

## Module - IV

### - Cross Drainage Works :-

#### Introduction:-

A cross drainage work is a structure which is constructed at the crossing of a canal & a natural drain, so as dispose of drainage water without interrupting the continuous canal supplies.

→ A cross drainage work is generally a costly construction & must be avoided as far as possible.

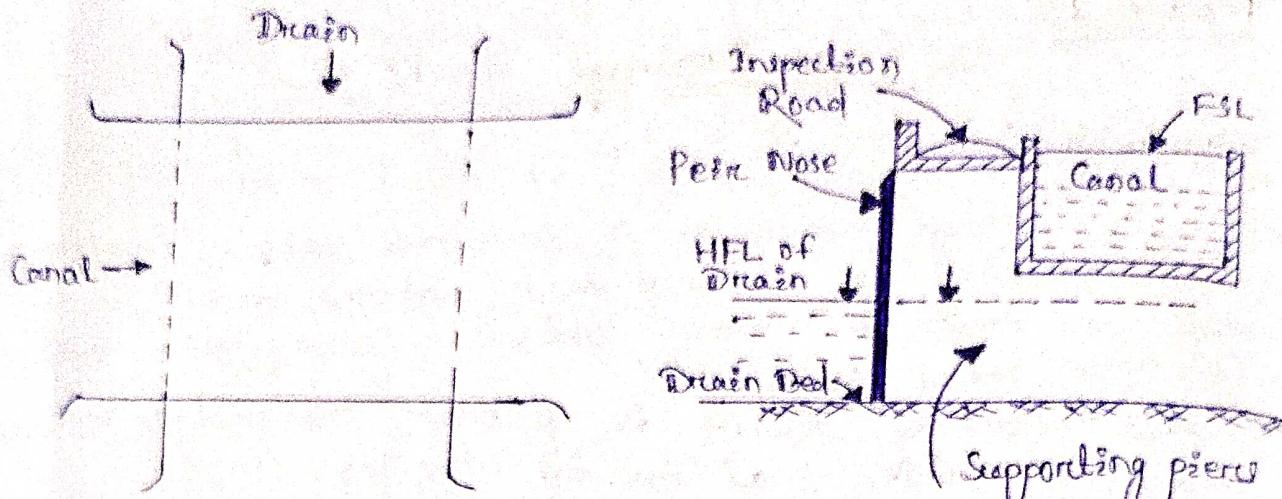
#### Types of Cross-drainage works:-

The drainage water intercepting the canal can be disposed of in either of the following ways:

- (i) By passing the canal over the drainage. This may be accomplished either through (i) an aqueduct; or through a (ii) Syphon-aqueduct.
- (ii) By passing the canal below the drainage. This may be accomplished either through a (i) super-passage; or through a (ii) Canal syphon generally called a syphon.
- (iii) By passing the drain through the canal, so that the canal water & drainage water are allowed to intermingle with each other. This may be accomplished through a (i) level crossing; or through (ii) inlets & outlets.

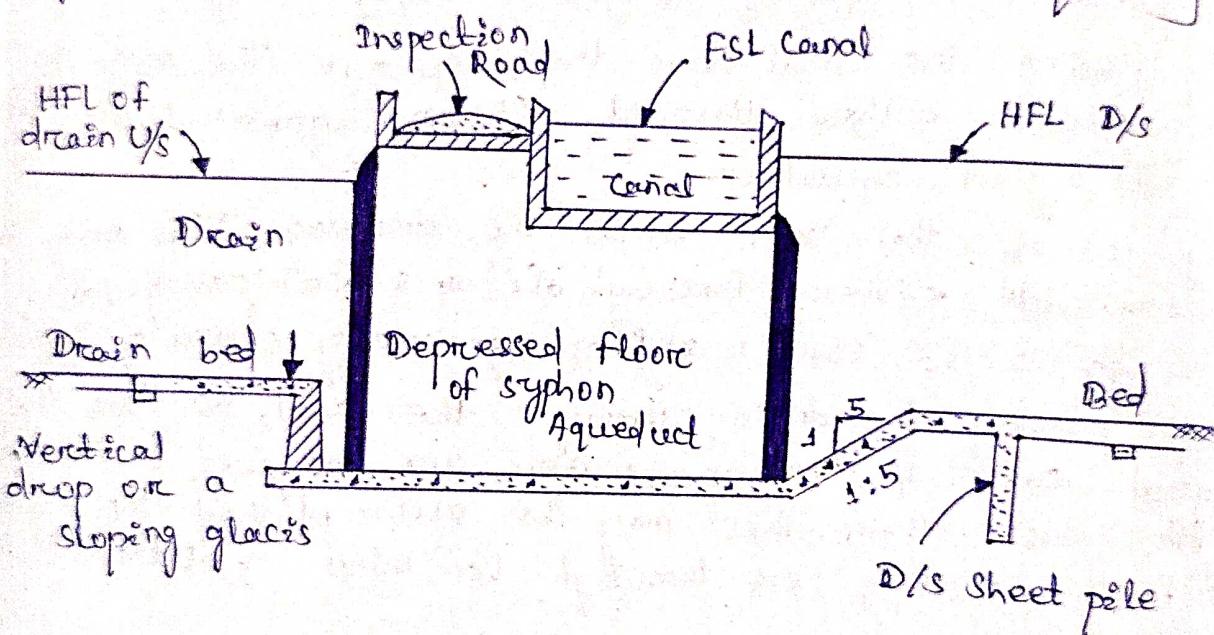
#### Aqueduct & Syphon Aqueduct:-

- In these works, the canal is taken over the natural drain, such that the drainage water runs below the canal either freely or under syphoning pressure.
- When the HFL of the drain is sufficiently below the bottom of the canal, so that the drainage water flows freely under gravity, the structure is known as an Aqueduct.
- However, if the HFL of the drain is higher than the canal bed & the water passes through the aqueduct barrels under syphonic action, the structure is known as Syphon Aqueduct.



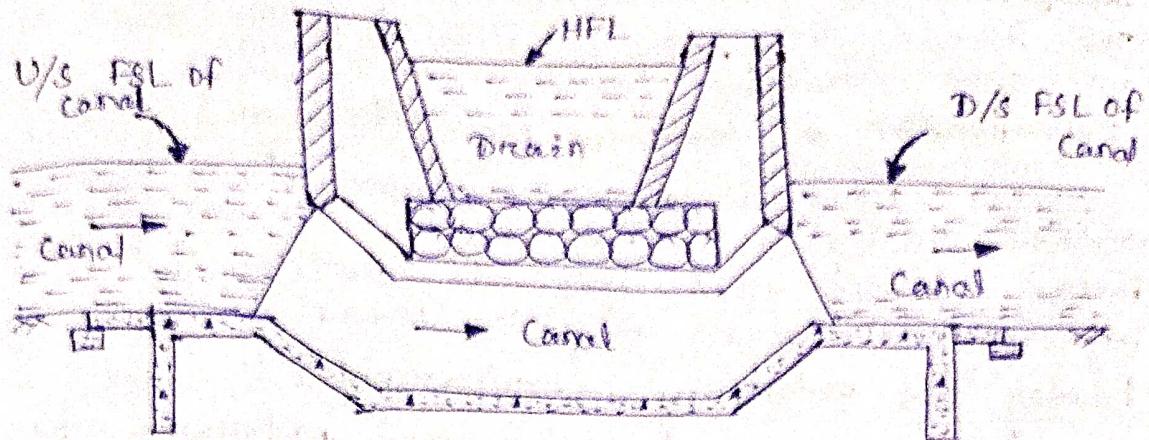
[Canal taken over the drain  
in an aqueduct or a  
syphon aqueduct]

[Typical cross-section of an  
aqueduct]



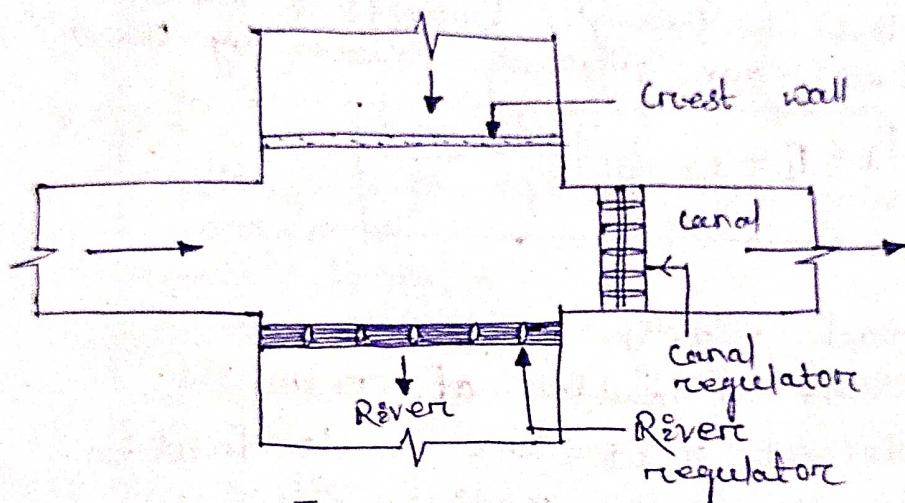
### Super-passage & Syphon:

- In these works, the drain is taken over the canal such that the canal water runs below the drain either freely or under syphonic pressure. When the FSL of the canal is sufficiently below the bottom of the drain through, so that the canal water flows freely under gravity, the structure is known as a Super-passage.
- However, if the FSL of the canal is sufficiently above the bed level of the drainage through, so that the canal flows under syphonic action under the through, the structure is known as a Canal syphon or a Syphon.



### Level Crossing :-

In this type of cross-drainage work, the canal water & drain water are allowed to intermingle with each other.



[Level crossing]

### Inlets & Outlets:-

An inlet is a structure constructed in order to allow the drainage water to enter the canal & get mixed with the canal water & thus to help in augmenting canal supplies.

When the drainage discharge is high or if the canal is small, so that the canal section can not take the entire drainage water, an outlet may sometimes be constructed to escape out the additional discharge at a suitable site, a little downstream along the canal.

## Design considerations for cross drainage works:

The following steps may be involved in the design of an cross drainage work.

### (i) Determination of maximum flood discharge:-

→ The high flood discharge for smaller drains may be worked out by using empirical formulae, & for large drains other reliable methods such as hydrograph analysis may be used.

### (ii) Fixing the waterway requirements:-

→ An approximate value of required waterway for the drain may be obtained by Lacy's formula,

$$P = 4.75 \sqrt{Q}$$

### (iii) Head loss through barrel:-

→ The head loss ( $h$ ) through barrels & the velocity ( $V$ ) through them are generally related by Darcy's formula,

$$h = \left[ 1 + f_1 + f_2 \frac{L}{R} \right] \frac{V^2}{2g} - \frac{V_a^2}{2g}$$

$V_a$  = Approach velocity

$f_1$  = Coefficient of head loss at entry

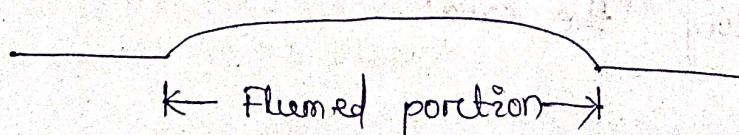
$f_2$  = Coefficient of head loss due to friction

$R$  = Hydraulic mean radius

### (iv) Fluming of Canal:-

→ The contraction in the waterway of the canal will reduce the length of barrels or width of barrels. This likely to produce economy in many cases.

→ This generally not done in case of earthen banks.

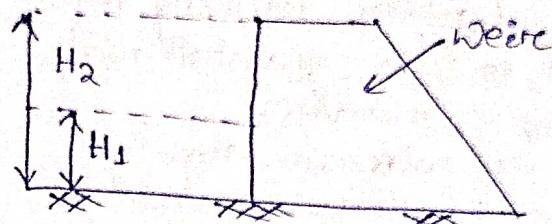


## Weir & barrage:

### Weir:

When the bed level of canal is at higher than the river level then the water can not be diverted towards the canal.

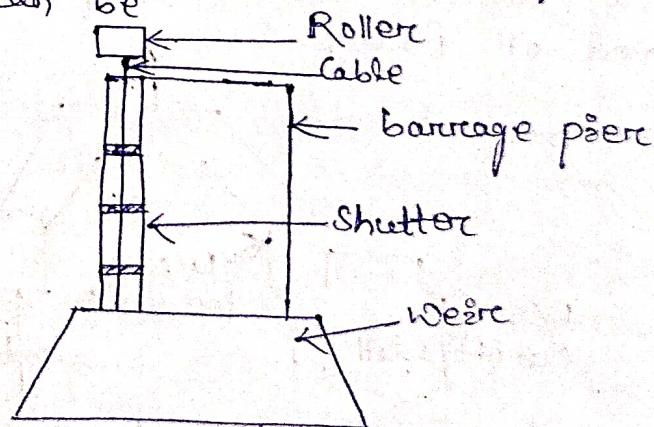
- > So as to raise the water level an obstruction is constructed which is called as Weir.
- > In weir most of the water is obstructed by raising the crest.
- > It may be constructed with masonry or concrete.
- > Water level raised from  $H_1$  to  $H_2$ .



### Barrage:

When the water level on the upstream side of the weir is required to be raised to different level at different times.

