SEEPAGE

Seepage is a process in which fluid flow through the porous medium of soil mass from higher head to lower head. Normally there are 3 heads. in case of flow of fluid in pipes But in case of flow through soil mass only 2 heads

(i) Pressure head
(ii) Datum head

Pressure head:- It is observe by referring the water table at the point of consideration or to determine the pressure head by placing the piezometer at the point of consideration.

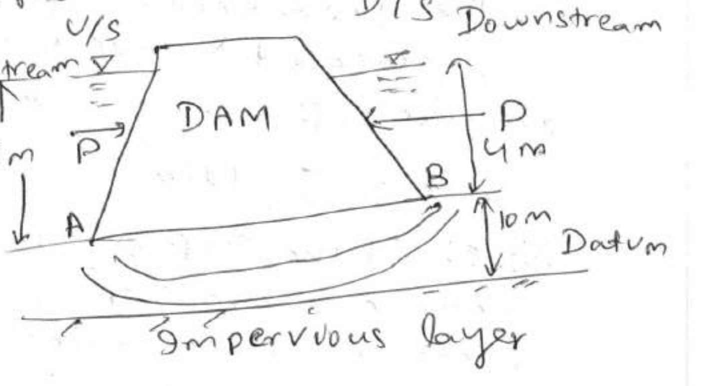
Datum head:- In case of flow through soil normally assume that the point which at the lower head is consider as the datum line for the point of consideration.

Seepage head is equal to hydraulic head is equal to the total head difference between the two points which are considered.

The path taken by the water to flow through the soil mass is called flow line. Flow line is represent an individual water particle flow so a group of flow lines to get a form of a flow of water.

The line joining equal head point of a flow line is called equipotential line.

- Equipotential line & the flow lines are prepared each other. They combine to form a flownet



A

PH + DH = TH

6 + 10 = 16

B

4 + 10 = 14m.

Head difference = $(TH)_A - (TH)_B$

$h = 2\text{ m}$ = Seepage head.

Seepage head:- It is the head difference between total head under which the flow is possible from one point to another point $v = \frac{h}{L}$

Terminology:

Seepage pressure (P_s) :- when the water is seeping through the soil mass the total head discipate as the various frictions and in producing frictional drag in the direction of flow.

- The drag force is the seepage pressure in soil mass in the direction of flow

$$P_s = h\gamma_w \quad kN/m^2$$

If $i = \frac{h}{z} \Rightarrow h = iz$ then $P_s = iz\gamma_w$

z = depth of water / flow of water inside the soil mass upto z depth

Seepage force (J) transmitted to the soil mass of total cross sectional area A is

$$J = P_s A = iz\gamma_w A$$

Seepage force per unit volume is given by

$$J = \frac{iz\gamma_w A}{zA} = i\gamma_w$$

The seepage pressure always act in the direction of flow. The vertical effective pressure may be decreased or increased due to seepage pressure depending upon the direction of flow. Thus the effective pressure in a soil mass subjected to seepage pressure is given by

$$\sigma' = z\gamma' \pm P_s = z\gamma' \pm iz\gamma_w$$

If the flow occurs in downward direction the effective pr. is increased & +ve sign is used. If flow occurs in upward direction effective pr. decreased & -ve sign is used.

Unit of J N/m^3 i is dimensionless.

Note: If the seepage takes place in vertically downward direction then seepage pressure acts in the downward direction which helps in compressing the soil and making the soil more dense as a result of which the permeability, compressibility and void ratio are decrease. The effective stress and shear strength of soil (bearing capacity of soil) will increase

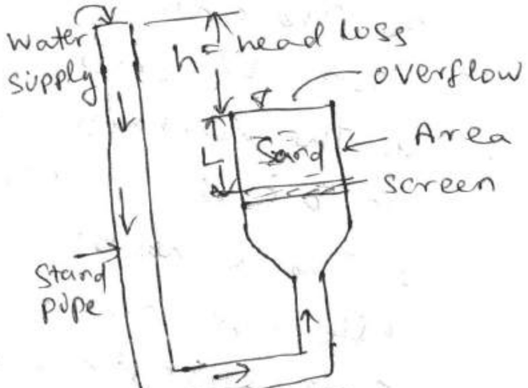
Stream function (ψ) :-

It is a Scalar function and it will depend on 2 coordinate (x & z)

Potential function:- It is also a scalar function depend on 2 coordinates (x & z). It is denoted as ϕ & it is also called as velocity potential function.

