# Soil Mechanics-II
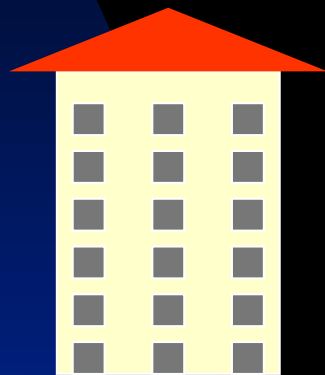## Course Overview and objetices

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ground

*SIVA*

# Soil Mechanics-II

- Objectives:
- To apply principles of soil mechanics to engineering problems pertaining to retaining structures, foundations and embankments.
  - Retaining Structures include Retaining wall, dikes, dams etc.
  - Foundation: Types and design principles
  - Embankments: Filling and cutting etc.

# Course Overview

**1. Permeability**

- Permeability through stratified layer of soils.

- Seepage,

- Quick sand conditions,

- Design of filters.

## 2. Stress **Distribution**

- Westergard and Boussineq's theories.

- Pressure bulb,

- stress distribution diagram on horizontal and vertical planes.

- Stress at a point outside the loaded area. Newmark's influence charts.

- Vertical stresses due to a line and strip loads.

- Fadum's charts, approximate method.

## 3. Consolidation

- Normally consolidated and over-consolidated clays.
- Detennination of pre-consolidation pressure.
- Time-settlement diagrams.
- Settlement analysis.
- Theories of settlement of building.

## 4. Earth Pressures

- Active and passive earth pressure.

- Pressure at rest.

- Coulomb's and Rankine's theories.

- Pencelete method.

-  Coulmann's method.

## 5. Bearing Capacity

- Definition: gross, net, ultimate, safe and allowable bearing capacity.

- Sources of obtaining bearing capacity.

- Presumptive values from Codes.

- Plate loading and penetration tests.

- Terzaghi's theory and analysis.

- Hanson's theory,

- Effect of water table on bearing capacity

**6. Stability of Slopes**

- Types of slopes,

-  Factors affecting stability,

- Methods of analysis: Taylor's stability number method, Swedish circle method.

- Types of failure and remedial measurements.

- **7. Soil Stabilization**

- Basic principles and objectives.

-  Various methods of soil stabilization.

**8. Earthen Dams**

- Types of dams. Components and functions,

- Earth dams.

  - General design consideration and

  - Typical cross-section.

  - General Design Considerations.

**9. Introduction to deep foundations:**

- ◆ Types of piles,

- ◆ Load carrying capacity of piles,

- ◆ Group action, negative skin friction,

- ◆ Pile load test.

**10. Soil Improvement:**

- **Basic principles ,objectives and methods.**

**11. Soil Dynamics:**

- sources of dynamic loading,
- spring-mass-dashpot system,
- application to machine foundations, liquefaction.

# Distribution of Marks:

- **Total Marks: 100**

- **Sessional Marks: 60**
  - ◆ **Assignments: 10**
  - ◆ **Quiz: 10**
  - ◆ **Mid Semester Exam: 20**
  - ◆ **Practical/Viva voce Exam: 20**

- **Final End Semester Exam: 40**

# SOIL PERMEABILITY AND SEEPAGE

- Soils are assemblages of solid particles with interconnected voids where water can flow from a point of **high energy to a point** of **low energy.**

- **The study of flow water through porous media is important for stability analyses of earth retaining structures subjected to seepage force**

- **Permeability:**

- The property of soils that allows water to pass through them at some rate

- The property is a product of the granular nature of the soil, although it can be affected by other factors (such as water bonding in clays). Different soil has different permeabilities.

■ The permeability of soils has a decisive effect on the stability of foundations, seepage loss through embankments of reservoirs, drainage of sub grades, excavation of open cuts in water bearing sand, rate of flow of water into wells and many others.

