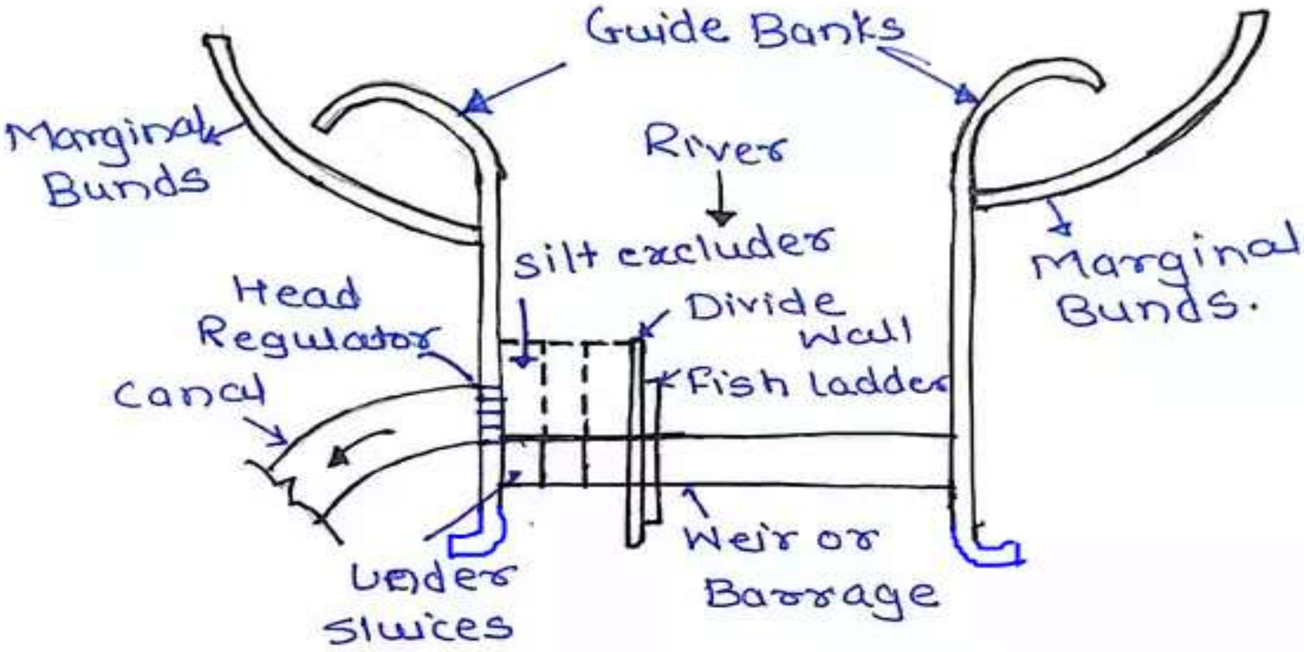
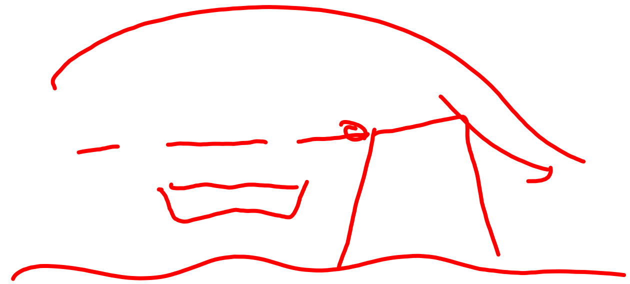
Diversion Headwork

- The structure constructed at the head of the canal in order to raise and divert the silt free water of a river toward the canal is known as diversion headworks.
- Most suitable location of canal headworks is trough stage of river

Component Parts of Diversion Headworks:

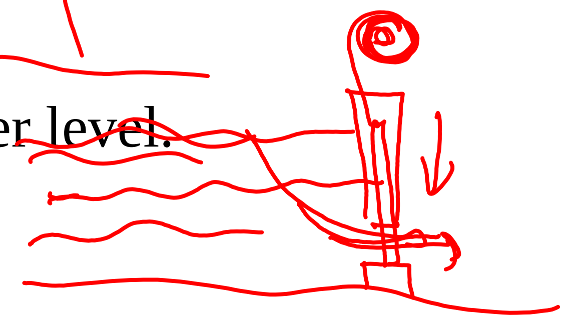


* Layout of Diversion Headworks *



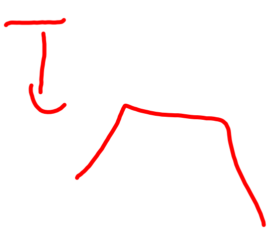
1. Weir and barrage:

Structure constructed across the river to raise water level.



Weir

- shutters of maximum height 1.2 m are provided on the crest to raise the water level.
- Low control on flow
- Low cost
- High crest level with low shutters



Barrage

- Barrage is an arrangement of adjustable gates over the weir.
- Relatively high control on flow
- High cost
- Low crest level with large gates

2. Under sluice (Scouring Sluice)

- It flushes away the silt deposited in front of head regulator.
- It passes about 10% to 20% of design flood during rainy season.
- The crest of under sluice is kept about 1 to 1.5 m lower than crest of weir

3. Divide Wall

- It is a masonry or concrete structure constructed at right angle to the weir or barrage.
- It separates the under sluice portion from weir portion.
- It avoids cross current.
- Side walls of the fish ladder

- ## 4. Fish Ladder/Fish Passage

The structure provided for the safe passage of fish upstream and downstream is called as fish ladder

Velocity in fish ladder is around 0.3 m/s and for most strongest fish velocity is 3 m/s.

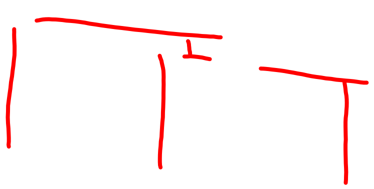
5. Canal Head Regulator

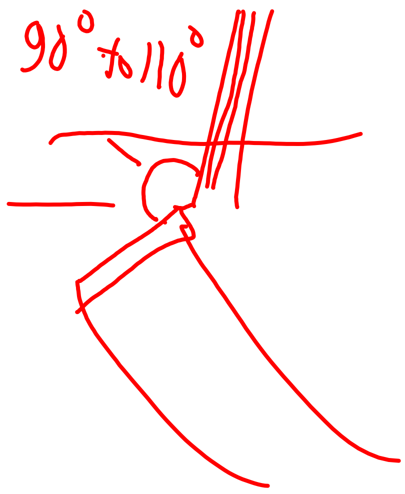
The structure constructed at the head of canal to regulate the flow in off taking canal is called as canal head regulator

Angle between head regulator and weir axis is 900 to 1100 but 1100 is more effective.

It consists of gates which are operated from top by suitable mechanical device.

It regulates the supply of water entering into canal.





6. Silt Control Devices

1. Silt Excluder: Structure constructed at the river bed upstream of canal head regulator that prevents the silt from entering into main canal

2. Silt Ejector: Structure constructed at the canal bed downstream of canal head regulator that removes the silt that has entered the main canal.

It is also called as silt extractor.

7. River Training Works

Guide Bank: Structure Constructed to guide the flow in desired direction i.e structure constructed across the river is called as Guide bank.

