PERMEABILITY

Porous material :- The material which contain void space (interstics) are normally called porous material.

- Porous material are permeable in nature as the void space are interconnected or contineous through which a fluid can easily pass.

- All types of soil are porous material as there is void space in it but the cross section dimension of the void space are different for different soils.

Definition of Permeability :- Permeability is a property of soil by virtue of which it permits the flow of water through it.

→ It is an engineering property of soil mass.

- For fine grain soils the void space are less so the permeability is slow but in case of coarse grain soils the void space is high so the permeability is high.

- Completely impervious soil doesnot exist in nature but some soils are termed as impermeable in nature as the flow of water is very small. (ex: Colloidal clay)

- Permeability is an important engineering property of soil which helps in solving many engineering problems like (i) Settlement of a building

(ii) Seepage

(iii) earth retaining structure

(iv) Stability of slope

- Flow of gravity water / free water is influenced by the gravitational force but it depends on the permeability of soil.

* Hydraulic head :- Total head = pressure head + velocity head + Datum head

(i) pressure head :- It is the head which is indicate by the help of piezometer

(ii) velocity head :- The velocity or water is extremely low in case of soil so it can be neglected

(iii) Datum head :- It is the vertical distance of the point of consideration from the datum line (reference line) in case of water flows through soil mass the point which is at lower head is consider as the datum line (or reference point).

Total head = Datum head + pressure head

= Piezometric head

Note:- The line joining the different piezometric level is called piezometric surface / hydraulic gradient line. (HGL)

Darcy's law:-

In 1856 he demonstrate an experient on the laminar flow in case of homogeneous soil. He gave a formulae of velocity at which the water flow through soil mass

Bernoulli's eqn

Total head at a point in water under motion is given by

$$h = \frac{u}{\gamma_w} + \frac{V^2}{2g} + z$$

u/γ_w = pressure head

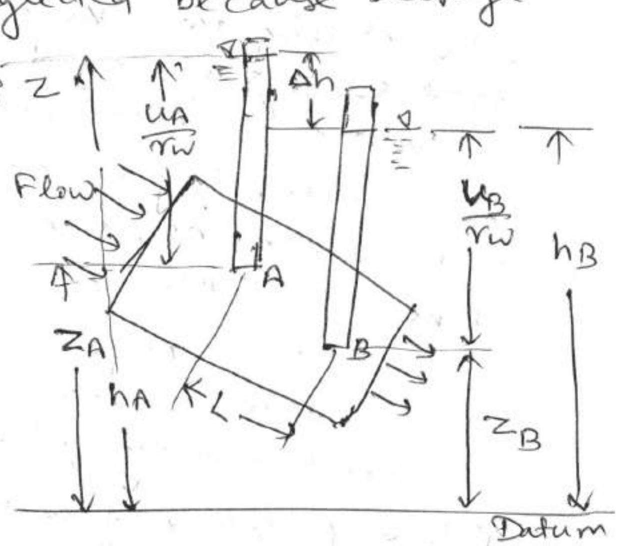
$V^2/2g$ = velocity head

z = datum head

h = total head

If Bernoulli's eqn is applied to the flow of water through a porous soil medium the velocity head can be neglected because seepage velocity is small

Total head $h = \frac{u}{\gamma_w} + z$



Open stand pipes called piezometers are installed at point A & B

The levels to which water rises in the piezometer tubes situated at points A & B are known as piezometric levels of point A & B respectively

The loss of head between two points A & B

$$\Delta h = h_A - h_B = \left(\frac{u_A}{\gamma_w} + Z_A\right) - \left(\frac{u_B}{\gamma_w} + Z_B\right)$$

head loss Δh $i = \frac{\Delta h}{L}$ i = hydraulic gradient

L = distance between points A & B - length of flow over which the loss of head occured.

Darcy's law: French water works Engineer

The law of flow of water through soil was studied by Darcy (1856) who demonstrate experimentally that for laminar flow conditions in a saturated soil. The rate of flow or the discharge per unit time is proportional to the hydraulic gradient.

