

**ECONOMICAL & PHYSICAL JUSTIFICATION FOR CANAL**

CHAPTER **5**

**Advantages of Lining**

- Seepage Control
- Prevention of Water-Logging
- Increase in Channel Capacity
- Increase in Commanded Area
- Reduction in Maintenance Costs
- Elimination of Flood Dangers

**Selection of suitable type of lining**

- Low cost
- Impermeability
- Hydraulic efficiency (i.e. reduction in rugosity coefficient)
- Durability
- Resistance to erosion
- Repairability
- Structural stability

**Financial Justification and Economics of Canal Lining**

**(i) Annual benefits:**

(a) *Saved seepage water by lining:*

Let, the rate of water is sold to the cultivators = Tk.  $R_1$ /cumec

If  $m$  cumecs of water is saved by lining the canal annually, then the money saved by lining = Tk.  $m R_1$

(b) *Saving in maintenance cost:*

Let, the average cost of annual upkeep of unlined channel = Tk.  $R_2$

If  $p$  is the percentage fraction of the saving achieved in maintenance cost by lining the canal, then the amount saved =  $pR_2$  Tk.

∴ The total annual benefits =  $mR_1 + p R_2$

**(ii) Annual costs:**

Let, the capital expenditure required on lining is  $C$  Tk. & the lining has a life of  $Y$  years

∴ Annual depreciation charges =  $C/Y$  Tk.

∴ Interest of the capital  $C = C(r/100)$

[∵  $r$  = percent of the rate of annual interest]

∴ Average annual interest =  $C/2(r/100)$  Tk.

[∵ Since the capital value of the asset decreases from  $C$  to zero in  $Y$  years]

∴ The total annual costs of lining =  $C/Y + C/2(r/100)$

$$\therefore \text{Benefit cost ratio} = \frac{\text{Annual Benefits}}{\text{Annual Costs}} = \frac{mR_1 + pR_2}{\frac{C}{Y} + \frac{C}{2} \times \frac{r}{100}}$$

If  $p$  is taken as 0.4, then

$$\text{Benefit cost ratio} = \frac{mR_1 + 0.4R_2}{\frac{C}{Y} + \frac{C}{2} \times \frac{r}{100}}$$

**Problem:**

An unlined canal giving a seepage loss of 3.3 cumec per million square meters of wetted area is proposed to be lined with 10 cm thick cement concrete lining, which costs Tk. 180 per 10 square meters. Given the following data, work out the economics of lining and benefit cost ratio.

Annual revenue per cumec of water from all crops	Tk. 3.5 lakhs
Discharge in the channel	83.5 cumecs
Area of the channel	40.8 m <sup>2</sup>
Wetted perimeter of the channel	18.8 m
Wetted perimeter of the lining	18.5 m
Annual maintenance cost of unlined channel per 10 square meter	Tk. 1.0

**Solution:**

Let us consider 1 km reach of canal. Therefore, the wetted surface per km =  $18.8 \times 1000 = 18,800 \text{ m}^2$

**(i) Annual Benefits****(a) Seepage loss**

$$\begin{aligned} \text{Seepage loss in unlined canal @ 3.3 cumec per million sq. m} &= (3.3/10^6) \times 18,800 \text{ cumec/km} \\ &= 62,040 \times 10^{-6} \text{ cumec/km} \end{aligned}$$

Assume, seepage loss in lined channel at 0.01 cumec per million square meter of wetted perimeter

$$\therefore \text{Seepage loss in unlined canal} = (0.01/10^6) \times 18,800 = 188 \times 10^{-6} \text{ cumecs/km}$$

$$\text{Net saving} = (62,040 \times 10^{-6} - 188 \times 10^{-6}) \text{ cumec/km} = 0.06185 \text{ cumec/km}$$

$$\text{Annual revenue saved per km of channel} = (0.06185 \times 3.5) \text{ lakhs} = 0.21648 \text{ lakhs} = 21,648 \text{ Tk.}$$

**(b) Saving in maintenance**

$$\text{Annual maintenance cost of unlined channel for 10 square meter} = \text{Tk. 1}$$

$$\text{Total wetted perimeter per 1 km length} = 18,800 \text{ m}^2$$

$$\therefore \text{Annual maintenance charge for unlined channel per km} = \text{Tk. 1,880}$$

Assume that 40% of this is saved in lined channel

$$\text{Annual saving in maintenance charges} = \text{Tk. } (0.4 \times 1880) = \text{Tk. 752}$$

$$\therefore \text{Total annual benefits per km} = \text{Tk. } (21,648 + 752) = \text{Tk. 22,400}$$

**(ii) Annual Costs**

$$\text{Area of lining per km of channel} = 18.5 \times 1000 = 18500 \text{ m}^2$$

$$\text{Cost of lining per km of channel @ Tk. 180 per } 10 \text{ m}^2 = (18500 \times 180/10) \text{ Tk.} = 333000 \text{ Tk.}$$

Assume, life of lining as 40 years

$$\text{Depreciation cost per year} = \text{Tk. } (3,33,000/40) = \text{Tk. 8325}$$

Assume 5% rate of interest

$$\text{Average annual interest} = C/2 (r/100) = 3,33,000/2 \times (5/100) = \text{Tk. 8325}$$

$$\therefore \text{Total annual cost} = \text{Tk. } (8325 + 8325) = \text{Tk. 16,650}$$

$$\text{Benefit cost ratio} = \text{Annual benefits/Annual costs} = 22,400/16,650 = 1.35$$

Benefit cost ratio is more than unity, and hence, the lining is justified.

## Causes of failure of weir or barrage on permeable foundation:

### 1. Failure due to Subsurface Flow

#### (a) Failure by Piping or undermining

The water from the upstream side continuously percolates through the bottom of the foundation and emerges at the downstream end of the weir or barrage floor. The force of percolating water removes the soil particles by scouring at the point of emergence. As the process of removal of soil particles goes on continuously, a depression is formed which extends backwards towards the upstream through the bottom of the foundation. A hollow pipe like formation thus develops under the foundation due to which the weir or barrage may fail by subsiding. This phenomenon is known as failure by piping or undermining.

#### (b) Failure by Direct uplift

The percolating water exerts an upward pressure on the foundation of the weir or barrage. If this uplift pressure is not counterbalanced by the self weight of the structure, it may fail by rapture.