- > Barrage is an arrangement of adjustable gates or shutters etc. by opening the adjustable gates.
- > Hence the water level can be raised by shutter.



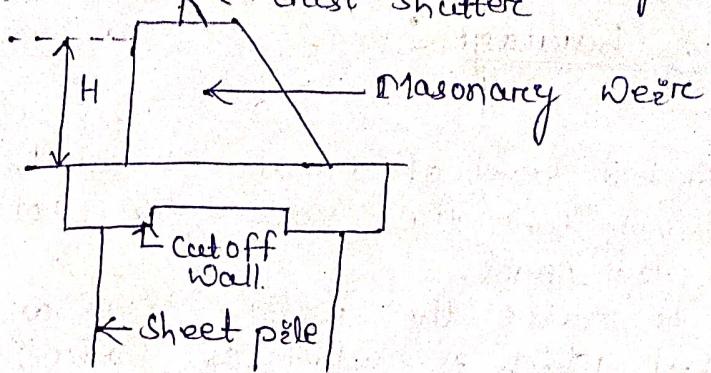
### Types of Weir:

The following are different types of weirs

- Masonry Weir
- Rock fill Weir
- Concrete Weir
- Masonry Weir:

- > Masonry Weir is constructed over the impervious floor.
- > Cut off walls are provided at both sides of floor.
- > Sheet piles are provided at both side of floor.
- > The crest shutters are provided to raise the water level if required.

→ The shutters are dropped down during flood.

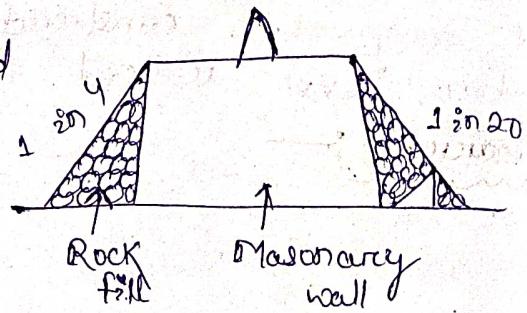


### (b) Rock-fill Weir:

→ It consists of masonry wall which is provided with adjustable crest shutters.

→ The U/S rockfill is constructed with boulders forming slope of 1 in 4 & grouted with cement mortar.

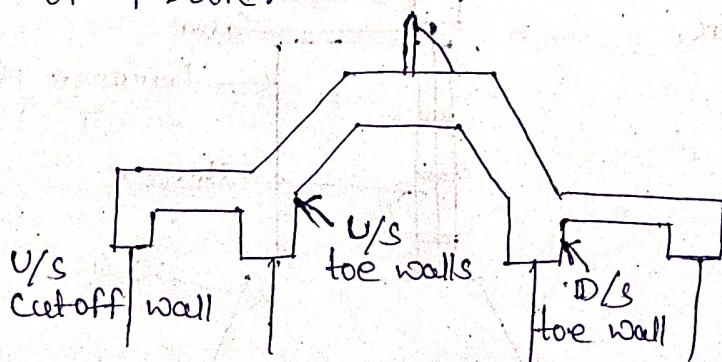
→ The downstream sloping consist of core walls & boulders grouted with cement mortar in 1 in 20.



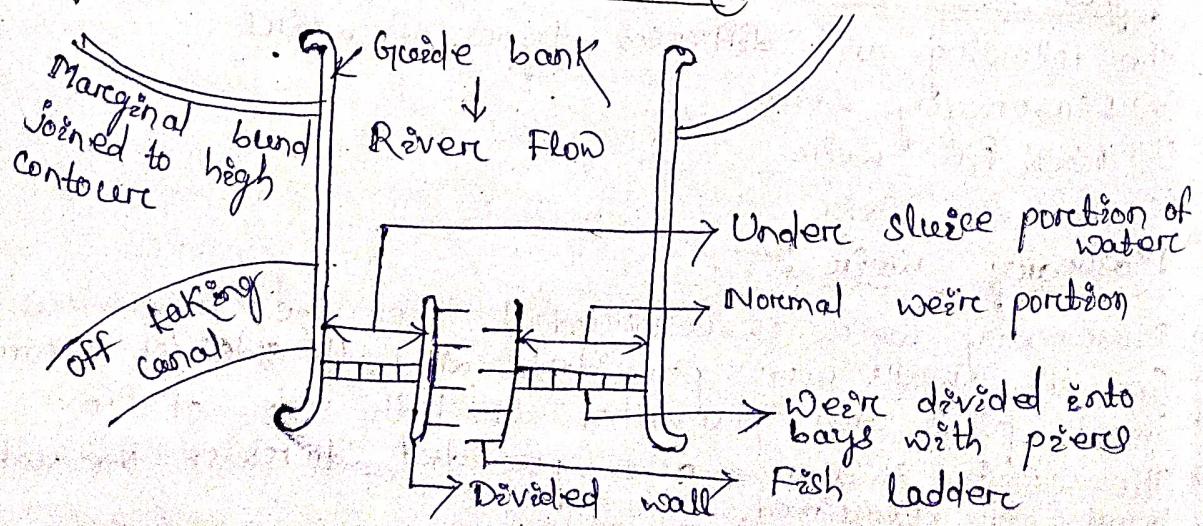
### (c) Concrete Weir:

→ Now a days the weir is constructed with reinforced cement concrete.

→ The impervious flood & weir are made monolithic. The cut off walls are provided at the U/S & D/S end of floor.



### Layout of diversion head work:



## Components of Diversion head work :-

Weir or barrage

Divide wall

Scouring sluice or venter sluice.

Fish ladder

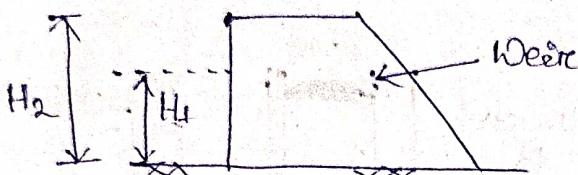
Canal head regulator

Silt excluder

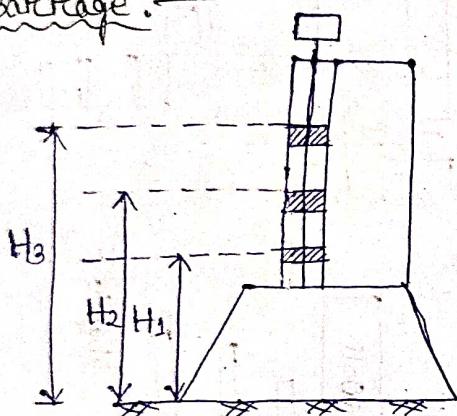
Guide bank

Marginal embankment or dyke

Weir :-



Barrage :-



Divide wall :-

The divide wall is a long wall constructed at right angles to the weir or barrage made by stone masonry or cement concrete.

On U/S side the wall is extended upto canal cover & on D/S it is extended upto launching apron.

It also helps in the entry of silt free water into the canal by forming silt water pocket.

It controls the eddy current in front of canal head.

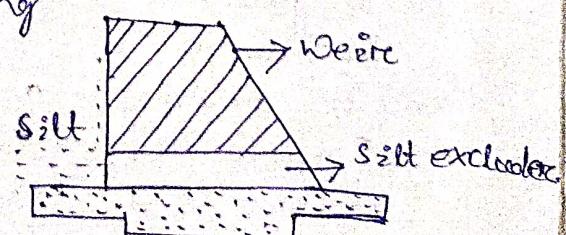
It resists the overtopping effect of the weir/barrage caused by presence of water.

Scouring sluices or venter sluices :-

The scouring sluices are the opening provided at the base of the weir or barrage.

These openings are provided with adjustable gates.

Normally gates are kept closed so that the silt get deposited.



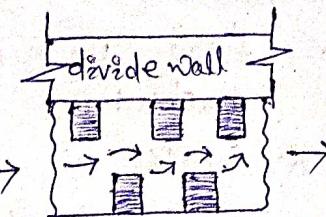
→ When silt deposition becomes appreciable the gates are opened & the muddy water flows towards D/S side.

#### 4. Fish Ladders:

→ The fish ladder is provided just by the side of the divide wall for the free movement of fishes.

→ The tendency of fish is to move from upstream to downstream in winters & from d/s to U/S in monsoon.

→ In this fish ladder the baffle walls are constructed in a zigzag manner so that the velocity of flow does not exceed 3 m/sec.



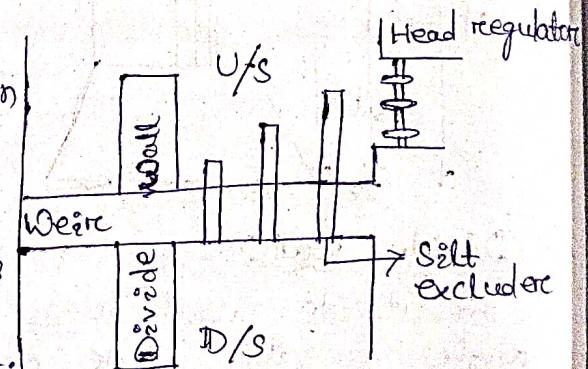
#### 5. Canal Head Regulators:

→ A structure which is constructed at the head of the canal to regulate the flow of water is known as canal head regulator.



#### 6. Silt Excluder:

→ The heavy silt cause sedimentation in the pocket. So to eliminate the suspended heavy silt, the silt excluder is provided.



#### 7. Guide Bank:

→ It is an earthen embankment with curved heads on both sides.

→ The upstream curved head extends upto 1.5 L & d/s curved head extends upto 0.25 L from centre line of the barrage.

→ It serves the following purposes:-

(i) It protects the barrage from the effect of scouring & erosion.

(ii) It provides a straight approach towards the barrage.

(iii) It prevents the tendency of changing the course of river.

## Dyke or marginal embankment:

These are constructed parallel to the river bank on both sides.

It retains the flood water or storage water within a specified section.

It protects valuable agricultural land from devastation during heavy flood.

## Chapter-

## Theory of Seepage & design of Weir & barrage:

## Failure of Weir/barrage due to Sub surface flow:

### i) By piping/Under mining:

The water from the U/S side continuously percolates through the bottom of the foundation & emerges at the downstream side. The force of percolating water may lift up the soil by progressive removal of soil from beneath the foundation. The phenomenon is known as failure by piping or undermining.

### ii) By uplift pressure:

The percolating water exerts an upward pressure on the foundation of the weir/barrage.

If this uplift pressure is not counter balanced by self weight of dam it may fail by rupture.

## Design Consideration for cross drainage work:

### i) Determination of maximum flood discharge:

The high flood discharge for smaller drains may be worked out by using empirical formula & for larger drains, reliable methods are used such as hydrograph.

### ii) Fixing the water way requirements:

An approximate value of required water way for the drain may be obtained by using Lacey's formula

$$P = 4.75 Y Q$$

### iii) Afflux & head loss through Syphon barrels:

The head loss can be calculated by,

$$h = \left[ 1 + f_1 + f_2 \frac{L}{R} \right] \frac{v^2}{2g} - \frac{V_a^2}{2g}$$

### (iv) Flushing of the canal:

The contraction in the waterway of the canal will reduce the length or the width of aqueduct.

### Bligh's Creep Theory:

- Bligh's creep theory states that the percolating water creeps along the profile of the bottom of the hydraulic structure which is in contact with the subsoil.
- The path traced by the percolating water is known as creep length.
- The loss of head per unit creep length is known as hydraulic gradient which is constant throughout the passage.
- Loss of head is proportional to creep length.

Let  $H$  = depth of water on one side.

$S$  = length of impermeable floor

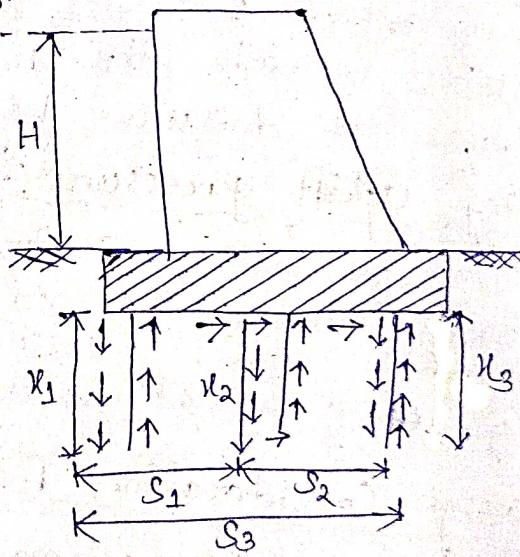
$x_1, x_2, x_3$  = length of sheet piles

$$\text{Length of creep} = S + 2x_1 + 2x_2 + 2x_3$$

Hydraulic gradient per unit

$$\text{Creep length} = \frac{H}{L}$$

$$= \frac{S + 2x_1 + 2x_2 + 2x_3}{H}$$



The reciprocal of hydraulic gradient i.e.  $\frac{L}{H}$  is known as Bligh's creep coefficient ( $C$ )

$$C = \frac{L}{H} \Rightarrow L = CH$$

$$\Rightarrow \boxed{\frac{H}{L} = \frac{1}{C}}$$

### (a) Safety against piping:

Creep length should be sufficient to have safe hydraulic gradient, i.e.  $\boxed{\frac{H}{L} = \frac{1}{C}}$

According to Bligh's creep theory,  $\frac{H}{L} \leq \frac{1}{C}$  there will be no danger of piping.