# Hydraulic Gradient

- As per *Bernoulli's equation,* the total head at any point in water under steady flow condition may be expressed as

- Total head = pressure head + velocity head + elevation head

As the water flows from *A to B, there is an energy loss which is represented by the difference* in the total heads $H_A$, and $H_B$

$$H_A - H_B = \left( Z_A + \frac{p_A}{\gamma_w} + \frac{V_A^2}{2g} \right) - \left( Z_B + \frac{p_B}{\gamma_w} + \frac{V_B^2}{2g} \right) = h$$

where, *pA and pB = pressure heads, VA and VB = velocity, g - acceleration due to gravity, yw = unit* weight of water, *h = loss of head.*

For all practical purposes the velocity head is a small quantity and may be neglected. The loss of head of *h units is effected as the water flows from A to B. The loss of head per unit length of flow* may be expressed as

*i  = h/L*
Where  i  is called the *hydraulic gradient.*

# DARCY'S LAW

- Darcy in 1856 derived an empirical formula for the behavior of flow through saturated soils. He found that the quantity of water *q per sec flowing through a cross-sectional area of soil under* hydraulic gradient *i* can be expressed by the formula.

- *q = kiA*

- or the velocity of flow can be written as *v = ki*

  - where *k is termed the hydraulic conductivity (or coefficient of permeability)with units of velocity.*

  - *A* is the cross-sectional area of soil normal to the direction of flow

  - It is found that, on the basis of extensive investigations made since Darcy introduced his law in 1856, this law is valid strictly for fine grained types of soils.

# METHODS OF DETERMINATION OF HYDRAULIC CONDUCTIVITY OF SOILS

- Methods that are in common use for determining the coefficient of permeability *k can be classified* under laboratory and field methods.

- Laboratory methods:
  - Constant head permeability method
  - Falling head permeability method

- Field methods:
  - Pumping tests
  - Bore hole tests

- Indirect Method:
  - Empirical correlations

# CONSTANT HEAD PERMEABILITY TEST

- The sample of length *L and cross-sectional area A is* subjected to a head *h which is constant during the progress of a test. A test is performed by allowing* water to flow through the sample and measuring the quantity of discharge *Q in time t.*

$$Q = k\frac{h}{L}At$$

$$\text{or} \quad k = \frac{QL}{hAt}$$



- The constant head permeameter test is more suited for coarse grained soils such as gravelly sand and coarse and medium sand.
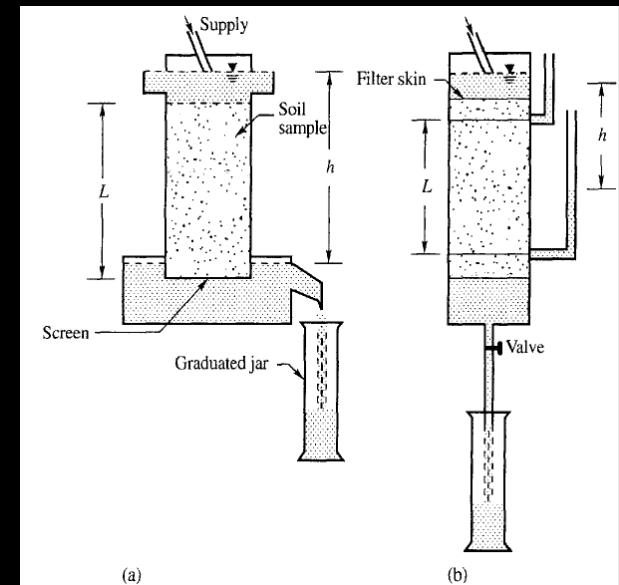
# Problem

- A constant head permeability test was carried out on a cylindrical sample of sand 4 in. in diameter and 6 in. in height. 10 in3 of water was collected in 1.75 min, under a head of 12 in. Compute the hydraulic conductivity in ft/year and the velocity of flow in ft/sec.

# HYDRAULIC CONDUCTIVITY IN STRATIFIED LAYERS OF SOILS

- Hydraulic conductivity of a disturbed sample may be different from that of the undisturbed sample even though the void ratio is the same.