### 2. Failure by Surface Flow

#### (a) By hydraulic jump

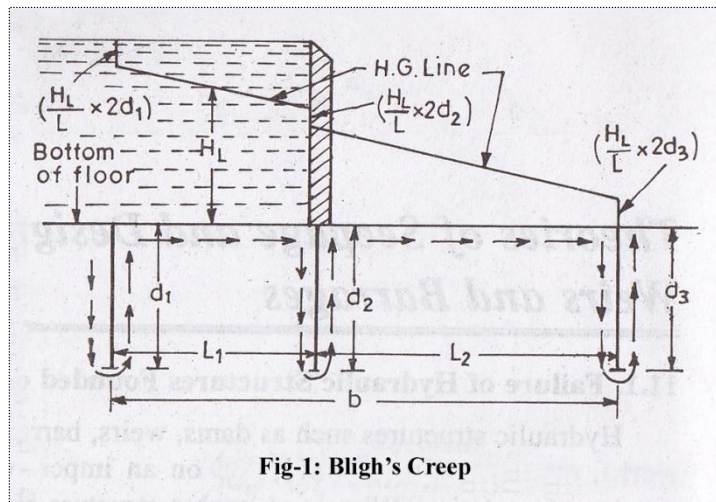
When the water flows with a very high velocity over the crest of the weir or over the gates of the barrage, then hydraulic jump develops. This hydraulic jump causes a suction pressure or negative pressure on the downstream side which acts in the direction uplift pressure. If the thickness of the impervious floor is sufficient, then the structure fails by rapture.

#### (b) By scouring

During floods, the gates of the barrage are kept open and the water flows with high velocity. The water may also flow with very high velocity over the crest of the weir. Both the cases can result in scouring effect on the downstream and on the upstream side of the structure. Due to scouring of the soil on both sides of the structure, its stability gets endangered by shearing.

### Bligh's Creep Theory for Seepage Flow

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 contour of the structure. The length of the path thus traversed by water is called the length of the creep. 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. Further, Bligh makes no distinction between horizontal and vertical creep.



Consider a section as shown in Fig above. Let  $H_L$  be the difference of water levels between upstream and downstream ends. Water will seep along the bottom contour as shown by arrows. It starts percolating at  $A$  and emerges at  $B$ . The total length of creep is given by

$$\begin{aligned} L &= d_1 + L_1 + d_2 + L_2 + d_3 + L_3 \\ &= (L_1 + L_2 + L_3) + 2(d_1 + d_2 + d_3) \\ &= b + 2(d_1 + d_2 + d_3) \end{aligned}$$

$$\text{Head loss per unit length or hydraulic gradient} = \left[ \frac{H_L}{b + 2(d_1 + d_2 + d_3)} \right] = \frac{H_L}{L}$$

Head losses equal to  $\left(\frac{H_L}{L} \times 2d_1\right)$ ,  $\left(\frac{H_L}{L} \times 2d_2\right)$ ,  $\left(\frac{H_L}{L} \times 2d_3\right)$ ; will occur respectively, in the planes of three vertical cut offs. The hydraulic gradient line (H.G. Line) can then be drawn as shown in figure above.

**(i) 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. Different values of C for different types of soils are tabulated in Table –1 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

**Note:** The hydraulic gradient i.e.  $H_L/L$  is then equal to  $1/C$ . Hence, it may be stated that the hydraulic gradient must be kept under a safe limit in order to ensure safety against piping.

**(ii) 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. Say for example, if at any point, the ordinate of H.G line above the bottom of the floor is 1 m, then 1 m head of water will act as uplift at that point. If  $h'$  meters is this ordinate, then water pressure equal to  $h'$  meters will act at this point, and has to be counterbalanced by the weight of the floor of thickness say  $t$ .

$$\therefore \text{Uplift pressure} = \gamma_w \times h'$$

[where  $\gamma_w$  is the unit weight of water]

$$\text{Downward pressure} = (\gamma_w \times G).t$$

[Where  $G$  is the specific gravity of the floor material]

For equilibrium,

$$\gamma_w \times h' = \gamma_w \times G.t$$

$$\Rightarrow h' = G \times t$$

Subtracting  $t$  on both sides, we get

$$(h' - t) = (G \times t - t) = t(G - 1)$$

$$\Rightarrow t = \left( \frac{h' - t}{G - 1} \right) = \left( \frac{h}{G - 1} \right)$$

Where,  $h' - t = h =$  Ordinate of the H.G line above the top of the floor

$G - 1 =$  Submerged specific gravity of the floor material

**Lane's Weighted Creep Theory**

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. However, Lane, on the basis of his analysis carried out on about 200 dams all over the world, stipulated that the horizontal creep is less effective in reducing uplift (or in causing loss of head) than the vertical creep. He, therefore, suggested a weightage factor of 1/3 for the horizontal creep, as against 1.0 for the vertical creep.

Thus in Fig–1, the total Lane's creep length ( $L_l$ ) is given by

$$\begin{aligned} L_l &= (d_1 + d_1) + (1/3) L_1 + (d_2 + d_2) + (1/3) L_2 + (d_3 + d_3) \\ &= (1/3) (L_1 + L_2) + 2(d_1 + d_2 + d_3) \\ &= (1/3) b + 2(d_1 + d_2 + d_3) \end{aligned}$$

To ensure safety against piping, according to this theory, the creep length  $L_l$  must no be less than  $C_1 H_L$ , where  $H_L$  is the head causing flow, and  $C_1$  is Lane's creep coefficient given in table –2

**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

**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:

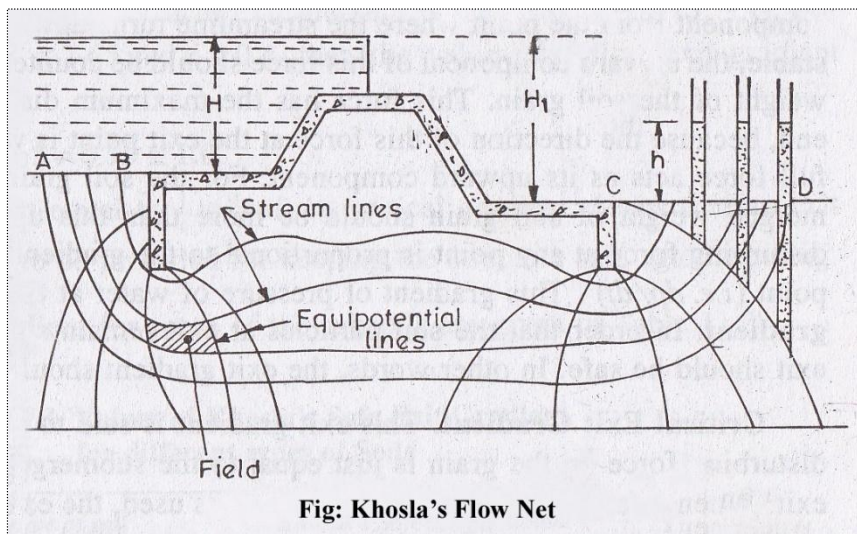
- (a) The seepage water does not creep along the bottom contour of pucca flood as started by Bligh, but on the other hand, this water moves along a set of stream-lines. This steady seepage in a vertical plane for a homogeneous soil can be expressed by *Laplacian* equation:

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

Where,  $\phi$  = 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.