QUICK SAND :- (Quick condition/ Boiling condition / Piping condition)

The effective stress is reduced due to upward flow of flow when the head causing upward flow is increased a stage is eventually reached when the effective stress is reduced to zero. The condition so developed is known as quick condition



Upward flow of water through soil

During quick sand condition

$$\sigma' = z\gamma' - P_s = 0$$

$$\text{or } P_s = z\gamma'$$

$$i z \gamma_w = z\gamma'$$

$$i = \frac{\gamma'}{\gamma_w}$$

upward gradient, hydraulic gradient

$$\boxed{i = \frac{\gamma'}{\gamma_w}}$$

Critical hydraulic gradient:- The hydraulic gradient at which the effective stress becomes zero is known as Critical hydraulic gradient.

$$i_c = \frac{\gamma'}{\gamma_w}$$

Substituting value of γ' in terms of void ratio

$$\boxed{i_c = \frac{G-1}{1+e}}$$

Taking $G = 2.67$ $e = 0.67$ $i_c = 1$ in sand

i.e. the head causing the flow is equal to the length of the specimen.

This means that an upward hydraulic gradient of magnitude $\frac{G-1}{1+e}$ will be just sufficient to start phenomenon of boiling. This is for cohesionless soil.

sand becomes quick at this gradient
This occurs in fine sands with low permeability
In case of gravels with high permeability much higher velocity of flow will be required to cause the condition.
The cohesive soils donot become quick as soon as the effective stress is reduced to zero.

Summarised below:-

1. Quick sand is not a special type of soil. It is a hydraulic condition
2. A cohesionless soil becomes quick when the effective stress is equal to zero
3. The critical gradient at which a cohesionless soil becomes quick is about unity
4. The discharge required to maintain a quick condition in a soil increases as the permeability of soil increases
5. The cohesive soil does not become quick when the effective stress is equal to zero as it still posses some strength equal to cohesion intercept.

In sand Shear strength $\tau_f = \sigma' \tan\phi$

When $\sigma' = 0$ $\tau_f = 0$

In clay $\tau_f = c + \sigma' \tan\phi$ c = cohesion intercept

τ_f = Shear strength of soil ϕ = Angle of shearing resistance

6. A quick condition is most likely to occur in silt and fine sand

Note: To avoid the quick sand condition normally provide coarse grained sand & gravel to such kind of soil to enhance the seepage discharge by increasing permeability of soil Hence i of soil is also increased

→ when $i = i_c$ then the quick sand condition occurs
- At such condition the soil is so weak that it cannot support the wt. of a human or animal.
- But they can't float easily in such soil.

98

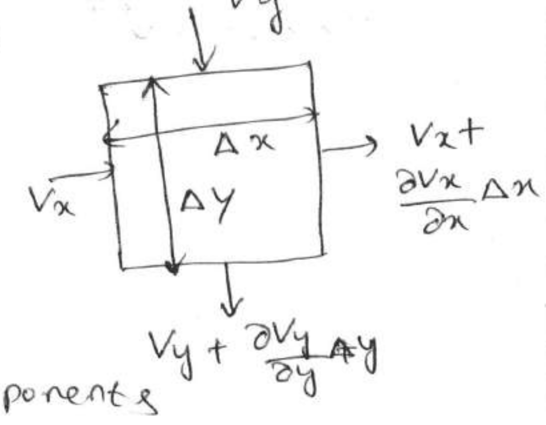
Two dimensional flow Laplace equation :-

- Determination of quantity of seepage & distribution of seepage pressure.

If the seepage takes place in 2 dimensional coordinates then it can be study by the help of Laplace equation.

Assumption :

1. The saturated porous medium is incompressible. The size of the pore spaces doesnot change with time, regardless of water pressure,
2. Darcy's law for flow through porous medium is valid.
3. There is no change in the degree of saturation in the zone of soil through which water seeps & the quantity of water flowing into any element volume is equal to the quantity which flows out in the same length of time
4. The hydraulic boundary conditions at entry and exit are known.
5. Water is incompressible.



