CE 353

Dr. TALAT BADER

Chapter 5-1
Flow of Water in Soils

Dr. Talat Bader

Flow of Water

- *Soil is a three phase medium*

  Solids

  Water

  Air

- *Water in soils occur in various conditions*
- *Water can flow through the voids in a soil from a point of high energy to a point of low energy*

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Why Studying Flow of Water in Porous Media ?

- *To estimate the quantity of underground seepage*
- *To determine the quantity of water that can be discharged form a soil*
- *To determine the pore water pressure/effective geostatic stresses, and to analyze earth structures subjected to water flow.*
- *To determine the volume change in soil layers (soil consolidation) and settlement of foundation*

Flow of Water in Soil Depends on:

1- Porosity of the soil

2- Type of the soil

- ***particle size***
- ***particle shape***
- ***degree of packing***

3- Viscosity of the fluid

- *Temperature*
- *Chemical Components*

Flow of Water in Soil Depends on:

4- Total head

(difference in energy) - Pressure head

- Velocity head

- Elevation head

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Flow of Water in Soil Depends on:

- *The degree of compressibility of a soil is expressed by the coefficient of permeability of the soil "k."*

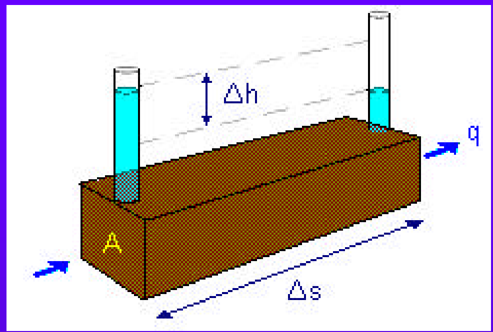
k cm/sec, ft/sec, m/sec

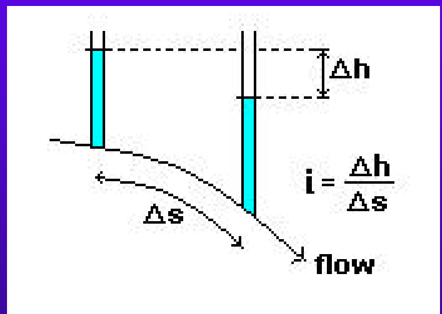
Permeability

- ❖Darcy's law
- ❖Void ratio
- ❖Stratified soil
- ❖Seepage velocity
- ❖Temperature

Permeability /

Darcy's law





- The rate of flow of water q (volume/time) through cross-sectional area A is found to be proportional to hydraulic gradient I

$$i = \Delta h / \Delta s$$

$$v = \frac{q}{A} = ki$$

Where

v is flow velocity

k is coefficient of permeability with dimensions of velocity (length/time).

Coefficient of Permeability k

- The value of the coefficient of permeability k depends on:
  - the average size of the pores

    And is related to

    - ✓ the distribution of particle sizes,
    - ✓ particle shape
    - ✓ soil structure

Coefficient of Permeability k

- Typical Values of permeability's
- A small proportion of fine material in a coarse-grained soil can lead to a significant reduction in permeability.

Typical Values of permeability's

SOIL TYPE	k(mm/sec)	Relative Permeability
coarse gravel, jointed rock	$> 10^{0}$	high
sand, fine sand	$10^{0} - 10^{-2}$	medium
silty sand, dirty sand	$10^{-2} - 10^{-4}$	low
silt, fine sandstone	$10^{-4} - 10^{-6}$	very low
clay, mudstone w/o joints	$< 10^{-6}$	impermeable

- Observation: As the grain size of the soil decreases, the permeability decreases significantly. This is due to the higher SSA of fine-grained soils.

Void Ratio & Permeability

- Permeability of all soils is strongly influenced by the density of packing of the soil particles which can be simply described through void ratio e or porosity n.

Permeability/Sand

$$k = .01(d_{10})^2$$

- Hazen Formula

Where D_{10}=is the effective particle size in mm

$$k = \frac{1}{K_0 k_T S_S^2} \cdot \frac{e^3}{1+e} \cdot \frac{g_w}{h}$$

- Kozeny-Carman equation

Where k_o = factor depending on the shape

k_T = factor depending on the tortuosity of the pores

Ss = surface area of the solid particles per unit volume of solid material

γ_w= unit weight of the pore water

h = viscosity of the pore water

Simplifying the Equation= $k = C * \frac{e^3}{1+e} = C * e^2$

Permeability/Clay

- Kozeny-Carman equation does not work well for silts and clays
- For clays it is typically found that

$$Log_{10} k = \frac{e - e_k}{C_k}$$

Where k_o = permeability change index

k_T = reference void ratio

For many natural clays C_k is approximately equal to half the natural void ratio.