- This may be due to a change in the structure or due to the stratification of the undisturbed soil or a combination of both of these factors.

- Two fine-grained soils at the same void ratio, one dispersed and the other flocculated, will exhibit different permeabilities.

- The average permeability of stratified soil can be computed if the permeabilities of each layer are determined in the laboratory.

# Flow in the Horizontal Direction

■ When the flow is in the horizontal direction the hydraulic gradient i remains the same for all the layers. Let *v1, V2, ..., Vn be the discharge velocities in the corresponding strata then*

$$Q = kiZ = (v_1 z_1 + v_2 z_2 + \cdots + v_n z_n) \quad = (k_1 i z_1 + k_2 i z_2 + \cdots + k_n i z_n)$$

Therefore,

$$k_h = \frac{1}{Z}(k_1 z_1 + k_2 z_2 + \cdots + k_n z_n)$$

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# Hydraulic conductivity of some soils

## (after Casagrande and Fadum, 1939)

| $k$ (cm/sec) | Soils type | Drainage conditions |
|---|---|---|
| $10^1$ to $10^2$ | Clean gravels | Good |
| $10^1$ | Clean sand | Good |
| $10^{-1}$ to $10^{-4}$ | Clean sand and gravel mixtures | Good |
| $10^{-5}$ | Very fine sand | Poor |
| $10^{-6}$ | Silt | Poor |
| $10^{-7}$ to $10^{-9}$ | Clay soils | Practically impervious |

Coefficient of Permeability $k$ (m/s)

$10^0$   $10^{-1}$   $10^{-2}$   $10^{-3}$   $10^{-4}$   $10^{-5}$   $10^{-6}$   $10^{-7}$   $10^{-8}$   $10^{-9}$   $10^{-10}$   $10^{-11}$

| Drainage | Good | Poor | Practically Impervious |
|---|---|---|---|
| Soil types | Clean gravel / Clean sands, clean sand and gravel mixtures | Very fine sands, organic and inorganic silts, mixtures of sand silt and clay, glacial till, stratified clay deposits, etc. | "Impervious" soils, e.g., homogeneous clays below zone of weathering |

"Impervious" soils modified by effects of vegetation and weathering

# Flow in the Vertical Direction
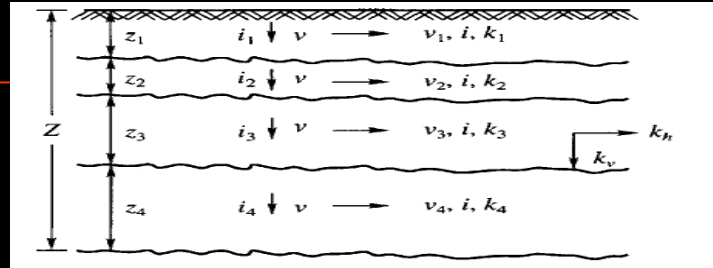


When flow is in the vertical direction, the hydraulic gradients for each of the layers are different. Let these be denoted by $i_1, i_{2.......} i_n$. Let h be the total loss of head as the water flows from the top layer to the bottom through a distance of Z. The average hydraulic gradient is h/Z. The principle of continuity of flow requires that the downward velocity be the same in each layer. Therefore,

$$v = k_v \frac{h}{Z} = k_1 i_1 = k_2 i_2 = \cdots = k_n i_n$$

If $h_1, h_2, h_3.....h_n$ are the head losses in each of the layers, we have
$h = h_{1+} h_{2+} h_{3+}.....+h_n$

*Solving the above:*

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

It should be noted that in all stratified layers of soils the horizontal permeability is generally greater than the vertical permeability

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# EMPIRICAL CORRELATIONS FOR HYDRAULIC CONDUCTIVITY

- **Granular Soils:** **Velocity of flow:**

$$v_a = \frac{q}{a} = \frac{\gamma_w R_i^2}{8\mu} = \frac{\gamma_w i d^2}{32\mu}$$

  - where, $R$ = *radius of a capillary tube of sectional area a,*

  -  $q$ = *discharge through the tube,*

  - $v$ = *average* velocity through the tube,

  - $\mu$ = *coefficient of viscosity.*

- Extensive investigations of filter sands by Hazen (1892) led to the equation $k(m/s) = CD_e{}^2$

  - where De is a characteristic effective grain size which was determined to be equal to D10 (10% size).