Consider an element of soil of size Δx, Δy & of unit thickness ⊥lar to the plane of paper

Let V_x & V_y entry velocity components in x & y directions respectively

$\left(V_x + \frac{\partial V_x}{\partial x}\Delta x\right)$ & $\left(V_y + \frac{\partial V_y}{\partial y}\Delta y\right)$ velocity components at exist of the element

According to assumption 3 stated above

Quantity of water entering the element = quantity of water leaving the element

$$V_x(\Delta y \cdot 1) + V_y(\Delta x \cdot 1) = \left(V_x + \frac{\partial V_x}{\partial x}\Delta x\right)(\Delta y \cdot 1) + \left(V_y + \frac{\partial V_y}{\partial y}\Delta y\right)(\Delta x \cdot 1)$$

From which

$$\frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} = 0 \quad \text{— ① Continuity eqn}$$

Assumption 2 $\quad v_x = k_x i_x = k_x \frac{\partial h}{\partial x}$

$$V_y = k_y i_y = k_y \frac{\partial h}{\partial y}$$

h = hydraulic head under which water flows

k_x & k_y = coefficient of permeability in x & y directions

Substituting in eqn (1)

we get $\quad \frac{\partial^2 (k_x h)}{\partial x^2} + \frac{\partial^2 (k_y h)}{\partial y^2} = 0$

For an isotropic soil $k_x = k_y = k$

$$\boxed{\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} = 0}$$ Laplace eqn in terms of Seepage head

Substituting $\phi = kh$

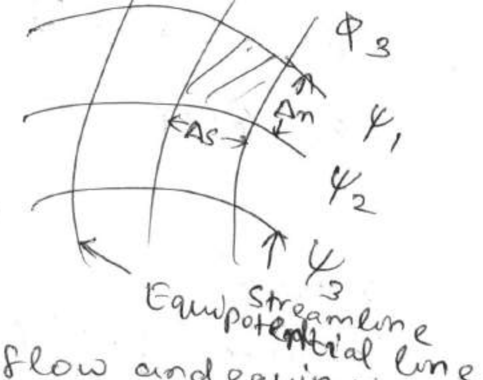
$$\boxed{\frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2} = 0}$$ Laplace equation in terms of potential function

This is the Laplace equation of flow in 2 dimension.

FlowNet :-

- It is a graphical representation of the stream line & the equipotential line. The stream line represents the flow of one individual water particle and the equipotential line represents the equal head points.

Characteristics / properties of flownet :-



1. In isotropic soil the flow lines and equipotential lines intersect at right angles to each other indicating that the direction of flow is $\perp$lar to the equipotential lines.
2. The spaces between consecutive flow and equipotential lines form elementary squares (a circle can be inscribed touching all four lines)
3. The head drop will be same between successive equipotentials also the in each flow channels will be the same
4. The transitions are smooth being elliptical or parabolic in shape
5. The smaller the size of elementary square the greater will be the velocity and hydraulic gradient.

* A flownet represents the solution for Laplace's equation for the relevant bandary conditions.

The space between two adjacent flow lines is called flowpath or flow channel. and the figure formed on the flownet between any two adjacent flow lines and adjacent equipotential lines is referred to as flowfield

Δn → It is the difference between two stream line

Δs – It is the difference between two potential functions.

As we have consider the flow field to be square so the value of $\boxed{\frac{\Delta s}{\Delta n} = 1}$

Uses of flownet :-

- Determination of rate of seepage
- Determination of hydrostatic pressure
- Determination of seepage pressure
- Determination of exit gradient

Methods for obtaing flownet :-

Following methods are available

a. Analytical method
b. Electrical flow analogy
c. Capillary flow analogy
d. Sand model
e. Graphical method.

a. Analytical method :- which requires a mathematical Solution of Laplace eqn Can be use in relatively simple Cases of flow where the boundary conditions can be expressed by equations.

- It can be solved by numerical technique or using finite difference method
- This method is quite traditional and time consuming method.

b. Electrical analogy method :-

- An electrical model is made with proper boundary condition to analyse the flow of water inside the soilmass as in case of dam
- There are 3types of electrical analogy model
  1. By providing electrical analogy tray
  2. Potential analyser method.
  3. By conducting paper method
- This method of constructing flownet is also not accurate.

c. Capillary flow Analogy

- It gives an accurate representation of seepage through soil mass.
- The flow lines can be observed directly by providing the dye container.
- The plastic model can be quickly prepared and the flownet obtained by this method of good quality.

