Diversion Headworks

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Diversion Headworks

Introduction

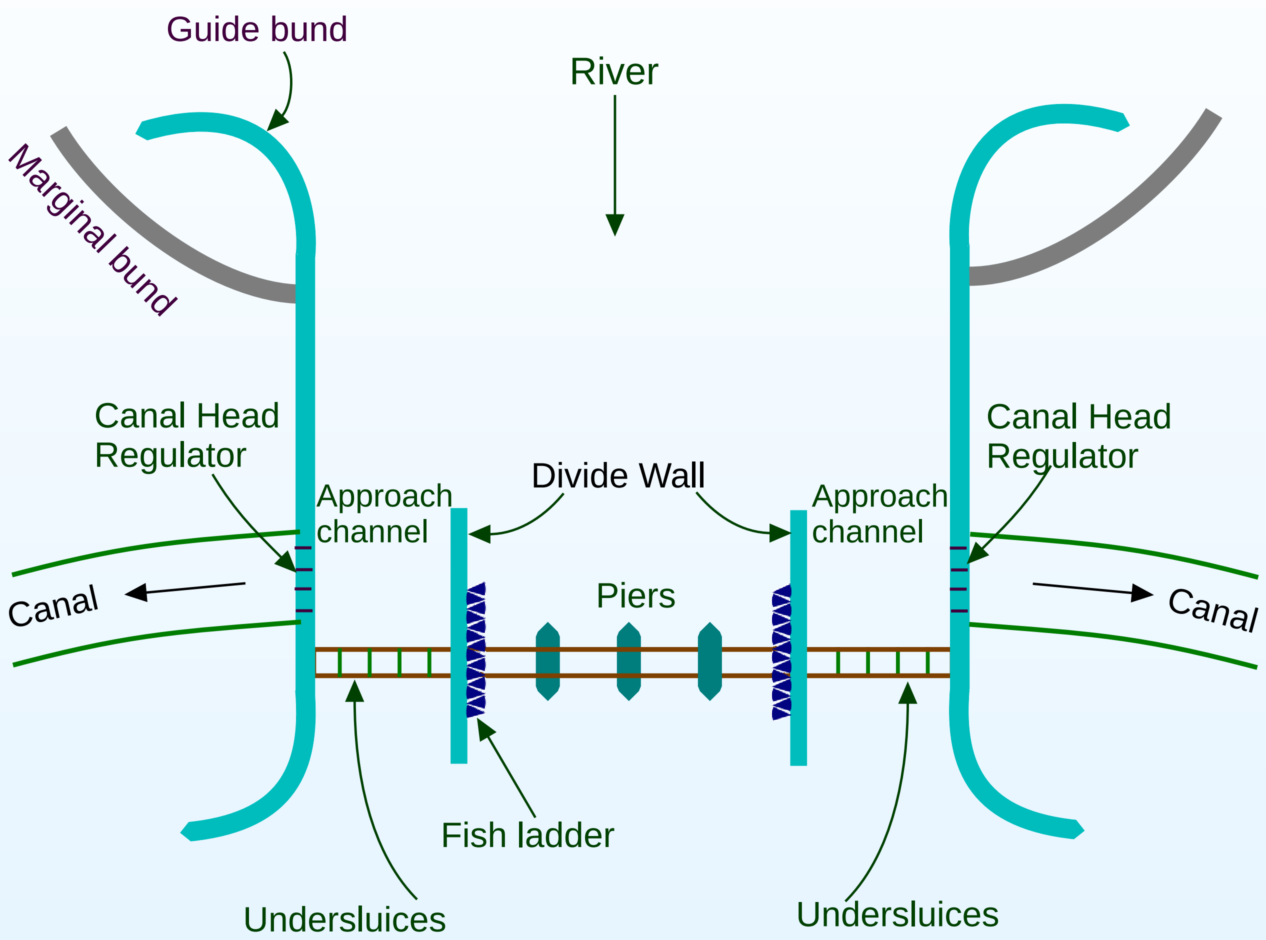
An irrigation canal usually draws its supplies from rivers. In order to divert the water from the river into the canal, certain structures are constructed across the river and at the head of the off-taking canal. These works are known as **Diversion Headwork**s or **Canal Headworks**.

Headworks comprise a **weir** or a **barrage** on the river and a **canal head regulator** on the off-taking canal. The weir is used to create local pondage and raising of water level so as to provide sufficient head for the canal discharge. It regulates the flow through the canal and through the river downstream.

Regulation

Diversion

Layout



Typical Layout of a Diversion Headwork

Components

Various components of a diversion headworks are:

1. Weir or Barrage
2. Divide Wall
3. Fish Ladder
4. Approach Channel
5. Silt Excluder
6. Canal Head Regulator
7. River Training Works (Marginal Bunds and Guide Bunds)