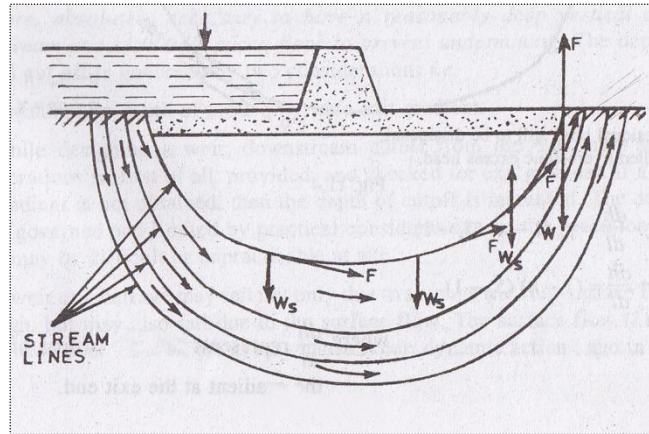
**Fig: Khosla’s Flow Net**

**Equipotential Lines:** (1) 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  $h_1$  while entering the soil; and when it emerges at the down-stream end into the atmosphere, its head is zero. Thus, the head  $h_1$  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  $h = h_1$ , 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.



- (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  $1/4$  to  $1/5$  of the critical exit gradient is ensured, so as to keep the structure safe against piping.

The submerged weight ( $W_s$ ) of a unit volume of soil is given as:

$$\gamma_w (1 - n) (S_s - 1)$$

Where,  $\gamma_w$  = unit weight of water.

$S_s$  = Specific gravity of soil particles

$n$  = Porosity of the soil material

For critical conditions to occur at the exit point

$$F = W_s$$

Where F is the upward disturbing force on the grain

Force F = pressure gradient at that point =  $dp/dl = \gamma_w \times dh/dl$

**Khosla's Method of independent variables for determination of pressures and exit gradient for seepage below a weir or a barrage**

In order to know as to how the seepage below the foundation of a hydraulic structure is taking place, it is necessary to plot the flow net. In other words, we must solve the *Laplacian* equations. This can be accomplished either by mathematical solution of the Laplacian equations, or by Electrical analogy method, or by graphical sketching by adjusting the streamlines and equipotential lines with respect to the boundary conditions. These are complicated methods and are time consuming. Therefore, for designing hydraulic structures such as weirs or barrage or pervious foundations, *Khosla* has evolved a simple, quick and an accurate approach, called *Method of Independent Variables*.

In this method, a complex profile like that of a weir is broken into a number of simple profiles; each of which can be solved mathematically. Mathematical solutions of flownets for these simple standard profiles have been presented in the form of equations given in Figure (11.5) and curves given in Plate (11.1), which can be used for determining the percentage pressures at the various key points. The simple profiles which are most useful are:

- (i) A straight horizontal floor of negligible thickness with a sheet pile line on the u/s end and d/s end.
- (ii) A straight horizontal floor depressed below the bed but without any vertical cut-offs.
- (iii) A straight horizontal floor of negligible thickness with a sheet pile line at some intermediate point.

The key points are the junctions of the floor and the pile lines on either side, and the bottom point of the pile line, and the bottom corners in the case of a depressed floor. The percentage pressures at these key points for the simple forms into which the complex profile has been broken is valid for the complex profile itself, if corrected for

- (a) Correction for the Mutual interference of Piles
- (b) Correction for the thickness of floor
- (c) Correction for the slope of the floor

**(a) Correction for the Mutual interference of Piles:**

The correction *C* to be applied as percentage of head due to this effect, is given by

$$C = 19 \sqrt{\frac{D}{b'}} \left( \frac{d+D}{b} \right)$$

Where,

*b'* = The distance between two pile lines.

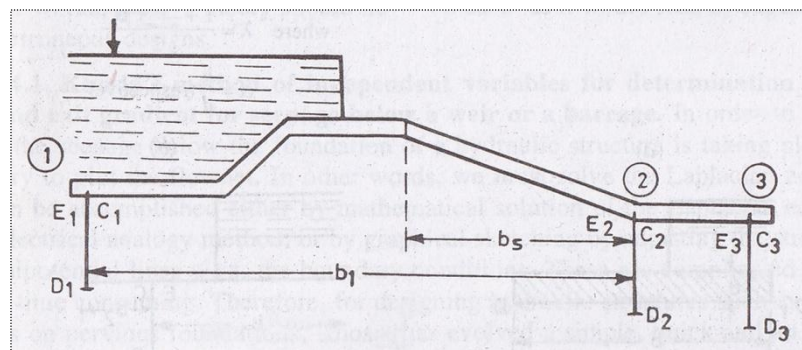
*D* = The depth of the pile line, the influence of which has to be determined on the neighboring pile of depth

*d*. *D* is to be measured below the level at which interference is desired.

*d* = The depth of the pile on which the effect is considered

*b* = Total floor length

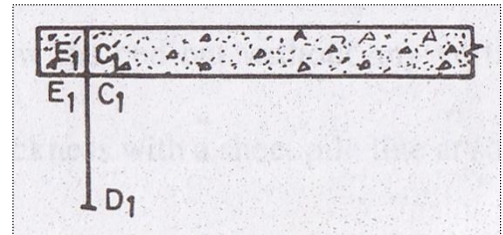
The correction is positive for the points in the rear of back water, and subtractive for the points forward in the direction of flow. This equation does not apply to the effect of an outer pile on an intermediate pile, if the intermediate pile is equal to or smaller than the outer pile and is at a distance less than twice the length of the outer pile.



Suppose in the above figure, we are considering the influence of the pile no (2) on pile no (1) for correcting the pressure at  $C_1$ . Since the point  $C_1$  is in the rear, this correction shall be positive. While the correction to be applied to  $E_2$  due to pile no (1) shall be negative, since the point  $E_2$  is in the forward direction of flow. Similarly, the correction at  $C_2$  due to pile no (3) is positive and the correction at  $E_2$  due to pile no (2) is negative.

**(b) Correction for the thickness of floor:**

In the standard form profiles, the floor is assumed to have negligible thickness. Hence, the percentage pressures calculated by Khosla's equations or graphs shall pertain to the top levels of the floor. While the actual junction points  $E$  and  $C$  are at the bottom of the floor. Hence, the pressures at the actual points are calculated by assuming a straight line pressure variation.



Since the corrected pressure at  $E_1$  should be less than the calculated pressure at  $E_1'$ , the correction to be applied for the joint  $E_1$  shall be negative. Similarly, the pressure calculated  $C_1'$  is less than the corrected pressure at  $C_1$ , and hence, the correction to be applied at point  $C_1$  is positive.