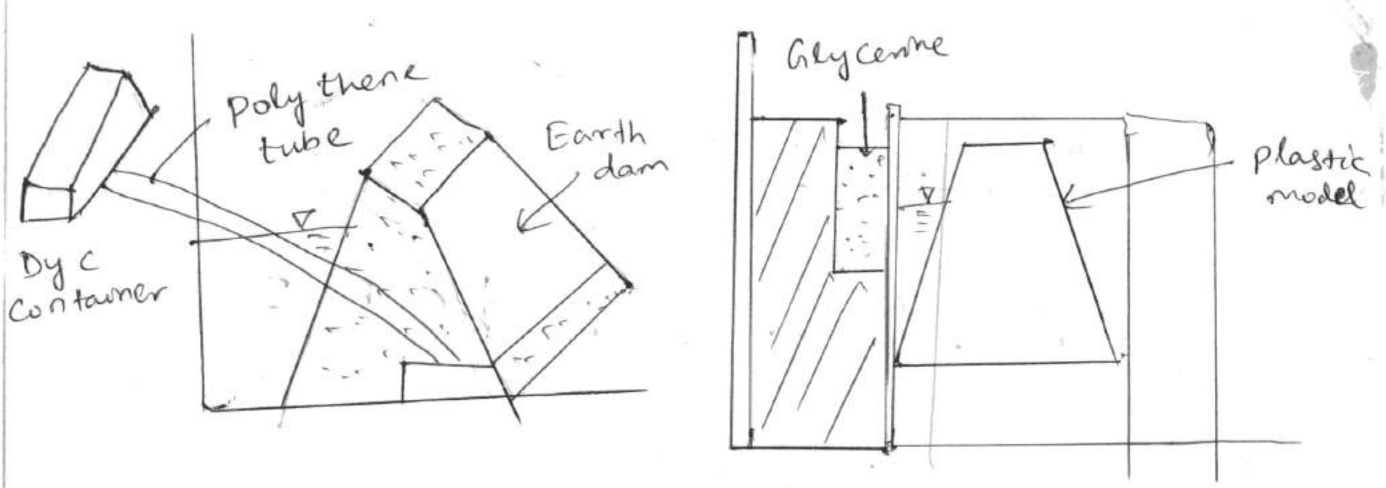


Fig (d)

d. Sand model

- A small scale of soil model is used to draw the flownet.
- The main use of soil model is to demonstrate the fundamentals of a flownet and seepage through the dam.
- This method is very time consuming as the construction of soil model requires large time.