### Safety against uplift pressure:

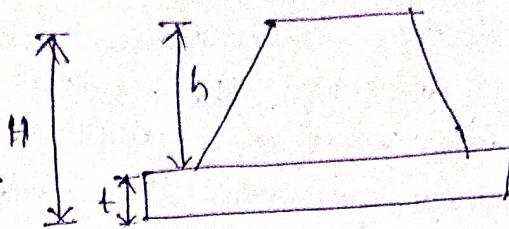
For equilibrium from the uplift pressure must be counterbalanced by self wt. of Moore  $\gamma_w H = \gamma_w G_f \cdot t$

$$\Rightarrow H = G_f \cdot t$$

$$\Rightarrow (H-t) = (G_f \cdot t - t)$$

$$\Rightarrow h = t(G_f - 1)$$

$$\Rightarrow t = \frac{h}{G_f - 1}$$



$h$  = ordinate of hydrostatic gradient from the floor

$H$  = from the line of floor

$t$  = thickness of floor

Considering FOS as  $\frac{4}{3}$ ,  $t = \frac{4}{3} \frac{h}{G_f - 1}$

### Limitations of Blyth's theory:

- (i) No distinction b/w horizontal & vertical creep.
- (ii) No significance of exit gradient.
- (iii) The assumption that the head loss is proportional to creep length may not be true.
- (iv) No distinction between short & long sheet pile.

### Lane's Weighted Creep Theory:

Lane, on the basis of his analysis carried out about 200 dams all over the world, stipulated that the horizontal creep is less effective in reducing uplift than the vertical creep.

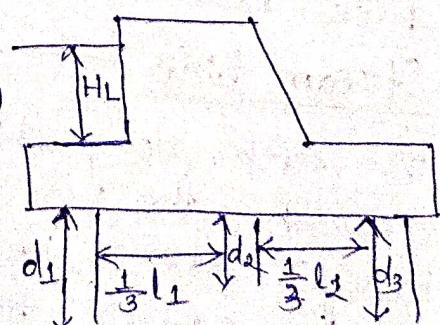
He, therefore, suggested a weightage factor of  $\frac{1}{3}$  for the horizontal creep, as against 1.0 for the vertical creep.

The total Lane's creep length ( $L_t$ ) is given as :

$$L_t = (d_1 + d_1) + \frac{1}{3} L_1 + (d_2 + d_2) + \frac{1}{3} L_2 + (d_3 + d_3)$$

$$= \frac{1}{3} \cdot (L_1 + L_2) + 2(d_1 + d_2 + d_3)$$

$$= \frac{1}{3} \cdot b + 2(d_1 + d_2 + d_3)$$



## Khosla's Theory:

- Since 1910 the hydraulic structures were designed on the basis of Bligh's creep theory.
- But some structures get badly affected because of undermining.
- Further investigation were made by Dr. A.H. Khosla & detected the actual pressure.
- Deep vertical cutoff at the d/s end of impervious floor prevents the undermining more effectively.
- The exit gradient are determined from flow pattern & permeability.
- Depending on various factors the following terms are determined.
  - (i) Exit gradient
  - (ii) Length of floor
  - (iii) Thickness of floor
  - (iv) Depth of sheet piles.
- According to Khosla the steady seepage in a vertical plane for a homogeneous soil can be expressed as Laplacian eq<sup>n</sup>.

$$\frac{d^2\phi}{dx^2} + \frac{d^2\phi}{dz^2} = 0$$

where,  $\phi$  = Flow potential =  $Kh$

$K$  = Co-efficient of permeability

$h$  = Pressure head

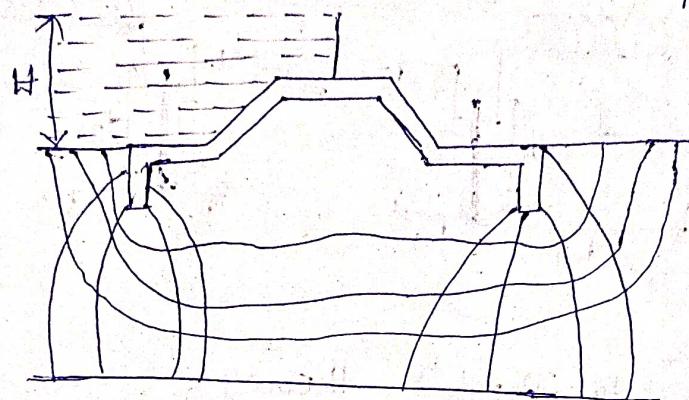
It represents two sets of curve intersecting each other, one set of lines is called stream line & the other is called equipotential line. The resultant flow diagram showing both the sets of curve is called a flow net.

## Stream line:

- The path along which the subsurface water flows through the soil indicated the stream line.
- Every water particle traces out its own streamline while moving from U/s to d/s below the foundation of the hydraulic structure. The first stream line just follows the bottom surface of foundation.

## Equipotential Line:

Every stream line possesses a certain head  $H$  (i.e., the depth of water on U/S), when it first enters the soil. This head goes on decreasing as it travels towards the d/s & ultimately becomes zero, on different streamlines there may be a point of equal residual head ' $h$ '. If these points are joined, then a curve as obtained known as equipotential line.



## Exit Gradient:

The exit gradient is said to be critical, when the upward disturbing force on the grain is just equal to the submerged weight of the grain at the exit. When a factor of safety equal to 4 or 5 is used, the exit gradient can then be taken as the safe exit gradient.

$$\text{Now, } \omega_s = \gamma_w (1-n) (G_f - 1)$$

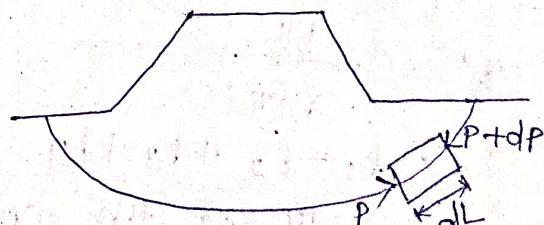
For critical conditions

$$F = \omega_s$$

$$\Rightarrow \frac{dP}{dL} = \gamma_w \cdot \frac{dh}{dL}$$

$$\Rightarrow \gamma_w \cdot \frac{dh}{dL} = \gamma_w (1-n) (G_f - 1)$$

$$\Rightarrow \boxed{\frac{dh}{dL} = (1-n) (G_f - 1) = \frac{G_f - 1}{1+n}}$$

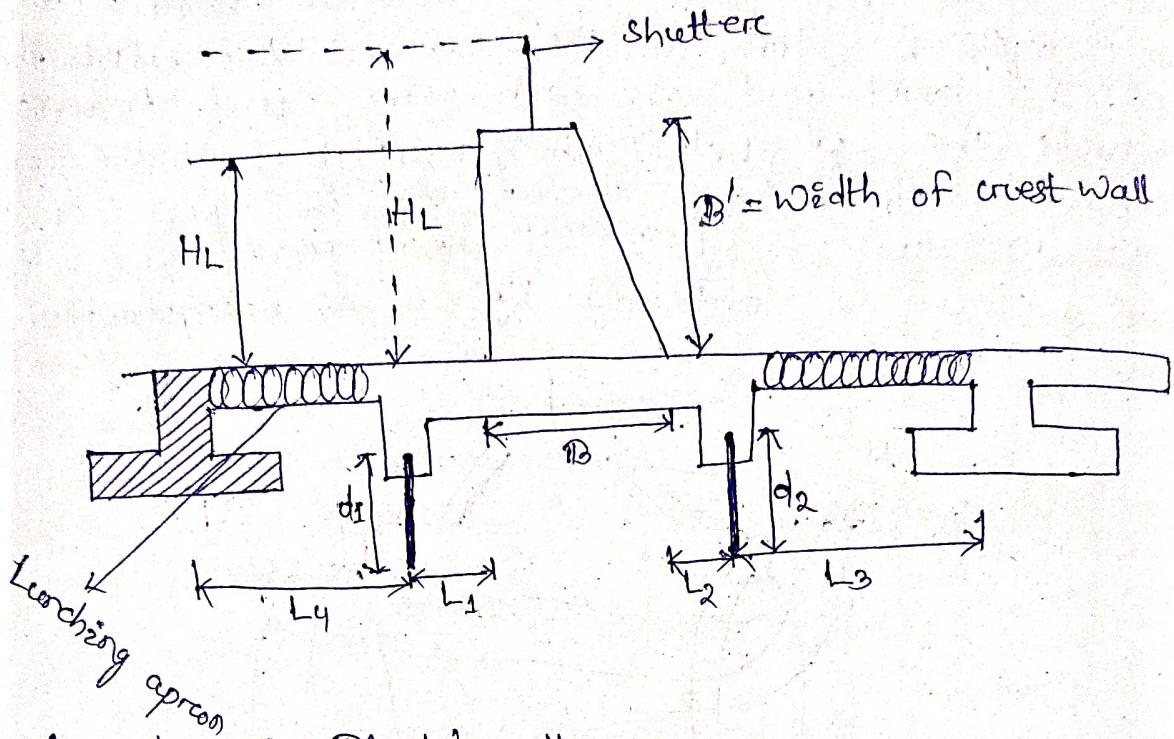


For river sand,  $G_f = 2.65$   $n = 0.4$ ,

$$\therefore \text{critical exit} = (1-0.4) (2.65-1) = 1$$

$$\therefore \text{exit} = \frac{1}{4} \text{ to } \frac{1}{5} \text{ of critical}$$

## Design of Weir & Barrage:-



According to Bligh's theory,

$$L_2 = 2 \cdot 21 C \sqrt{\frac{H_L}{13}} \text{ having crest shutter}$$

$$L_2 = 2 \cdot 21 C \sqrt{\frac{H_L}{10}} \text{ No shutter}$$

$$L_2 + L_3 = 18 C \sqrt{\frac{H_L}{13} \cdot \frac{q}{75}} \text{ with shutters}$$

$$L_2 + L_3 = 18 C \sqrt{\frac{H_L}{10} \cdot \frac{q}{75}} \text{ No shutter}$$

$$B' = \frac{H_L}{\sqrt{G-1}}$$

$$L = l_1 + l_2 + l_3 + l_4$$

$B'$  = width of the crest wall

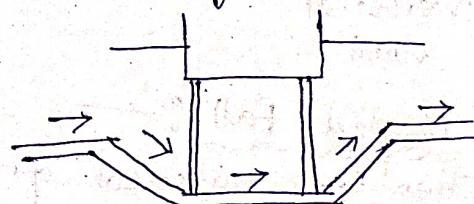
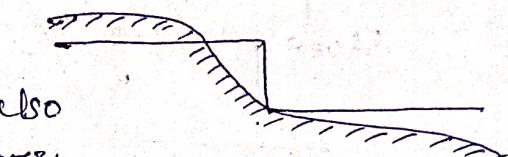
$$q = \frac{Q}{B'}$$

## Canal Falls :-

Whenever the available natural ground slope is steeper than the designed bed slope of the channel, the difference is adjusted by vertical falls known as canal falls.

### Necessity of Canal fall :-

- (i) When the slope of the ground suddenly changes to steeper slope, the permissible bed slope can not be maintained. It requires excessive earthwork in filling to maintain the slope. In such a case canal falls are provided to avoid excessive earth work in filling.
- (ii) When the slope is more or less uniform, in that case also the canal falls are necessary.
- (iii) In cross drainage work, when the difference between bed level of canal & that of drainage is small canal fall is necessary to carry the canal water below the stream.



### Proper Location :-

- The location of a fall in a canal depends on the topography of the country through which the canal is passing.
- In case of branch canal & distributary channels, the falls are located with consideration to command area.
- The location of the falls may also be influenced by the possibility of combining it with a bridge.