# The essential points are:

1. The flow of water through soils is governed by Darcy's law, which states that the average flow velocity is proportional to the hydraulic gradient.

2. The proportionality coefficient in Darcy's law is called the coefficient of permeability or hydraulic conductivity, k.

3. The value of k is influenced by the void ratio, particle size distribution, and the wholeness of the soil mass.

4. Homogeneous clays are practically impervious while sands and gravels are pervious.

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# Effects of Seepage

The interaction between soils and percolating water has an important influence on:

- The design of foundations and earth slopes,
- The quantity of water that will be lost by percolation through a dam or its subsoil.

- As water flows through soil it exerts a frictional drag on the soil particles resulting in head losses. The frictional drag is called seepage force in soil mechanics.

- It is often convenient to define seepage as the seepage force per unit volume (it has units similar to unit weight). which we will denoted $j_s$. If the head loss over a flow distance, *L. is* $\Delta h$ *the seepage force is given as:* $j_s = \dfrac{\Delta h \, \gamma_w}{L} = i \gamma_w$
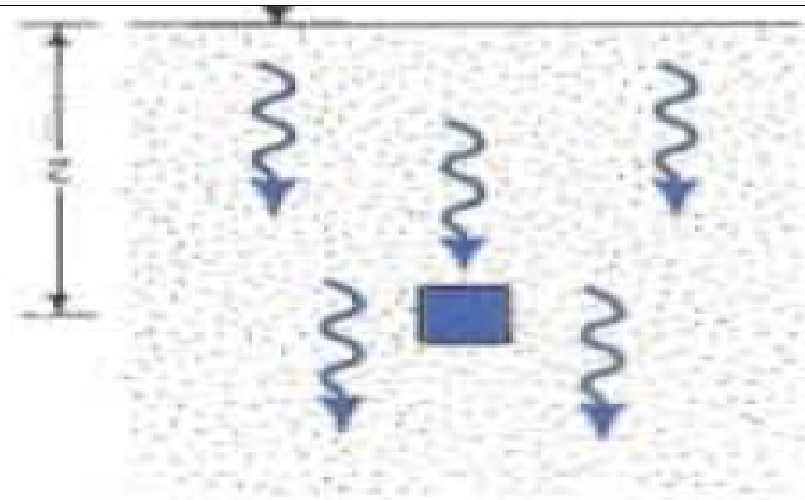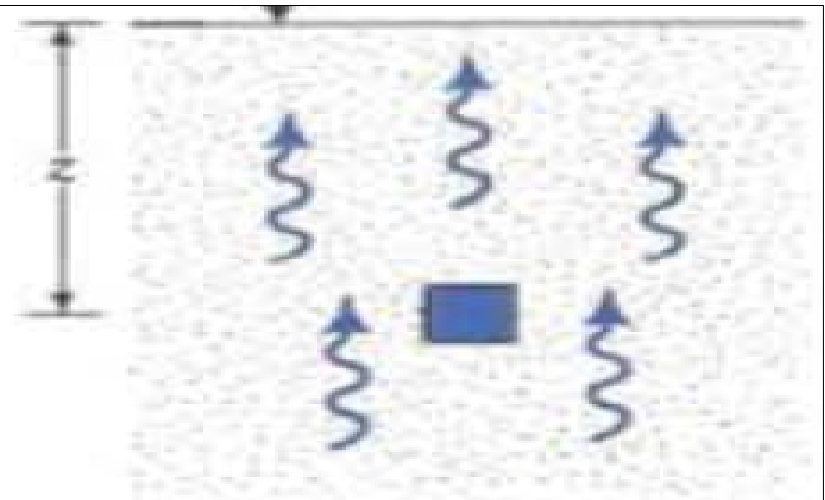
(a) Downward seepage     (b) Upward seepage