Weir

Classification

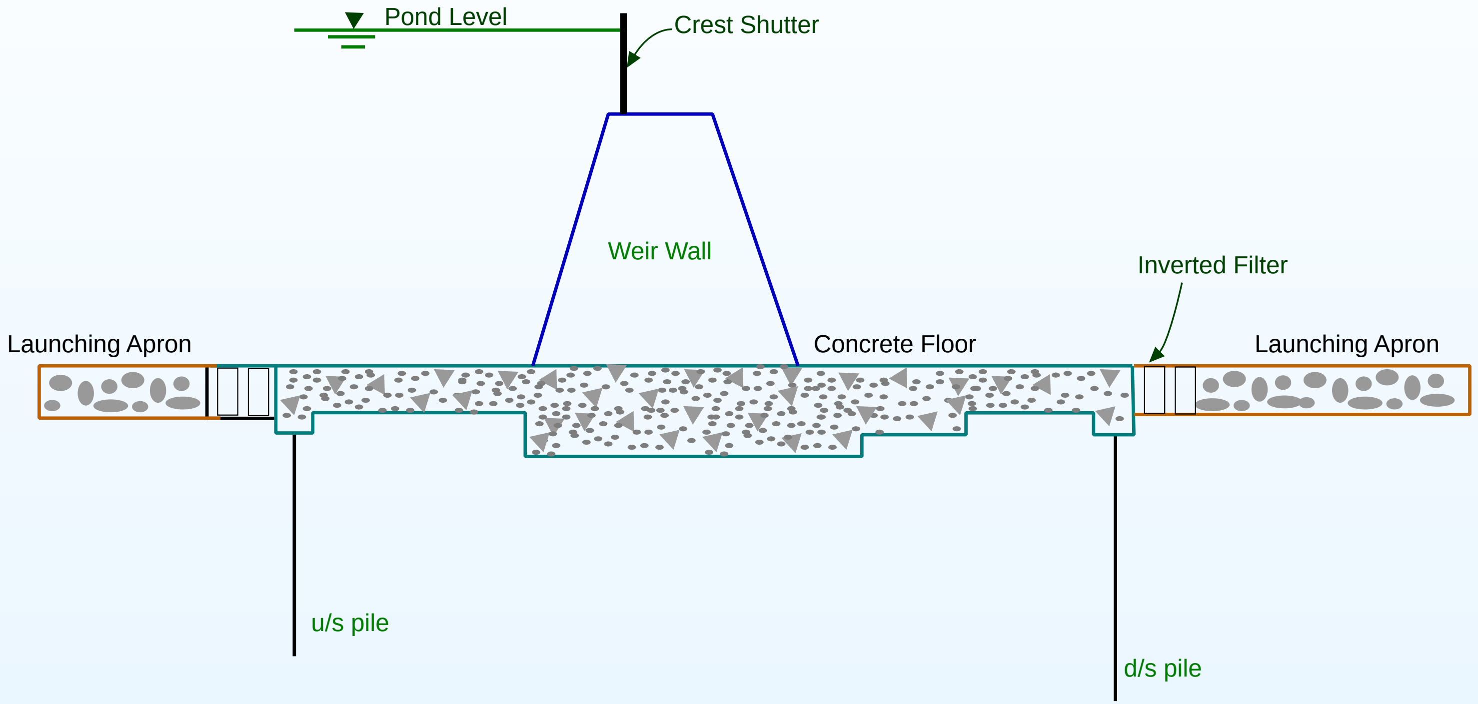
As per materials of construction

1. Rockfill Weir
2. Masonry Weir
3. Concrete Weir

As per control of surface flow

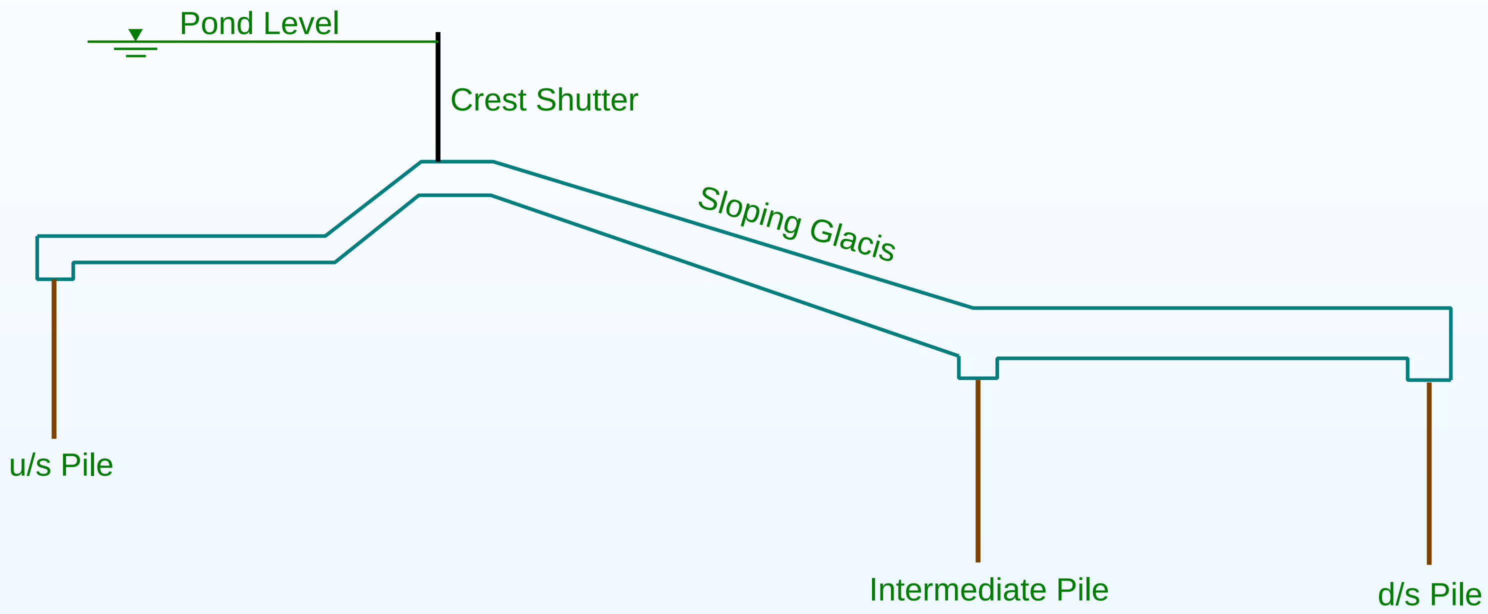
1. Vertical Drop Weir
2. Sloping Glacis Weir
3. Barrage

Weir



Vertical Drop Weir

Weir



Concrete Weir with Sloping d/s Glacis

Barrage

In case of a barrage, the crest is kept at a lower level and raining of water level is accomplished by gates. During flood these gates can be raised clear off the high flood level and thus enable the high flood to pass with minimum of afflux (heading up of water on the upstream side). A barrage provides better control on water level in the river. However, it is costlier than the other types of weir.

Teesta Barrage

Causes of Failure

Diversion headworks are usually located in areas where only permeable foundations are available for constrcution of the weirs. Hence, the state of subsurface flow directly affects the stability of the structures.
Various causes of failure of the weirs on permeable foundations may be classified into two broad categories-

- Failure due to seepage or sub-surface flow
- Failure due to surface flow

Seepage Failure

Seepage flow may cause the failure of a weir in two ways-

- Piping or undermining
- Uplift

Piping Failure

If the water percolating through the foundation has sufficient energy when it emerges at the downstream end of the impervious floor, it may dislodge the soil particles there. With the removal of surface soil particle, there is further concentration of flow into the resulting depression and more soil is removed. This process of erosion progressively extends backwards towards the upstream side and results in hollow pipe-like formation beneath the weir floor. The floor may subside in the hollows so formed causing a piping failure of the structure.

Remedial Measures

- Provide sufficient length of the impervious floor so that the path of percolation is increased and the hydraulic gradient at the exit is reduced.
- Provide sheet piles at the upstream and downstream ends of the impervious floor.

Seepage Failure

Uplift Failure

The water percolating through the foundation exerts an upward pressure on the impervious floor. This pressure is known as uplift pressre. If the uplift pressure is not counterbalanced by the weight of the floor, it may fail by rupture.

Remedial Measures

- Provide sufficient thickness of the impervious floor.
- Provide pile at the u/s end of the impervious floor to reduce the uplift pressure.

Bligh's Creep Theory

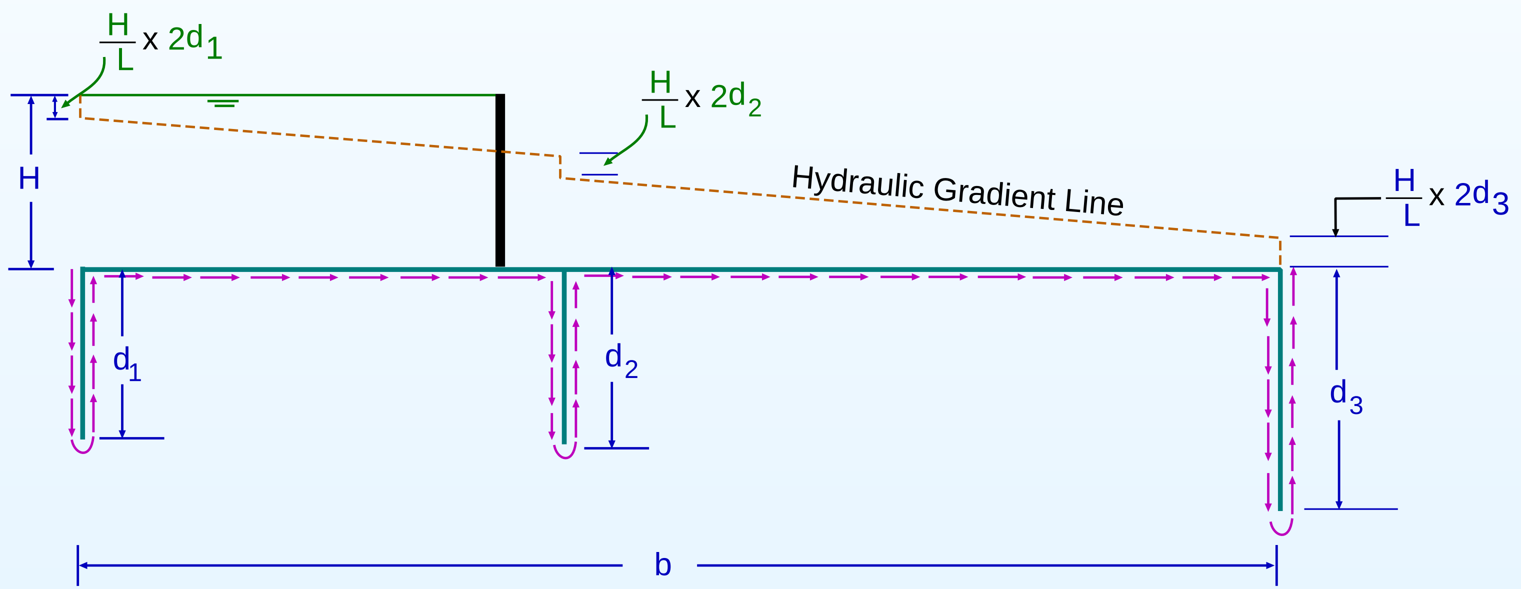
W.G. Bligh presented a theory for subsurface flow in 1910, which is known as *Bligh's Creep theory*. According to this theory, water creeps along the base profile of the structure which is in contact of the subsoil. The length of the path traversed by the percolating water is termed as *creep length*.

Bligh assumed that the head loss per unit length of creep, i.e., the hydraulic gradient is constant throughout the percolating path. This in turn indicates that the head loss is proportional to the creep length.

Bligh made no distinction between horizontal creep and vertical creep.

Bligh's Creep Theory

Let us consider a weir impounding water of depth H, having horizontal floor length of b with three vertical cutoffs (sheet piles) at key locations. The percolating water will then follow the path indicated by the arrows. So, creep length, $L = b + 2(d_1 + d_2 + d_3)$ and the hydraulic gradient is $H/L = H/[b + 2(d_1 + d_2 + d_3)]$.



Bligh's Creep Path and Hydraulic Gradient Line

The reciprocal of the hydraulic gradient line, i.e., $C = L/H$, is known as *Bligh's coefficient of creep*.

Bligh's Creep Theory

According to Bligh, to ensure the safety of the impervious floor against the two possible ways of failure, following critera should be satisfied.

Safety against piping

The length of the creep should be sufficient to provide a safe hydraulic gradient according to the type of soil: $L = CH$

The hydraulic gradient (H/L) is then equal to (1/C) and according to Bligh, if the actual hydraulic gradient is $\leq (1/C)$, there will be no danger of piping.

The seepage head is measured from the u/s water level to the lowest d/s water level. For the worst case scenario, H should be calculated considering maximum u/s water level and no discharge as the d/s end.

Recommended values of C

Type of soil	**C**	**Safe hydraulic gradient**
Light sand and mud	18	1/18
Fine micaceous sand	15	1/15
Coarse grained sand	12	1/12
Sand mixed with boulder and gravel	5 to 9	1/9 to 1/5

Bligh's Creep Theory

Safety against uplift

The ordinate of the subsoil hydraulic gradient line above the **bottom** of the floor at any point represents the residual seepage head or the uplift pressure at that point.

Thus if h' is the ordinate of the hydraulic grade line (HGL) above the **bottom** of the floor, then uplift pressure at that point is $\gamma h'$, where γ is the specific weight of water.

