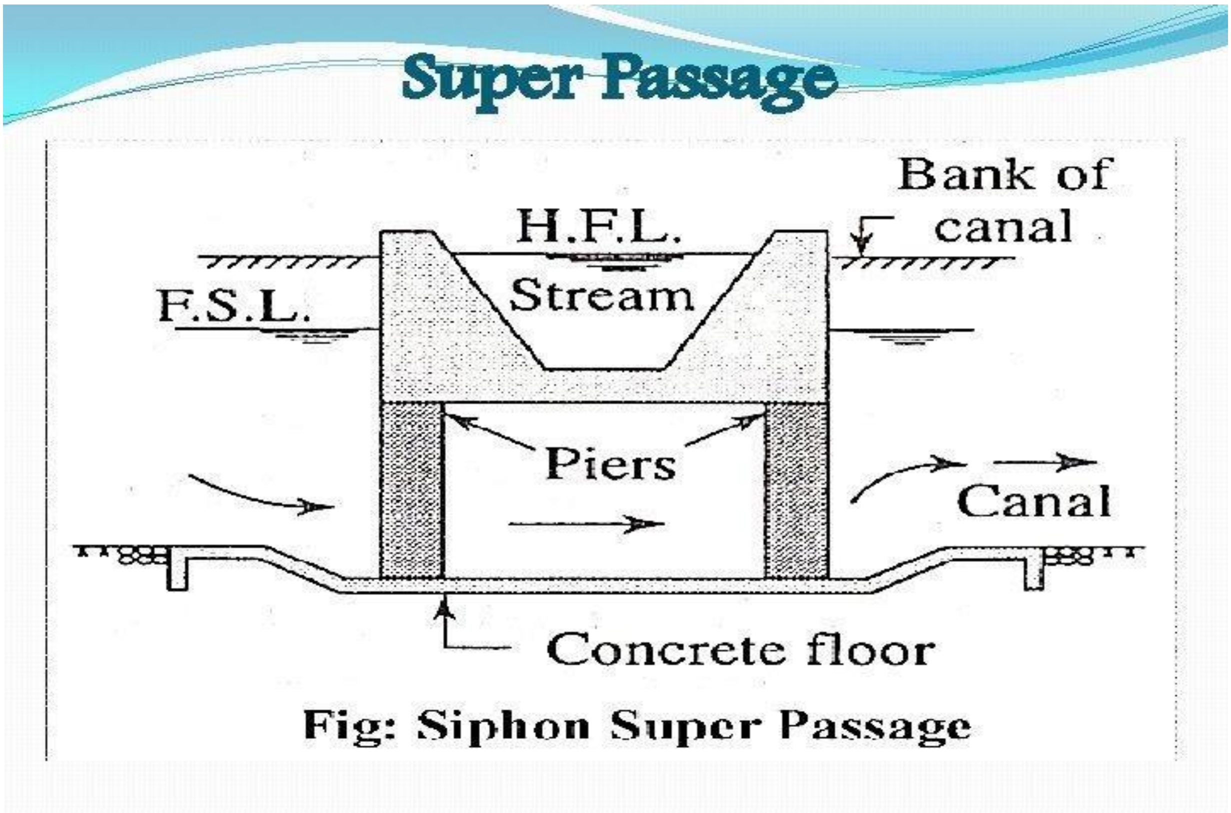


II. **<u>Type-II Drainage Passes Over the irrigation Canal:</u>**

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.