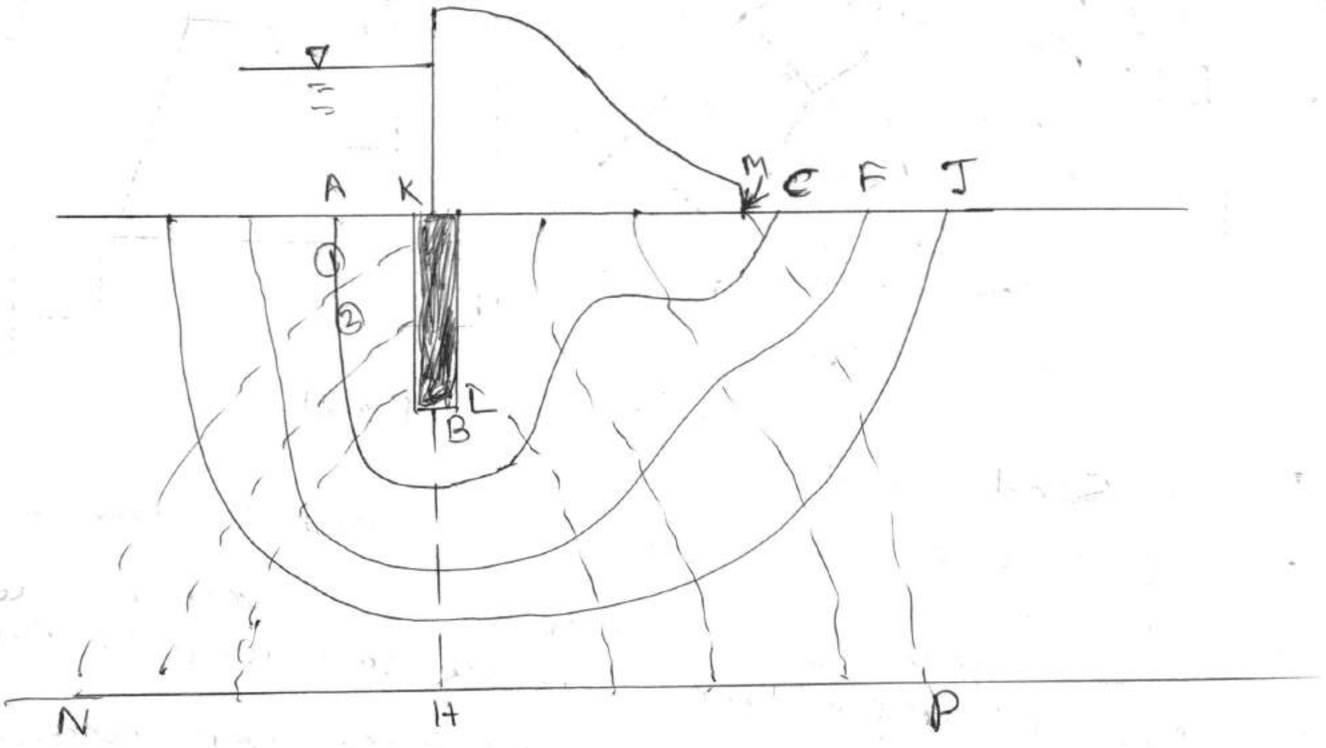
Note:

→ The flow is assume as a 2 dimensional flow

- In many soil engg problems such as flow through large earth dam, seepage under a sheet pile is seepage below large gravity dam.
- The velocity has only 2 components i.e. v_x, v_y

e. Graphical method :-

- It is a most commonly used method
- According the hydraulic boundaries and the limitation of flow lines are drawn
- For preparing a flownet a lot of practice and patience is needed
- However the hydraulic quantities like discharge and pore water pressure can be calculated easily by considering a rough diagram of flownet.
- This method of preparing flownet is also not accurate.



procedure for drawing the flownet :-

1. First identify the hydraulic boundary conditions. The upstream bed level GDAK represents 100% potential line & downstream bed level CFJ 0% potential line. The 1st flow line KLM hugs the hydraulic structure and is formed by the flow of water on the upstream of the sheet pile, the downstream of the sheet pile and at the interface of the base of the dam and soil surface. The last flow line is indicated by impervious stratum NP

2. Draw a trial flow line ABC adjacent to the boundary line. The line must be at right angles to the upstream & downstream beds.

The location of the 1st trial line is determined from experience. An experienced person will make a good estimate of the 1st trial line and subsequent work would be reduced.

3. Starting from the upstream end divide the 1st flow channel into approximate squares by equipotential lines. The size of the square should change gradually.

4. Extend downward the equipotential lines forming the sides of the squares. These extensions point out approximate width of squares such as square is marked (1) & ②

other sides of the squares are set equal to the widths as determined above. Irregularities are smoothened out and the next flow line DF is drawn, joining these bases while sketching the flow line care should be taken to make flow fields as approximate squares throughout.

5. The equipotential lines are further extended downward & one more flow line GHJ is drawn repeating the step 4

6. If the flow fields in the last flow channel are inconsistent with the actual boundary conditions the whole procedure is repeated after taking a new trial flow line.

It is not necessary that last flow channel should make complete squares. The flow fields in the last channel may be approximate rectangles with the same length to width ratio.

Suggestions by A. Casagrande - for benefit of the sketcher

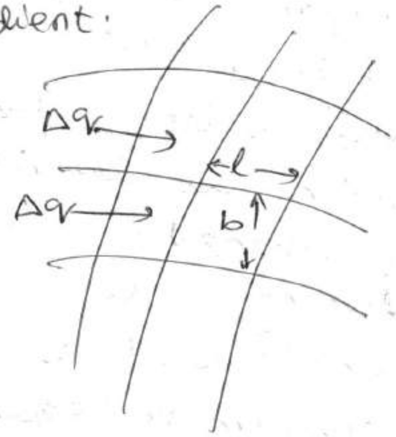
1. Every opportunity to study well constructed flownets should be utilised to get the feel of the problem
2. 4 to 5 flow channels are usually sufficient for 1st attempt.
3. The entire flownet should be sketched roughly before details are adjusted.
4. The fact that all transitions are smooth and are of elliptical or parabolic shape should be born in mind.
5. The boundary flow lines and boundary equipotentials should 1st be recognised & sketched.