If the floor thickness at that point is t and specific gravity of the floor material is G, then downward force per unit area, due to the weight of the floor is $\gamma G t$. The for equilibrium

$$\gamma h' = \gamma G t$$

so,

$$t = \frac{h'}{G}$$

However, h' i.e., the HGL above the bottom of the floor can be known only after the floor thickness is determined. From the above equation, $h' = tG$. Subtracting t from both the sides we get, $h' - t = tG - t = t(G-1)$. So,

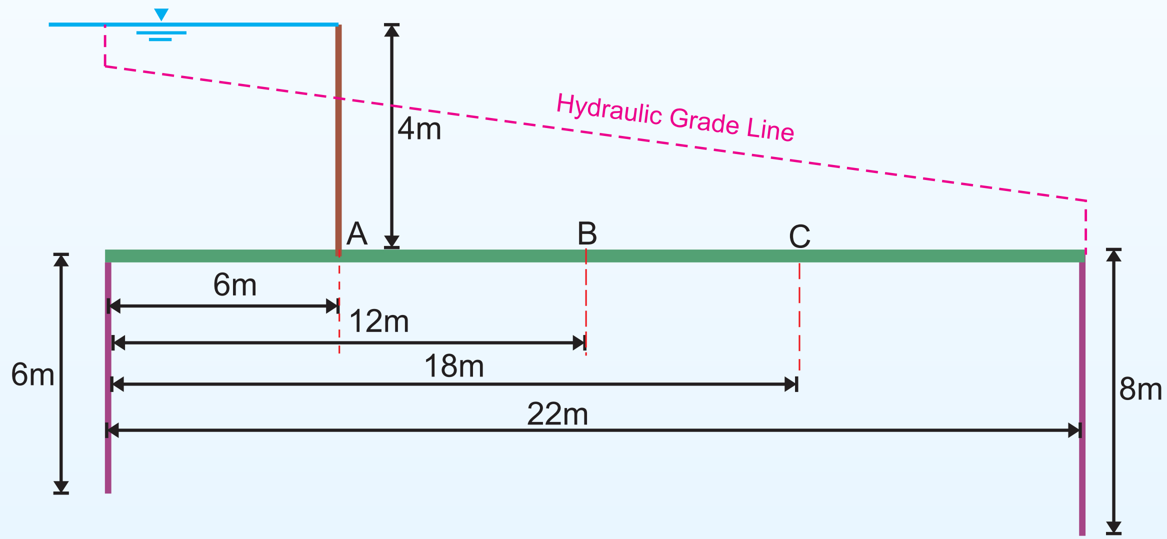
$$t = \frac{h' - t}{G-1} = \frac{h}{G-1}$$

where $h = h' - t$ is the ordinate of the HGL measured above the top of the floor. $(G-1)$ is actually the submerged unit weight of the floor material. Usually a factor of safety of (4/3) is adopted. Hence

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

Example

The following figure shows the section of a hydraulic structure founded on sand. Calculate the average hydraulic gradient. Also, find the uplift pressures at points A, B and C, and determine the required floor thicknesses at these points. Assume specific gravity of the floor material, $G = 2.24$.



Solution

Total length of creep, $L =$

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Total length of creep, $L = (2 \times 6 + 22 + 2 \times 8) = 50\text{m}$

Hydraulic gradient = $H/L =$

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Total length of creep, $L = (2 \times 6 + 22 + 2 \times 8) = 50\text{m}$

Hydraulic gradient = H/L =$4/50 = 1/12.5$

1. Uplift pressure at A:

Solution

Total length of creep, $L = (2 \times 6 + 22 + 2 \times 8) = 50\text{m}$

Hydraulic gradient = H/L =$4/50 = 1/12.5$

1. Uplift pressure at A:

Creep length upto A,

Solution

Total length of creep, $L = (2 \times 6 + 22 + 2 \times 8) = 50$m

Hydraulic gradient = H/L =$4/50 = 1/12.5$

1. Uplift pressure at A:

Creep length upto A,$L_A = 6 \times 2 + 6 = 18$ m

Unbalanced head, $h_A = 4 - 18 \times \frac{1}{12.5} = 2.56$m

Uplift pressure, $p_A = \gamma h_A = 9.807 \times 2.56 = 25.106$ kN/m^2

Required thickness, $t_A = \frac{4}{3} \frac{h_A}{(G-1)} = \frac{4}{3} \frac{2.56}{(2.24-1)} = 2.753$ m

2. Uplift pressure at B:

Solution

Total length of creep, $L = (2 \times 6 + 22 + 2 \times 8) = 50\text{m}$

Hydraulic gradient = H/L =$4/50 = 1/12.5$

1. Uplift pressure at A:

Creep length upto A,$L_A = 6 \times 2 + 6 = 18$ m

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2. Uplift pressure at B:

Creep length upto B,

Solution

Total length of creep, $L = (2\times 6+22+2\times 8) = 50$m

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Required thickness, $t_A = \frac{4}{3}\frac{h_A}{(G-1)} = \frac{4}{3}\frac{2.56}{(2.24-1)} = 2.753$ m

2. Uplift pressure at B:

Creep length upto B,$L_B = 6\times 2+12 = 24$ m

Unbalanced head, $h_B = 4-24\times \frac{1}{12.5} = 2.08$m

Uplift pressure, $p_B = \gamma h_B = 9.807\times 2.08 = 20.4$ kN/m^2

Required thickness, $t_B = \frac{4}{3}\frac{h_B}{(G-1)} = \frac{4}{3}\frac{2.08}{(2.24-1)} = 2.237$ m

3. Uplift pressure at C:

Solution

Total length of creep, $L = (2\times 6+22+2\times 8) = 50\text{m}$

Hydraulic gradient = H/L =$4/50 = 1/12.5$

1. Uplift pressure at A:

Creep length upto A,$L_A = 6\times 2+6 = 18$ m

Unbalanced head, $h_A = 4-18\times \frac{1}{12.5} = 2.56\text{m}$

Uplift pressure, $p_A = \gamma h_A = 9.807\times 2.56 = 25.106\ \text{kN/m}^2$

Required thickness, $t_A = \frac{4}{3}\frac{h_A}{(G-1)} = \frac{4}{3}\frac{2.56}{(2.24-1)} = 2.753$ m

2. Uplift pressure at B:

Creep length upto B,$L_B = 6\times 2+12 = 24$ m

Unbalanced head, $h_B = 4-24\times \frac{1}{12.5} = 2.08\text{m}$

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Required thickness, $t_B = \frac{4}{3}\frac{h_B}{(G-1)} = \frac{4}{3}\frac{2.08}{(2.24-1)} = 2.237$ m

3. Uplift pressure at C:

Creep length upto C,

Solution

Total length of creep, $L = (2 \times 6 + 22 + 2 \times 8) = 50\text{m}$

Hydraulic gradient = H/L =$4/50 = 1/12.5$

1. Uplift pressure at A:

Creep length upto A,$L_A = 6 \times 2 + 6 = 18$ m

Unbalanced head, $h_A = 4 - 18 \times \frac{1}{12.5} = 2.56\text{m}$

Uplift pressure, $p_A = \gamma h_A = 9.807 \times 2.56 = 25.106$ kN/m^2

Required thickness, $t_A = \frac{4}{3}\frac{h_A}{(G-1)} = \frac{4}{3}\frac{2.56}{(2.24-1)} = 2.753$ m

2. Uplift pressure at B:

Creep length upto B,$L_B = 6 \times 2 + 12 = 24$ m

Unbalanced head, $h_B = 4 - 24 \times \frac{1}{12.5} = 2.08\text{m}$

Uplift pressure, $p_B = \gamma h_B = 9.807 \times 2.08 = 20.4$ kN/m^2

Required thickness, $t_B = \frac{4}{3}\frac{h_B}{(G-1)} = \frac{4}{3}\frac{2.08}{(2.24-1)} = 2.237$ m

3. Uplift pressure at C:

Creep length upto C,$L_C = 6 \times 2 + 18 = 30$ m

Unbalanced head, $h_B = 4 - 30 \times \frac{1}{12.5} = 1.6\text{m}$

Uplift pressure, $p_B = \gamma h_C = 9.807 \times 1.6 = 15.69$ kN/m^2

Required thickness, $t_C = \frac{4}{3}\frac{h_C}{(G-1)} = \frac{4}{3}\frac{1.6}{(2.24-1)} = 1.72$ m

Limitations

1. Bligh made no distinction between horizontal and vertical creep.
2. Bligh's method holds good so long as the horizontal distance between the pile lines is greater than twice their depth.
3. Bligh did not mention anything about exit gradient. Safety against undermining cannot simply be obtained by considering a simple average hydraulic gradient, less than a permissible value.
4. Bligh made no distinction between outer and inner faces of sheet piles or the intermediate sheet pile.
5. In reality, loss of head in not linearly proportional to creep length.
6. Uplift pressure distribution is not linear and follows sine curve.
7. Bligh did not mention about the necessity of providing a d/s pile, which is actually absolutely essential.

Lane’s Theory

One of the major limitations of Bligh’s creep theory was no distinction between horizontal creep and vertical creep. In 1932, after investigating 290 dams and weirs all over the world, Lane found that the vertical creep is more effective than the horizontal creep. He suggested a weight of 3 for the vertical creep and 1 for horizontal creep. For inclined floors, the weight may be taken equal to $(1+2\theta/90)$ where θ is in degrees. This theory is known as **Lane’s Weighted Creep Theory**.