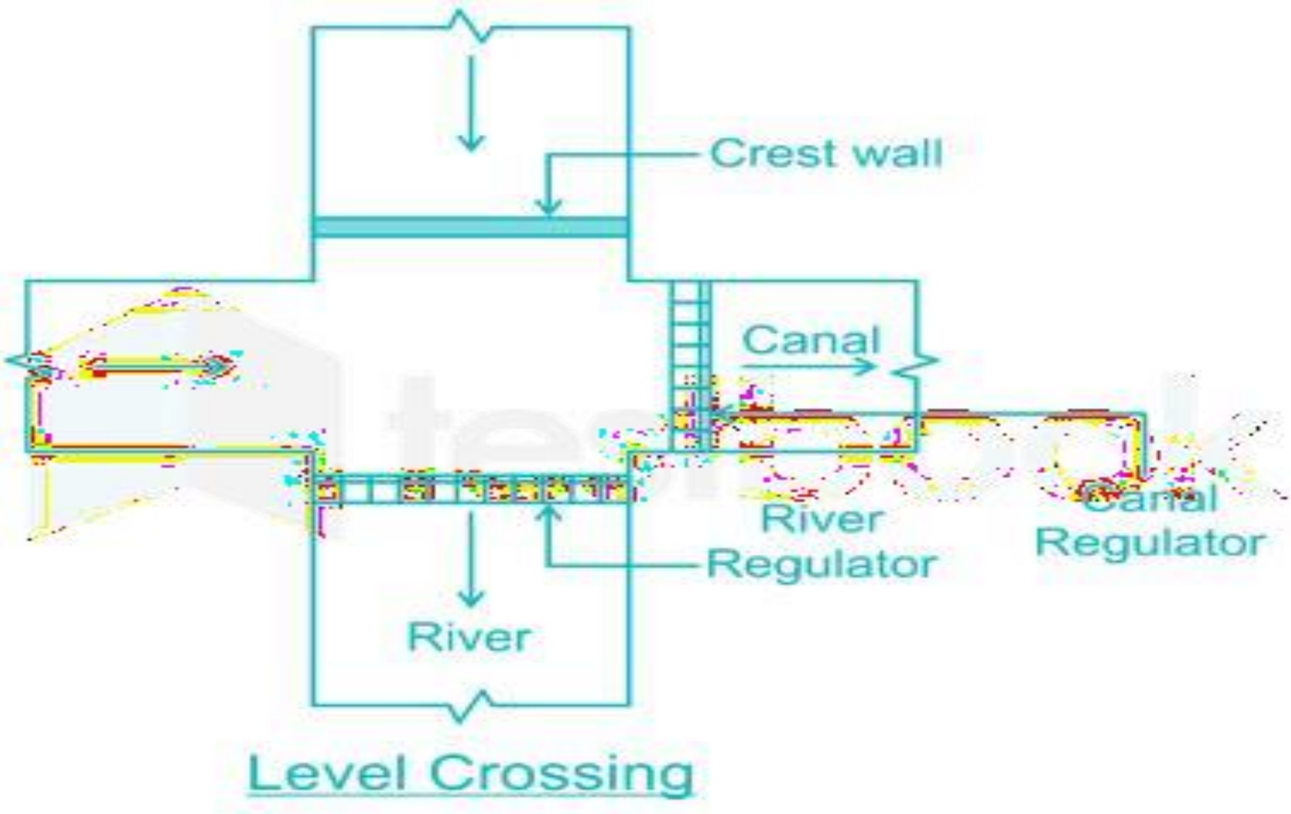


b) Syphon super passage:The hydraulic structure in which the drainage is taken over the irrigation canal, but the canal water passes below the drainage under syphonic action is known as siphon super passage. This structure is suitable when the bed level of drainage is below the full supply level of the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



III. <u>Type III Drainage and Canal Intersect each other at the same level:</u>

- Level crossing: When the bed level of canal and the stream are approximately the same and quality of water in canal and stream is not much different, the cross drainage work constructed is called level crossing where water of canal and stream is allowed to mix. With the help of regulators both in canal and stream, water is disposed through canal and stream in required quantity. Level crossing consists of following components (i) crest wall (ii) Stream regulator (iii) Canal regulator.


Crest wall
Canal
River
Regulator
Canal
Regulator
River
Level Crossing


Chesapeake and Delaware Canal (east entrance), Delaware
Image courtesy of Waterway Images (2006)
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➢ Inlet and outlet:When irrigation canal meets a small stream or drain at same level, drain is allowed to enter the canal as in inlet. At some distance from this inlet point, a part of water is allowed to drain as outlet which eventually meets the original stream. Stone pitching is required at the inlet and outlet. The bed and banks between inlet and outlet are also protected by stone pitching. This type of CDW is called Inlet and Outlet.