CALCULATION OF SEEPAGE DISCHARGE AND SEEPAGE PRESSURE

Seepage discharge calculation

1. Sketch the coffer dam on scale.
2. Measure head difference (H).
3. Make flow net.
4. Find $n_f$ and $n_d$ from flow net.
5. Calculate seepage discharge

\[ Q = k \frac{n_f}{n_d} H b \]

\( b = \text{width of channel} = 56 \text{ cm} \)

For calculation, consider \( H = 20 \text{ cm} \).

Blowout of Coffer dam

![Figure 1: Schematic diagram showing liquefaction potential zone](image)

1. Calculate submerged unit weight of soil, \( \gamma' \).
2. Calculate critical gradient, \( i_c \).

\[
i_c = \frac{\gamma'}{\gamma_w}
\]

3. Calculate head right at the bottom (A) and at D/2 distance from point A of the pile. (D is the depth of the pile).

\[
H_A = (H - n_{DA} \times \Delta H) \quad H_B = (H - n_{DB} \times \Delta H)
\]

\( n_{DA} \) = number of head drops at A, \( \Delta H \) = head drop for each equi-potential line = \( H/n_d \)

You get values in terms of \( H \)

4. \[ H_{\text{average}} = \frac{1}{2} (H_A + H_B) \]

5. \[ i = \frac{H_{\text{average}}}{D} \]

6. In order to blowout the dam, \( i = i_c \)

Calculate \( H \) for blowout with this.

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One side of the coffer dam

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sand with \( G_s = 2.65 \)

\( D_{10} = 0.0264 \text{ cm} \)

and \( e = 0.81 \)

Impermeable layer
Seepage

Darcy’s law is applicable when flow of water is in one direction. In real world problems, seepage occurs in all three dimensions. Solution for 3D problems is complicated and needs advanced mathematical calculations. In many cases, 3D problems are simplified to 2D and seepage flow is calculated accordingly.

Equation of 2D Steady Flow

Conditions:

- Darcy’s law is valid
- $K$ is same in all dimensions (homogenous material)

Let’s consider a 2-D seepage flow system as shown in figure 1.

Darcy’s Law explains:

\[ Q = k \cdot i \cdot A \]

At section $X$ (for 1 m. strip),

\[ q_x = k \cdot i_x \cdot dy \cdot 1 \]

At section $Y$ (for 1 m. strip),

\[ q_y = k \cdot i_y \cdot dx \cdot 1 \]

At section $X+dx$

\[ q_{x+dx} = k \cdot i_{x+dx} \cdot dy \cdot 1 \]

At section $Y+dy$

\[ q_{y+dy} = k \cdot i_{y+dy} \cdot dx \cdot 1 \]

As the flow is steady, net flow should be 0.

\[ (q_{y+dy} + q_{x+dx}) - (q_y + q_x) = 0 \]

or

\[ (k \cdot i_{x+dx} \cdot dy + k \cdot i_{y+dy} \cdot dx) - (k \cdot i_x \cdot dy + k \cdot i_y \cdot dx) = 0 \]
or 

\[(i_{x+dx} - i_x) dy + (i_{y+dy} - i_y) dx = 0\]  \hspace{1cm} (1)

But 

\[i_x = \frac{\partial h}{\partial x}\] and \[i_y = \frac{\partial h}{\partial y}\]

\[i_{x+dx} = i_x + \frac{\partial i_x}{\partial x} dx\] and \[i_{y+dy} = i_y + \frac{\partial i_y}{\partial y} dy\]

Substituting these values in equation (1)

\[\frac{\partial i_x}{\partial x} dx dy + \frac{\partial i_y}{\partial y} dy dx = 0\]

Or

\[\frac{\partial}{\partial x} \left( \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left( \frac{\partial h}{\partial y} \right) = 0\]

Therefore,

\[\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} = 0\] \hspace{1cm} (2)

This equation is called **Laplace Equation**.

**Solution for Laplace equation:**

- Analytical method (mathematical)
- Numerical method (Finite Element, Finite Difference)
- Flow models (sand, glass bead)
- Analog model (electric, heat)
- Graphical method (flow net)

Graphical method is discussed in this chapter.

**Graphical Solution (Flow Net)**

- It is quick and simple.
- No special equipment is needed.
- Drawing improves understanding.