According to Darcy's law for laminar flow condition

$V \propto i$

or $V = Ki$

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

where V = velocity of water flowing in soil mass

K = Coefficient of permeability

i = hydraulic gradient

h = head loss during the flow

L = unit length in the direction of flow

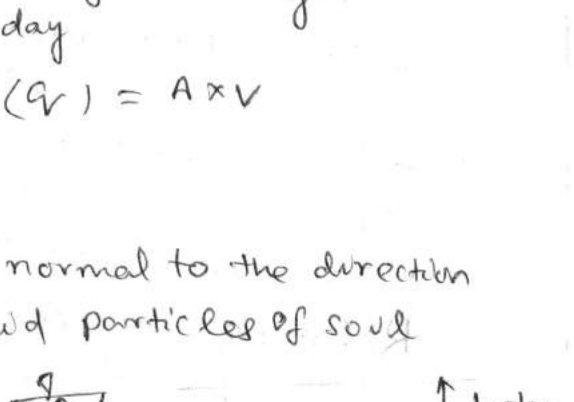
- For unit value of hydraulic gradient the coefficient of permeability is equal to the velocity of flow of water in the soil mass when $i = 1$ $V = K$
- The unit of k is equal to the unit of velocity in mm/sec, cm/sec, m/sec., m/day

For the calculation of discharge $(q) = A \times V$

$q = AV$

$q = kiA$

A = It is the cross sectional area normal to the direction of flow, it includes the solid particles of soil as well as the void space in it.

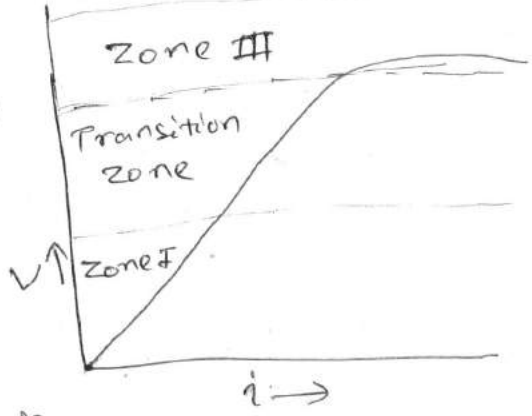


If a soil sample of length L & cross sectional A is subjected to differential head of water $h_1 - h_2$ the hydraulic gradient i will be equal to $\frac{h_1 - h_2}{L}$ & $q = k\left(\frac{h_1 - h_2}{L}\right)A$

Type of soil	Value of k	Drainage condition
1. Gravel	10^1 to 10^2	very good
2. Coarse & medium sand	10^{-2} to 10^1	good
3. Fine sand & loose silt	10^{-4} to 10^{-2}	fair
4. Dense silt & clay	10^{-5} to 10^{-4}	Poor
5. For very fine & dense clay	10^{-8} to 10^{-5}	very Poor

Variation of velocity V with i divided 3 zones

1. Laminar flow zone (I)
2. Transition zone (II)
3. Turbulent flow zone (III)



When i gradually increased the flow is laminar in zone I & II. At higher i flow becomes turbulent

i decreased laminar flow only in zone I

For most soil the flow of water through voidspace, can be considered laminar $V \propto i$ condition may exist

In fracture rock, stone, gravels & very coarse sand turbulent flow $V \propto i$ is not valid.

Note: The flow is possible only in the void space but we consider the entire crossectional area both void space & solid particle.

- The water flow through the soil mass is considered to be laminar flow.
- The laminar flow is possible in case of the grain soil but in case of coarse grain soil the flow may be turbulent.

Relation between Discharge velocity & Seepage velocity

The velocity of flow V is the rate of discharge of water per unit of total Crossectional area A of soil

Total area of cross section = Area of solids (A_s) + Area of Voids A_v

The flow takes through the voids the actual or true velocity of flow will be more than the discharge velocity. This actual velocity is called Seepage velocity (V_s) & is defined as the rate of discharge of percolating water per unit cross sectional area of voids ⊥lar to the direction of flow.

$$q = VA = V_s A_v$$

$$V_s = V \frac{A}{A_v} \quad \text{But} \quad \frac{A_v}{A} = \frac{V_v}{V} = n$$

$$V_s = V \frac{A}{A_v} = V \times \frac{1}{n} = \frac{V}{n} = \frac{1+e}{e} V$$

$$\frac{V_s}{V} = \frac{1}{n}$$

V_s is also proportional to hydraulic gradient

$V_s = K_p i \qquad K_p$ = coefficient of percolation

From Darcy's law $V = Ki$

$$\frac{V_s}{V} = \frac{K_p}{K} = \frac{1}{n}$$

$$K_p = \frac{K}{n}$$

Validity of Darcy's law :- Darcy's law is valid only for laminar flow conditions in soil.