Application/Uses of flownet :-

A flownet can be utilized for following purposes

a. Determination of seepage / discharge
b. Determination of hydrostatic pressure
c. Determination of seepage pressure
d. Determination of exit gradient.

Seepage :-



Let b & l be width and length of the field

Δh = head drop through the field

Δq = discharge passing through the flow channel

H = total hydraulic head causing flow
= Difference between upstream and downstream head

$\Delta q = k \times \frac{\Delta h}{l} \times b \times 1$ (considering unit thickness)

N_d = total No. of potential drops in the complete flownet

$\Delta h = \frac{H}{N_d}$

Hence $\Delta q = k \frac{H}{N_d}\left(\frac{b}{l}\right)$

Total discharge through complete flownet is given by $q = \sum \Delta q = k \frac{H}{N_d} \times \frac{b}{l} \times N_f$

$= k H \frac{N_f}{N_d} \times \frac{b}{l}$

N_f = total No. of flow channels in the flownet.

When the field is square hence $b = l$

$$\boxed{q = k H \frac{N_f}{N_d}}$$ → This is the required expression for discharge passing through a flownet and is valid for isotropic soils $k_x = k_y = k$

the ratio N_f/N_d is a characteristic of flownet

- It is known as shape factor
- It is independent of K
- It depends only on the configuration or shape of soil mass

Hydrostatic pressure :-

pressure head = Total head - elevation head

The down stream water level is normally termed as datum point.

The hydrostatic pr. at any point within soil mass is given by $u = h_w \gamma_w$ h_w = piezometric head

u = hydrostatic pr.

$h_w = h - Z$

where h = total head at that point

h_w = hydrostatic head at a point

Z = datum head

$$\boxed{h = H - n\Delta h}$$

n = number of potential drops upto that point

Δh = potential drop per field = H/N_d

Seepage pressure : The hydraulic potential h at any point located after n potential drops each of value Δh is given by $h = H - n\Delta h$

Seepage pr at any point equals Hydraulic potential or hydraulic head multiplied by unit wt of water & is given by

$$\boxed{P_s = h\gamma_w = (H - n\Delta h)\gamma_w}$$

H = total head causing the flow

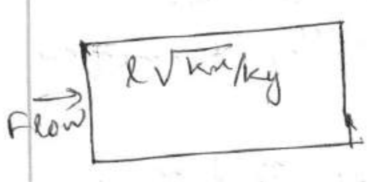
Exit gradient : It is the hydraulic gradient at the downstream end of the flow line where the percolating water leaves the soil mass and emerges into the free water at the down stream.

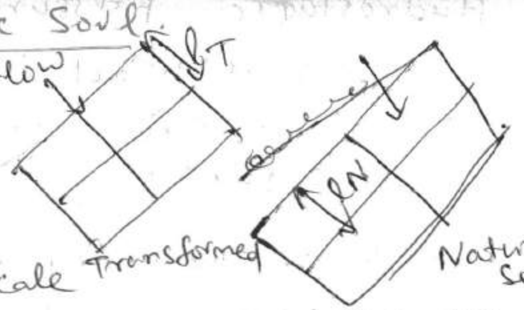
$$\boxed{i_e = \frac{\Delta h}{l}}$$

Δh = potential drop = H/N_d

$\Delta h = \frac{H}{N_d}$ l = average length of last field in the flownet at the exist end.

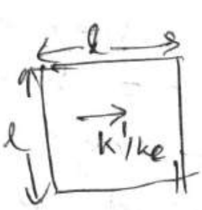
Seepage through anisotropic Soil

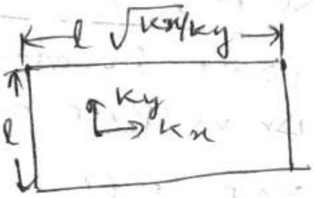




Natural scale Transformed Scale Transformed Natural Section

The transformed section can also be used to determine the head at any point while determining a gradient it is important to remember that the dimensions on the transformed section must be corrected while taking the distance over which the head is lost. To compute the gradient the head loss between equipotentials is divided by the distance l_N the flow distance between equipotentials on the natural scale & not by l_T the distance between equipotentials on the transformed scale.