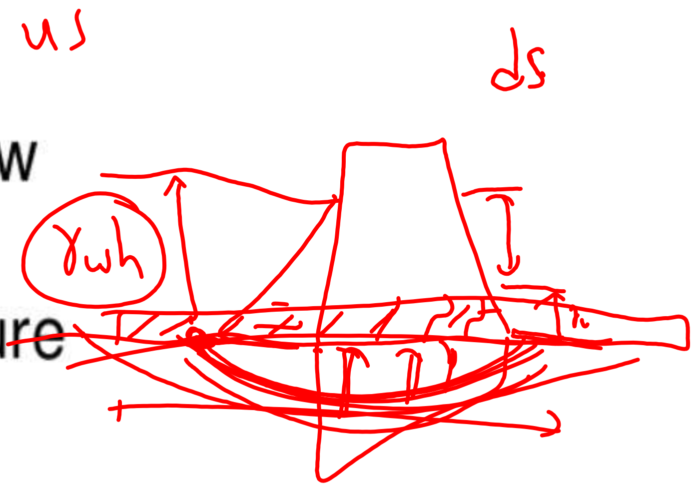
Guide bank constructed at river or weir site is called as Bell Bund.

Marginal Bund: Structure constructed parallel to river bank that prevent the spread of flood water in the adjoining area is called as marginal bund.

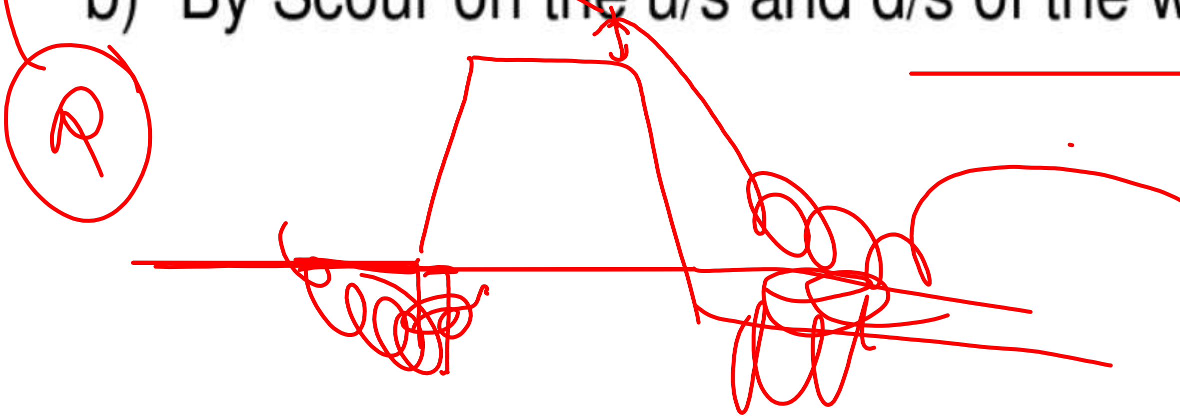
Causes of Failures of Weirs on Permeable Foundations

Causes of Failure:

1. Due to Seepage or Sub-surface Flow
   a) Piping or Undermining
   b) Rupture of Floor by Uplift Pressure



2. Due to Surface Flow
   a) By Suction due to Hydraulic Jump
   b) By Scour on the u/s and d/s of the weir

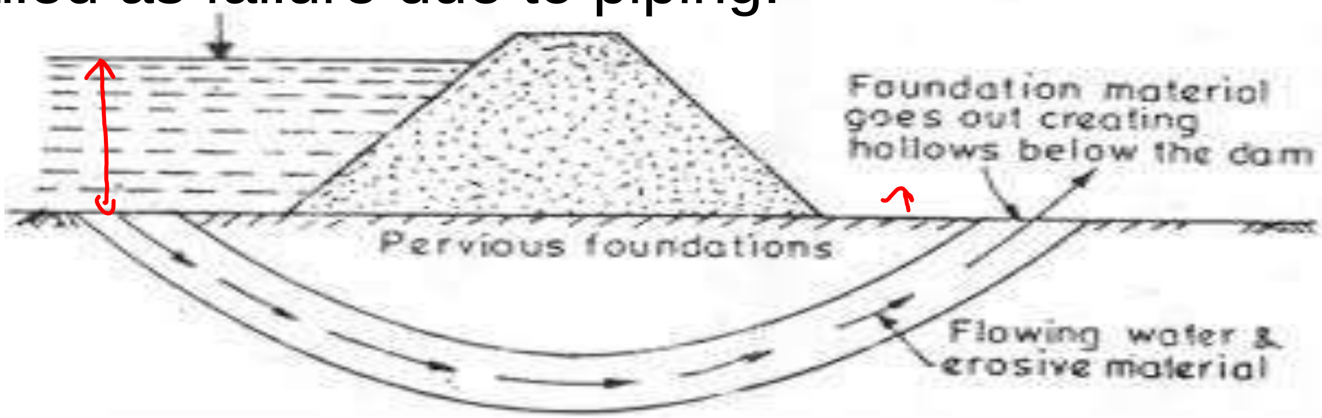


Failure due to piping or undermining

- If the water percolating below the foundation of hydraulic structure has sufficient energy when it emerges out at the D/S end of the floor, it lift up the soil particles at the end of the floor.

- This process of erosion extends backward towards the U/S side and results in the removal of particles thereby developing a pipe like hollow structure below the floor.

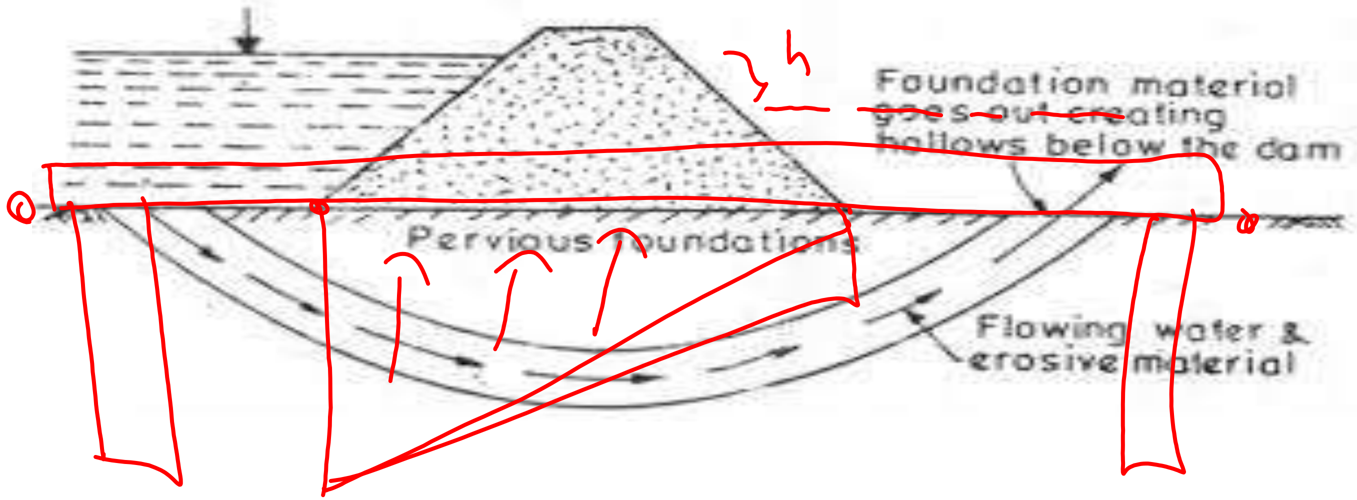
- The floor may subsides in the vacant space formed and fail which is called as failure due to piping.