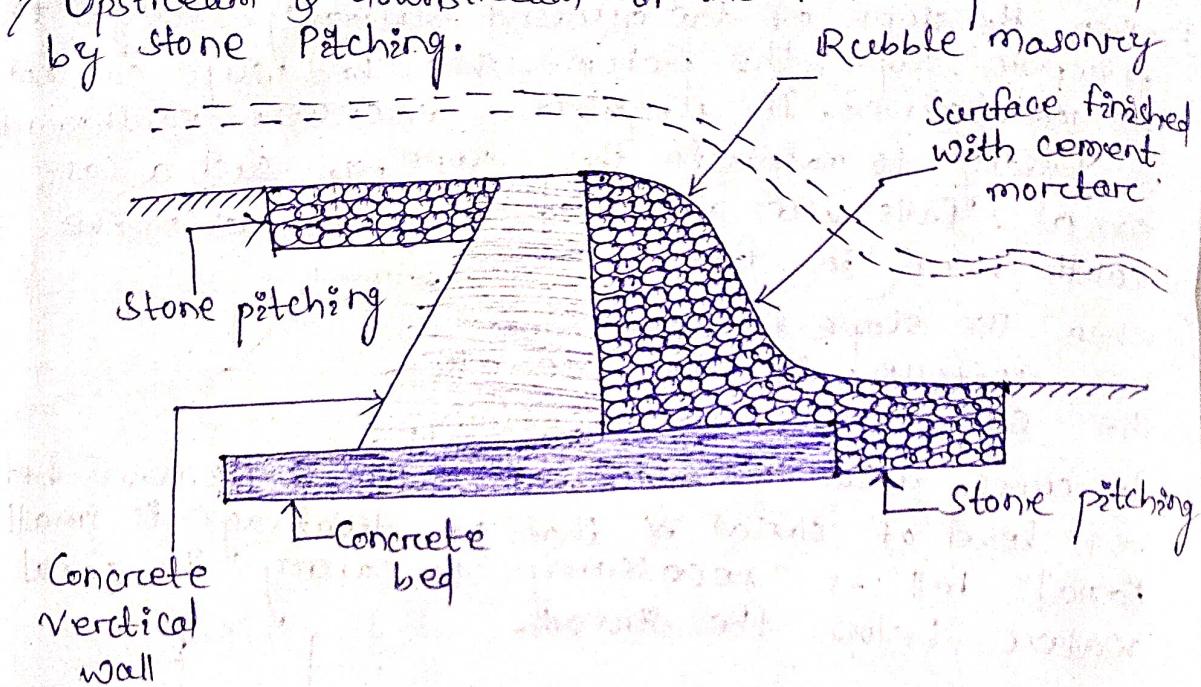
### Types of Canal fall :-

Depending on the ground level conditions & shape of the fall the various types of fall are;

#### ① Ogee fall :-

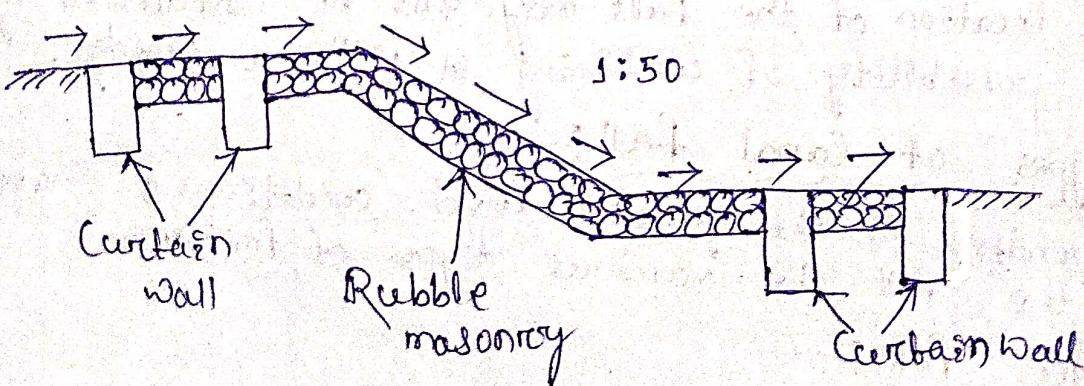
- The ogee fall was constructed by Sir Proby Caletley on the Ganga Canal.

- This type of fall has gradual convex & concave surfaces i.e. in the ogee form.
- The gradual convex & concave surface is provided with an aim to provide smooth transition & to reduce disturbance & impact.
- A hydraulic jump is formed which dissipates a part of Kinetic energy.
- Upstream & downstream of the fall is provided by stone pitching.



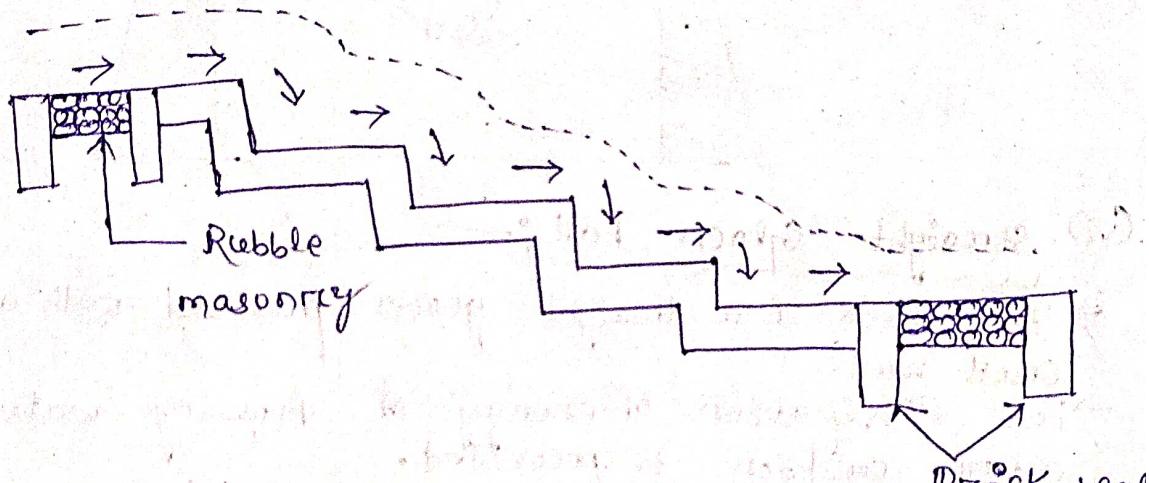
### (ii) Rapid fall :—

- When the natural ground level is even & rapid, this rapid fall is suitable.
- It consists of long sloping gables.
- Certain walls are provided on both U/S & D/S sides.
- Rubble masonry with cement grouting is provided from U/S certain wall to d/s certain wall.
- Masonry surface is finished with a rich cement mordant.



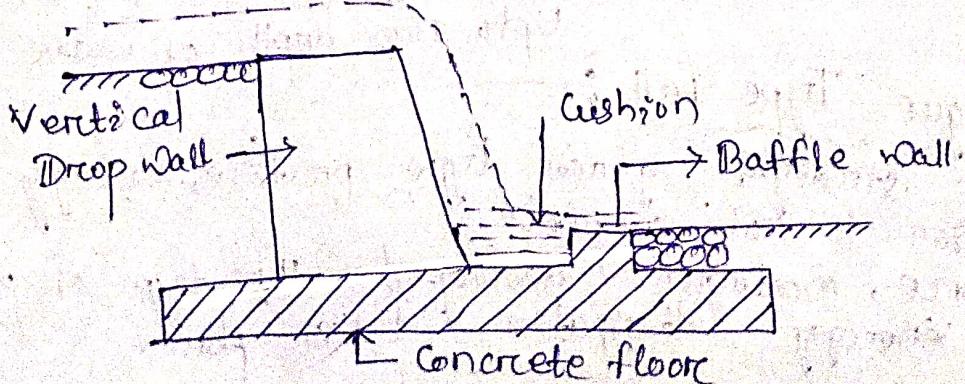
## Stepped fall :-

- It consists of a series of vertical drops in the form of steps.
- This steps is suitable in places where sloping ground is very long & require a long glace to connect the higher bed level U/S with lower bed level d/s.
- It is practically a modification of rapid fall.
- The sloping glace is divided into a number drops to bring down the canal bed step by step to protect the canal bed & sides from damage by erosion.
- Brick walls are provided at each drop. The bed of the canal within the fall is protected by rubble masonry with surface finishing by rich cement mortars.



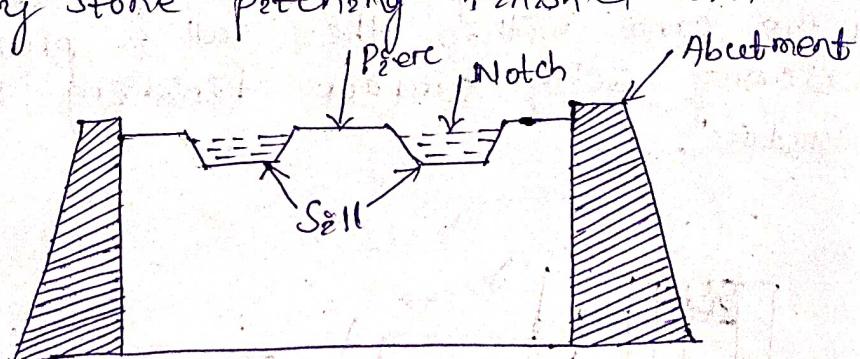
## (ii) Vertical drop fall / Saroda fall :-

- In the simple type, canal U/S bed is on the level of upstream curtain wall, canal U/S bed level is below the crest of curtain wall.
- In both the cases, a cistern is formed to act as water cushion.
- Floor is made of concrete U/S & d/s side stone pitching with cement grouting is provided.
- This type of fall is called Saroda Canal UP & therefore, it is also called Saroda fall.



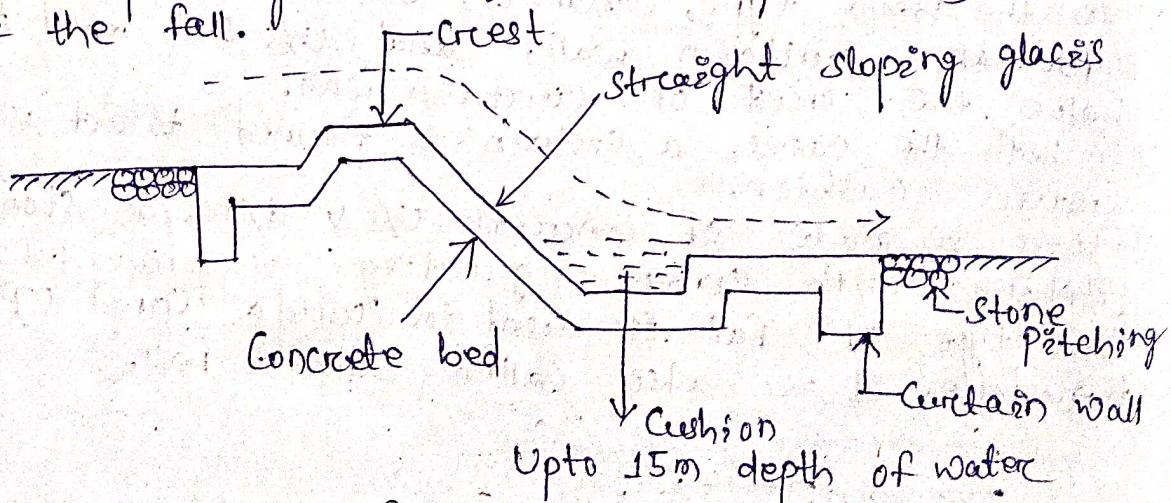
### (v) Trapezoidal Notch Wall:

- It was designed by Reed in 1894.
- In this type a body or foundation wall across the channel consisting of several trapezoidal notches between side pier & intermediate pier is constructed.
- The sill of the notches are kept at upstream bed level of the canal.
- The body wall is made of concrete.
- An impermeable floor is provided to resist the scouring effect of falling water.
- Upstream & downstream side of the fall is protected by stone pitching finished with cement grooving.



### (vi) Straight Glacié Fall:

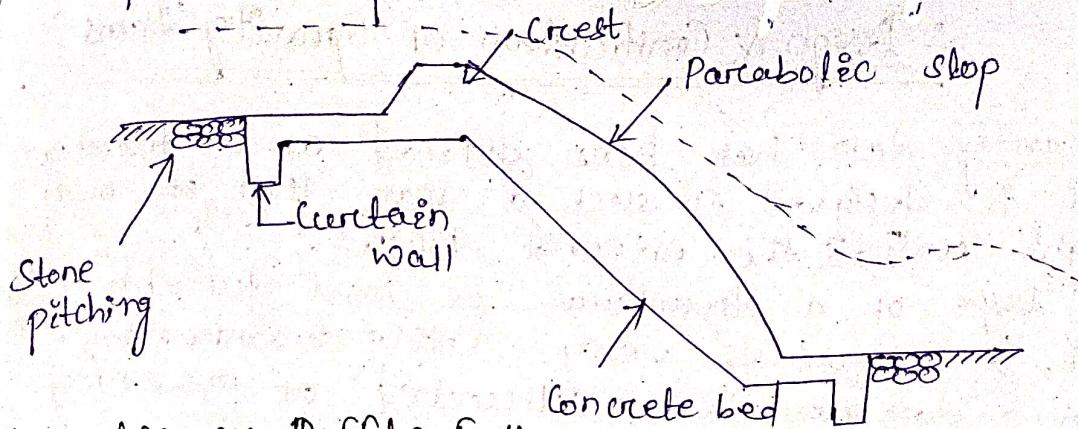
- It consists of a straight glacié provided with a crest wall.
- For dissipation of energy of flowing water, a water cushion is provided.
- Certain walls are provided at toe & heel.
- Stone pitching is required at upstream & downstream of the fall.