- If the seepage direction is downwards, then the resultant seepage stresses are in the same direction as the gravitational effective stresses. $\sigma'_z = \gamma'z + iz\gamma_w = \gamma'z + j_sz$

- In case of upwards seepage, they are in opposite direction and $\sigma'_z = \gamma'z - iz\gamma_w = \gamma'z - j_sz$

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# Effect of seepage on structures

Foundation failures due to 'piping' are quite common.

Piping is a phenomenon by which the soil on the downstream sides of some hydraulic structures get lifted up due to excess pressure of water. The pressure that is exerted on the soil due to the seepage of water is called the seepage force or pressure.
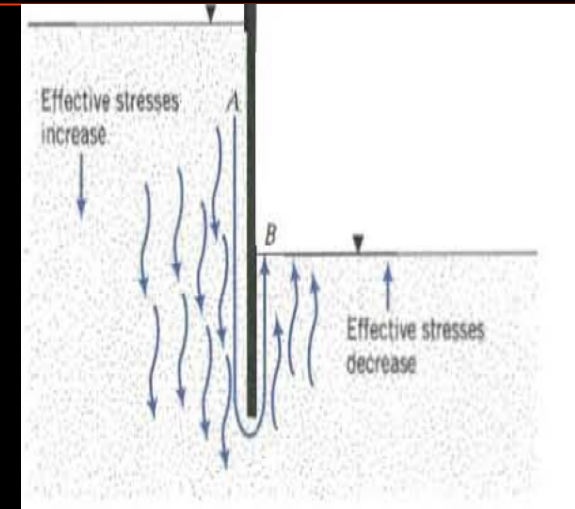
Effects of seepage on the effective stresses near a retaining wall.

# Effects of Seepage Cont'd

In the stability of slopes, the seepage force is a very important factor. Shear strengths of soils are reduced due to the development of neutral stress or pore pressures.

A detailed understanding of the hydraulic conditions is therefore essential for a satisfactory design of structures. The computation of seepage loss under or through a dam, the uplift pressures caused by the water on the base of a concrete dam and the effect of seepage on the stability of earth slopes can be studied by constructing flow nets.

# Effect of seepage on structures

- Water is seeping downward through a soil layer a in Fig.