Seepage Theory

According to Darcy's Law, the apparent velocities of liquid through porous media are

$$u = -k\frac{\partial h}{\partial x},\ \ v = -k\frac{\partial h}{\partial y},\ \ w = -k\frac{\partial h}{\partial z}$$

where k is the coefficient of permeability, u, v, w are respectively the x-, y- and z-components of velocity, and h is the hydraulic head causing the flow. Substituting these in the continuity equation,

$$\frac{\partial u}{\partial x} + \frac{\partial u}{\partial y} + \frac{\partial u}{\partial z} = 0$$

and assuming k as a constant, we obtain

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2} = 0$$

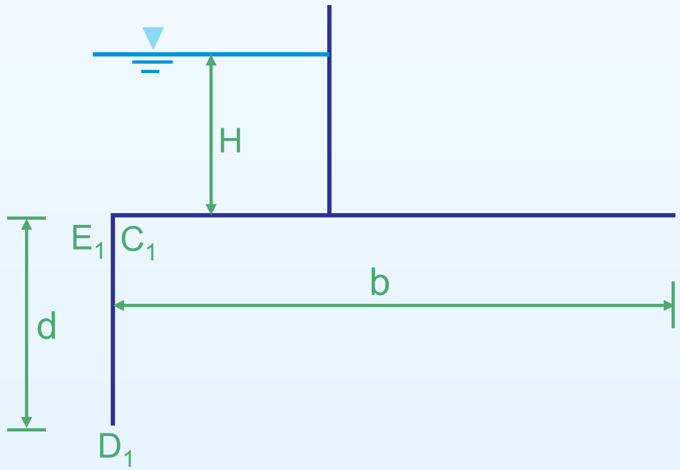
This is the well-known Laplace equation which governs the flow of liquid through porous medium. This equation assumes that,

1. The soil is homogeneous and isotropic
2. The voids are completely filled with water
3. No consolidation or expansion of the soil takes place
4. The soil and water are incompressible and
5. The flow obey's Darcy's law and is steady.

Khosla's Theory

The seepage equation (Laplace equation) cannot be solved exactly for usual canal structures having complex boundary conditions. Khosla (1954) alongwith other investigators obtained solutions of the equation for a number of simple profiles, using method of independent variables. Solutions for these simple profiles are obtained in terms of pressure head ratio ϕ at *key* points. These key points are the junction points of sheet piles with floor. This method is commonly known as *Khosla's method of Independent Variables*.

Simple Structure 1



Sheet Pile at u/s end

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

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

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

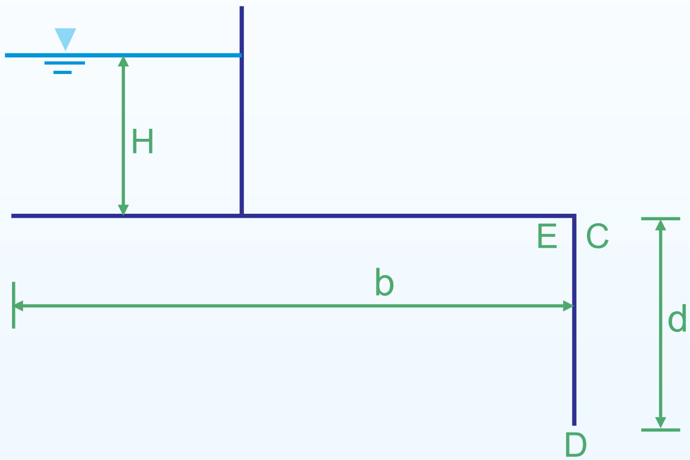
$$\phi_D = \frac{1}{\pi}\cos^{-1}\left[\frac{\lambda-1}{\lambda}\right]$$

$$\phi_{C_1} = 100-\phi_E$$

$$\phi_{D_1} = 100-\phi_D$$

Khosla's Theory

Simple Structure 2



Sheet Pile at d/s end

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

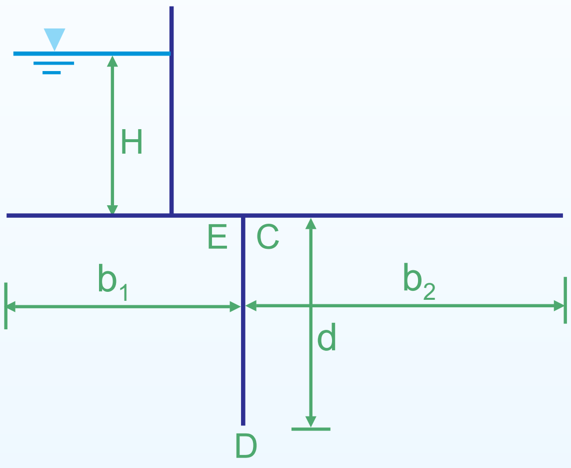
$$\lambda = \frac{1}{2}\left[1+\sqrt{1+\alpha^2}\right]$$

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

$$\phi_D = \frac{1}{\pi}\cos^{-1}\left[\frac{\lambda-1}{\lambda}\right]$$

Khosla's Theory

Simple Structure 3



Intermediate Sheet Pile

$$\alpha_1 = \frac{b_1}{d}$$

$$\alpha_2 = \frac{b_2}{d}$$

$$\lambda_1 = \frac{1}{2}[\sqrt{1+\alpha_1^2} - \sqrt{1+\alpha_2^2}]$$

$$\lambda_2 = \frac{1}{2}[\sqrt{1+\alpha_1^2} + \sqrt{1+\alpha_2^2}]$$

$$\phi_C = \frac{1}{\pi}\cos^{-1}\left[\frac{\lambda_1+1}{\lambda_2}\right]$$

$$\phi_D = \frac{1}{\pi}\cos^{-1}\left[\frac{\lambda_1}{\lambda_2}\right]$$

$$\phi_E = \frac{1}{\pi}\cos^{-1}\left[\frac{\lambda_1-1}{\lambda_2}\right]$$

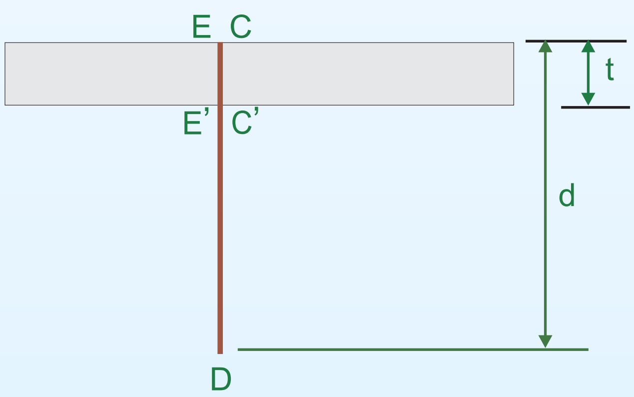
Corrections

The uplift pressures obtained for the simple forms are corrected for

- Floor Thickness
- Mutual Interference of Piles
- Slope of the Floor

Correction for Floor Thickness

The key points E or (E_1) and C (or C_1) correspond to the level at the top of the floor. The values of the pressure at the actual points E' (or E_1') and C' (or C_1') are interpolated assuming linear variation of key points.



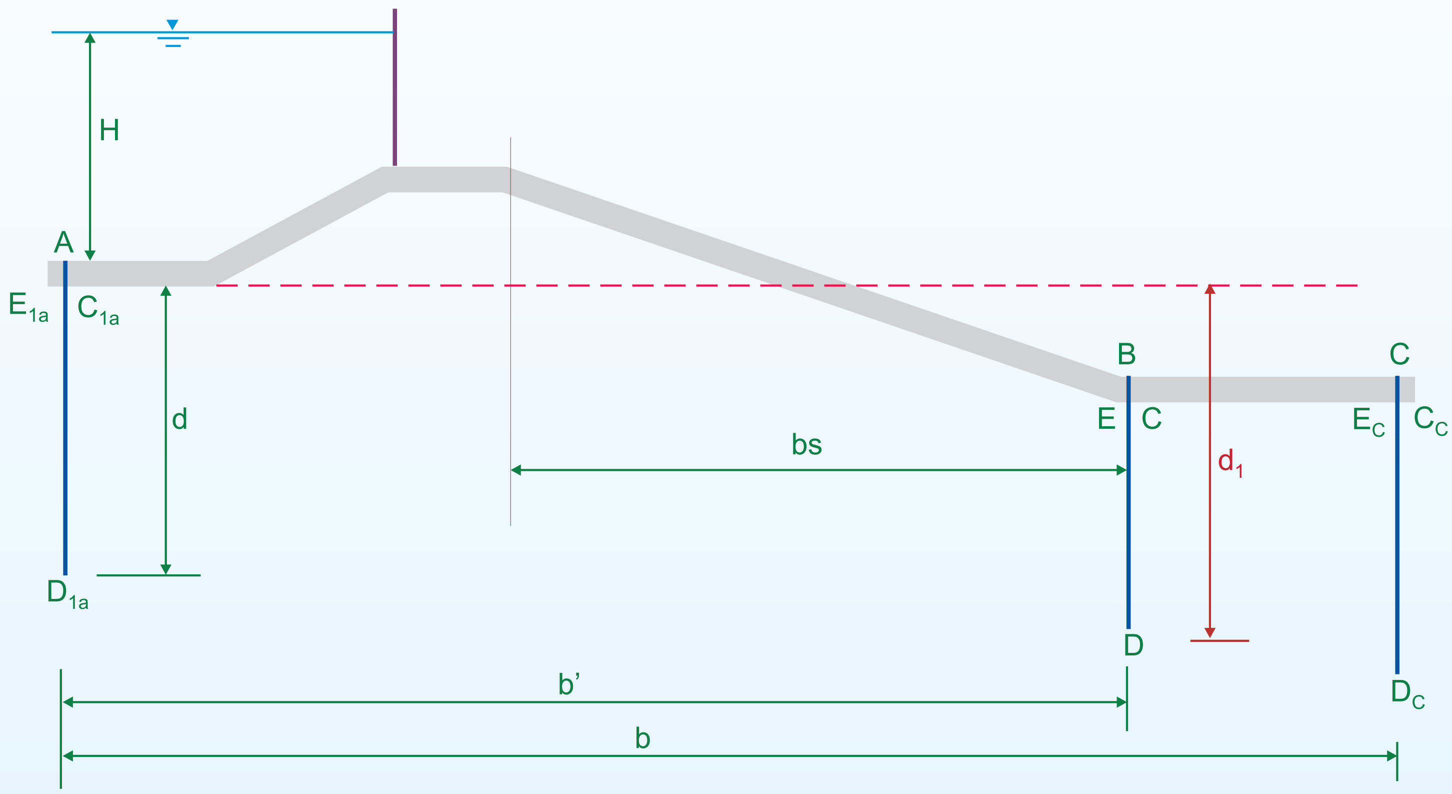
$$\phi_E' = \phi_E - \frac{\phi_E - \phi_D}{d} t$$

$$\phi_C' = \phi_C + \frac{\phi_D - \phi_C}{d} t$$

where t is the thickness of the floor.