### (vii) Montague Type Fall:

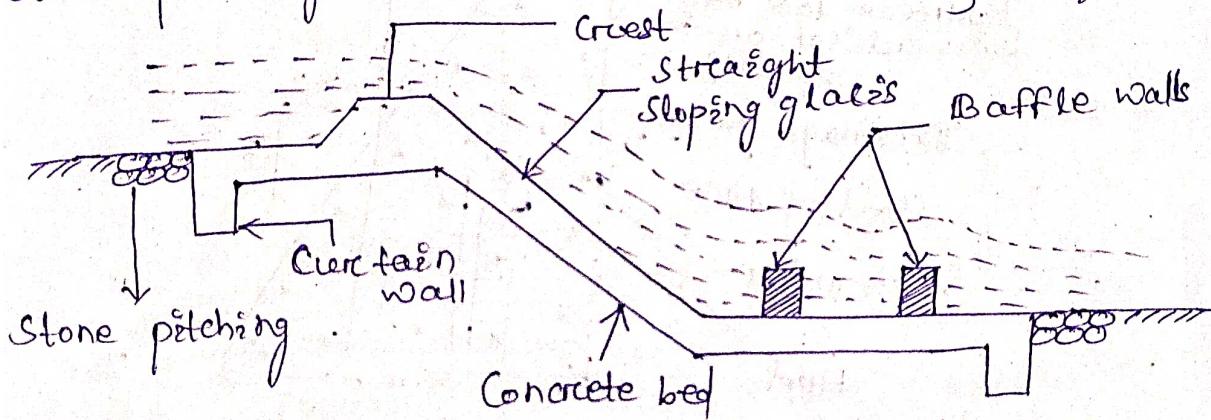
- In the straight glacié type profile, energy dissipation is not complete.
- Therefore, montague developed this type of profile where energy dissipation takes place.

H.S profile is parabolic.



### i) Inglis or Baffle fall :-

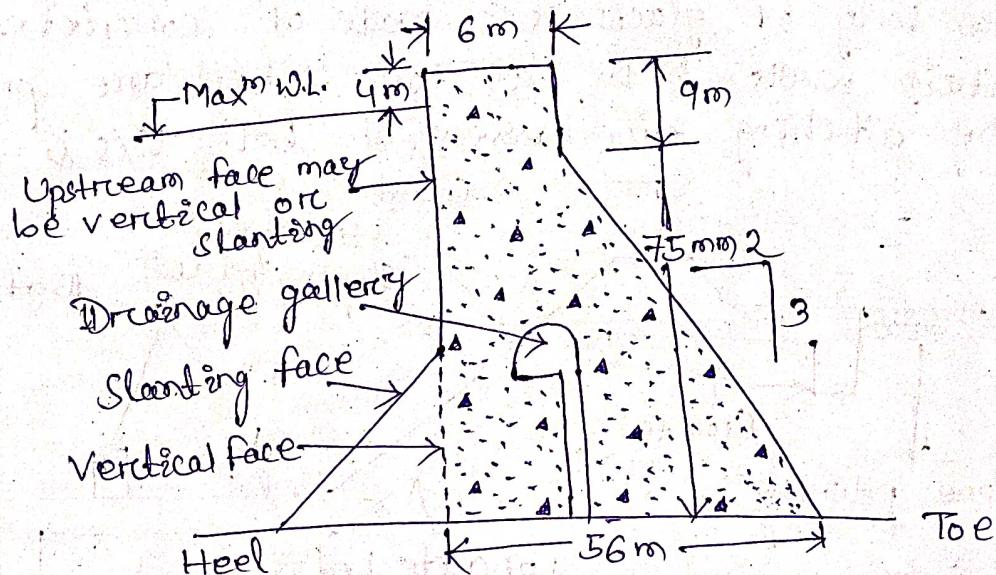
Here glaces is straight & sloping, but baffle wall provided on the downstream floor dissipate the energy. Main body of glaces is made of concrete. Curtain walls both at toe & heel are provided. Stone pitching are essential both V/S & D/S ends.



## Design & Construction of Gravity Dam:

- A gravity dam has been defined as a structure which is designed in such a way that its own weight resists the external forces.
- This type of a structure is most durable & solid, & requires very little maintenance. Such a dam may be constructed of masonry or concrete.

### Typical Cross-Section:



[A typical cross-section of a concrete gravity dam]

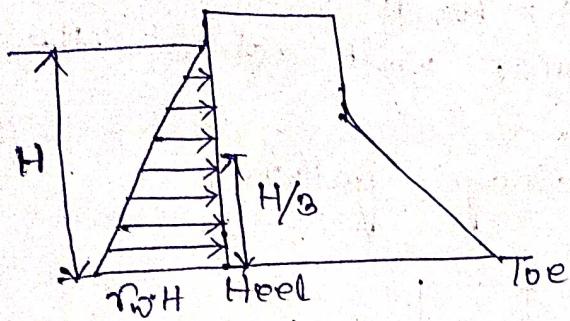
### Forces Acting on Gravity Dam:

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 stabilizing force is the weight of the dam itself.

## Water Pressure:

Case-I



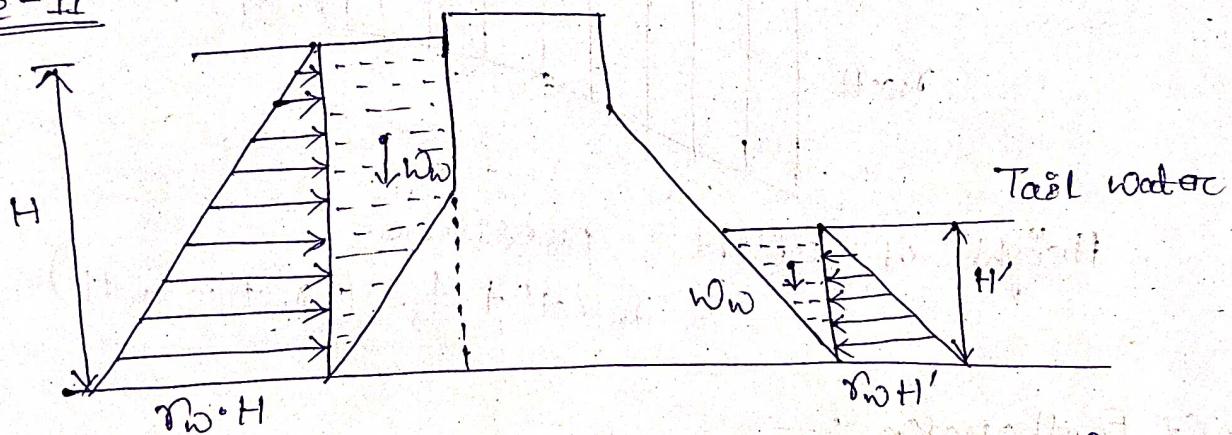
$$P = r_w g h$$

$$A \Delta = \frac{1}{2} \times r_w \times H \times H$$

$$P_w = \text{Water pressure} = \frac{1}{2} \cdot r_w \cdot H^2$$

$P_w$  acts at C.G. of the triangle i.e.,  $\frac{H}{3}$  from the bottom section

Case-II



$$\text{Water pressure at U/S, } = \frac{1}{2} r_w \cdot H \cdot H + w_w$$

Where,  
 $w_w$  = Wt. of water retained on slanting inclined height on upstream side.

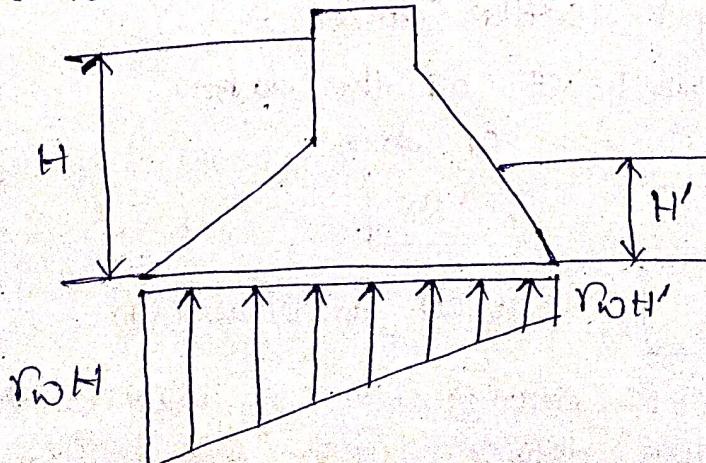
In downstream side,

$$\text{Water pressure} = \frac{1}{2} r_w \cdot H \cdot H' + w_w'$$

Where,  
 $w_w'$  = Wt. of water retained on slanting height on downstream side.

(2) Uplift Pressure:

Case-I :- Without drainage work

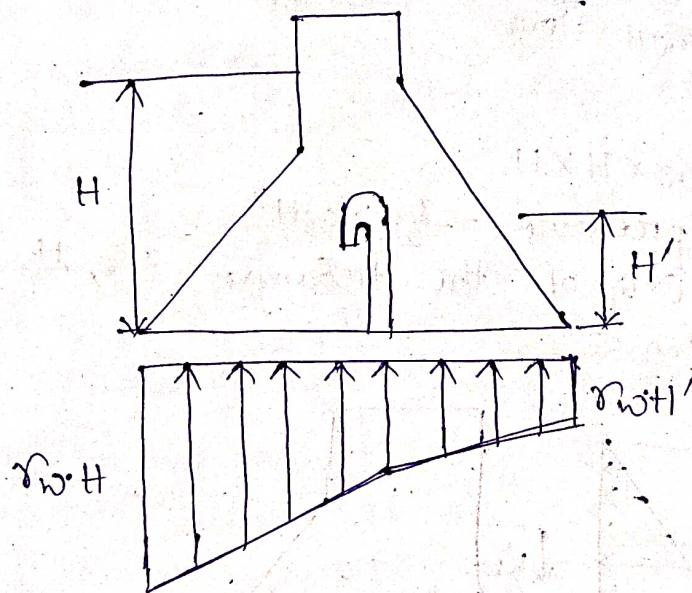


Uplift pressure is acting on upstream side =  $\gamma_w \cdot H$

In downstream side =  $\gamma_w \cdot H'$

& the resultant force will act at the C.G by the trapezoidal form.

Case-II :- with drainage gallery



$$\text{Height of uplift pressure} \\ = \gamma_w \cdot H' + \frac{1}{3} (\gamma_w H - \gamma_w H')$$

### (3) Earthquake :-

→ Pressure generated due to earthquake in two ways;

(1) Vertical acceleration

(2) Horizontal acceleration

### (1) Vertical Acceleration :-

→ The vibration due to earthquake the soil particles move in upward & downward direction.

→ If it is acting in upward direction, it is balanced by the weight of the dam.

→ When it is acting in downward direction the foundation get settle down.

If  $w$  = Total wt. of the dam

Net effective wt. of dam.

$$= w - \frac{w}{g} \times ae$$

$$ae = g \times Ke \rightarrow \text{vertical acceleration}$$

$Ke$  = fraction of earthquake in vertical direction  
its value varies from 0.1 to 0.2.

$$= \omega - \frac{\omega}{g} \times g \times K_p$$

$$F_{ev} = \omega (1 - K_p)$$

## 2) Horizontal Acceleration:

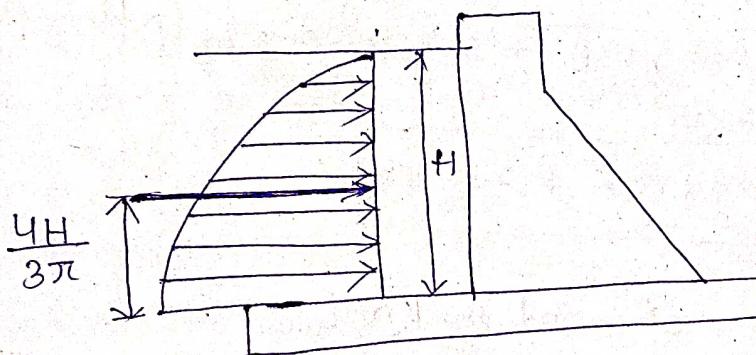
It is divided into 2 types

(i) Hydrodynamic,

(ii) Inertia force

Earthquake acceleration is acting in both U/S & D/S.

If acceleration is acting in upstream direction, the water will give exact amount of force against the dam. which is named as hydrodynamic pressure.



$$P_e = 0.555 K_h \cdot \gamma_w \cdot H^2$$

where,

$K_h$  = Earth pressure coefficient

$$= \frac{1 - \sin \phi}{1 + \sin \phi}$$

Hydrodynamic pressure i.e.,  $P_e$  is always acts at  $\frac{4H}{3\pi}$  height from the bottom.

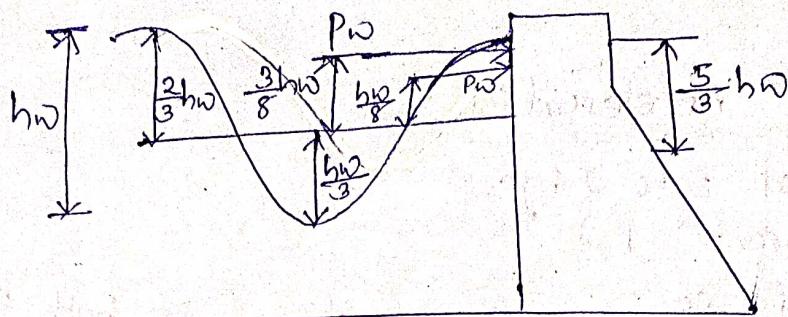
Moment of dam against hydrodynamic pressure,

$$M_e = P_e \times \frac{4H}{3\pi}$$

Horizontal force of inertia:

$$\begin{aligned} \text{force generated due to h.E} &= \frac{\omega}{g} \times d_h \\ &= \frac{\omega}{g} \times g \times K_h \\ &= \omega \times K_h \end{aligned}$$

## (4) Wave Pressure



$$h_w = \text{wt. of water}$$

$$P_w = 2.4 \gamma_w h_w$$

$$P_w = \frac{1}{2} (P_w) \times \frac{5}{3} h_w$$

$$h_w = 0.032 \sqrt{V \cdot F} + 0.763 - 0.271 F^{1/4}$$

$$F < 32 \text{ Km}$$

$$h_w = 0.032 \sqrt{V \cdot F} \quad F > 32 \text{ Km}$$

Where,

$V$  = Velocity of wind in Km/hour

$F$  = Straight length of water exposure in Km.