From the experiments on flow through pipes Reynold's found that the flow is laminar so long as the velocity of flow is less than a lower critical velocity V_c in terms of Reynold's number

$$\frac{V_c d \rho_w}{\eta g} = 2000$$

where V_c = lower critical velocity in the pipe (cm/sec)

d = dia. of pipe (cm)

ρ_w = density of water (g/ml)

η = viscosity of water (g sec/cm²)

g = acceleration due to gravity

Flow through soil depends upon the dimensions of pore spaces.

Flow through sand remain laminar

$$\frac{V D_a \rho_w}{\eta g} \leq 1$$

where V = velocity of flow (cm/sec)

$D_a = D_{10} = D$ (uniform soil)

$V = Ki$

D_a = Dia of average particle (cm)

$\eta = 1 \times 10^{-5}$ g sec/cm² $\quad g = 981$ cm/sec²

$K = 100 D_m^2 = 100 D_{10}^2 \qquad D \approx 0.05$ cm $= 0.5$ mm

Critical Re may vary from 0.1 to 75 for Darcy's law to be valid.

Note:

In general the Reynold's number is less than 2000 for laminar flow But in case of water flow in the soil mass the Reynold number should be less than equal to 1. which is not possible in case of Coarse grained Soil as the size of Void space is large so the flow could be turbulent.

In case of coarse grained soil the sizes of void space is large hence the rate of flow is high comparatively and the Reynold's number is also high so, considering the flow the Reynold's number should be turbulent.

- For laminar flow the relation between hydraulic gradient & the velocity of water is linear but in case of turbulent flow the relation is not linear hence the equation becomes.

$$V = K(i')^n$$

Factors affecting permeability:-

Darcy's law $q = kiA$

An equation reflecting the influence of the characteristics of permanent fluid & the soil on permeability was developed by Taylor (1948)

Based on Poiseuille's law for laminar flow through a circular capillary tube. The flow through a porous medium is considered similar to a flow through a bundle of capillary tubes.

Poiseuille's law for flow through soil pores

$$q = \left(C \frac{\gamma_w}{\eta} \frac{e^3}{1+e} D_s^2 \right) iA$$

If compare with Darcy's law

$$K = D_s^2 \frac{\gamma_w}{\eta} \left(\frac{e^3}{1+e} \right) C$$

C = new shape factor
η = viscosity
e = void ratio
K = coefficient of permeability
D_s = effective particle size

Factors are

1. Grain / Particle size
2. Properties of pore fluid
3. Void ratio of the soil
4. Structural arrangement of soil particles
5. Entrapped air & presence of foreign matter
6. Adsorbed water in clayey soil
7. Degree of saturation.

1. Effect of Size & shape of particle :-

permeability varies approximately as the square of grain size. Since soil consists of different grain sizes Allen Hazen (1892) based on his experiments on filter sands of particle size between 0.1 & 3mm found that K can be expressed as

$K = C D_{10}^2$

D_{10} = effective diameter

C = constant equal to 100

The smaller the grain size the smaller the voids & thus lower the permeability

Effect of properties of pore fluid

It indicates that the k is directly proportional to the unit wt of water & inversely proportional to its viscosity. The unit wt of water does not change much with change in temperature is great variation in viscosity with temp. other factors remains constant the effect of property of water on the values of permeability can be expressed

$$k \propto \frac{\gamma_w}{\eta}$$

$$\frac{k_1}{k_2} = \frac{\eta_2}{\eta_1} \times \frac{\gamma_{w_1}}{\gamma_{w_2}} = \frac{\eta_2}{\eta_1}\frac{\rho_{w_1}}{\rho_{w_2}}$$