Transformed field Actual field / True section

The Continuity equation for two dimensional flow

$$\frac{\partial V_x}{\partial x} + \frac{\partial V_y}{\partial y} = 0$$

Applying Darcy's law $V_x = k_x i_x = k_x \frac{\partial h}{\partial x}$

$$V_y = k_y i_y = k_y \frac{\partial h}{\partial y}$$

For anisotropic soil $k_x \neq k_y$

For anisotropic flow medium

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

Which is not a Laplace eqn.

$$\frac{k_x}{k_y} \frac{\partial^2 h}{\partial x^2} \neq \frac{\partial^2 h}{\partial y^2} = 0$$

Letusputting $x_n = x\sqrt{k_y/k_x}$

Where x_n is the new coordinate variable in x direction.

Now the above equation is

$$\boxed{\frac{\partial^2 h}{\partial x_n^2} + \frac{\partial^2 h}{\partial y^2} = 0}$$

The profile is transformed according to relationship between x & x_n flownet sketches on the transformed section

This is Laplace form

To plot flownet for such a case the cross section through anisotropic soil is plotted to a natural scale in the y direction & to a transformed scale in the x direction all the dimensions are ||el to x-axis being reduced by multiplying by the factor $\sqrt{k_y/k_x}$

The field of transformed section will be square one while the field of the actual section will be rectangular one having its length in x-direction equalto $\sqrt{k_x/k_y}$ times the width in the y-direction

K_x = permeability coefficient in x direction of the actual anisotropic soil field

K' = equivalent permeability of the transformed field

$K' = K_e$ = effective permeability

$\Delta q = k' \frac{\Delta h}{l}(l \times 1)$ For transformed section

Actual field $\Delta q = k_x \frac{\Delta h}{l\sqrt{k_x/k_y}}(l \times 1)$

since the quantity of flow is same

$K' \frac{\Delta h}{l} l = k_x \frac{\Delta h}{l(\sqrt{k_x/k_y})}(l)$

$K' = k_x\sqrt{k_y/k_x} = \sqrt{k_x k_y}$

$q = k' H \frac{N_f}{N_d} = \sqrt{k_x k_y}\, H \frac{N_f}{N_q}$

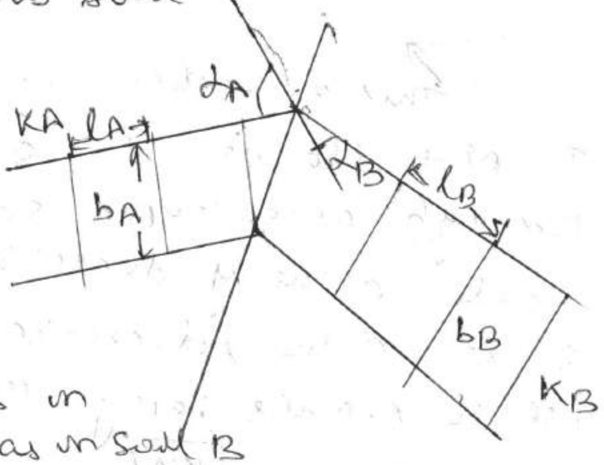
$$\boxed{q = \sqrt{k_x k_y}\frac{N_f}{N_d}}$$

Seepage through non homogeneous soil

- In case of flow ⊥lar to soil strata the loss of head and rate of flow are influenced primarily by less pervious soil whereas in the case of flow ||el to the strata the rate of flow is essential controlled by comparatively more pervious soil.