$h_w$  = Height of wave from top of crest to trough.

$P_w$  = Max<sup>m</sup> capacity of pressure always act at  $\frac{5}{8} h_w$  height from the free surface of water.

$P_w$  = Wave pressure always acts at  $\frac{5}{3} h_w$  from free surface of water.

## (5) Silt Pressure

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 :

$$P_{\text{silt}} = \frac{1}{2} \cdot \gamma_{\text{sub}} \cdot h^2 K_a \text{ & it acts at } \frac{h}{3} \text{ from base}$$

Where,

$K_a$  is the coefficient of active earth pressure of silt

$$K_a = \frac{1 - \sin \phi}{1 + \sin \phi}$$

Where,  $\phi$  is the angle of internal friction of soil, cohesion is neglected.

$\gamma_{\text{sub}}$  = Submerged unit weight of silt material.

$h$  = height of silt deposited.

### Ice pressure:

The ice which may be formed on the water surface of the reservoir in cold countries; may sometimes melt & expand.

The magnitude of this force varies from 250 to  $1500 \text{ KN/m}^2$  depending upon temperature variations. On an average, a value of  $500 \text{ KN/m}^2$  may be allowed under ordinary conditions.

### Weight of the dam:

The weight of the dam body & its foundation is the major resisting force.

### Combination of forces:

The design of a gravity dam should be checked for two cases, i.e.

- (i) When Reservoir is full
- (ii) When Reservoir is empty.

### Case-I Reservoir full case:

#### (a) Normal Load Combinations:

- Water pressure upto normal pool level, normal uplift, silt pressure & ice pressure. This class of loading is taken when ice force is zero.
- Water pressure upto normal pool level, normal uplift, earthquake forces & silt pressure.
- Water pressure upto maximum reservoir level (maximum pool level), normal uplift & silt pressure.

#### (b) Extreme Load Combinations:

- Water pressure due to maximum pool level, extreme uplift pressure without any reduction due to drainage & silt pressure.

### Case-II Reservoir empty case:

- Empty reservoir without earthquake forces to be computed for determining bending diagrams, etc. for reinforcement design, for greeting studies or other purposes.

Empty reservoir with a horizontal earthquake force produced towards the upstream has to be checked for non-development of tension at toe.

## Modes of failure & Criteria for Structural Stability of Gravity Dam:

A gravity dam may fail in the following ways:

- (1) By oversteering (or rotation) about the toe.
- (2) By crushing.
- (3) By development of tension, causing ultimate failure by crushing.
- (4) By shear failure called sliding.

### (1) Over-steering:

- If the resultant of all the forces acting on a dam at any of its sections, passes outside the toe, the dam shall rotate & oversteer about the toe.
- The ratio of the righting moments about toe (anti clockwise) to the oversteering moments about toe (clockwise) is called the factor of safety against oversteering.
- Its value, generally varies between 2 to 3.

### (2) Compression or Crushing:

- A dam may fail by the failure of its materials, e.g. the compressive stresses produced may exceed the allowable stresses, & the dam material may get crushed.

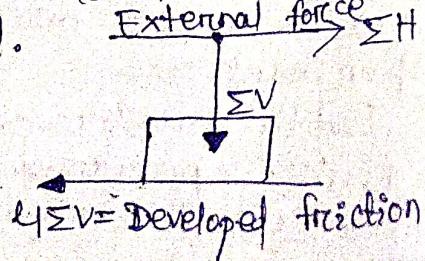
### (3) Tension:

- Masonry & concrete gravity dams are usually designed in such a way that no tension is developed anywhere, because these materials can not withstand sustained tensile stresses.
- If subjected to such stresses, these materials may finally crack.

### (4) 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 the level.

$$\frac{4 \sum V}{\Sigma H} > 1$$



## Earth Dams & Rock fill Dams:-

### Introduction :-

Earth dams & earth levees are the most ancient type of embankments, as they can be built with the natural materials with a minimum of processing & primitive equipment.

### Types of Earth Dams :-

The earth dam can be of the following three types:

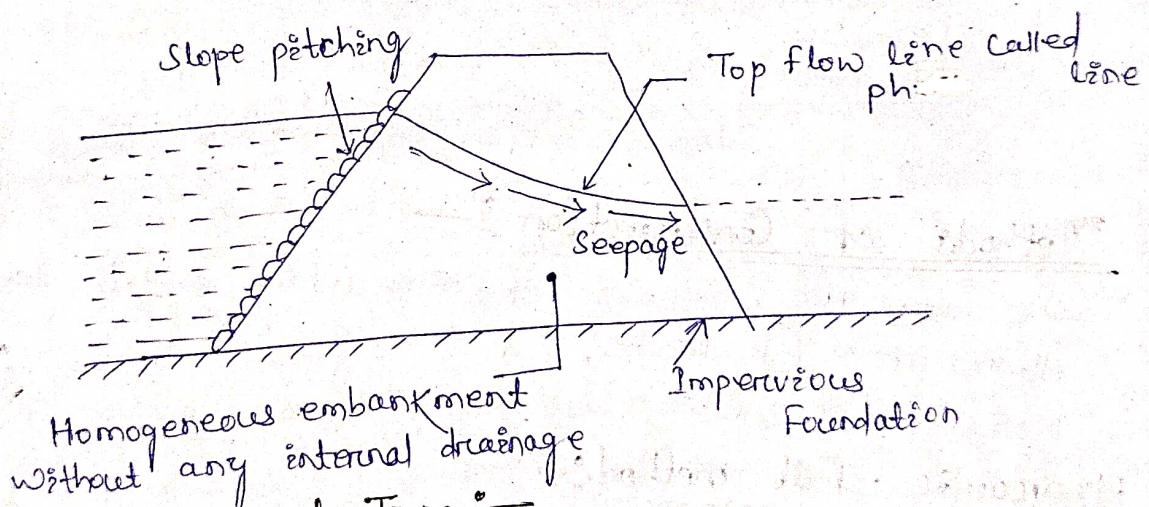
Homogeneous Embankment type

Zoned Embankment type

Diaphragm type

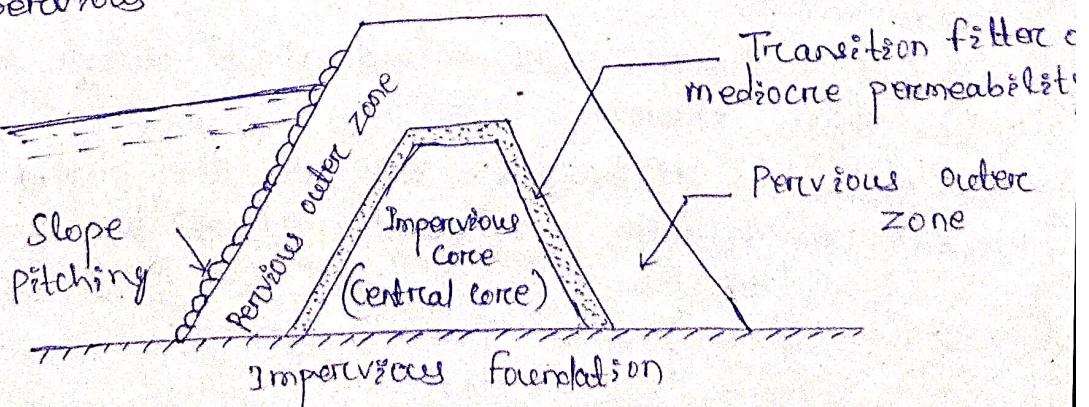
### Homogeneous Embankment type :-

- > The simplest type of an earth embankment consists of a single material & 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 economically or locally available.



### Zoned Embankment Type :-

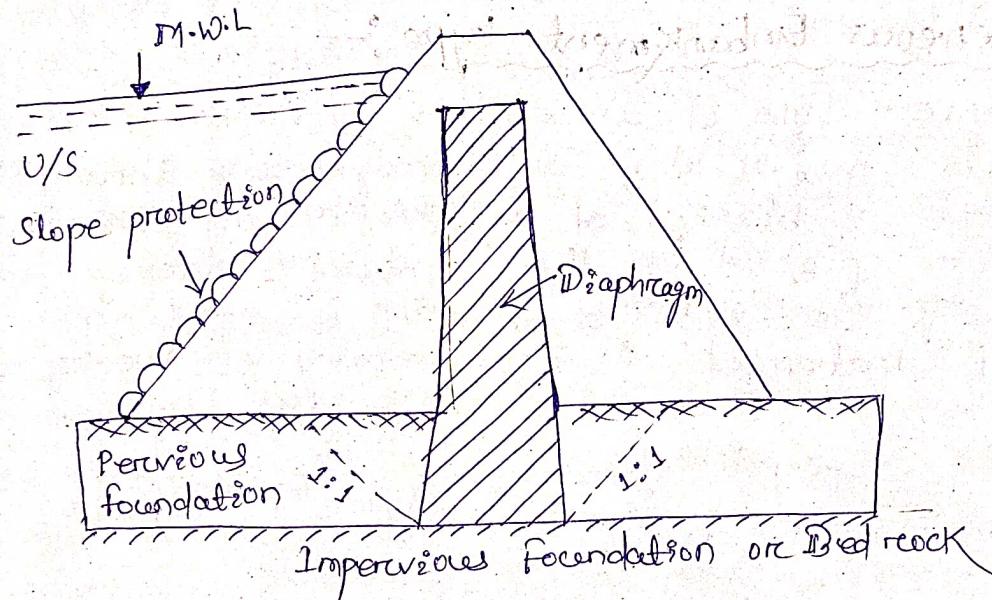
- > Zoned embankments are usually provided with a central impermeable core, covered by a comparatively permeable transition zone, which is finally surrounded by a much more permeable outer zone.



- 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 impermeable core & also distributes the load over a large area of foundations.

### 3. Diaphragm Type Embankments:

- Diaphragm type embankments have a thin impermeable core, which is surrounded by earth or rock fill. The impermeable core, called diaphragm, is made of impermeable soils, concrete, steel, timber or any other material. It acts as a water barrier to prevent seepage through the dam.



### Methods of Construction:

There are two methods of constructing earthen dams:

(1) Hydraulic - fill method.

(2) Roller - fill method

#### (1) Hydraulic - fill method:

- In this method of construction, the dam body is constructed by excavating & transporting soils by using water. Pipes called flumes, are laid along the outer edge of the embankment.

- The soil materials are mixed with water & pumped into these flumes.

- The slush is discharged through the outlets in the flumes at suitable intervals along their lengths.

## Rolled-Fill Method:-

The embankment is constructed by placing suitable soil materials in thin layers (15 to 30 cm) & compacting them with rollers.

The soil is brought to the site from borrow pits & spread by bulldozers, etc. in layers. These layers are thoroughly compacted by rollers of designed weights.

## Causes of failure of Earthen Dams :-

The various causes leading to the failure of earthen dams can be

(1) Hydraulic failures

(2) Seepage failures

### (1) Hydraulic Failures:-

About 40% of earth dam failures have been attributed to these causes. The failure under this category, may occur due to the following reasons:

#### (a) By overtopping:-

The water may overtop the dam, if the design flood is under estimated or if the spillway is of insufficient capacity or if the spillway gates are not properly operated. Sufficient freeboard should, therefore, be provided as an additional safety measure.

#### (b) Erosion of upstream face:-

The waves developed near the top water surface due to the winds, try to notch-out the soil from the upstream face & may even, sometimes, cause the slip of the upstream slope.

#### (c) Cracking due to frost action:-

Frost in the upper portion of the dam may cause heaving & cracking of the soil with dangerous seepage & consequent failure.

#### (d) Erosion of downstream face by gully formation:-

Heavy rains falling directly over the downstream face & the erosive action of the moving water, may lead to the formation of gullies on the downstream face, ultimately leading to the dam failure.