However, for complex problems, finite element is better.

Laplace equation requires 2 families of curves that meet at right angle. One is called *flow line* and the other is called *equi-potential line*. The network of these lines is called "**Flow Net**" (figure 2).

**Properties of flow net**

- Same flow quantity (\(\Delta q\)) through each flow channel.
- Same head drop (\(\Delta h\)) between each adjacent pair of equi-potential lines (except for partial drop).
In Figure 2, let 
\[ \Delta q = \frac{q}{n_f} \]  
(3) \[ \Delta h = \frac{H}{n_d} \]  
(4)

**Seepage Calculation Using Flow Net**

If our flow nets are going to have the properties of the lines mentioned above, we need to draw them in a certain way.

From Figure 3, 
\[ \Delta q = k.i.A = k.\frac{\Delta h}{l}b.1 = k.\Delta h.\frac{b}{l} \]

\(\Delta q\) and \(\Delta h\) should be the same for every element. Then, \(\frac{b}{l}\) must also be the same for every element.
\[ \frac{b}{l} = \text{side length ratio (same for all elements)} \]

or

\[ \frac{q}{n_f} = k \cdot \frac{H}{n_d} \cdot \frac{b}{l} \]

Therefore,

\[ q = k \cdot H \cdot \frac{n_f}{n_d} \cdot \frac{b}{l} \]

i.e.

\[ q = k \cdot H \cdot S \cdot \frac{b}{l} \]

where,

\[ S = \frac{n_f}{n_d} \]

However, if we can make \( \frac{l}{b} = 1 \) by making square flow net grid,

\[ q = k \cdot H \cdot S \]

and

\[ Q = q \cdot L \]

where, \( L \) is the length of dam in a perpendicular direction

**Method of Drawing Flow Net**

- Identify boundaries
  - upstream and downstream surfaces are equi-potential lines as they represent atmospheric pressure. Therefore, all flow lines intersect them at right angle.
  - Body of impervious layer is a flow line, and equi-potential lines intersect them at right angle.
- Sketch 2 - 3 flow channels.
- Sketch equi-potential lines.
- Iterate, erasing and re-sketching lines to form "square" with \( l/b = 1 \). If required check the square pattern by drawing a circle.
- Perform seepage computation for \( q \) and then calculate \( Q \).

Shown in figure 4 is an example of flow net under a sheet pile.
Note

For \( k_x \neq k_y \),

we make horizontal scale = \( \sqrt{\frac{k_y}{k_x}} \times \) vertical Scale

and plot the structure. Then we follow the same procedure. This gives,

\[ q = \sqrt{k_x k_y} \cdot \frac{H n_f}{n_d} \]

Use of Flow Net

Uplift pressure under hydraulic structure

From figure 5,

\[ n_d = 7 \quad H = 7 \text{ m} \]
\[ \text{Head Loss at each equi-potential line} = \frac{7}{7} = 1 \text{ m} \]
\[ \text{Head at A, i.e. } h_A = (9 - 1 \times 1) = 8 \text{ m} \]
\[ \text{Uplift pressure } U_A = 8 \cdot \gamma_w \]

Likewise, \( U_B = 7 \cdot \gamma_w \)
Figure 5 Calculation of uplift pressure

Method to determine pore pressure and uplift pressure

- Determine head at point where pore pressure is required.
- Express the head as a value referred to the point itself as a datum.
- Calculate pore pressure, \( U_A = h_A \cdot \gamma_w \)

**Caution:**

- Most common mistake is to be inconsistent about datum.
- Head = (a value) (referenced to) (a datum)
- To calculate a pore pressure, the best datum from the head is the point itself.
- Count head either to head water or to tail water.

Effective stress \( \sigma' = \sigma - u \)

If \( u = \sigma \), \( \sigma' = 0 \) (We will have liquefaction)

At liquefaction, \( \sigma = u_A \)
\[ \gamma' \cdot Z = i \cdot \gamma_w \cdot Z \]
Therefore,

\[ i = \frac{(G_i - 1)\gamma_w}{\gamma' \gamma_w} = \frac{G_s - 1}{1 + e} \]

This is called critical gradient \((i_c)\)

\[ i_c = \frac{G_s - 1}{1 + e} \quad (7) \]