1 & 2 used to refer to quantities at temp. T_1 & T_2

standard room temperature 27°C

$$K_{27} = K \frac{\eta}{\eta_{27}}$$

Greater the viscosity lower is the permeability

3. Effect of void ratio :- The effect of void ratio on the values of permeability can be expressed as

$$\frac{k_1}{k_2} = \left(\frac{e_1^3}{1+e_1}\right) \Big/ \left(\frac{e_2^3}{1+e_2}\right)$$

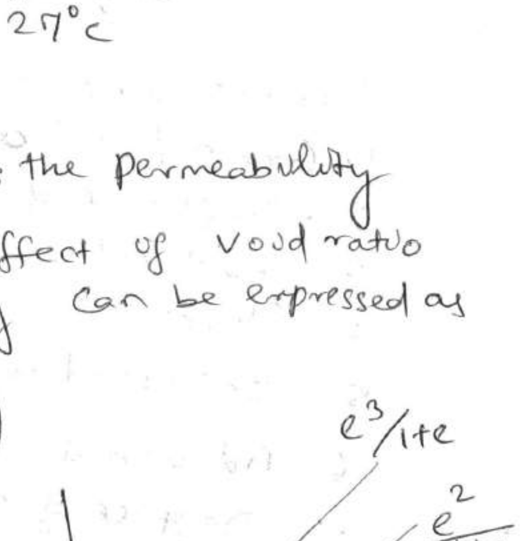
e on natural scale

k on logarithmic scale

plot of K versus $\frac{e^3}{1+e}$ should be straight line for both coarse & fine grained soils

K_1 = permeability at void ratio e_1

K_2 = " " " e_2



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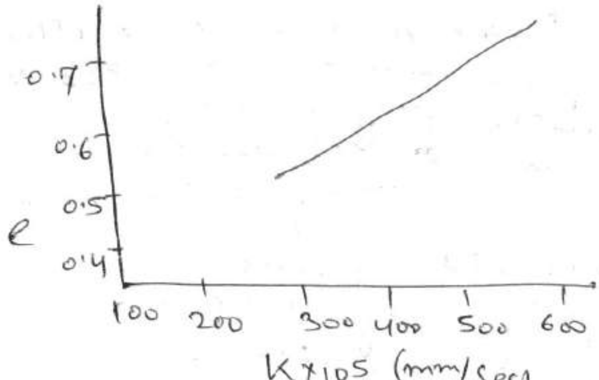
log k versus e also a straight line approximates a st. line for many soils within wide range of permeability



Structural arrangement of particles :-

- It is an important soil characteristic influencing permeability especially of fine grained soils. The structural arrangement of the particle may vary at the same void ratio depending upon the method of deposition or compacting soil mass. The structure may be entirely different for a disturbed sample as compared to an undisturbed sample. Stratified soil masses have marked variations in their permeabilities in direction ||el and ⊥lar to stratification.
- Permeability ||l to the stratification being always greater

Degree of saturation :- The permeability test is always conducted on fully saturated soil sample. Higher the degree of saturation higher the permeability.

Presence of entrapped air & other foreign matter

It has pronounced effect on permeability

It reduces the permeability of soil organic foreign matter has the tendency to move towards the flow channels & choke them thus decreasing permeability.

Effect of adsorbed water :- The adsorbed water surrounding the fine soil particles is not free to move and reduces the effective pore space available for the passage of water.

Determination of Coefficient of Permeability :-

The value of K can be determined in many method

a. Laboratory methods
  a. Constant head permeability test
  b. Falling head permeability test