**(c) Correction for the slope of the floor**

A correction is applied for a slopping floor, and is taken as *positive for the downward slopes*, and *negative for the upward slopes* following the direction of flow. Values of correction of standard slopes such as 1 : 1, 2 : 1, 3 : 1, etc. are tabulated in Table 7.4

Slope (H : V)	Correction Factor
1 : 1	11.2
2 : 1	6.5
3 : 1	4.5
4 : 1	3.3
5 : 1	2.8
6 : 1	2.5
7 : 1	2.3
8 : 1	2.0

The correction factor given above is to be multiplied by the horizontal length of the slope and divided by the distance between the two pile lines between which the sloping floor is located. This correction is applicable only to the key points of the pile line fixed at the start or the end of the slope.

**Exit gradient ( $G_E$ )**

It has been determined that for a standard form consisting of a floor length ( $b$ ) with a vertical cutoff of depth ( $d$ ), the exit gradient at its downstream end is given by

$$G_E = \frac{H}{d} \times \frac{1}{\pi\sqrt{\lambda}}$$

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

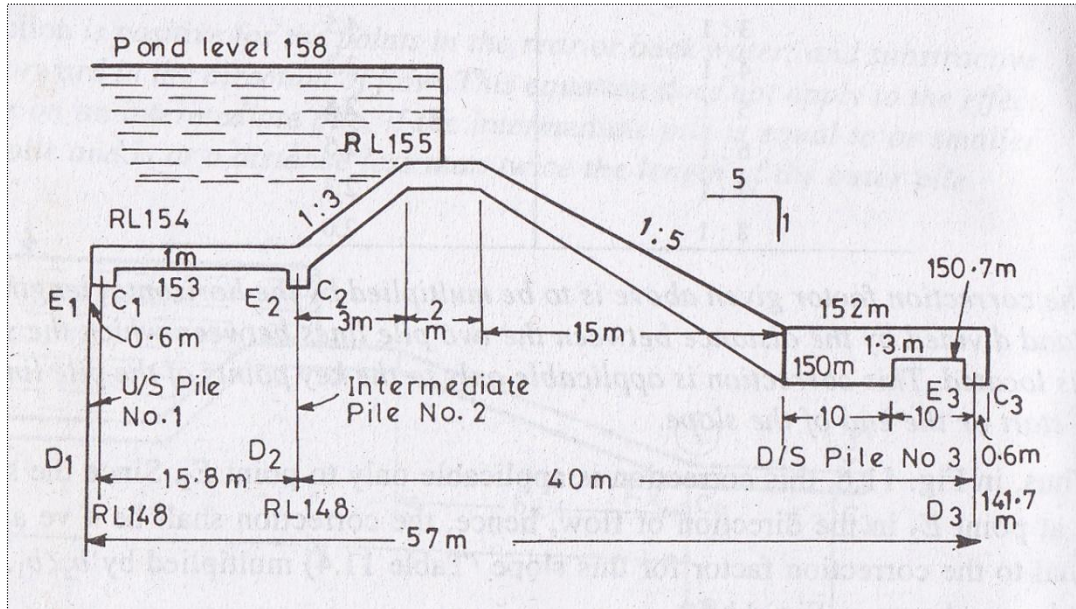
$$\alpha = b/d$$

H = Maximum Seepage Head

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)

### Problem-2

Determine the percentage pressures at various key points in figure below. Also determine the exit gradient and plot the hydraulic gradient line for pond level on upstream and no flow on downstream



### Solution:

#### (1) For upstream Pile Line No. 1

Total length of the floor,  $b = 57.0 \text{ m}$

Depth of u/s pile line,  $d = 154 - 148 = 6 \text{ m}$

$$\alpha = b/d = 57/6 = 9.5$$

$$1/\alpha = 1/9.5 = 0.105$$

From curve plate 11.1 (a)

$$\phi_{C1} = 100 - 29 = 71 \%$$

$$\phi_{D1} = 100 - 20 = 80 \%$$

These values of  $\phi_{C1}$  must be corrected for three corrections as below:

#### Corrections for $\phi_{C1}$

(a) Correction at  $C_1$  for Mutual Interference of Piles ( $\phi_{C1}$ ) is affected by intermediate pile No.2

$$\begin{aligned} \text{Correction} &= 19 \sqrt{\frac{D}{b'} \left( \frac{d+D}{b} \right)} \\ &= 19 \times \sqrt{\frac{5}{15.8}} \times \left( \frac{5+5}{57} \right) \\ &= 1.88 \% \end{aligned}$$

Where,  $D = \text{Depth of pile No.2} = 153 - 148 = 5 \text{ m}$

$d = \text{Depth of pile No. 1} = 153 - 148 = 5 \text{ m}$

$b' = \text{Distance between two piles} = 15.8 \text{ m}$

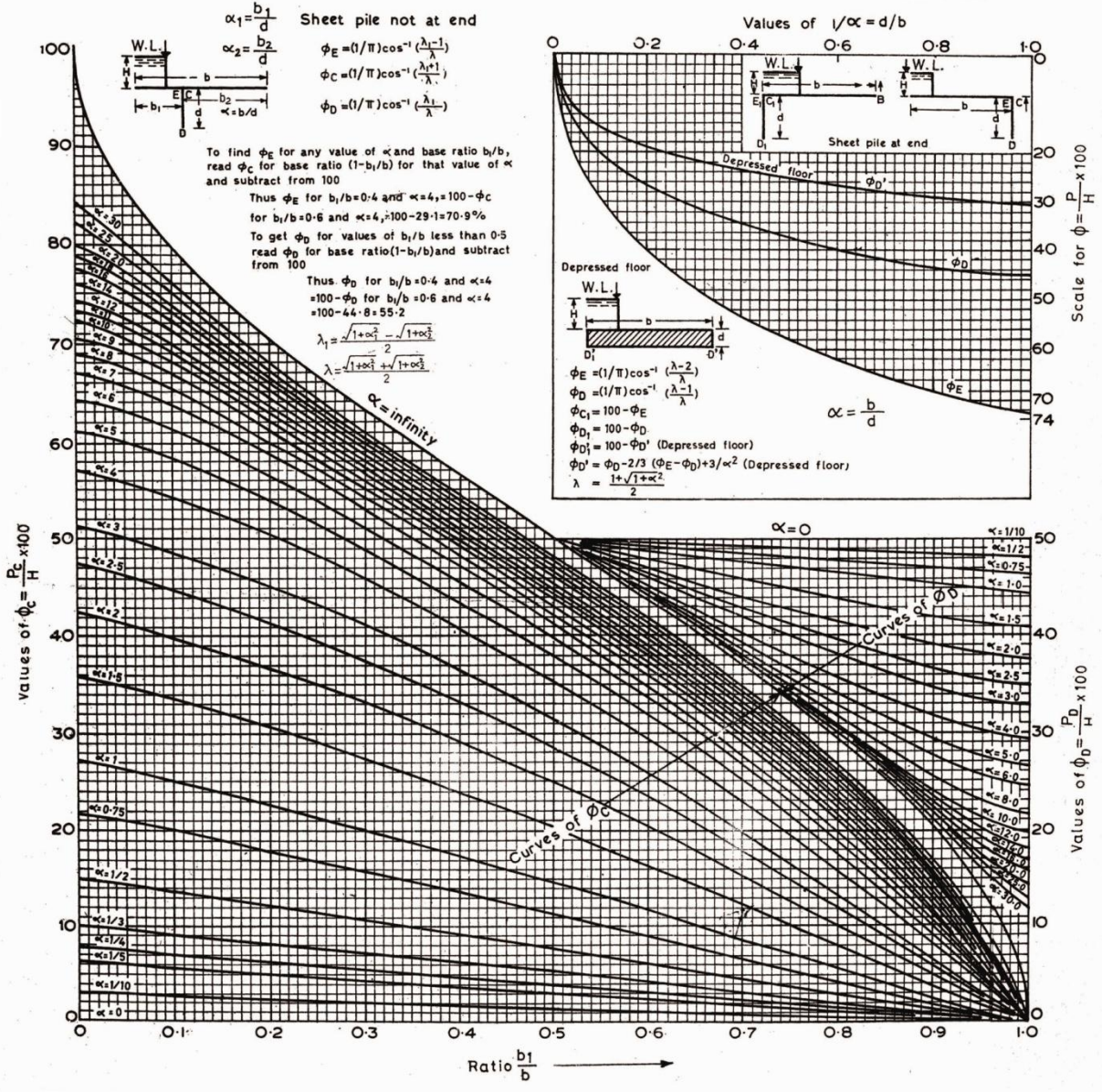
$b = \text{Total floor length} = 57 \text{ m}$