Prevention

- Providing sufficient length of impervious floor so that path of seepage is increased and hydraulic gradient is reduced.

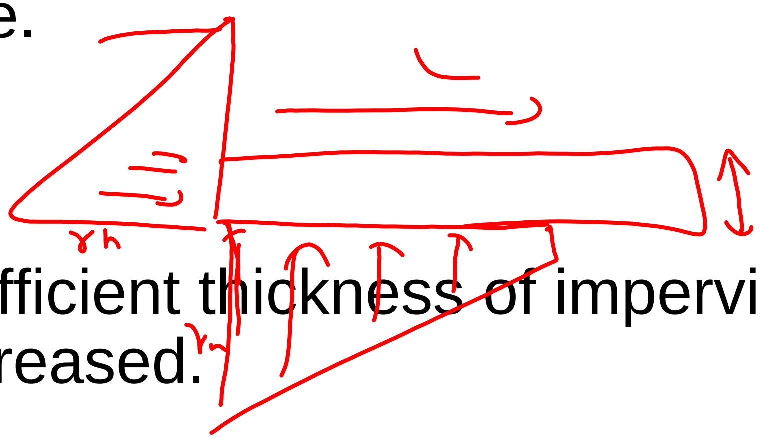
- Providing sheet piles at the **d/s side** also increases seepage path length.



Failure due to Direct Uplift

- The water percolating below the foundation of hydraulic structure exerts an upward pressure on the impervious floor which is known as uplift pressure.

- If this uplift pressure is not counter balanced, the structure fail due to rupture.



Prevention

- Providing sufficient thickness of impervious floor so that self weight is increased.

- Providing sheet piles at the **u/s side.**

Seepage Theories

1. Bligh's creep theory
2. Lane weighted creep theory
3. Khosla theory

❖ Bligh's creep theory

- According to Bligh's Theory, the percolating water follows the outline of the base of the foundation of the hydraulic structure. In other words, water creeps **along the bottom of the structure.**
- The length of the path thus traversed by water is called as creep length.
- Further, it is assumed in this theory, that the loss of head is proportional to the length of the creep. If H_L is the total head loss between the upstream and the downstream, and L is the length of creep, then the loss of head per unit of creep length (i.e. H_L/L) is called the hydraulic gradient or percolating coefficient.
- Further, Bligh makes no distinction between horizontal and vertical creep.

- Consider a section a shown in Figure below.

Let H_L be the difference of water levels between upstream and downstream ends.
Water will seep along the base of structure.

Creep Length (L) = b + 2(d1 + d2 + d3)

$= d_1 + d_1 + l_1 + d_1 + d_2 + l_2 + d_3 + d_3$

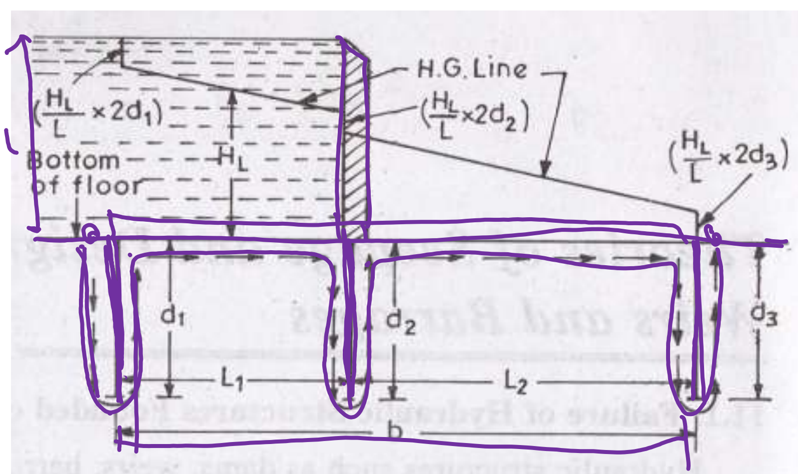


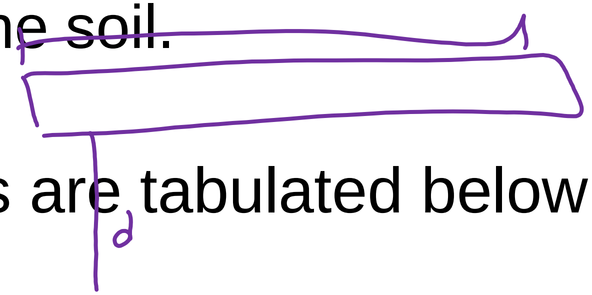
Fig-1: Bligh's Creep

(a) Safety against piping or undermining;

According to Bligh, the safety against piping can be ensured by providing sufficient creep length, given by

$$L = C.H_L,$$

where C is the Bligh's Coefficient for the soil.



values of C for different types of soils are tabulated below:

SL No.	Type of Soil	Value of C	Safe Hydraulic gradient should be less than
1	Fine micaceous sand	15	1/15
2	Coarse grained sand	12	1/12
3	Sand mixed with boulder and gravel, and for loam soil	5 to 9	1/5 to 1/9
4	Light sand and mud	8	1/8

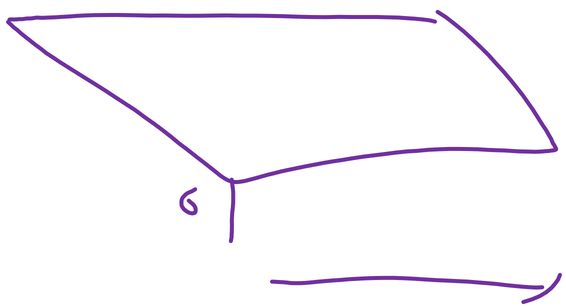
(b) Safety against uplift pressure

The ordinates of the H.G line above the bottom of the floor represent the residual uplift water head at each point.

$$t = \frac{h}{G-1}$$

This value is increased by 33 % to provide sufficient factor of safety.