Corrections

Mutual Interference of Piles



Corrections

Mutual Interference of Piles

Correction C_i (in %) for interference of pile B for the key point C_{1a} of A is

$$C_i = 19\sqrt{\frac{d_1}{b'}}\,\frac{d_1+d}{b}$$

where b' is the distance between the two adjacent pile, d_1 is the depth of the interfering pile measured *below the level at which the interference is being calculated*, d is the depth of the other pile, b is the total floor length.

The correction C_i is additive for upstream points and negative for points downstream of the interfering pile. The correction is calculated only for the key points of the adjacent pile towards the interfering pile.

- Interference of pile A will be on pile B, at key point E (-ve)
- Interference of pile B will be on pile A, at key point C_{1a} (+ve)
- Interference of pile B will be on pile C, at key point E_C (-ve)
- Interference of pile C will be on pile B, at key point C (+ve)

Corrections

Correction for Slope of the Floor

The correction for slope of the floor is applied to the pressures of the key point (on the side of the sloping floor) of that pile which is fixed at either the beginning or end of the slope. The correction is positive for positive slope (i.e., level of the floor is decreasing in the direction of the) and negative for the negative slope.

In the previous figure, correction for slope is applicable only to the pressure at E of pile B and is positive.

If b_s is the horizontal length of the sloping floor and b' is the distance between the two pile lines between which the sloping floor is located, then the amount of slope correction is equal to $C_s \frac{b_s}{b'}$. The value of C_s depends on the slope of the floor.

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

Exit Gradient

For the simple profile of the d/s sheet pile, the exit gradient G_E is given as

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

where, H is the effective head, d is the depth of the d/s pile and $\lambda = \frac{1}{2}[1+\sqrt{1+\alpha^2}]$.

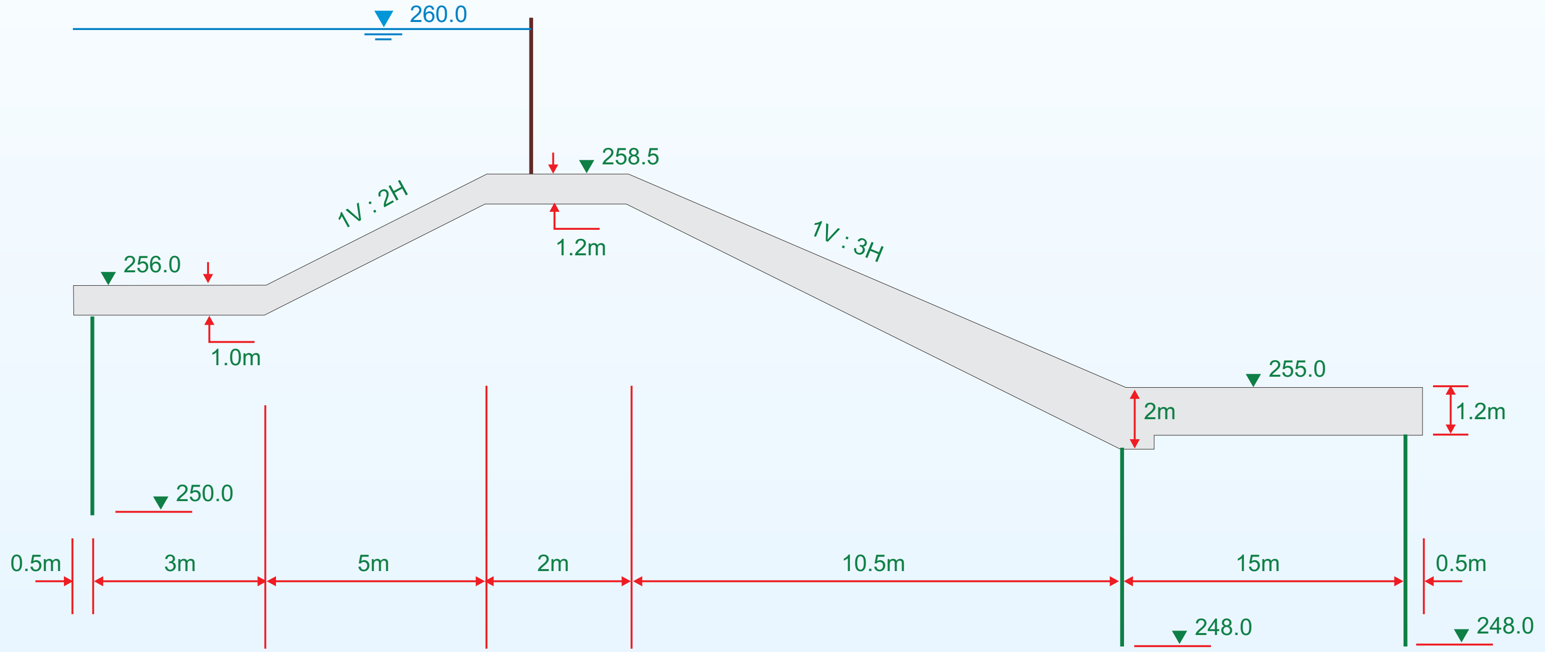
If there is no pile at the d/s end, then $d = 0$ and the G_E becomes infinity. It is, therefore, necessary that a vertical sheet pile is always provided at the downstream end of the floor.

To prevent piping, the exit gradient must not be allowed to exceed the critical value of the exit gradient, which depends on the type of the soil. The value of the critical exit gradient for sand varies from 1/5 to 1/7.

Example

Example

Using Khosla's method, obtain the residual seepage pressures at the key points for the weir profile shown in the figure. Also calculate the value of the exit gradient. Assume no flow condition.



Solution

Upstream Pile

Solution

Upstream Pile

Depth of the pile, d =

Solution

Upstream Pile

Depth of the pile, d = 256.00-250.00 = 6.00 m

Solution

Upstream Pile

Depth of the pile, d = 256.00-250.00 = 6.00 m

Total floor length, b =

Solution

Upstream Pile

Depth of the pile, d = 256.00-250.00 = 6.00 m

Total floor length, b = (0.5+3+5+2+10.5+15+0.5)m = 36.5m

Solution

Upstream Pile

Depth of the pile, d = 256.00-250.00 = 6.00 m

Total floor length, b = (0.5+3+5+2+10.5+15+0.5)m = 36.5m

$\alpha = \frac{b}{d} = \frac{36.5}{6.0} = 6.083$

Solution

Upstream Pile

Depth of the pile, d = 256.00-250.00 = 6.00 m

Total floor length, b = (0.5+3+5+2+10.5+15+0.5)m = 36.5m

$\alpha = \frac{b}{d} = \frac{36.5}{6.0} = 6.083$

$\lambda = \frac{1}{2}[1 + \sqrt{1 + \alpha^2}] = 3.582$

Solution

Upstream Pile

Depth of the pile, d = 256.00-250.00 = 6.00 m

Total floor length, b = (0.5+3+5+2+10.5+15+0.5)m = 36.5m

$\alpha = \frac{b}{d} = \frac{36.5}{6.0} = 6.083$

$\lambda = \frac{1}{2}[1+\sqrt{1+\alpha^2}] = 3.582$

$\phi_E = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda-2}{\lambda}\right) = 0.354 = 35.4\%$

Solution

Upstream Pile

Depth of the pile, d = 256.00-250.00 = 6.00 m

Total floor length, b = (0.5+3+5+2+10.5+15+0.5)m = 36.5m

$$\alpha = \frac{b}{d} = \frac{36.5}{6.0} = 6.083$$

$$\lambda = \frac{1}{2}\left[1 + \sqrt{1+\alpha^2}\right] = 3.582$$

$$\phi_E = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda-2}{\lambda}\right) = 0.354 = 35.4\%$$

$$\phi_D = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda-1}{\lambda}\right) = 0.244 = 24.4\%$$

Solution

Upstream Pile

Depth of the pile, *d* = 256.00-250.00 = 6.00 m

Total floor length, *b* = (0.5+3+5+2+10.5+15+0.5)m = 36.5m

$\alpha = \frac{b}{d} = \frac{36.5}{6.0} = 6.083$

$\lambda = \frac{1}{2}[1+\sqrt{1+\alpha^2}] = 3.582$

$\phi_E = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda-2}{\lambda}\right) = 0.354 = 35.4\%$

$\phi_D = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda-1}{\lambda}\right) = 0.244 = 24.4\%$