Since the point  $C_1$  is in the rear in the direction of flow, the correction is (+) ve.

$\therefore$  Correction due to pile interference on  $C_1 = 1.88 \%$  (+ ve)

Khosla's Pressure Curves

Plate 11-1(a)



(b) Correction at  $C_1$  due to thickness of floor:

Pressure calculated from curve is at  $C_1'$ , (Fig. 7.1) but we want the pressure at  $C_1$ . Pressure at  $C_1$  shall be more than at  $C_1'$  as the direction of flow is from  $C_1$  to  $C_1'$  as shown; and hence, the correction will be + ve and

$$\begin{aligned} &= \left[ \frac{80\% - 71\%}{154 - 148} \right] \times (154 - 153) \\ &= (9/6) \times 1 \\ &= 1.5\% \text{ (+ ve)} \end{aligned}$$

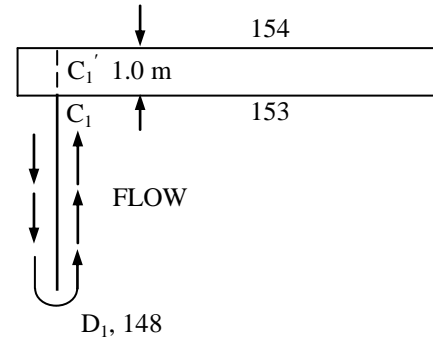


Fig: 5.1

(c) Correction due to slope at  $C_1$  is nil, as this point is neither situated at the start nor at the end of a slope

$$\begin{aligned} \therefore \text{Corrected } (\varphi_{C1}) &= 71\% + 1.88\% + 1.5\% \\ &= 74.38\% \text{ (ans)} \\ \text{And } (\varphi_{D1}) &= 80\% \end{aligned}$$

## (2) For intermediate Pile Line No. 2

$$\begin{aligned} d &= 154 - 148 = 6 \text{ m} \\ b &= 57 \text{ m} \\ \alpha &= b/d = 57/6 = 9.5 \end{aligned}$$

Using curves of plate 11.1 (b), we have  $b_1$  in this case

$$\begin{aligned} b_1 &= 0.6 + 15.8 = 16.4 \\ b &= 57 \text{ m} \\ \therefore b_1/b &= 16.4/57 = 0.298 \text{ (for } \varphi_{C2}) \\ 1 - b_1/b &= 1 - 0.298 = 0.702 \end{aligned}$$

$$\begin{aligned} \varphi_{E2} &= 100 - 30 = 70\% && \text{(Where 30\% is } \varphi_C \text{ for a base ratio of 0.702 and } \alpha = 9.5) \\ \varphi_{C2} &= 56\% && \text{(For a base ratio 0.298 and } \alpha = 9.5) \\ \varphi_{D2} &= 100 - 37 = 63\% && \text{(Where 37\% is } \varphi_D \text{ for a base ratio of 0.702 and } \alpha = 9.5) \end{aligned}$$

## Corrections for $\varphi_{E2}$

(a) Correction at  $E_2$  for sheet pile lines. Pile No. (1) will affect the pressure at  $E_2$  and since  $E_2$  is in the forward direction of flow, this correction shall be - ve. The amount of this correction is given as:

$$\begin{aligned} \text{Correction} &= 19 \sqrt{\frac{D}{b'}} \left( \frac{d+D}{b} \right) \\ &= 19 \times \sqrt{\frac{5}{15.7}} \times \left( \frac{5+5}{57} \right) \\ &= 1.88\% \text{ (- ve)} \end{aligned}$$

Where,  $D$  = Depth of pile No.1, the effect of which is considered =  $153 - 148 = 5$  m  
 $d$  = Depth of pile No. 2, the effect on which is considered =  $153 - 148 = 5$  m  
 $b'$  = Distance between two piles =  $15.8$  m  
 $b$  = Total floor length =  $57$  m

(b) Correction at  $E_2$  due to floor thickness

$$\begin{aligned} &= \frac{\text{Obs } \varphi_{E2} - \text{Obs } \varphi_{D2}}{\text{Distance between } E_2 D_2} \times \text{Thickness of floor} \\ &= \left[ \frac{70\% - 63\%}{154 - 148} \right] \times 1.0 = (7/6) \times 1.0 = 1.17\% \end{aligned}$$

Since the pressure observed is at  $E_2'$  and not at  $E_2$ , (Fig. 7.2) and by looking at the direction of flow, it can be stated easily that pressure at  $E_2$  shall be less than that at  $E_2'$ , hence, this correction is negative,

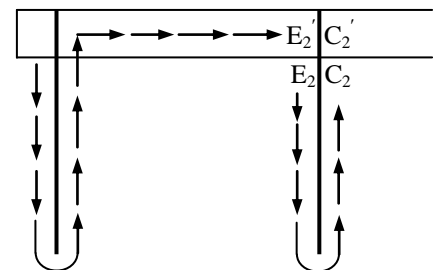


Fig: 5.2

$$\therefore \text{Correction at } E_2 \text{ due to floor thickness} = 1.17\% \text{ (- ve)}$$