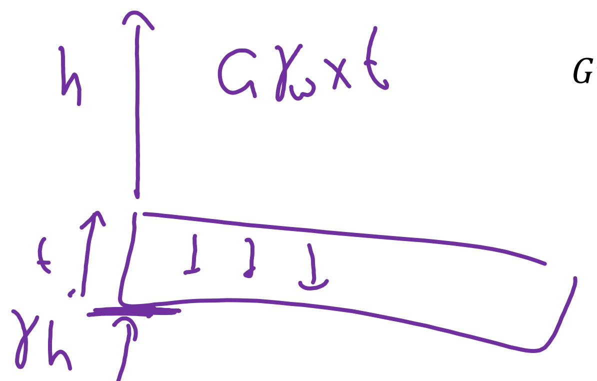
$$t = \frac{4}{3}\frac{h}{G-1}$$



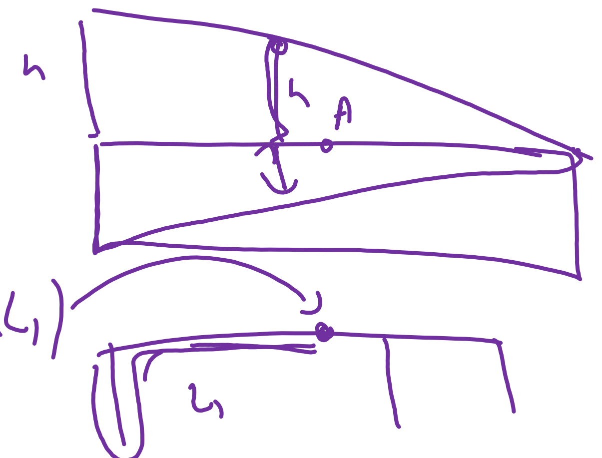
If the height of the hydraulic gradient line above the floor of thickness t is h and the specific gravity of the material of the floor is G; the minimum thickness t of the floor downstream of the crest wall, is given by the equation

a) $t = \frac{h}{G-1}$ b) $t = \frac{h+1}{G}$ a) $t = \frac{h-1}{G+t}$ a) $t = \frac{h-1}{G-t}$

For no uplift



$$W \geq U$$
$$G\gamma_w t \geq \gamma_w(h+t)$$
$$t \geq \frac{h}{G-1}$$

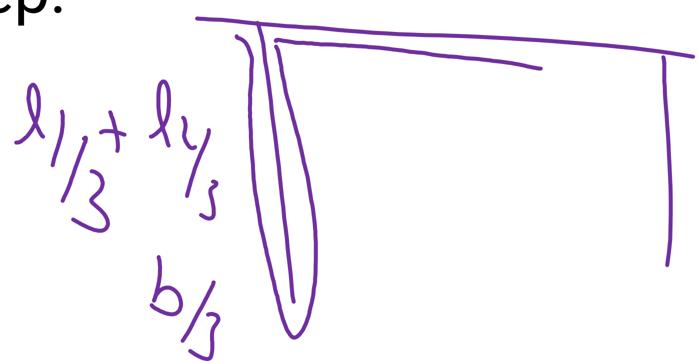


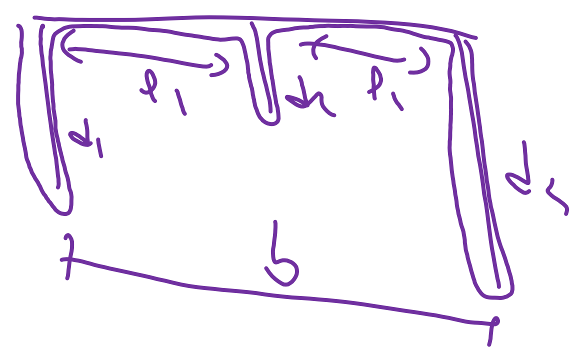
By using Bligh's theory for the design of the floor if the residual head at any section is 0.42 m and the specific gravity of a material is 2.4, what will be the thickness of the floor by providing F.O.S as 4/3?

Ans: 0.4 m

❖ Lane's Weighted Creep Theory

1. Bligh, in his theory, had calculated the length of the creep, by simply adding the horizontal creep length and the vertical creep length, thereby making no distinction between the two creeps.
2. However, Lane, on the basis of his analysis carried out on about 200 dams all over the world, stipulated that horizontal creep is **less effective** in reducing uplift (or in causing loss of head) than vertical creep.
3. He, therefore, suggested a weightage factor of 1/3 for the horizontal creep, as against 1.0 for the vertical creep.





The total Lane's creep length (Ll) is given by

$V = 1$

$H = 1/3$

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

$$i = \frac{h}{L}$$

$$\frac{h}{G-1}$$

$H' = h - i \times L'$

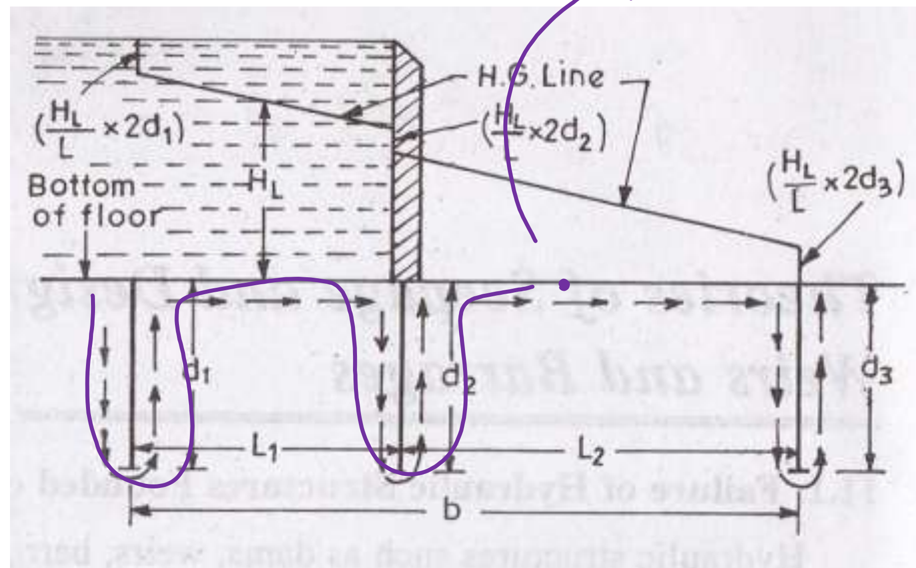


Fig-1: Bligh's Creep

To ensure safety against piping,
according to this theory,

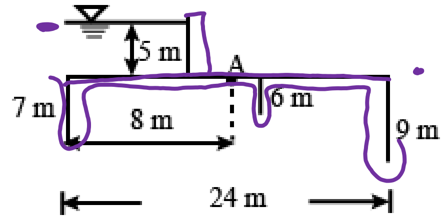
the creep length L_l must not be less than
C_1H_L, where H_L is the head causing flow, and C_1 is Lane's creep coefficient given in table –2

$L = CH$

Table – 2: Values of Lane's Safe Hydraulic Gradient for different types of Soils

SL No.	**Type of Soil**	**Value of Lane's Coefficient C_1**	**Safe Lane's Hydraulic gradient should be less than**
1	Very fine sand or silt	8.5	1/8.5
2	Fine sand	7.0	1/7
3	Coarse sand	5.0	1/5
4	Gravel and sand	3.5 to 3.0	1/3.5 to 1/3
5	Boulders, gravels and sand	2.5 to 3.0	1/2.5 to 1/3
6	Clayey soils	3.0 to 1.6	1/3 to 1/1.6

The figure shows a section of a hydraulic structure with three sheet piles founded on previous soil.