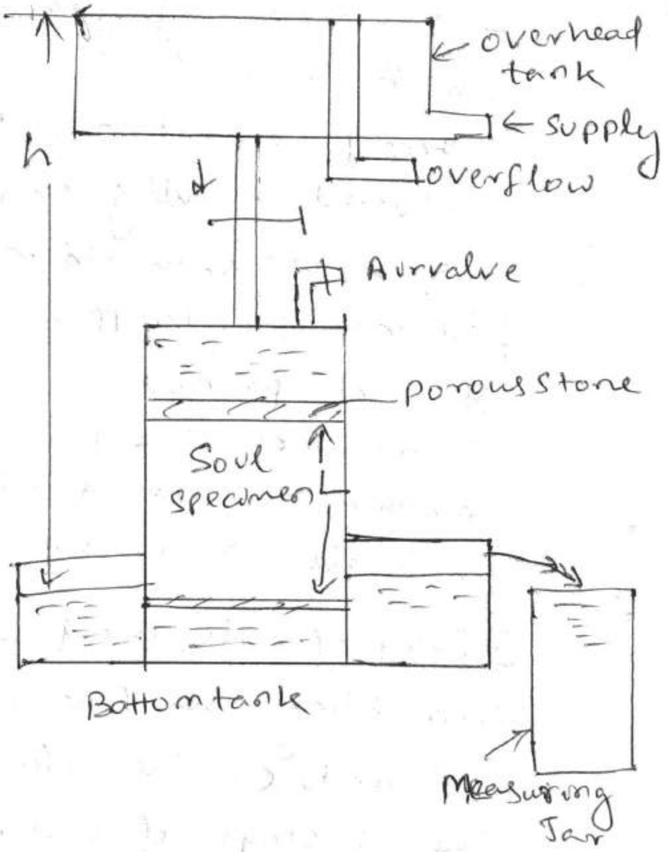
b. Field methods
  1. Pumping out tests
  2. Pumping in tests.

c. By consolidation test Calculate the coefficient of permeability of a soil

d. Indirect method
  (i) Computation from particle size or specific surface
  (ii) Analysis method.

Constant head permeability test

The principle in this set up is that the hydraulic head causing the flow is maintained constant, the quantity of water flowing through a soil specimen of known crossectional area & length in a given time is measured.



The test is used for coarse grained soils where discharge can be collected in a given time.
Applicable pervious soil
In impervious soil Q canbe collected very small.
Water flows from overhead tank consisting of 3 tubes the inlet tube, the overflow tube & outlet tube.
The constant hydraulic gradient i causing the flow is the head h (i.e, difference in the water levels of overhead & bottom tank) divided by the length 'L' of the sample.

From Darcy's law $q = \frac{Q}{t} = KiA$

Q = total quantity of flow collected in the measuring jar after flowing through soil in an elasped time interval t

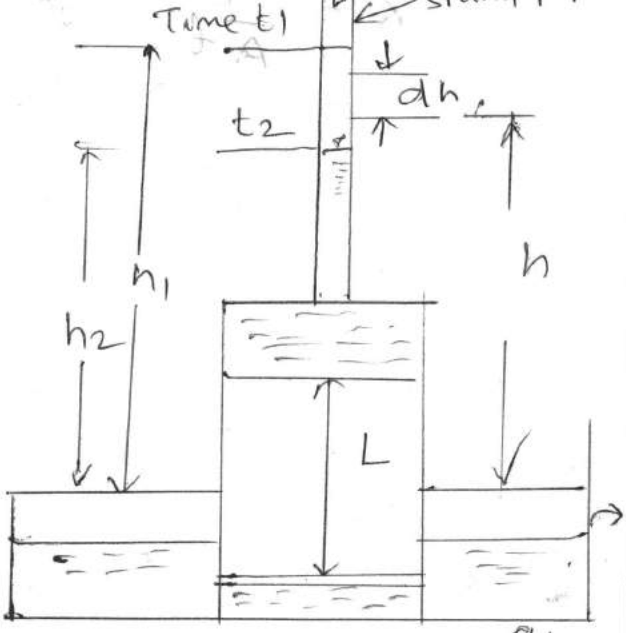
$$K = \frac{Q}{t} \times \frac{1}{iA} = \frac{Q}{t} \times \frac{L}{h} \times \frac{1}{A}$$

A = total cross sectional area of the sample

When steady state of flow is reached the total quantity of water Q in time 't' is collected in a measuring jar.

Falling head permeability test:-

It is used for less permeable soils where the discharge is small.



A stand pipe of known cross sectional area 'a' is fitted over the permeameter water is allowed to run down. The water level in the stand pipe constantly falls as water flows, observations are started after steady state of flow has reached.

The head at any time instant t is equal in the stand pipe & the bottom tank.