$\phi_{C_1} = 100 - \phi_E = 100 - 35.4 = 64.6\%$

Solution

Upstream Pile

Depth of the pile, d = 256.00-250.00 = 6.00 m

Total floor length, b = (0.5+3+5+2+10.5+15+0.5)m = 36.5m

$$\alpha = \frac{b}{d} = \frac{36.5}{6.0} = 6.083$$

$$\lambda = \frac{1}{2}\left[1 + \sqrt{1+\alpha^2}\right] = 3.582$$

$$\phi_E = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda-2}{\lambda}\right) = 0.354 = 35.4\%$$

$$\phi_D = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda-1}{\lambda}\right) = 0.244 = 24.4\%$$

$$\phi_{C_1} = 100 - \phi_E = 100 - 35.4 = 64.6\%$$

$$\phi_{D_1} = 100 - \phi_D = 100 - 24.4 = 75.6\%$$

Solution

Upstream Pile

Depth of the pile, d = 256.00-250.00 = 6.00 m

Total floor length, b = (0.5+3+5+2+10.5+15+0.5)m = 36.5m

$\alpha = \frac{b}{d} = \frac{36.5}{6.0} = 6.083$

$\lambda = \frac{1}{2}[1+\sqrt{1+\alpha^2}] = 3.582$

$\phi_E = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda-2}{\lambda}\right) = 0.354 = 35.4\%$

$\phi_D = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda-1}{\lambda}\right) = 0.244 = 24.4\%$

$\phi_{C_1} = 100 - \phi_E = 100 - 35.4 = 64.6\%$

$\phi_{D_1} = 100 - \phi_D = 100 - 24.4 = 75.6\%$

Corrections:

1. For thickness: $\frac{\phi_{D1}-\phi_{C1}}{d} \times t = \frac{75.6-64.6}{6} \times 1.0 = 1.833\%(+)$

Solution

Upstream Pile

Depth of the pile, d = 256.00-250.00 = 6.00 m

Total floor length, b = (0.5+3+5+2+10.5+15+0.5)m = 36.5m

$\alpha = \frac{b}{d} = \frac{36.5}{6.0} = 6.083$

$\lambda = \frac{1}{2}[1+\sqrt{1+\alpha^2}] = 3.582$

$\phi_E = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda-2}{\lambda}\right) = 0.354 = 35.4\%$

$\phi_D = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda-1}{\lambda}\right) = 0.244 = 24.4\%$

$\phi_{C_1} = 100 - \phi_E = 100 - 35.4 = 64.6\%$

$\phi_{D_1} = 100 - \phi_D = 100 - 24.4 = 75.6\%$

Corrections:

1. For thickness: $\frac{\phi_{D1}-\phi_{C1}}{d} \times t = \frac{75.6-64.6}{6} \times 1.0 = 1.833\%(+)$
2. For interference of intermediate pile on ϕ_{C_1} of upstream pile

Solution

Upstream Pile

Depth of the pile, d = 256.00-250.00 = 6.00 m

Total floor length, b = (0.5+3+5+2+10.5+15+0.5)m = 36.5m

$\alpha = \frac{b}{d} = \frac{36.5}{6.0} = 6.083$

$\lambda = \frac{1}{2}[1 + \sqrt{1+\alpha^2}] = 3.582$

$\phi_E = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda-2}{\lambda}\right) = 0.354 = 35.4\%$

$\phi_D = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda-1}{\lambda}\right) = 0.244 = 24.4\%$

$\phi_{C_1} = 100 - \phi_E = 100 - 35.4 = 64.6\%$

$\phi_{D_1} = 100 - \phi_D = 100 - 24.4 = 75.6\%$

Corrections:

1. For thickness: $\frac{\phi_{D1} - \phi_{C1}}{d} \times t = \frac{75.6-64.6}{6} \times 1.0 = 1.833\%(+)$
2. For interference of intermediate pile on ϕ_{C_1} of upstream pile

b'= (3+5+2+10.5)m = 20.5m;

Solution

Upstream Pile

Depth of the pile, d = 256.00-250.00 = 6.00 m

Total floor length, b = (0.5+3+5+2+10.5+15+0.5)m = 36.5m

$\alpha = \frac{b}{d} = \frac{36.5}{6.0} = 6.083$

$\lambda = \frac{1}{2}[1+\sqrt{1+\alpha^2}] = 3.582$

$\phi_E = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda-2}{\lambda}\right) = 0.354 = 35.4\%$

$\phi_D = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda-1}{\lambda}\right) = 0.244 = 24.4\%$

$\phi_{C_1} = 100 - \phi_E = 100 - 35.4 = 64.6\%$

$\phi_{D_1} = 100 - \phi_D = 100 - 24.4 = 75.6\%$

Corrections:

1. For thickness: $\frac{\phi_{D1}-\phi_{C1}}{d} \times t = \frac{75.6-64.6}{6} \times 1.0 = 1.833\%(+)$
2. For interference of intermediate pile on ϕ_{C_1} of upstream pile

b'= (3+5+2+10.5)m = 20.5m; d_1 = (256-1.0)-248.0 = 7.0m, d = (256.0-1.0)-250.0 = 5.0m.

Then correction C_i

Solution

Upstream Pile

Depth of the pile, d = 256.00-250.00 = 6.00 m

Total floor length, b = (0.5+3+5+2+10.5+15+0.5)m = 36.5m

$\alpha = \frac{b}{d} = \frac{36.5}{6.0} = 6.083$

$\lambda = \frac{1}{2}[1 + \sqrt{1+\alpha^2}] = 3.582$

$\phi_E = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda-2}{\lambda}\right) = 0.354 = 35.4\%$

$\phi_D = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda-1}{\lambda}\right) = 0.244 = 24.4\%$

$\phi_{C_1} = 100 - \phi_E = 100 - 35.4 = 64.6\%$

$\phi_{D_1} = 100 - \phi_D = 100 - 24.4 = 75.6\%$

Corrections:

1. For thickness: $\frac{\phi_{D1} - \phi_{C1}}{d} \times t = \frac{75.6 - 64.6}{6} \times 1.0 = 1.833\%(+)$
2. For interference of intermediate pile on ϕ_{C_1} of upstream pile

b'= (3+5+2+10.5)m = 20.5m; d_1 = (256-1.0)-248.0 = 7.0m, d = (256.0-1.0)-250.0 = 5.0m.

Then correction C_i

$$= 19\sqrt{\frac{d_1}{b'}}\,\frac{d_1+d}{b} = 19\sqrt{\frac{7}{20.5}}\,\frac{7+5}{36.5} = 3.65\%(+)$$

Solution

Upstream Pile

Depth of the pile, d = 256.00-250.00 = 6.00 m

Total floor length, b = (0.5+3+5+2+10.5+15+0.5)m = 36.5m

$\alpha = \frac{b}{d} = \frac{36.5}{6.0} = 6.083$

$\lambda = \frac{1}{2}[1 + \sqrt{1+\alpha^2}] = 3.582$

$\phi_E = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda-2}{\lambda}\right) = 0.354 = 35.4\%$

$\phi_D = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda-1}{\lambda}\right) = 0.244 = 24.4\%$

$\phi_{C_1} = 100 - \phi_E = 100 - 35.4 = 64.6\%$

$\phi_{D_1} = 100 - \phi_D = 100 - 24.4 = 75.6\%$

Corrections:

1. For thickness: $\frac{\phi_{D1} - \phi_{C1}}{d} \times t = \frac{75.6-64.6}{6} \times 1.0 = 1.833\%(+)$
2. For interference of intermediate pile on ϕ_{C_1} of upstream pile

b'= (3+5+2+10.5)m = 20.5m; d_1 = (256-1.0)-248.0 = 7.0m, d = (256.0-1.0)-250.0 = 5.0m.

Then correction C_i

$$= 19\sqrt{\frac{d_1}{b'}}\,\frac{d_1+d}{b} = 19\sqrt{\frac{7}{20.5}}\,\frac{7+5}{36.5} = 3.65\%(+)$$

So, ϕ_{C_1} (corrected) =

Solution

Upstream Pile

Depth of the pile, d = 256.00-250.00 = 6.00 m

Total floor length, b = (0.5+3+5+2+10.5+15+0.5)m = 36.5m

$\alpha = \frac{b}{d} = \frac{36.5}{6.0} = 6.083$

$\lambda = \frac{1}{2}[1 + \sqrt{1+\alpha^2}] = 3.582$

$\phi_E = \frac{1}{\pi} \cos^{-1}\left(\frac{\lambda - 2}{\lambda}\right) = 0.354 = 35.4\%$

$\phi_D = \frac{1}{\pi} \cos^{-1}\left(\frac{\lambda - 1}{\lambda}\right) = 0.244 = 24.4\%$

$\phi_{C_1} = 100 - \phi_E = 100 - 35.4 = 64.6\%$

$\phi_{D_1} = 100 - \phi_D = 100 - 24.4 = 75.6\%$

Corrections:

1. For thickness: $\frac{\phi_{D1} - \phi_{C1}}{d} \times t = \frac{75.6 - 64.6}{6} \times 1.0 = 1.833\%(+)$
2. For interference of intermediate pile on ϕ_{C_1} of upstream pile

b'= (3+5+2+10.5)m = 20.5m; d_1 = (256-1.0)-248.0 = 7.0m, d = (256.0-1.0)-250.0 = 5.0m.

Then correction C_i

$$= 19\sqrt{\frac{d_1}{b'}}\,\frac{d_1 + d}{b} = 19\sqrt{\frac{7}{20.5}}\,\frac{7+5}{36.5} = 3.65\%(+)$$

So, ϕ_{C_1} (corrected) =64.6 + 1.883 + 3.65 = 70.083 %.