If the specific gravity of the floor material is 2.24, as Lane's weighted creep theory, the minimum thickness required for the impervious floor at the point 'A' is
Ans(2.74 m)

Find i=H/L
Find Residual head

$$i = \frac{H}{L} = \frac{5}{\frac{1}{3}\times 24 + 2(7+9+6)} = \frac{5}{8+44} = 0.09$$

$$t = \frac{h}{G-1}$$

$$h = 5 - i \times (2\times 7 + 8/3) = 3.39\,m$$

$$t = 3.39/(2.24-1) = 2.73\,m$$

Uplift pressure = $\gamma_w h$

❖ Khosla's Theory and Concept of Flow Nets

- Many of the important hydraulic structures, such as weirs and barrage, were designed on the basis of Bligh's theory between the periods 1910 to 1925. In 1926 – 27, the upper *Chenab canal* siphons, designed on Bligh's theory, started posing undermining troubles. Investigations started, which ultimately lead to *Khosla's theory*. The main principles of this theory are summarized below:

- (a) The seepage water does not creep along the bottom contour of pucca floor as started by Bligh, but on the other hand, this water moves along a set of stream-lines. This steady seepage in a vertical plane for a homogeneous soil can be expressed by *Laplacian equation:*

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

- Where, φ = Flow potential = Kh; K = the co-efficient of permeability of soil as defined by Darcy's law, and h is the residual head at any point within the soil.

- The above equation represents two sets of curves intersecting each other orthogonally. The resultant flow diagram showing both of the curves is called a *Flow Net*.

Stream lines

- The streamlines represent the paths along which the water flows through the sub-soil. Every particle entering the soil at a given point upstream of the work, will trace out its own path and will represent a streamline. The first streamline follows the bottom contour of the works and is the same as Bligh's path of creep. The remaining streamlines follows smooth curves transiting slowly from the outline of the foundation to a semi-ellipse, as shown below.

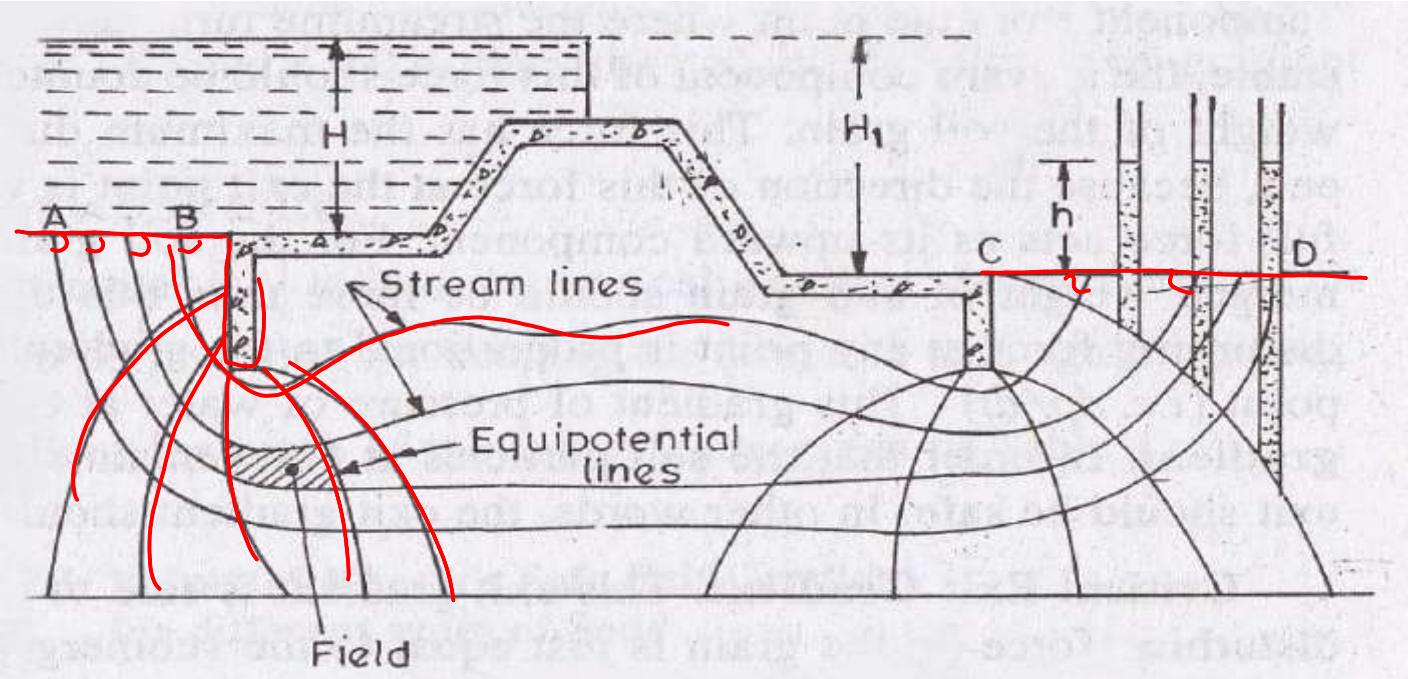


Fig: Khosla's Flow Net

Equipotential lines

- Treating the downstream bed as datum and assuming no water on the downstream side, it can be easily started that every streamline possesses a head equal to h1 while entering the soil; and when it emerges at the down-stream end into the atmosphere, its head is zero. Thus, the head h1 is entirely lost during the passage of water along the streamlines. Further, at every intermediate point in its path, there is certain residual head (h) still to be dissipated in the remaining length to be traversed to the downstream end. This fact is applicable to every streamline, and hence, there will be points on different streamlines having the same value of residual head h. If such points are joined together, the curve obtained is called an equipotential line.
- Every water particle on line AB is having a residual head h = h1, and on CD is having a residual head h = 0, and hence, AB and CD are equipotential lines.
- Since an equipotential line represent the joining of points of equal residual head, hence if piezometers were installed on an equipotential line, the water will rise in all of them up to the same level as shown in figure below.