  Two piezometers (A and B) located 2 m apart showed a head loss of 0.2 m. Calculate the resultant vertical effective stress for a soil element at a depth of 6 m as shown in Fig.
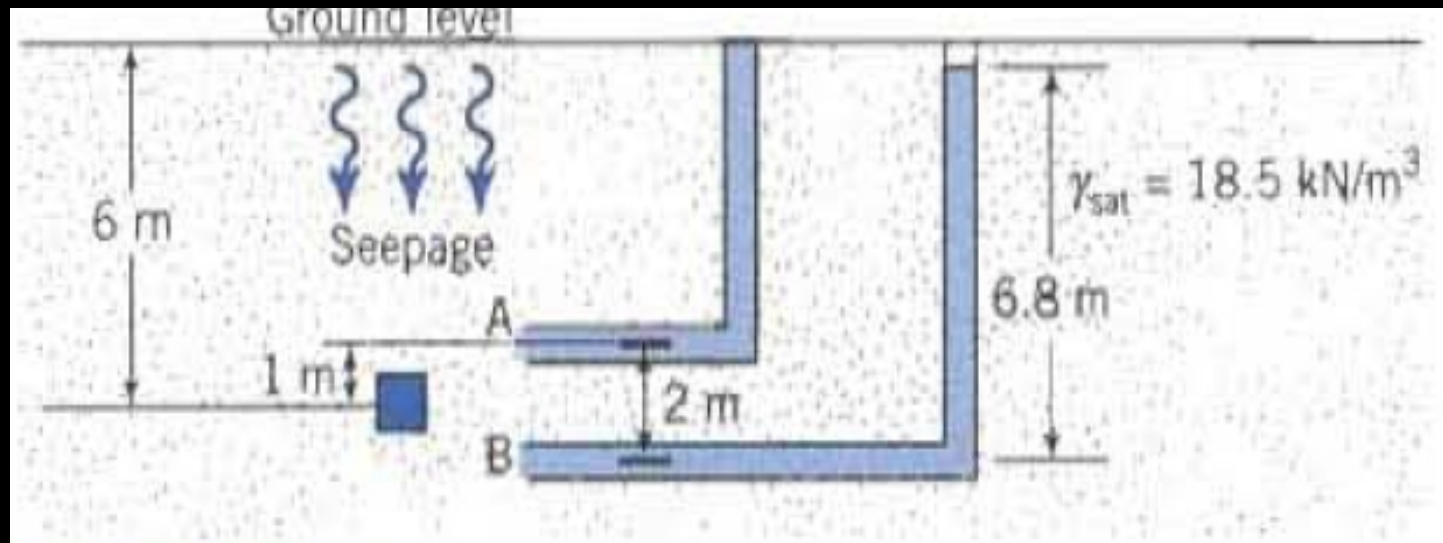
# Quicksand Conditions in soil



Stress diagrams
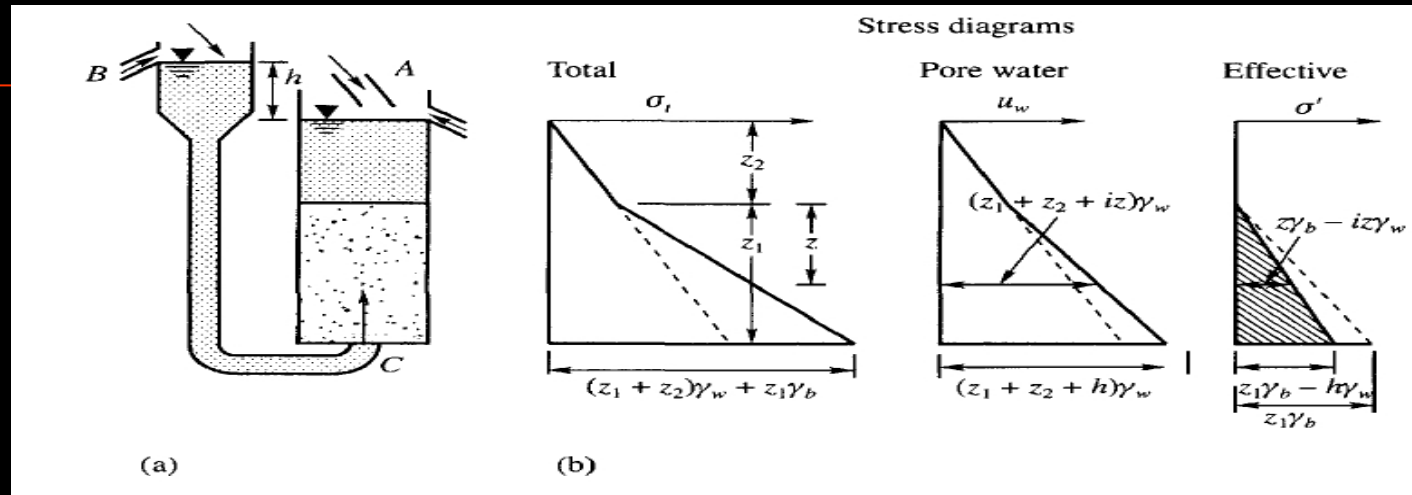
- The water surface in container B is kept above that of A by h units. This arrangement permits water to flow upwards through the sample in container A. The total piezometric or the pore water head at the bottom of the sample is given by $(z_1+z_2+h)$