(c) Correction at  $E_2$  due to slope is nil, as the point  $E_2$  is neither situated at the start of a slope nor at the end of a shape

Hence, corrected percentage pressure at  $E_2 = \text{Corrected } \phi_{E_2} = (70 - 1.88 - 1.17) \% = 66.95 \%$

### Corrections for $\phi_{C_2}$

(a) Correction at  $C_2$  due to pile interference. Pressure at  $C_2$  is affected by pile No.(3) and since the point  $C_2$  is in the back water in the direction of flow, this correction is (+) ve. The amount of this correction is given as:

$$\begin{aligned} \text{Correction} &= 19 \sqrt{\frac{D}{b'}} \left( \frac{d+D}{b} \right) \\ &= 19 \times \sqrt{\frac{11}{40}} \times \left( \frac{11+5}{57} \right) \\ &= 2.89 \% (+ \text{ve}) \end{aligned}$$

Where,  $D$  = Depth of pile No.3, the effect of which is considered below the level at which interference is desired =  $153 - 141.7 = 11.3$  m  
 $d$  = Depth of pile No. 2, the effect on which is considered =  $153 - 148 = 5$  m  
 $b'$  = Distance between two piles (2 &3) = 40 m  
 $b$  = Total floor length = 57 m

(b) Correction at  $C_2$  due to floor thickness. From Fig. 11.10, it can be easily stated that the pressure at  $C_2$  shall be more than at  $C_2'$ , and since the observed pressure is at  $C_2'$ , this correction shall be + ve and its amount is the same as was calculated for the point  $E_2 = 1.17 \%$

Hence, correction at  $C_2$  due to floor thickness =  $1.17 \%$  (+ ve)

(c) Correction at  $C_2$  due to slope. Since the point  $C_2$  is situated at the start of a slope of 3:1, *i.e.* an up slope in the direction of flow; the correction is negative

Correction factor for 3:1 slope from table 11.4 = 4.5

Horizontal length of the slope = 3 m

Distance between two pile lines between which the sloping floor is located = 40 m

$\therefore$  Actual correction =  $4.5 \times (3/40) = 0.34 \%$  (- ve)

Hence, corrected  $\phi_{C_2} = (56 + 2.89 + 1.17 - 0.34) \% = 59.72 \%$

### (3) Downstream Pile Line No. 3

$d = 152 - 141.7 = 10.3$  m

$b = 57$  m

$1/\alpha = 10.3/57 = 0.181$

From curves of Plate 11.1 (a), we get

$\phi_{D_3} = 26 \%$

$\phi_{E_3} = 38 \%$

### Corrections for $\phi_{E_3}$

(a) Correction due to piles. The point  $E_3$  is affected by pile No. 2, and since  $E_3$  is in the forward direction of flow from pile No. 3, this correction is negative and its amount is given by

$$\begin{aligned} \text{Correction} &= 19 \sqrt{\frac{D}{b'}} \left( \frac{d+D}{b} \right) \\ &= 19 \times \sqrt{\frac{2.7}{40}} \times \left( \frac{9+2.7}{57} \right) \\ &= 1.02 \% (- \text{ve}) \end{aligned}$$

Where,  $D$  = Depth of pile No.2, the effect of which is considered =  $150.7 - 148 = 2.7$  m  
 $d$  = Depth of pile No. 3, the effect on which is considered =  $150 - 141.7 = 9$  m  
 $b'$  = Distance between two piles = 40 m  
 $b$  = Total floor length = 57 m

(b) Correction due to floor thickness

From Fig. 7.3, it can be stated easily that the pressure at  $E_3$  shall be less than at  $E_3'$ , and hence the pressure observed from curves is at  $E_3'$ ; this correction shall be - ve and its amount

$$\begin{aligned} &= \left[ \frac{38\% - 32\%}{152 - 141.7} \right] \times 1.3 = (16/10.3) \times 1.3 \\ &= 0.76 \% (- \text{ve}) \end{aligned}$$

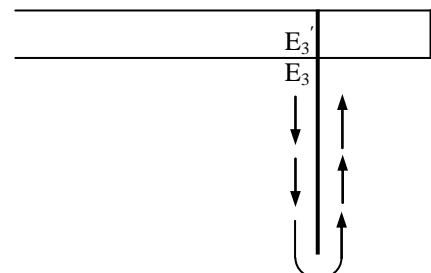


Fig:5.3

(c) Correction due to slope at  $E_3$  is nil, as the point  $E_3$  is neither situated at the start nor at the end of any slope

Hence, corrected  $\phi_{E3} = (38 - 1.02 - 0.76) \% = 36.22 \%$

The corrected pressures at various key points are tabulated below in Table below

<i>Upstream Pile No. 1</i>	<i>Intermediate Pile No.2</i>	<i>Downstream Pile No. 3</i>
$\phi_{E1} = 100 \%$	$\phi_{E2} = 66.95 \%$	$\phi_{E3} = 36.22 \%$
$\phi_{D1} = 80 \%$	$\phi_{D2} = 63 \%$	$\phi_{D3} = 26 \%$
$\phi_{C1} = 74.38 \%$	$\phi_{C2} = 59.72 \%$	$\phi_{C3} = 0 \%$

**Exit gradient**

Let the water be headed up to pond level, i.e. on RL 158 m on the upstream side with no flow downstream