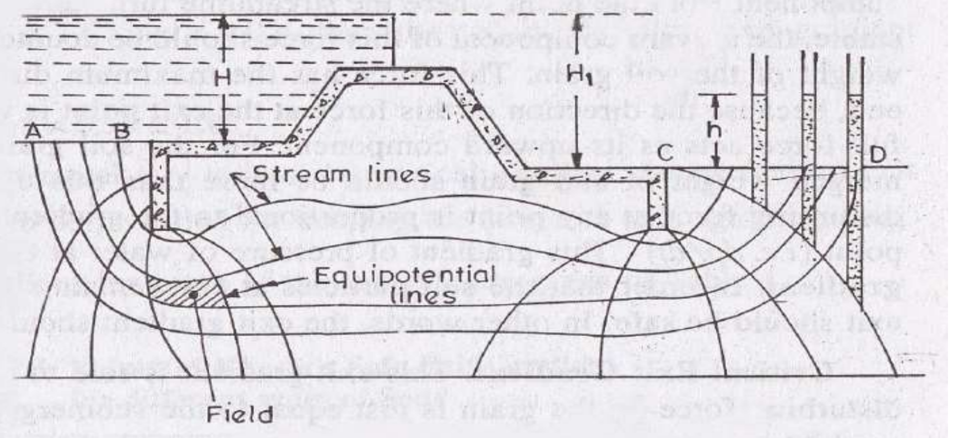
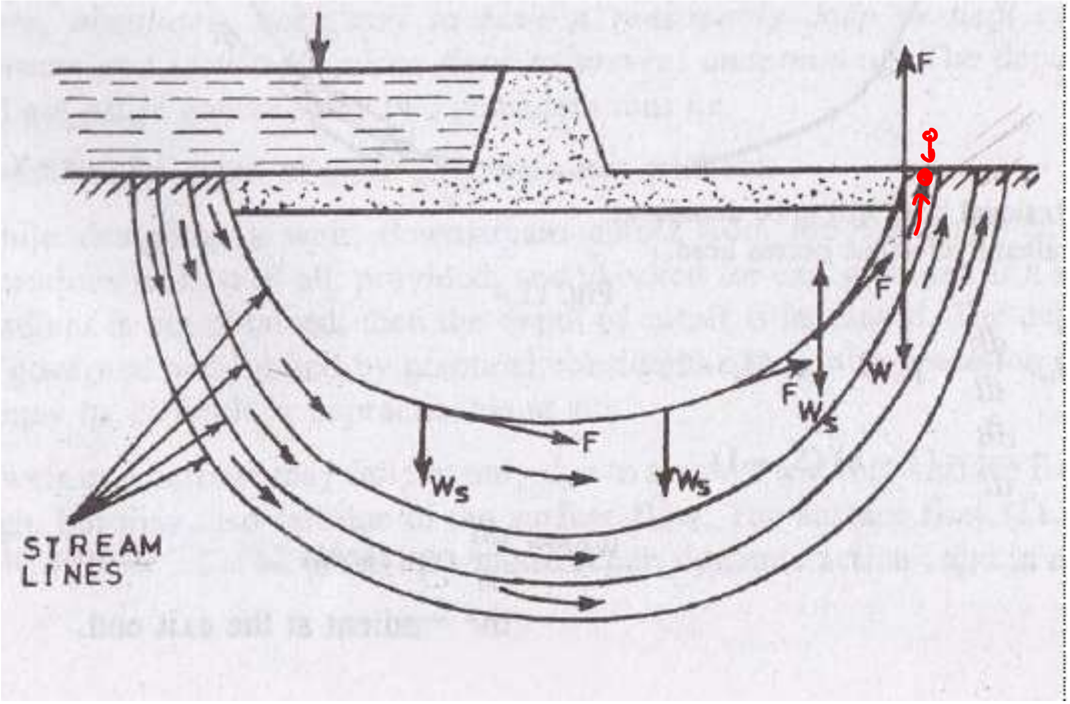


Fig: Khosla's Flow Net

- (b) The seepage water exerts a force at each point in the direction of flow and tangential to the streamlines as shown in figure above. This force (F) has an upward component from the point where the streamlines turns upward. For soil grains to remain stable, the upward component of this force should be counterbalanced by the submerged weight of the soil grain. This force has the maximum disturbing tendency at the exit end, because the direction of this force at the exit point is vertically upward, and hence full force acts as its upward component. For the soil grain to remain stable, the submerged weight of soil grain should be more than this upward disturbing force. The disturbing force at any point is proportional to the gradient of pressure of water at that point (i.e. dp/dl). This gradient of pressure of water at the exit end is called the ***exit gradient.*** In order that the soil particles at exit remain stable, the upward pressure at exit should be safe. In other words, the exit gradient should be safe.



Critical exit gradient

- This 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 to 5 is used, the exit gradient can then be taken as safe. In other words, an exit gradient equal to ¼ to 1/5 of the critical exit gradient is ensured, so as to keep the structure safe against piping.

$$\frac{4}{3} \times t$$

Khosla's Conclusion

1. The outer face of the end sheet piles are more effective than the inner ones and the horizontal length of floor.
2. If intermediate sheet pile is smaller in length than the outer one then they were ineffective. (except for local redistribution of pressure)
3. It was essential to have deep vertical cutoff at the D/s end of the floor to prevent from piping.
4. Piping of floor started from the tail end, if the exit gradient at the D/s end is more than the critical exit gradient. The soil particle will move with the flow of water causing degradation of sub soil and resulting in failure.

For safety, exit gradient must be less than the critical exit gradient.

Considering factor of safety, safe exit gradient is taken as ¼ to 1/5 of critical exit gradient

Exit gradient

- It has been determined that for a standard form consisting of a floor length ‘b’ with vertical cutoff of depth ‘d’, exit gradient as it’s downstream end is given by;

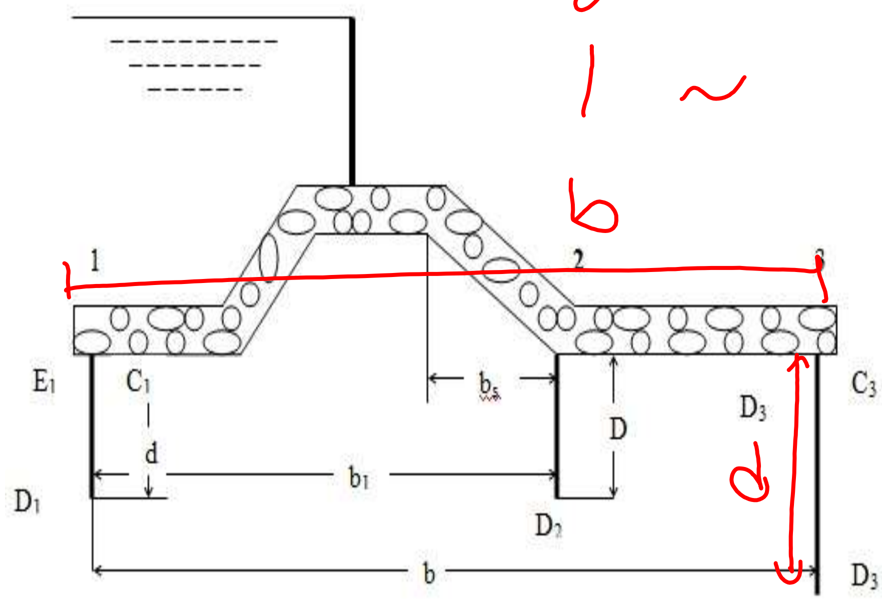
$$\text{Exit gradient, } G_E = \frac{H}{d}\frac{1}{\pi\sqrt{\lambda}}$$

$$\text{where, } \lambda = \frac{1+\sqrt{1+\alpha^2}}{2},\ \alpha = \frac{b}{d}$$

b is length of floor

d is depth of vertical cut off at d/s

$$G_{cr} = i = \frac{G_s - 1}{1+e}$$



the exit gradient in the absence of downstream cut-off is is infinite

Type of Soil	Safe exit gradient
Shingle	1/4 to 1/5 (0.25 to 0.20)
Coarse Sand	1/5 to 1/6 (0.20 to 0.17)
Fine Sand	1/6 to 1/7 (0.17 to 0.14)