Seepage Velocity

- Darcy's Law relates flow velocity (v) to hydraulic gradient (i).
- The volume flow rate q is calculated as the product of flow velocity v and total cross sectional area:

$$q = vA$$

- At the particulate level the water follows a tortuous path through the pores.
- The average velocity at which the water flows through the pores is the ratio of volume flow rate to the average area of voids Av on a cross section normal to the macroscopic direction of flow.
- This is the seepage velocity v_s

$$v_s = \frac{q}{A_v}$$

Seepage Velocity

- Porosity of soil is related to the volume fraction of voids

$$n = \frac{Vv}{V} = \frac{Av}{A}$$

$$Vs = \frac{V}{n}$$

- Seepage velocity can be measured in laboratory models by injecting dye into the seeping pore water and timing its progress through the soil.

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Temperature & Permeability

- The flow of water through confined spaces is controlled by its viscosity and the viscosity is controlled by temperature.
- An alternative permeability K (dimensions:

  coefficient depending only on the characteristics of the soil skeleton.

$$K = \frac{\eta k}{\gamma_w}$$

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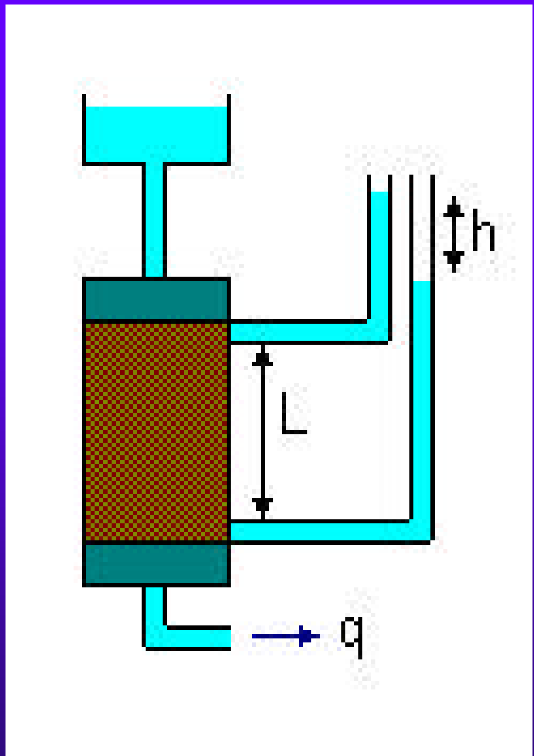
Laboratory Measurement of Permeability

- Permeameter
- Oedometer

Laboratory Measurement of Permeability

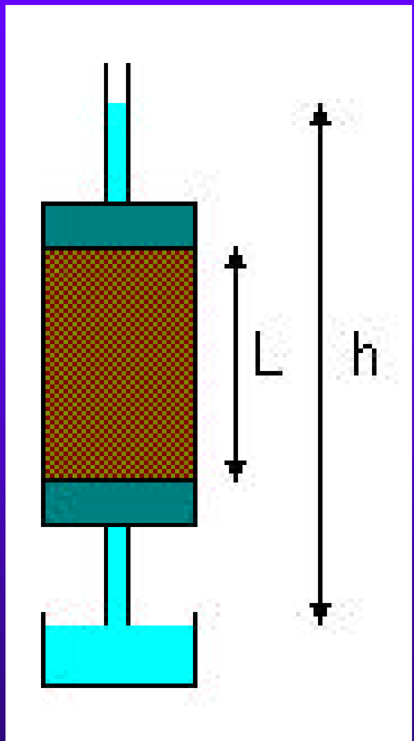
- Laboratory measurements of the permeability of soils can be made using a permeameter. For fine-grained soils (clays), the coefficient of permeability can be estimated directly or indirectly during one-dimensional compression tests in an oedometer

Constant Head Test



- Recommended for coarse-grained soils.
- Steady total head drop Δh is measured across gauge length L, as water flows through a sample of cross-section area A.
- $$k = \frac{ql}{Ah}$$

Falling Head Test



- Recommended for fine-grained soils.
- Total head h in standpipe of area a is allowed to fall; heads h_1 and h_2 are measured at times t_1 and t_2.
- Hydraulic gradient $\Delta h/L$ varies with time.