The maximum seepage head,  $H = 158 - 152 = 6 \text{ m}$

The depth of d/s cur-off,  $d = 152 - 141.7 = 10.3 \text{ m}$

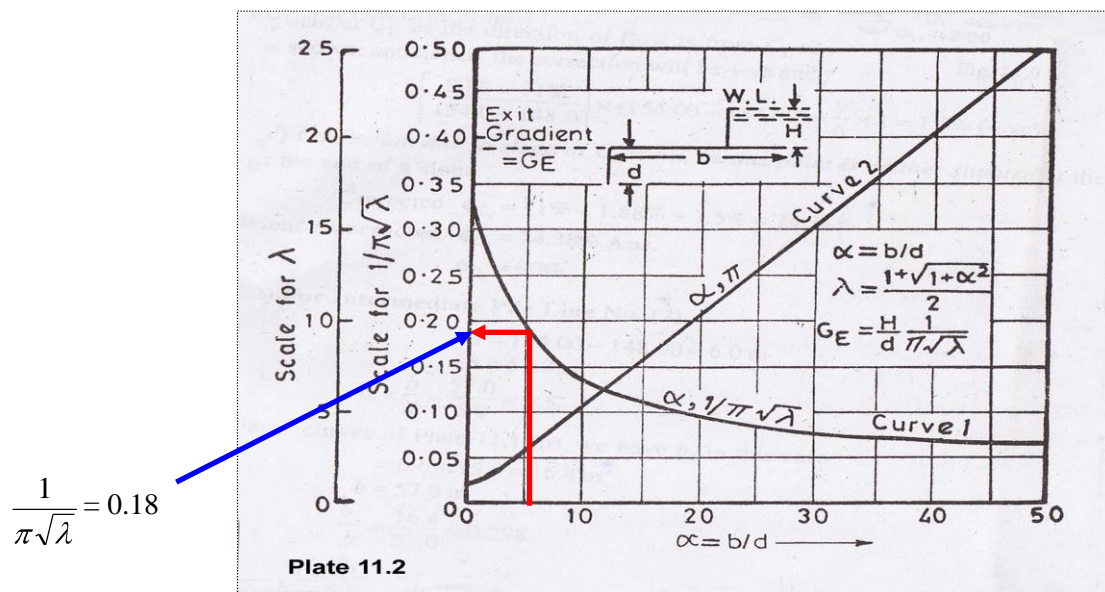
Total floor length,  $b = 57 \text{ m}$

$\alpha = b/d = 57/10.3 = 5.53$

For a value of  $\alpha = 5.53$ ,  $\frac{1}{\pi\sqrt{\lambda}}$  from curves of Plate 11.2 is equal to 0.18.

Hence,  $G_E = \frac{H}{d} \times \frac{1}{\pi\sqrt{\lambda}} = \frac{6}{10.3} \times 0.18 = 0.105$

Hence, the exit gradient shall be equal to 0.105, i.e. 1 in 9.53, which is very much safe.



**Practice Problems:**

1. An unlined canal giving a seepage loss of  $3.3 \text{ m}^3/\text{s}$  per million sq.m of wetted area is proposed to be lined with 10 cm thick cement concrete lining which cost Tk.18/sq.m. Given the following data work out the economics of lining and benefit cost ratio.

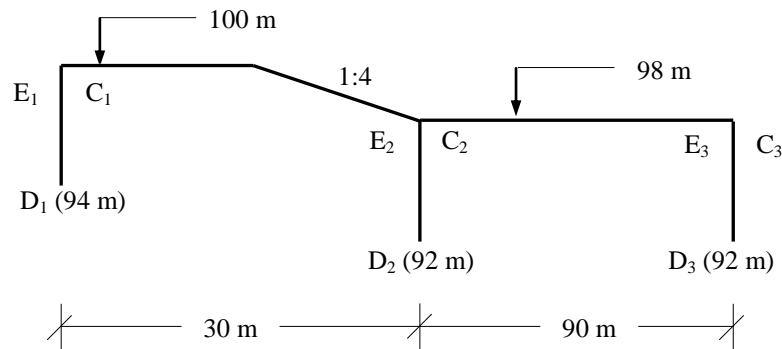
Annual revenue per cumec of water	Tk. 3.5 lacs
Discharge in the canal	$83.5 \text{ m}^3/\text{s}$
Area of the canal	$40.8 \text{ m}^2$
Wetted perimeter of the canal	18.8 m
Wetted perimeter of the lining	18.5 m
Annual maintenance cost of unlined canal	Tk. 0.1/sq.m

Assume any suitable data if required

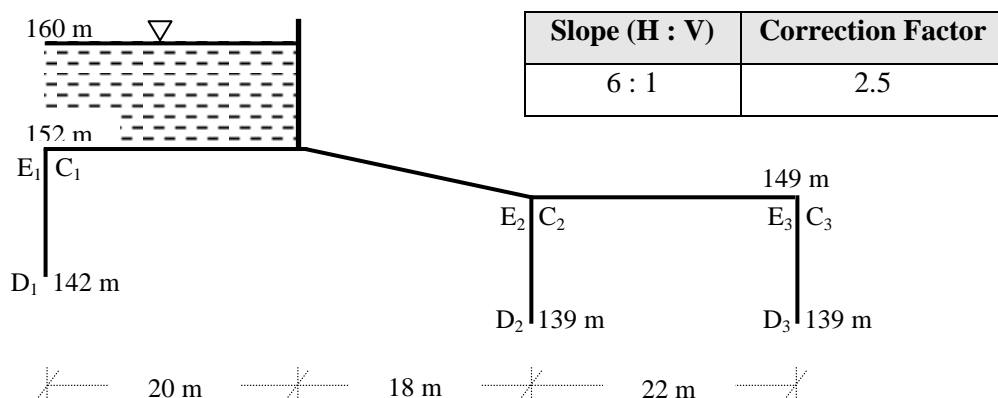
2. A canal of length 5 km and of discharge capacity  $3.5 \text{ m}^3/\text{s}$  is proposed to be lined with boulder lining. The total cost of lining is estimated as 4 lakhs. The life of lining is considered as 60 years. Justify the lining in the canal from the following data:

Rate of interest	8 %
Seepage loss	2 %
Revenue for irrigation water	Tk. 75 per hec-m
Maintenance cost per km for lined canal	Tk. 1000
Maintenance cost per km for unlined canal	Tk. 2500
Base period of crop	120 days
Additional benefit/km	Tk. 1000

3. Use Khosla's curves to calculate the percentage uplift pressure at various key points for a barrage foundation profile shown in figure below applying necessary corrections. Assume the thickness of the floor is 0.8 m. Also find exit gradient considering upstream pond level at 103 m.



4. Use Khosla's curves to calculate the percentage uplift pressure at points  $C_1, E_2, C_2, D_3$  and  $E_3$  for a barrage foundation profile shown in figure below applying necessary corrections. Also determine the exit gradient. [Assume: floor thickness = 1 m]



5. Using Khosla's curves, determine the following for the apron shown below:  
 [Assume: floor thickness = 1 m]

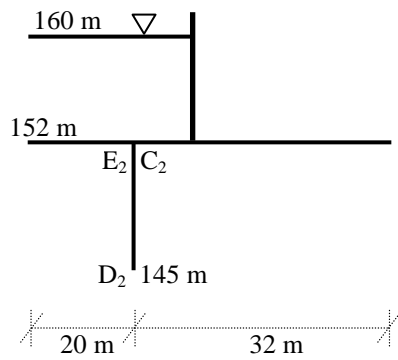


Fig. (i)

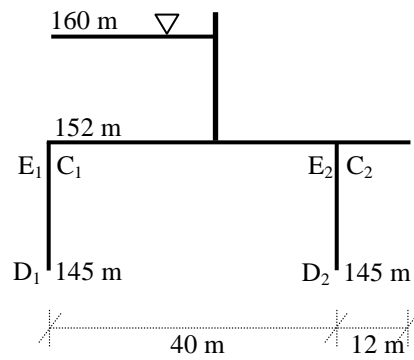


Fig. (ii)