Let h_1 & h_2 be heads at time interval t_1 & t_2 $(t_2 > t_1)$

h be head at any intermediate time interval t

& $-dh$ be the change in the head in a smaller time interval dt ($-$ve sign since h decreases t increases)

From Darcy's law the rate of flow q

$$q = \frac{(-dh \cdot a)}{dt} = kiA$$

$$i = \frac{h}{L} \qquad \frac{kh}{L} A = -\frac{dh}{dt} a$$

$$\text{or} \quad \frac{AK}{aL} dt = -\frac{dh}{h}$$

$$\text{Integrating} \quad \frac{AK}{aL} \int_{t_1}^{t_2} dt = -\int_{h_1}^{h_2} \frac{dh}{h} = \int_{h_2}^{h_1} \frac{dh}{h}$$

$$\frac{AK}{aL}(t_2 - t_1) = \log_e \frac{h_1}{h_2}$$

$t_2 - t_1 = t$ we get

$$K = \frac{aL}{At} \log_e \frac{h_1}{h_2} = 2.3 \frac{aL}{At} \log_{10} \frac{h_1}{h_2}$$

Permeability of Stratified Soil deposits :-

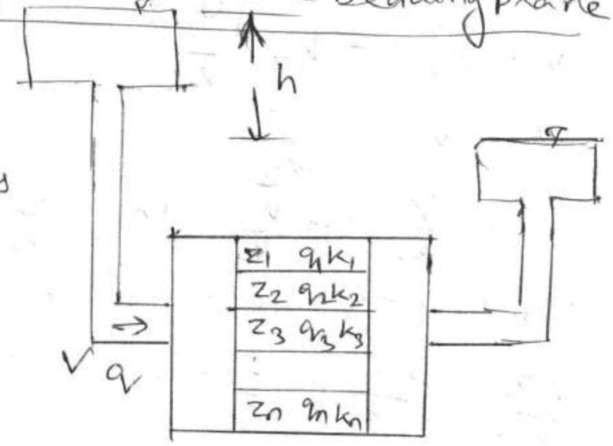
In nature soil mass may consist of several layers deposited one above the other. The bedding planes may be horizontal, inclined or vertical

Bedding plane - area of separation between rock strata made by a situation deposition of sediment.

- Each layer assumed to be homogeneous & isotropic has its own coefficient of permeability.

The average permeability of the whole deposit will depend upon the direction of flow with relation to the direction of bedding plane

(a) <u>Average permeability parallel to the bedding plane :-</u>



Let $z_1, z_2 \cdots z_n$ = thickness of layers

$k_1, k_2\, k_n$ = permeability of layers

For flow parallel to the bedding planes i will be same for all the layers

$V = ki$ K is different

V is different in different layers

k_x = average permeability of the soil deposit ll to the bedding plane

Total discharge through soil deposit

= Sum of the discharge through individual layers

$q = q_1 + q_2 + q_3 + \cdots + q_n$

$q = k_x\, i = k_1 i z_1 + k_2 i z_2 + \cdots + k_n i z_n$

$$k_x \text{ or } k_h = \frac{k_1 z_1 + k_2 z_2 + \cdots + k_n z_n}{z_1 + z_2 + \cdots + z_n}$$

(b) Average permeability ⊥lar to the bedding planes :-

Velocity of flow & unit discharge will be same through each layer. Head loss through each layer will be different

Total head loss h

$h_1, h_2, h_3 \cdots h_n$ head loss through individual layers

$h = h_1 + h_2 + \cdots + h_n$

$h_1 = i_1 z_1 \quad h_2 = i_2 z_2$

$h_n = i_n z_n$

$h = i_1 z_1 + i_2 z_2 + \cdots + i_n z_n \quad -(1)$

K_z = Avg. permeability ⊥lar to bedding plane

$V = k_z i = k_z \frac{h}{Z}$

or $h = \frac{VZ}{k_z}$

$i_1 = \frac{V}{k_1} \quad i_2 = \frac{V}{k_2} \quad i_n = \frac{V}{k_n}$

Substituting these values in eqn (1)

$$\frac{VZ}{k_z} = \frac{Vz_1}{k_1} + \frac{Vz_2}{k_2} + \cdots + \frac{Vz_n}{k_n}$$

$$k_z \text{ or } k_v = \frac{Z}{\frac{z_1}{k_1} + \frac{z_2}{k_2} + \cdots + \frac{z_n}{k_n}}$$