Solution

Intermediate Pile

Depth of the pile, d =

Solution

Intermediate Pile

Depth of the pile, d = 255.00-248.00 = 7.00 m

Solution

Intermediate Pile

Depth of the pile, d = 255.00-248.00 = 7.00 m

Distance from the u/s of the floor, b_1 =

Solution

Intermediate Pile

Depth of the pile, d = 255.00-248.00 = 7.00 m

Distance from the u/s of the floor, b_1 = (0.5+3+5+2+10.5)m = 21.0m

Solution

Intermediate Pile

Depth of the pile, d = 255.00-248.00 = 7.00 m

Distance from the u/s of the floor, b_1 = (0.5+3+5+2+10.5)m = 21.0m

Distance from the u/s of the floor, b_2 =

Solution

Intermediate Pile

Depth of the pile, d = 255.00-248.00 = 7.00 m

Distance from the u/s of the floor, b_1 = (0.5+3+5+2+10.5)m = 21.0m

Distance from the u/s of the floor, b_2 = (15.0+0.5)m = 15.5m

Solution

Intermediate Pile

Depth of the pile, d = 255.00-248.00 = 7.00 m

Distance from the u/s of the floor, b_1 = (0.5+3+5+2+10.5)m = 21.0m

Distance from the u/s of the floor, b_2 = (15.0+0.5)m = 15.5m. Then

$$\begin{aligned}
\alpha_1 &= \frac{b_1}{d} = \frac{21.0}{7} = 3.0 \\
\alpha_2 &= \frac{b_2}{d} = \frac{15.5}{7} = 2.2143 \\
\lambda_1 &= \frac{1}{2}[\sqrt{1+\alpha_1^2} - \sqrt{1+\alpha_2^2}] = 0.366 \\
\lambda_2 &= \frac{1}{2}[\sqrt{1+\alpha_1^2} + \sqrt{1+\alpha_2^2}] = 2.796 \\
\phi_C &= \frac{1}{\pi}\cos^{-1}\left[\frac{\lambda_1+1}{\lambda_2}\right] = 0.3375 = 33.75\% \\
\phi_D &= \frac{1}{\pi}\cos^{-1}\left[\frac{\lambda_1}{\lambda_2}\right] = 0.4582 = 45.82\% \\
\phi_E &= \frac{1}{\pi}\cos^{-1}\left[\frac{\lambda_1-1}{\lambda_2}\right] = 0.5728 = 57.28\%
\end{aligned}$$

Solution

Intermediate Pile: *Corrections*

i) For ϕ_E

a) Correction for thickness

Solution

Intermediate Pile: *Corrections*

i) For ϕ_E

a) Correction for thickness$= \frac{\phi_E - \phi_D}{d} \times t = \frac{57.28-45.82}{7} \times 2 = 3.28\%(-)$

b) Correction for slope:

Solution

Intermediate Pile: *Corrections*

i) For ϕ_E

a) Correction for thickness$= \frac{\phi_E - \phi_D}{d} \times t = \frac{57.28-45.82}{7} \times 2 = 3.28\%(-)$

b) Correction for slope:$b_s = 10.5$ m, $b' = (3+5+2+10.5) = 20.5$ m, C_s for slope 1:3 = 4.5.

Then Correction for slope

Solution

Intermediate Pile: *Corrections*

i) For ϕ_E

a) Correction for thickness$= \frac{\phi_E - \phi_D}{d} \times t = \frac{57.28-45.82}{7} \times 2 = 3.28\%(-)$

b) Correction for slope:$b_s = 10.5$ m, $b' = (3+5+2+10.5) = 20.5$ m, C_s for slope 1:3 = 4.5.

Then Correction for slope$= C_s \frac{b_s}{b'} = 4.5 \times \frac{10.5}{20.5} = 2.31\%(+)$

c) Interference of upstream pile :

Solution

Intermediate Pile: *Corrections*

i) For ϕ_E

a) Correction for thickness$= \frac{\phi_E - \phi_D}{d} \times t = \frac{57.28 - 45.82}{7} \times 2 = 3.28\%(-)$

b) Correction for slope:$b_s = 10.5$ m, $b' = (3+5+2+10.5) = 20.5$ m, C_s for slope 1:3 = 4.5.

Then Correction for slope$= C_s \frac{b_s}{b'} = 4.5 \times \frac{10.5}{20.5} = 2.31\%(+)$

c) Interference of upstream pile : b'= (3+5+2+10.5)m = 20.5m;

Solution

Intermediate Pile: *Corrections*

i) For ϕ_E

a) Correction for thickness$= \frac{\phi_E - \phi_D}{d} \times t = \frac{57.28 - 45.82}{7} \times 2 = 3.28\%(-)$

b) Correction for slope:$b_s = 10.5$ m, $b' = (3+5+2+10.5) = 20.5$ m, C_s for slope 1:3 = 4.5.

Then Correction for slope$= C_s \frac{b_s}{b'} = 4.5 \times \frac{10.5}{20.5} = 2.31\%(+)$

c) Interference of upstream pile : b'= (3+5+2+10.5)m = 20.5m; d_1 = (255.0-2.0)-250.0 = 3.0m, d = (255.0-2.0)-248.0 = 5.0m. Then correction C_i

Solution

Intermediate Pile: *Corrections*

i) For ϕ_E

a) Correction for thickness$= \frac{\phi_E - \phi_D}{d} \times t = \frac{57.28-45.82}{7} \times 2 = 3.28\%(-)$

b) Correction for slope:$b_s = 10.5$ m, $b' = (3+5+2+10.5) = 20.5$ m, C_s for slope 1:3 = 4.5.

Then Correction for slope$= C_s \frac{b_s}{b'} = 4.5 \times \frac{10.5}{20.5} = 2.31\%(+)$

c) Interference of upstream pile : b'= (3+5+2+10.5)m = 20.5m; d_1 = (255.0-2.0)-250.0 = 3.0m, d = (255.0-2.0)-248.0 = 5.0m. Then correction C_i

$$= 19\sqrt{\frac{d_1}{b'}}\,\frac{d_1+d}{b} = 19\sqrt{\frac{3}{20.5}}\,\frac{3+5}{36.5} = 1.59\%(-)$$

So, ϕ_E (corrected) =

Solution

Intermediate Pile: *Corrections*

i) For ϕ_E

a) Correction for thickness$= \frac{\phi_E - \phi_D}{d} \times t = \frac{57.28-45.82}{7} \times 2 = 3.28\%(-)$

b) Correction for slope:$b_s = 10.5$ m, $b' = (3+5+2+10.5) = 20.5$ m, C_s for slope 1:3 = 4.5.

Then Correction for slope$= C_s \frac{b_s}{b'} = 4.5 \times \frac{10.5}{20.5} = 2.31\%(+)$

c) Interference of upstream pile : b'= (3+5+2+10.5)m = 20.5m; d_1 = (255.0-2.0)-250.0 = 3.0m, d = (255.0-2.0)-248.0 = 5.0m. Then correction C_i

$$= 19\sqrt{\frac{d_1}{b'}}\,\frac{d_1+d}{b} = 19\sqrt{\frac{3}{20.5}}\,\frac{3+5}{36.5} = 1.59\%(-)$$

So, ϕ_E (corrected) =57.28 - 3.28 + 2.31 - 1.59 = 54.72%.

Solution

Intermediate Pile: *Corrections*

i) For ϕ_E

a) Correction for thickness$= \frac{\phi_E - \phi_D}{d} \times t = \frac{57.28-45.82}{7} \times 2 = 3.28\%(-)$

b) Correction for slope:$b_s = 10.5$ m, $b' = (3+5+2+10.5) = 20.5$ m, C_s for slope 1:3 = 4.5.

Then Correction for slope$= C_s \frac{b_s}{b'} = 4.5 \times \frac{10.5}{20.5} = 2.31\%(+)$

c) Interference of upstream pile : b'= (3+5+2+10.5)m = 20.5m; d_1 = (255.0-2.0)-250.0 = 3.0m, d = (255.0-2.0)-248.0 = 5.0m. Then correction C_i

$$= 19\sqrt{\frac{d_1}{b'}}\frac{d_1+d}{b} = 19\sqrt{\frac{3}{20.5}}\frac{3+5}{36.5} = 1.59\%(-)$$

So, ϕ_E (corrected) =57.28 - 3.28 + 2.31 - 1.59 = 54.72%.

ii) For ϕ_C

a) Correction for thickness

Solution

Intermediate Pile: *Corrections*

i) For ϕ_E

a) Correction for thickness$= \frac{\phi_E - \phi_D}{d} \times t = \frac{57.28-45.82}{7} \times 2 = 3.28\%(-)$

b) Correction for slope:$b_s = 10.5$ m, $b' = (3+5+2+10.5) = 20.5$ m, C_s for slope 1:3 = 4.5.