- (i) Find pressure at critical points with thickness correction

- (ii) Find pressure at  $C_1$  and  $E_2$  with interference correction

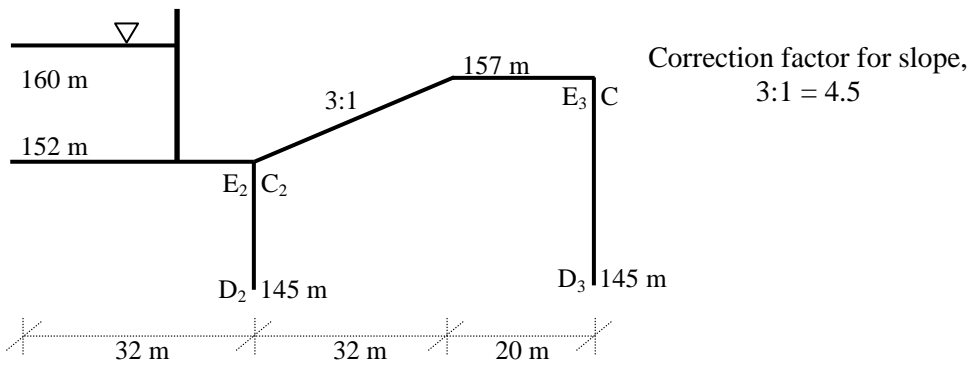


Fig. (iii)

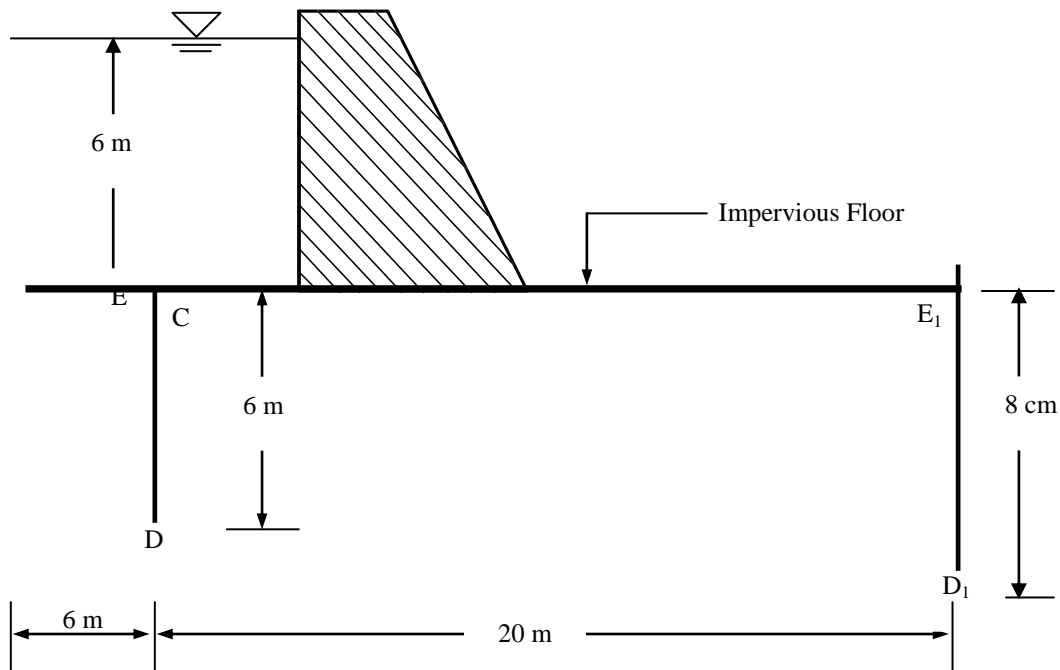
- (iii) Find pressure at point  $C_2$  with slope correction

6. Using Khosla's curves, determine the following for the apron shown below: **(Spring-2006)**

- (i) Uplift pressure at points E, D, C,  $E_1$  and  $D_1$

- (ii) Exit gradient

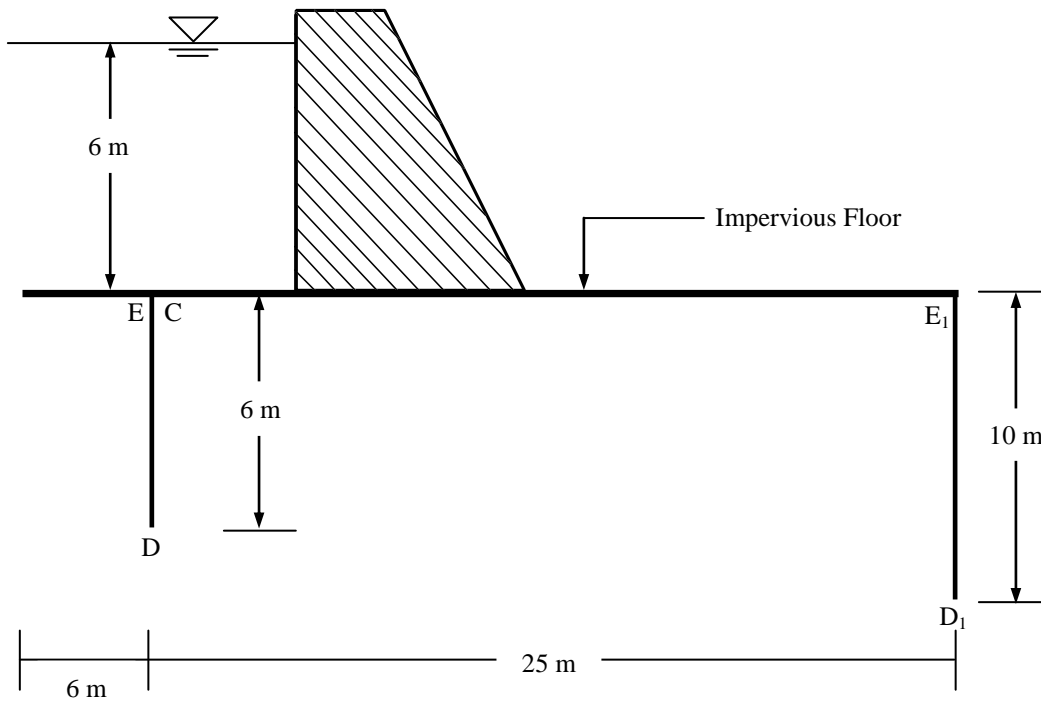
Neglect the effect of floor thickness.



7. Using Khosla's curves, determine the following for the apron shown below:

- (i) Uplift pressure at points C, E<sub>1</sub> and D<sub>1</sub>
- (ii) Exit gradient

Assume floor thickness = 1 m



8. Using the Khosla's curves, determine the following for the apron shown below:

- (iii) If percentage of pressure at C<sub>2</sub> is 56%, what will be the percentage of pressure at this point after corrections due to pile interference and slope
- (iv) Find exit gradient where, correction factor for slope, 3:1 = 4.5,

Assume floor thickness = 1 m