Percentage of pressure at points on sheet pile

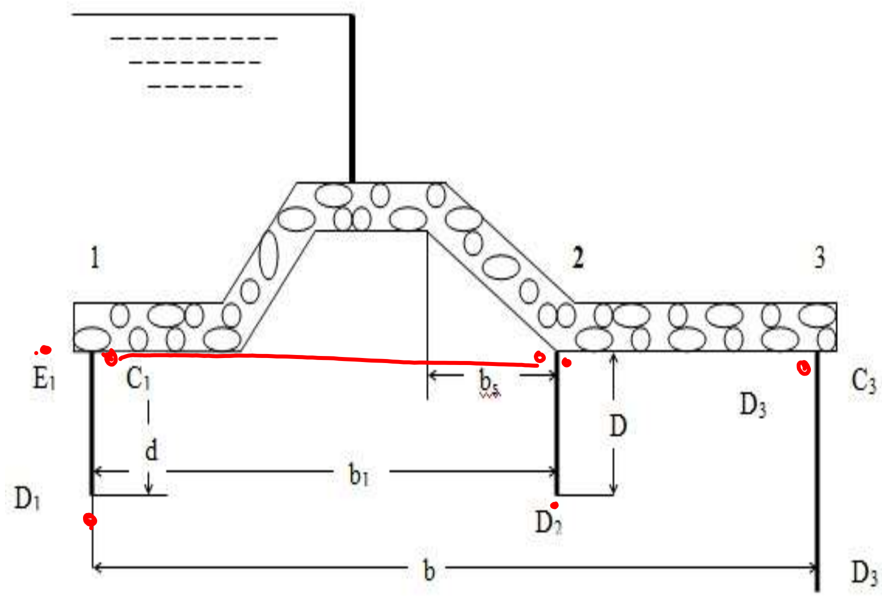
$$\lambda = \frac{1+\sqrt{1+\alpha^2}}{2}, \qquad \alpha = \frac{b}{d}$$

$$\phi_E = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda-2}{\lambda}\right)$$

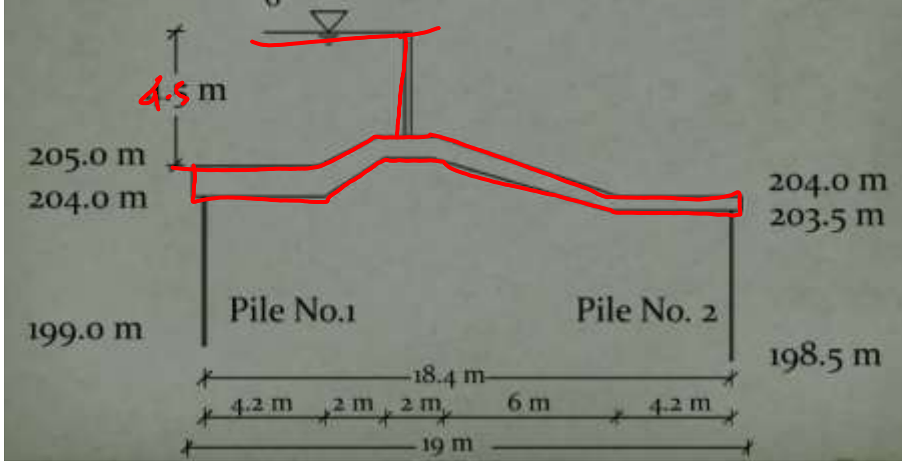
$$\phi_D = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda-1}{\lambda}\right)$$

$$\phi_{C1} = 100 - \phi_E$$

$$\phi_{D1} = 100 - \phi_D$$

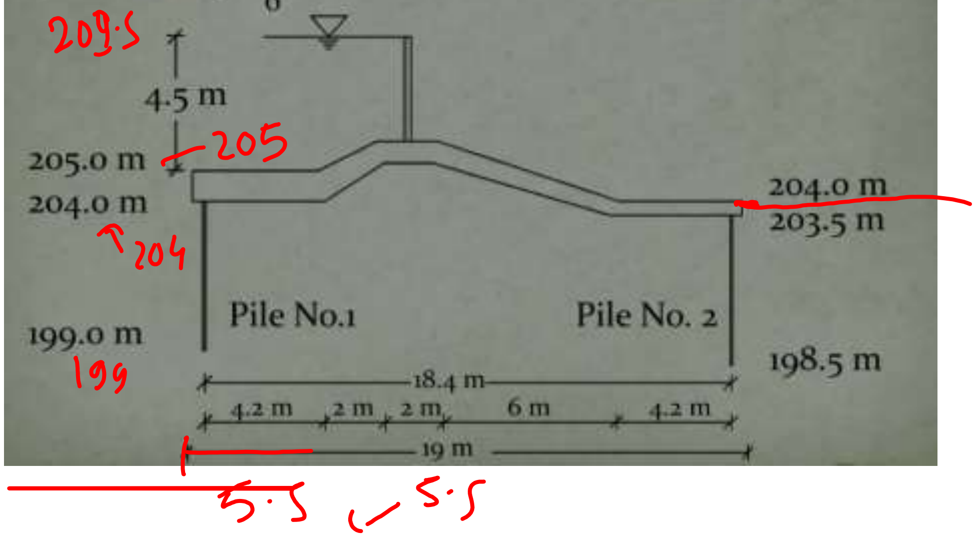


Determine the percentage pressure of the key points and exit gradient. Check if the given structure is safe against piping action or not. The permissible exit gradient $G_e = \frac{1}{6}$.



100, 72.70,81.69,26.27,17.7,0
not safe(1/4.762)

Determine the percentage pressure of the key points and exit gradient. Check if the given structure is safe against piping action or not. The permissible exit gradient $G_e = \frac{1}{6}$.



If safe exit gradient is not given
And void ratio is given

$$i = \frac{h}{L} = \frac{G_s - 1}{1 + e}$$

e, G quick sand

$$i_c = \frac{G_c - 1}{1 + e}$$

$$\frac{h}{d} \quad \frac{1}{\pi\sqrt{\lambda}}$$

$$\lambda = \frac{1 + \sqrt{1 + \alpha^2}}{2}$$

$$\alpha = \frac{b}{d} = \frac{19}{5}$$

$$\lambda =$$

The minimum width in the elementary profile of a gravity dam required to retain the water with a head of 60 m is [Take G = 2.4, C = 1, μ =0.65)