$$k = \frac{a}{A} \frac{L}{(t_2 - t_1)} \ln \frac{h_1}{h_2}$$

Measurement / Permeability Laboratory / Permeameter / Oedometer

Indirect Measurement

- Transient consolidation phenomena are controlled by the coefficient of consolidation. With knowledge of one-dimensional compliance m_v, coefficient of permeability k can be estimated from

$$C_v = \frac{k}{m_v g_w}$$

Direct measurement

- Direct measurement of permeability in oedometers is preferable.
- Flow pumps can be used to maintain a constant flow rate (q) across the sample and to measure the resultant constant head (h).
- The coefficient of permeability is then given by

$$k = qL / Ah$$

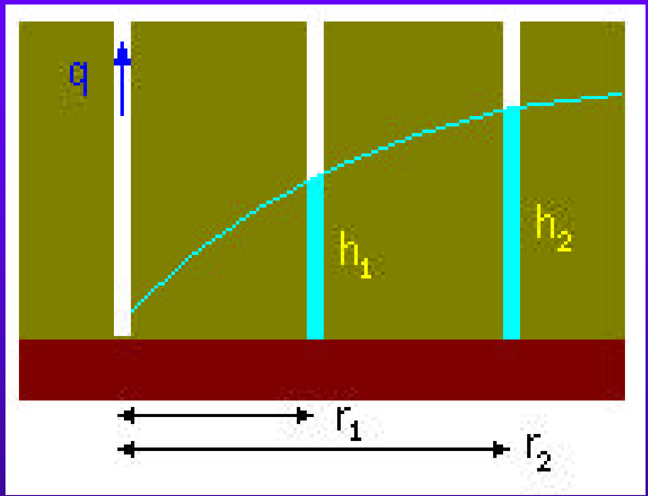
Field Measurement of Permeability

- Pumping test
- Constant head and falling head tests

- Field or in-situ measurement of permeability avoids the difficulties involved in obtaining and setting up undisturbed samples in a permeameter or oedometer and also provides information about bulk permeability, rather than merely the permeability of a small and possibly unrepresentative sample.

Measurement / Permeability Field

Pumping Test - Unconfined



- In a well-pumping test, the steady-state heads h_1 and h_2 in observation boreholes at radii r_1 and r_2 are monitored at flow rate q. If the pumping causes a drawdown in an unconfined (i.e. open surface) soil stratum then

$$k = \frac{q}{p}\frac{\ln(r_2 / r_1)}{(h_2^{\,2} - h_1^{\,2})}$$

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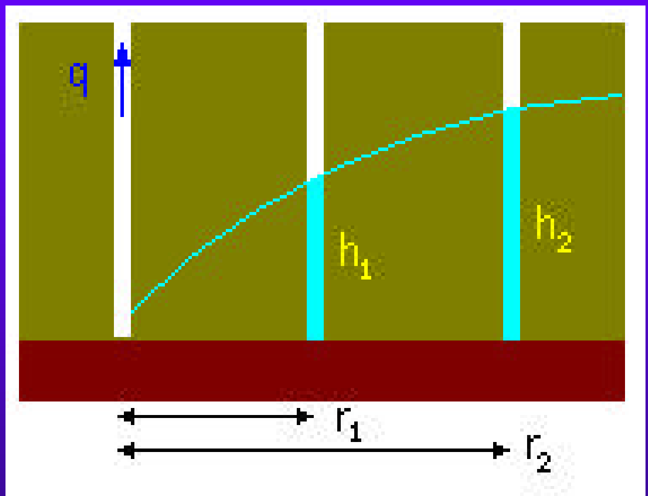
Measurement / Permeability Field

Pumping Test - Confined



- If the soil stratum is confined and of thickness t and remains saturated then

$$k = \frac{q}{2pt}\frac{\ln(r_2 / r_1)}{h_2 - h_1}$$

- Constant head and falling head tests with in-situ piezometers can also be used.

Constant Head & Falling Head Tests

- Field tests equivalent to the laboratory constant head and falling head tests can be performed in which controlled heads or flows are applied to piezometer tips.
- In general, conditions around such piezometers are not ideally cylindrically symmetric or spherically symmetric and an intake factor F (with dimensions of length) is required for each particular geometry.
- Values of the intake factor may be deduced from analytical or numerical studies.

Constant Head & Falling Head Tests

- For a borehole open to its base, of diameter D, and lined to the full depth F=2.75D.
- If the cased hole is through impermeable soil and the base of the casing is at the interface with a permeable stratum F=2D.
- For an intake formed by a cylindrical filter zone of diameter D and length L in an infinite isotropic stratum

$$F = \frac{2pL}{\ln\left[\frac{L}{D} + \sqrt{1 + \left(\frac{L}{D}\right)^2}\right]}$$

for L/D > 4

Measurement / Permeability Field

Constant Head & Falling Head Tests

- Then for a steady state, constant head test in which a flow q is required to maintain a head h:

$$k = \frac{q}{Fh}$$

- For a falling head test in which heads h_1 and h_2 are measured at times t_1 and t_2 in a borehole of area A:

$$k = \frac{A}{F(t_2 - t_1)} \ln(h_2 / h_1)$$

Field Method Based on Seepage Velocity

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