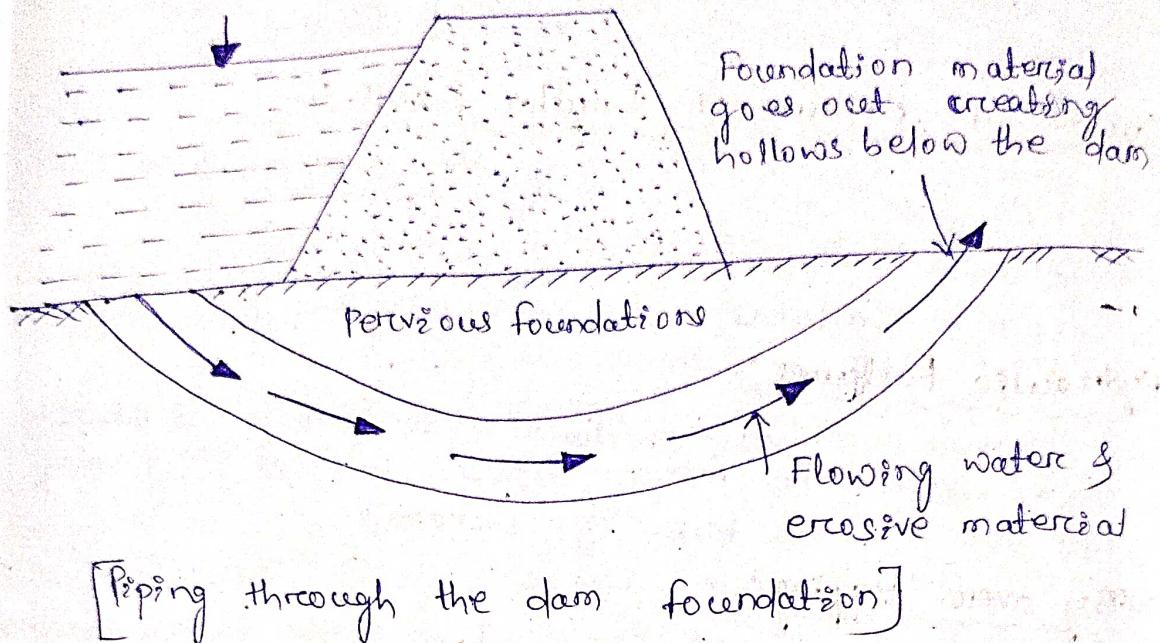
#### Seepage Failure:-

##### (e) Piping through foundations:-

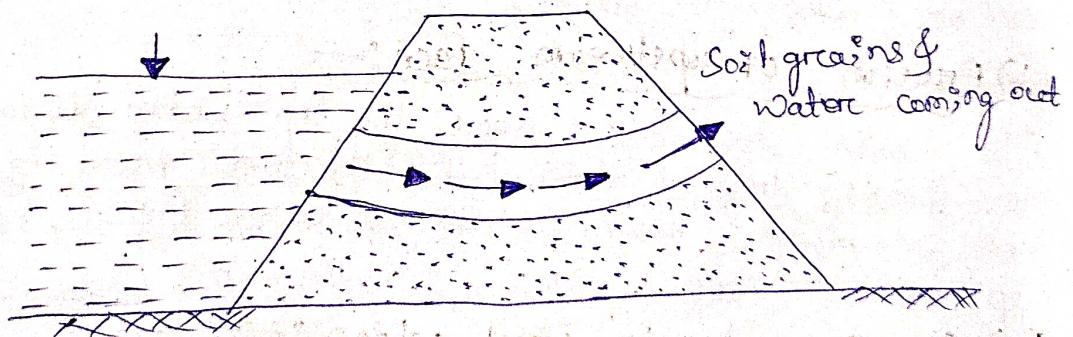
Sometimes, when highly permeable cavities or fissures are

Strata of coarse sand or gravel are present in the foundation of the dam.

→ Water may start seeping at a huge rate through them. This concentrated flow at a high gradient may erode the soil.



### (b) Piping through the dam body:



### (c) Sloughing of D/S Toe:

→ The process behind the sloughing of the toe is somewhat similar to that of piping.

→ The process of failure due to sloughing starts when the downstream toe becomes saturated & get eroded, producing a small slump or a miniature slide.

### Seepage Control in Earth Dam:

(1) Seepage control through embankments

(2) Seepage control through foundations

## Seepage Control Through Embankments :-

Drainage filters called 'Drains' are generally provided in the form of (a) rock toe

(b) horizontal blanket

(c) chimney drain

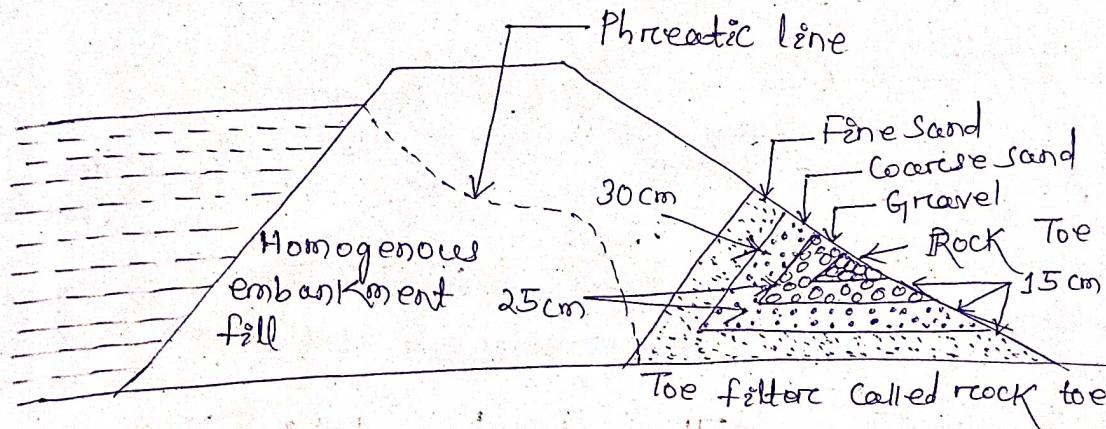
A multi-layered filter, generally called inverted filter or reverse filter.

### (a) Rock Toe or Toe Filter:-

The 'rock toe' consists of stones of size usually varying from 15 to 20 cm.

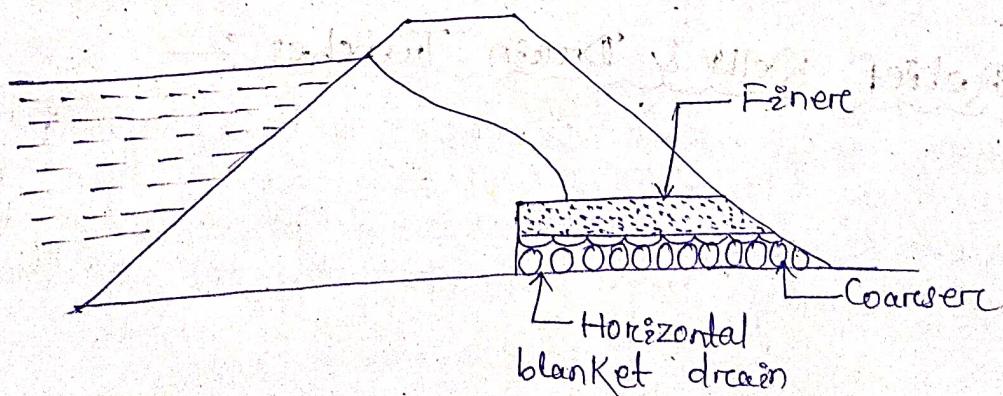
A toe filter (graded in layers) is provided as a transition zone, between the homogeneous embankment fill & rock toe.

Toe filter generally consists of three layers of fine sand, coarse sand, & gravel.



### (b) Horizontal Blanket or Horizontal Filter:-

The horizontal filter extends from the toe (d/s end) of the dam, inwards, upto a distance varying from 25 to 100 of the distance of the toe from the centre line of the dam.

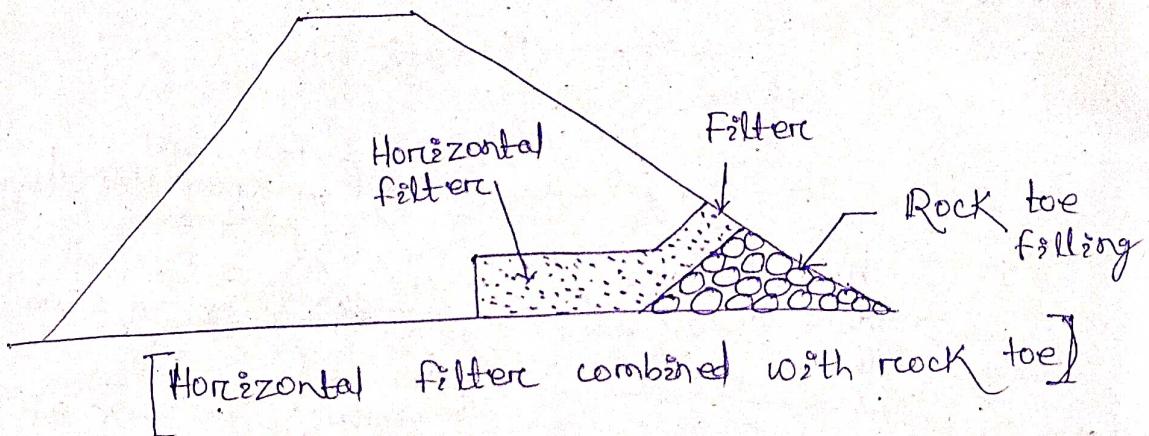
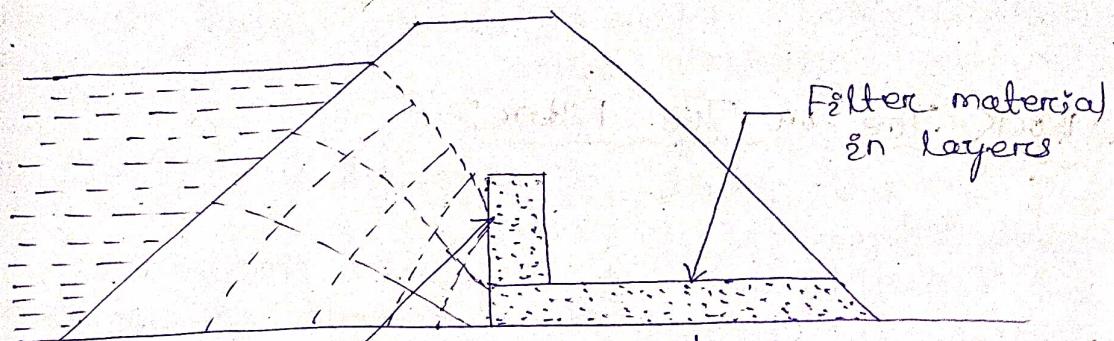


### (c) Chimney Drain:-

The horizontal filter, not only helps in bringing the phreatic line down in the body of the dam but also provides drainage of the foundation & helps in rapid

Consolidation. But, the horizontal filter tries to make the soil more pervious in the horizontal direction & thus causes stratification.

→ When large scale stratification occurs, such a filter becomes inefficient.



## (2) Seepage Control Through Foundations:

### (a) Impervious Cutoffs:

→ Vertical impervious cutoffs made of concrete or sheet piles may be provided at the upstream end (e.g. at heel) of the earth dam.

### (b) Relief Wells & Drain Trenches:

→ When large scale seepage takes place through the pervious foundation, overlain by a thin less pervious layer, there is a possibility that the water may boil up near the toe of the dam.

## Spillway:

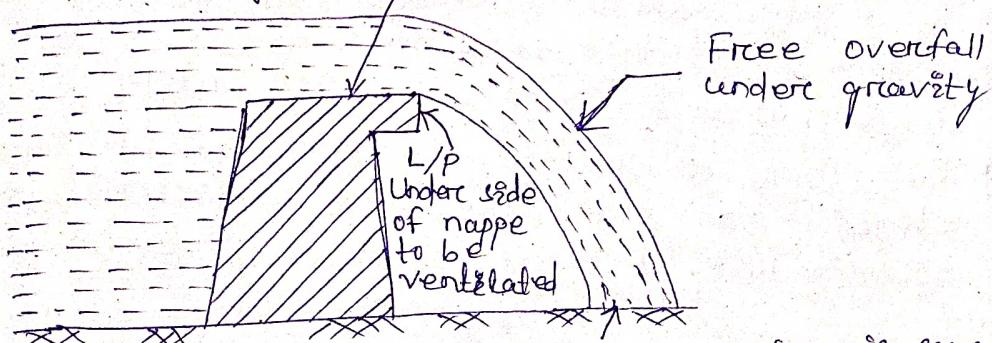
A spillway is a structure constructed at a dam site, for effectively disposing of the surplus water from upstream to downstream. Just after the reservoir gets filled up, up to the normal pool level, water starts flowing over the top of the spillway crest.

## Types of Spillway:

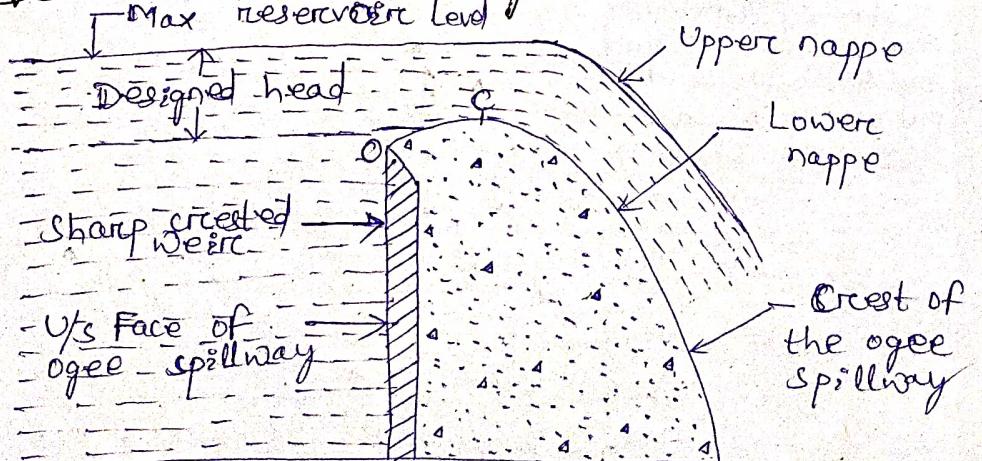
- (1) Straight Drop Spillway
- (2) Overflow Spillway generally called Ogee Spillway.
- (3) Chute Spillway often called Trough Spillway or Open Channel Spillway.
- (4) Side Channel Spillway
- (5) Shaft Spillway
- (6) Syphon Spillway

## Straight Drop Spillway or Overfall Spillway:

- This is the simplest type of spillway & may be constructed on small banks or on thin arch dams, etc.
- The water falls freely from the crest under the action of gravity.