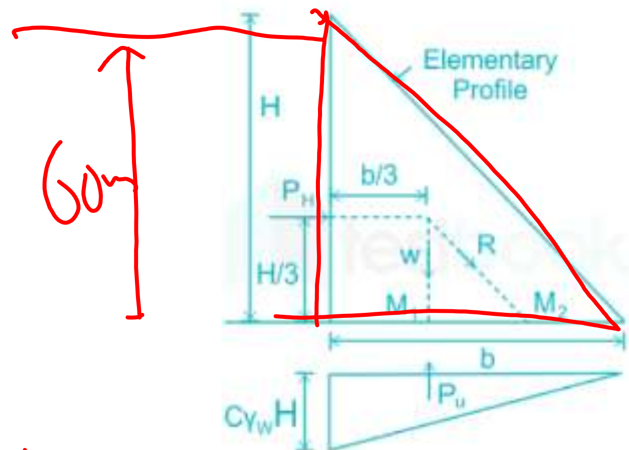
a) $39m$ b) $51m$ ✓ a) $66m$ a) $89m$

For no tension failure

$$B_{min} = \frac{H}{\sqrt{G-C}} = \frac{H}{\sqrt{2.4-1}} = 51m$$

~~*For no tension failure*~~ No sliding failure

$$B_{min} = \frac{H}{\mu(G-C)} = \frac{H}{\mu(G-C)} = 66$$



C = 1 uplift condition

C = 0 No uplift is considered

Design of silt excluder

I. Silt excluder are designed for 15 to 20 % of canal full supply discharge.

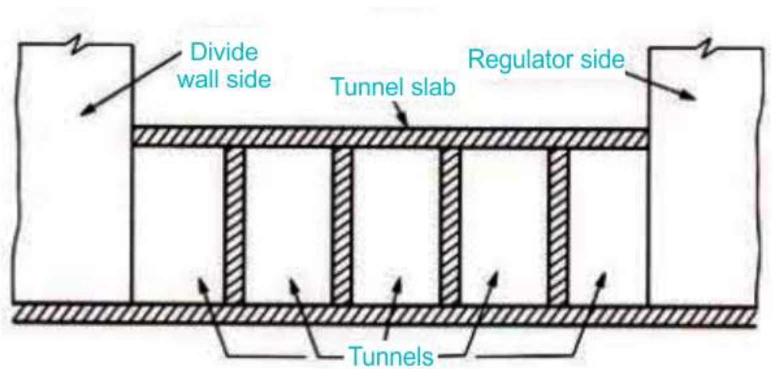
II. A minimum velocity of 3 m/s for ordinary straight reaches.

III. A common size of tunnel could be 2 m wide and 3 m high

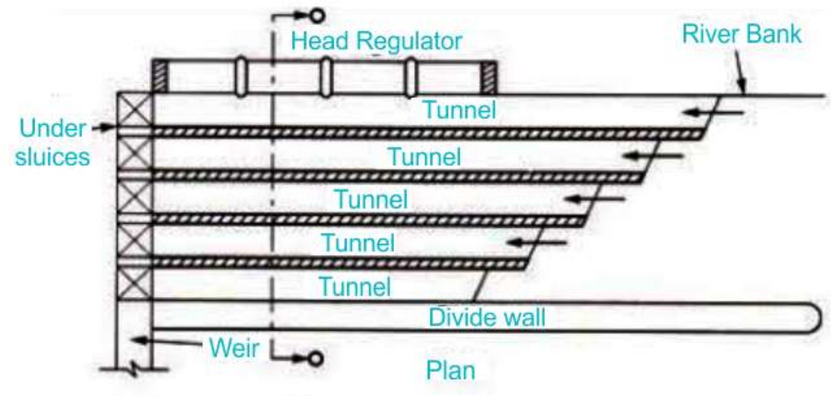
IV. Generally 4 to 6 tunnel are provided for each excluder.

V. At entrance. The tunnel are generally given a bell mouth shape and radius of bell mouthing generally varies from 2 to 6 time the tunnel width.

VI. Height of tunnel is 0.5 to 0.6 for sandy river and 0.8 to 1.2m for boulder stage river

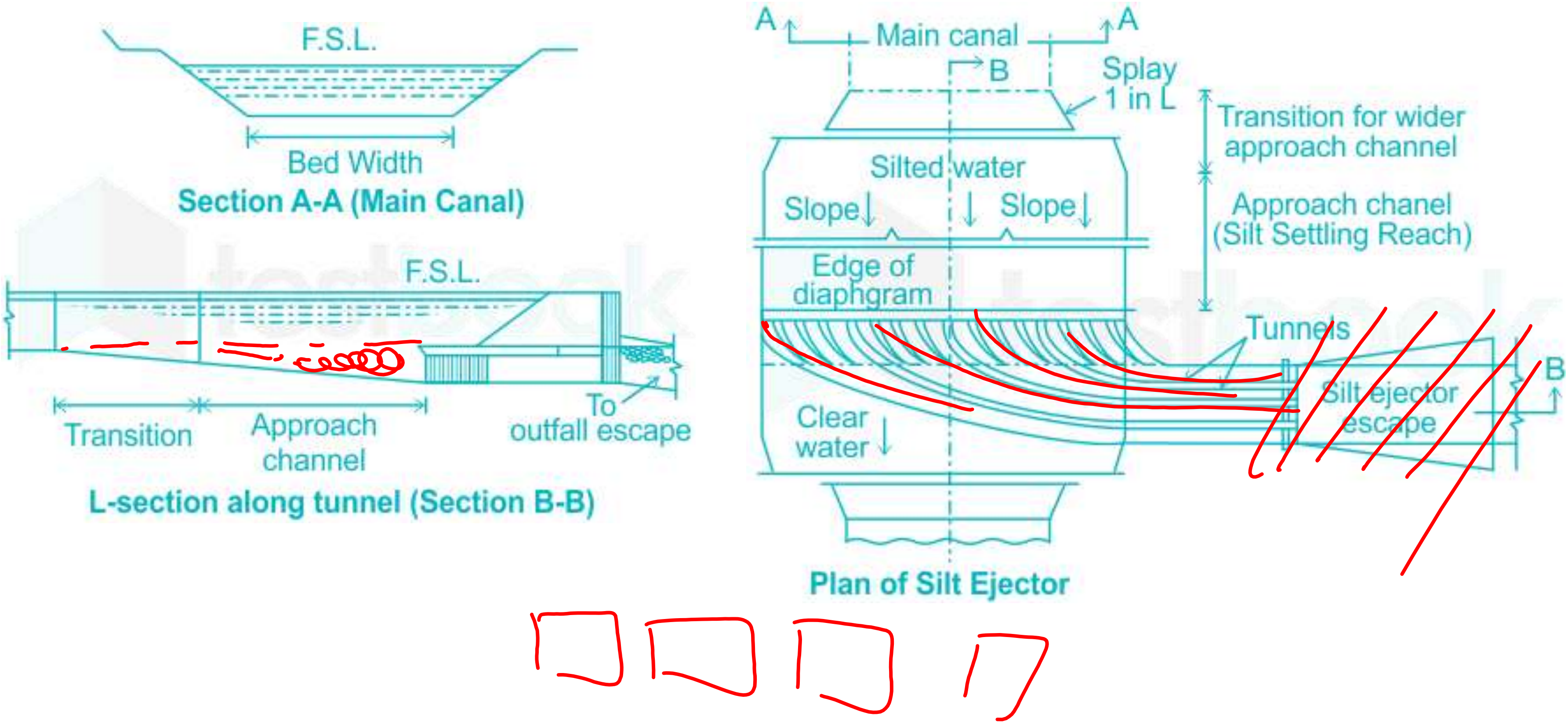


Section at 0.0



Plan

Design of slit ejector / extractor



Design of slit ejector

- Silt ejectors are designed for 10 to 20 % of the canal discharge.
- Bed of the canal is depressed by 0.3 m to 0.5 m at the mouth of the ejector so that approach velocities are reduced and the bed load may be trapped.
- The height of tunnel at entrance is kept at around 1/4 to 1/5 of depth of water in canal.
- The ideal distances between head regulator and silt ejector is usually between 150 m to 500 m..
- The section of the main tunnel at exit is usually designed to attain the velocity of around 3 m/s.
- The portion of the approach channel immediately upstream of the ejector should be pitched/lined for a length of 3 to 4 times the depth of the water in the channel so that there is no erosion of the bed and sides of the channel.