Then Correction for slope$= C_s \frac{b_s}{b'} = 4.5 \times \frac{10.5}{20.5} = 2.31\%(+)$

c) Interference of upstream pile : b'= (3+5+2+10.5)m = 20.5m; d_1 = (255.0-2.0)-250.0 = 3.0m, d = (255.0-2.0)-248.0 = 5.0m. Then correction C_i

$$= 19\sqrt{\frac{d_1}{b'}}\,\frac{d_1+d}{b} = 19\sqrt{\frac{3}{20.5}}\,\frac{3+5}{36.5} = 1.59\%(-)$$

So, ϕ_E (corrected) =57.28 - 3.28 + 2.31 - 1.59 = 54.72%.

ii) For ϕ_C

a) Correction for thickness$= \frac{\phi_D - \phi_C}{d} \times t = \frac{45.82-33.75}{7} \times 2 = 3.45\%(+)$

b) Interference of downstream pile :

Solution

Intermediate Pile: *Corrections*

i) For ϕ_E

a) Correction for thickness$= \frac{\phi_E - \phi_D}{d} \times t = \frac{57.28-45.82}{7} \times 2 = 3.28\%(-)$

b) Correction for slope:$b_s = 10.5$ m, $b' = (3+5+2+10.5) = 20.5$ m, C_s for slope 1:3 = 4.5.

Then Correction for slope$= C_s \frac{b_s}{b'} = 4.5 \times \frac{10.5}{20.5} = 2.31\%(+)$

c) Interference of upstream pile : b'= (3+5+2+10.5)m = 20.5m; d_1 = (255.0-2.0)-250.0 = 3.0m, d = (255.0-2.0)-248.0 = 5.0m. Then correction C_i

$$= 19\sqrt{\frac{d_1}{b'}}\,\frac{d_1+d}{b} = 19\sqrt{\frac{3}{20.5}}\,\frac{3+5}{36.5} = 1.59\%(-)$$

So, ϕ_E (corrected) =57.28 - 3.28 + 2.31 - 1.59 = 54.72%.

ii) For ϕ_C

a) Correction for thickness$= \frac{\phi_D - \phi_C}{d} \times t = \frac{45.82-33.75}{7} \times 2 = 3.45\%(+)$

b) Interference of downstream pile : b'= 15m

Solution

Intermediate Pile: *Corrections*

i) For ϕ_E

a) Correction for thickness$= \frac{\phi_E - \phi_D}{d} \times t = \frac{57.28-45.82}{7} \times 2 = 3.28\%(-)$

b) Correction for slope:$b_s = 10.5$ m, $b' = (3+5+2+10.5) = 20.5$ m, C_s for slope 1:3 = 4.5.

Then Correction for slope$= C_s \frac{b_s}{b'} = 4.5 \times \frac{10.5}{20.5} = 2.31\%(+)$

c) Interference of upstream pile : b'= (3+5+2+10.5)m = 20.5m; d_1 = (255.0-2.0)-250.0 = 3.0m, d = (255.0-2.0)-248.0 = 5.0m. Then correction C_i

$$= 19\sqrt{\frac{d_1}{b'}}\,\frac{d_1+d}{b} = 19\sqrt{\frac{3}{20.5}}\,\frac{3+5}{36.5} = 1.59\%(-)$$

So, ϕ_E (corrected) =57.28 - 3.28 + 2.31 - 1.59 = 54.72%.

ii) For ϕ_C

a) Correction for thickness$= \frac{\phi_D - \phi_C}{d} \times t = \frac{45.82-33.75}{7} \times 2 = 3.45\%(+)$

b) Interference of downstream pile : b'= 15m d_1 = (255.0-2.0)-248.0 = 5.0m, d = (255.0-2.0)-248.0 = 5.0m. Then correction C_i

Solution

Intermediate Pile: *Corrections*

i) For ϕ_E

a) Correction for thickness$= \frac{\phi_E - \phi_D}{d} \times t = \frac{57.28 - 45.82}{7} \times 2 = 3.28\%(-)$

b) Correction for slope:$b_s = 10.5$ m, $b' = (3+5+2+10.5) = 20.5$ m, C_s for slope 1:3 = 4.5.

Then Correction for slope$= C_s \frac{b_s}{b'} = 4.5 \times \frac{10.5}{20.5} = 2.31\%(+)$

c) Interference of upstream pile : b'= (3+5+2+10.5)m = 20.5m; d_1 = (255.0-2.0)-250.0 = 3.0m, d = (255.0-2.0)-248.0 = 5.0m. Then correction C_i

$$= 19\sqrt{\frac{d_1}{b'}}\frac{d_1 + d}{b} = 19\sqrt{\frac{3}{20.5}}\frac{3+5}{36.5} = 1.59\%(-)$$

So, ϕ_E (corrected) =57.28 - 3.28 + 2.31 - 1.59 = 54.72%.

ii) For ϕ_C

a) Correction for thickness$= \frac{\phi_D - \phi_C}{d} \times t = \frac{45.82 - 33.75}{7} \times 2 = 3.45\%(+)$

b) Interference of downstream pile : b'= 15m d_1 = (255.0-2.0)-248.0 = 5.0m, d = (255.0-2.0)-248.0 = 5.0m. Then correction C_i

$$= 19\sqrt{\frac{d_1}{b'}}\frac{d_1 + d}{b} = 19\sqrt{\frac{5}{15}}\frac{5+5}{36.5} = 3.01\%(+)$$

So, ϕ_C (corrected) =

Solution

Intermediate Pile: *Corrections*

i) For ϕ_E

a) Correction for thickness$= \frac{\phi_E - \phi_D}{d} \times t = \frac{57.28-45.82}{7} \times 2 = 3.28\%(-)$

b) Correction for slope:$b_s = 10.5$ m, $b' = (3+5+2+10.5) = 20.5$ m, C_s for slope 1:3 = 4.5.

Then Correction for slope$= C_s \frac{b_s}{b'} = 4.5 \times \frac{10.5}{20.5} = 2.31\%(+)$

c) Interference of upstream pile : b'= (3+5+2+10.5)m = 20.5m; d_1 = (255.0-2.0)-250.0 = 3.0m, d = (255.0-2.0)-248.0 = 5.0m. Then correction C_i

$$= 19\sqrt{\frac{d_1}{b'}}\,\frac{d_1+d}{b} = 19\sqrt{\frac{3}{20.5}}\,\frac{3+5}{36.5} = 1.59\%(-)$$

So, ϕ_E (corrected) =57.28 - 3.28 + 2.31 - 1.59 = 54.72%.

ii) For ϕ_C

a) Correction for thickness$= \frac{\phi_D - \phi_C}{d} \times t = \frac{45.82-33.75}{7} \times 2 = 3.45\%(+)$

b) Interference of downstream pile : b'= 15m d_1 = (255.0-2.0)-248.0 = 5.0m, d = (255.0-2.0)-248.0 = 5.0m. Then correction C_i

$$= 19\sqrt{\frac{d_1}{b'}}\,\frac{d_1+d}{b} = 19\sqrt{\frac{5}{15}}\,\frac{5+5}{36.5} = 3.01\%(+)$$

So, ϕ_C (corrected) =33.75 + 3.45 +3.01 = 40.21%.

Solution

Downstream Pile

Solution

Downstream Pile

Depth of the pile, d =

Solution

Downstream Pile

Depth of the pile, d = 255.00-248.00 = 7.00 m

Solution

Downstream Pile

Depth of the pile, d = 255.00-248.00 = 7.00 m

Total floor length, b = 36.5m

Solution

Downstream Pile

Depth of the pile, d = 255.00-248.00 = 7.00 m

Total floor length, b = 36.5m

$\alpha = \frac{b}{d} = \frac{36.5}{7.0} = 5.214$

Solution

Downstream Pile

Depth of the pile, d = 255.00-248.00 = 7.00 m

Total floor length, b = 36.5m

$\alpha = \frac{b}{d} = \frac{36.5}{7.0} = 5.214$

$\lambda = \frac{1}{2}[1 + \sqrt{1+\alpha^2}] = 3.155$

Solution

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$\phi_E = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda-2}{\lambda}\right) = 0.3807 = 38.07\%$

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$\phi_D = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda - 1}{\lambda}\right) = 0.2607 = 26.07\%$

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Corrections:

1. For thickness: $\frac{\phi_E-\phi_D}{d} \times t = \frac{38.07-26.07}{7} \times 1.2 = 2.057\%(-)$

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Corrections:

1. For thickness: $\frac{\phi_E-\phi_D}{d} \times t = \frac{38.07-26.07}{7} \times 1.2 = 2.057\%(-)$
2. For interference of intermediate pile on ϕ_E of downstream pile

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b'= 15m;

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b'= 15m; d_1 = (255.0-1.2)-248.0 = 5.8m, d = (255.0-1.2)-248.0 = 5.8m. Then correction C_i

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b'= 15m; d_1 = (255.0-1.2)-248.0 = 5.8m, d = (255.0-1.2)-248.0 = 5.8m. Then correction C_i

$$= 19\sqrt{\frac{d_1}{b'}}\,\frac{d_1+d}{b} = 19\sqrt{\frac{5.8}{15}}\,\frac{5.8+5.8}{36.5} = 3.75\%(-)$$

Solution

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So, ϕ_E (corrected) =

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$$= 19\sqrt{\frac{d_1}{b'}}\frac{d_1+d}{b} = 19\sqrt{\frac{5.8}{15}}\frac{5.8+5.8}{36.5} = 3.75\%(-)$$

So, ϕ_E (corrected) =38.07-2.057-3.75 = 32.263 %.

Solution

Exit Gradient

Here,

Acting Head, H = (260.0-255.0) m = 5.0 m

Solution

Exit Gradient

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Depth of the pile, d =

Solution

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So, exit gradient,

Solution

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So, exit gradient, $G_E = \frac{H}{d}\frac{1}{\pi\sqrt{\lambda}} = \frac{5}{7} \times \frac{1}{\pi\sqrt{3.154}} = 0.128$ = 1 in 7.81