## Ogee Spillway or Overflow Spillway:

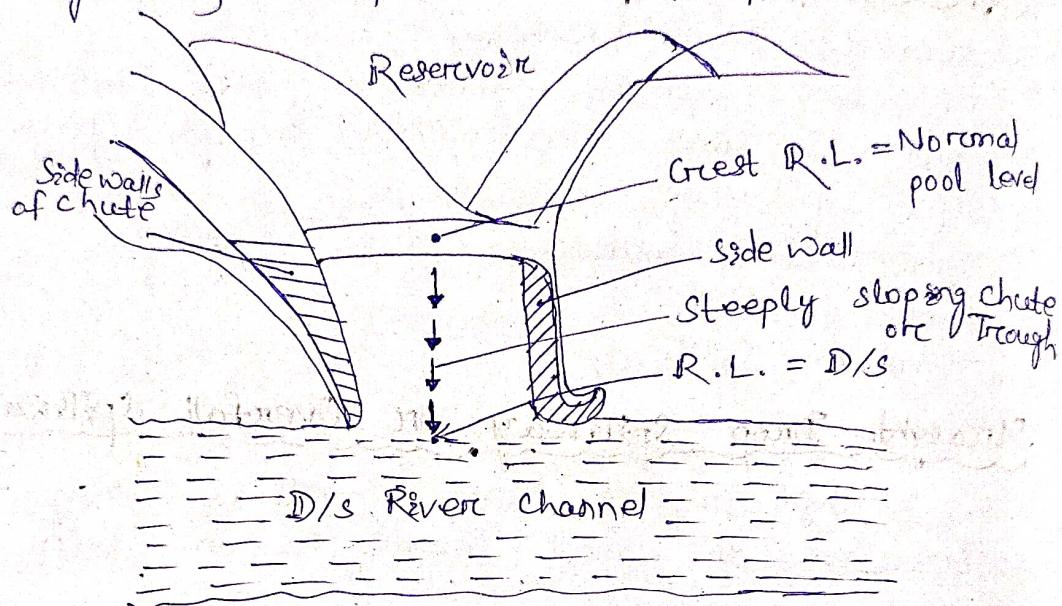


[Section of an ogee spillway with vertical U/S]

Ogee Spillway is an improvement upon the 'free overfall' Spillway, & is widely used with concrete, masonry, arch & buttress dams.

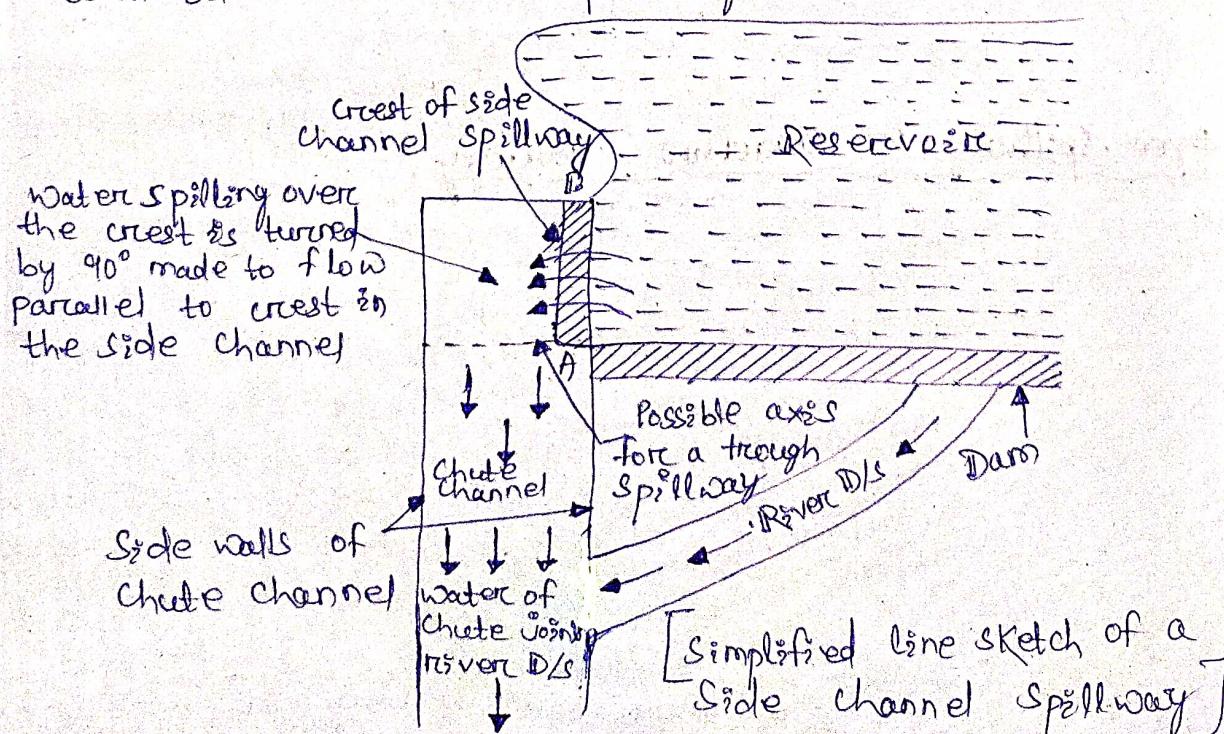
### (3) Chute Spillway or the Trough Spillway:

- The trough spillway or chute spillway is the simplest type of a spillway which can be easily provided independently & at low costs.
- It is lighter & adaptable to any type of foundation.



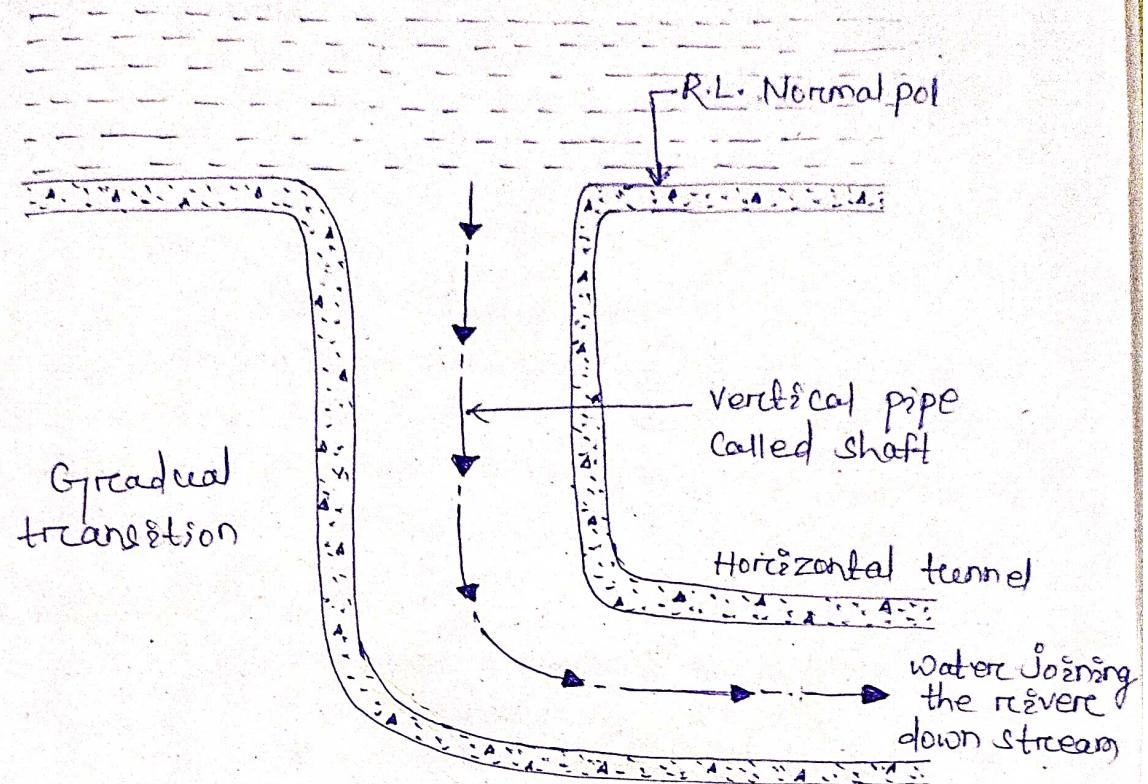
### (4) Side channel Spillway:

- In a side channel spillway the flow of water after spilling over the crest, is turned by  $90^\circ$  such that it flows parallel to the weir crest.
- This type of spillway is provided in narrow valleys where no side flanks of sufficient width to accommodate a chute spillway are available.



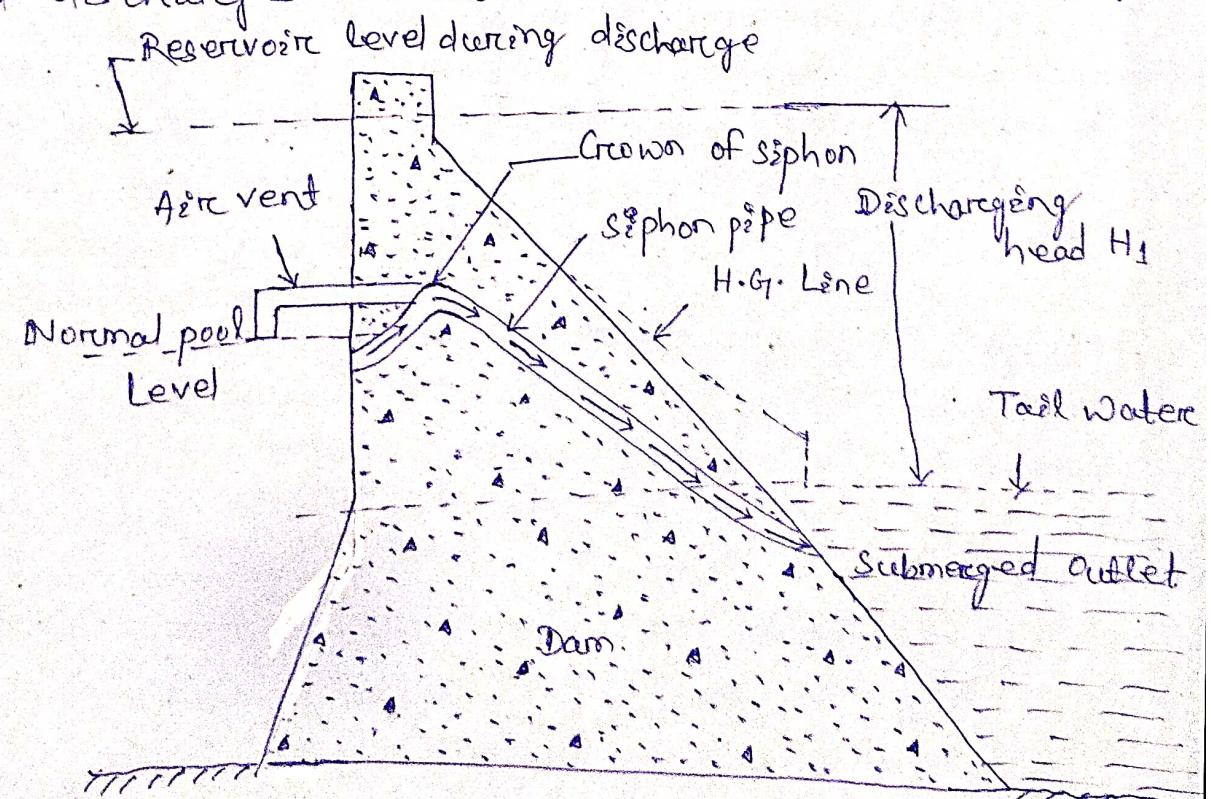
## Shaft Spillway:

In a shaft spillway, the water from the reservoir enters into a vertical shaft which conveys this water into a horizontal tunnel which finally discharges the water into the river downstream.



## Siphon Spillway:

A siphon spillway essentially consists of a siphon pipe, one end of which is kept on the upstream side & is in contact with the reservoir, while the other end discharges water on the downstream side.



[Siphon pipe installed within the gravity dam]

- When the water in the reservoir is upto or below the normal pool level, air entered the siphon through the vent & siphonic action cannot take place.
- When once the water level in the reservoir goes above the normal pool level, & if once the siphon is filled with water (i.e., it is primed); the water will start flowing through the siphon by siphonic action.