Two soils A & B

A part of a flownet from soil A to soil B



$K_A > K_B$

By principle of continuity the same rate of flow exists in the flow channel in soil A as in soil B

To determine the angle of incidence of flow paths with the boundary of the two flow channels

In soil B flownet figures are rectangles

A " " are squares

$$q_A = q_B$$

$$\text{But } q_A = k_A \frac{\Delta h}{l_A} b_A$$

$$q_B = k_B \frac{\Delta h}{l_B} b_B$$

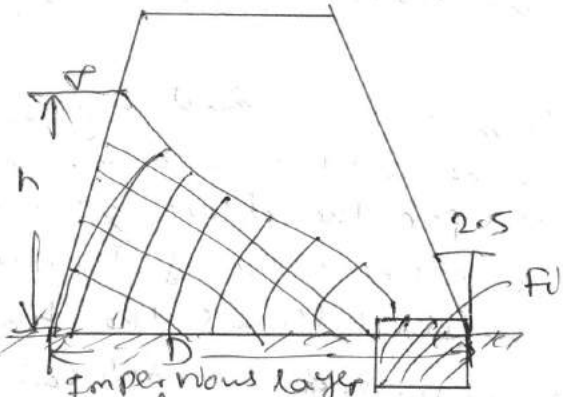
$$k_A \frac{\Delta h}{l_A} \cdot b_A = k_B \frac{\Delta h}{l_B} b_B$$

$$\frac{l_A}{b_A} = \tan\alpha \quad , \quad \frac{l_B}{b_B} = \tan\alpha_B$$

$$\frac{k_A}{\tan\alpha_A} = \frac{k_B}{\tan\alpha_B} \Rightarrow \boxed{\frac{\tan\alpha_A}{\tan\alpha_B} = \frac{k_A}{k_B}}$$

Some Special Cases

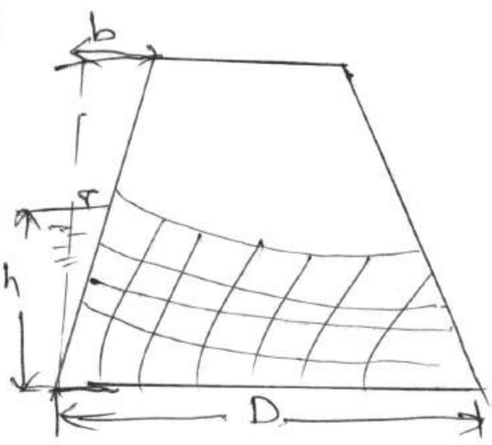
Flownet in earthdam with horizontal filter at downstream

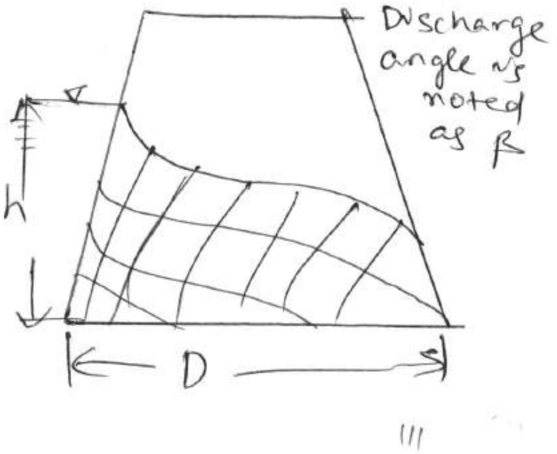


- By applying Kozney's solution such type of problem can be solve by using all the hydraulic boundary conditions. A parabola is made and point 'C' is centre of parabola

- The force boundary conditions are one for the stream function (initial & final condition)
- for potential function (initial & final condition)

* Seepage through earth dam with sloping discharge
* Seepage through earth dam with discharge angle less than 30 :-
* for different layer of soil flow line & equipotential line get deflected at the point of interface.
* seepage through earth dam with discharge angle 30 or < 60'





Top flow line in an earthdam :-

It is also know phreatic line

- It is defined as the line within a dam section below which there are +ve hydrostatic pressures in the dam.

The flow through a earth dam is bounded by a topflow line or phreatic line which is determined first. The location depends upon the drainage conditions. at the downstream toe & the inclination of the discharge face. The phreatic line mostly follows the base parabola of kozeny (1931) with slight modification at the beginning and the end as given by A.Casagrande

- The pr. is atmospheric on the pheratic line
- The pressure in the dam section below pheratic line are +ve hydrostatic pressure

Two simple cases will be dealt with in regard to the determination of top flow line

① Discharge takes place into a horizontal filter inside the downstream toe.

② Downstream slope of the dam forms in itself a medium for discharge & a horizontal filter is outside the downstream toe.