- Therefore, the pore water pressure $u_c$ at the bottom of the sample is $$u_C = (z_1 + z_2 + h)\gamma_w$$

- The total pressure head at the bottom of the sample is $$\sigma_C = (z_1 + z_2)\gamma_w + z_1\gamma_b$$

- The effective pressure at the bottom of sample is, therefore

$$\sigma'_C = \sigma_C - u_C = (z_1 + z_2)\gamma_w + z_1\gamma_b - (z_1 + z_2 + h)\gamma_w = z_1\gamma_b - h\gamma_w$$

- The general equation for effective pressure at any depth Z is given as: $\sigma'_z = z\gamma_b - iz\gamma_w$ indicates that there is a decrease in the effective pressure due to upward flow of water.

- At any depth z, $z\gamma_b$ *is the pressure of the submerged soil acting downward and* $iz\gamma_w$ is the seepage pressure acting upward. The effective pressure becomes zero when $\sigma'_z = z\gamma_b - iz\gamma_w = 0 \quad \text{or} \quad i = i_c = \dfrac{\gamma_b}{\gamma_w}$

- It indicates that the effective pressure reduces to zero when the hydraulic gradient attains a maximum value which is equal to the ratio of the submerged unit weight of soil and the unit weight of water.

- This gradient is known as the *critical hydraulic gradient $i_c$. In such* cases, cohesion less soils lose all of their shear strength and bearing capacity and a visible agitation of soil grains is observed. This phenomenon is known as *boiling or a quick sand condition*

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- We know that

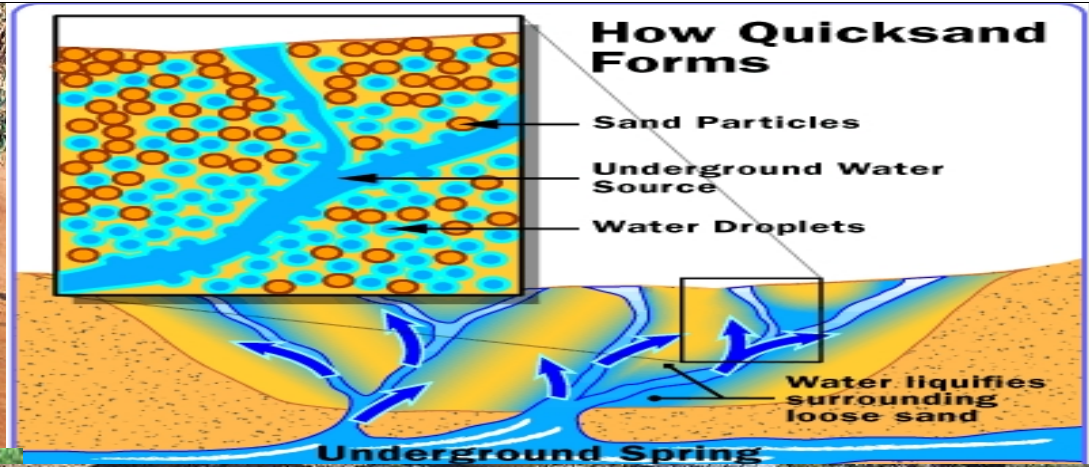$$\gamma_b = \frac{\gamma_w(G_s - 1)}{1+e}, \quad \text{we have}$$

- Hence

$$i_c = \frac{G_s - 1}{1+e}$$

- The critical gradient of natural granular soil deposits can be calculated if the void ratios of the deposits are known. For all practical purposes the specific gravity of granular materials can be assumed as equal to 2.65.
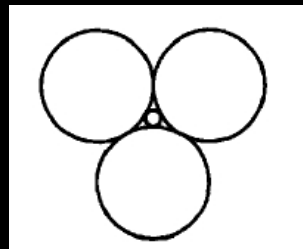
- Critical hydraulic gradients of granular soils

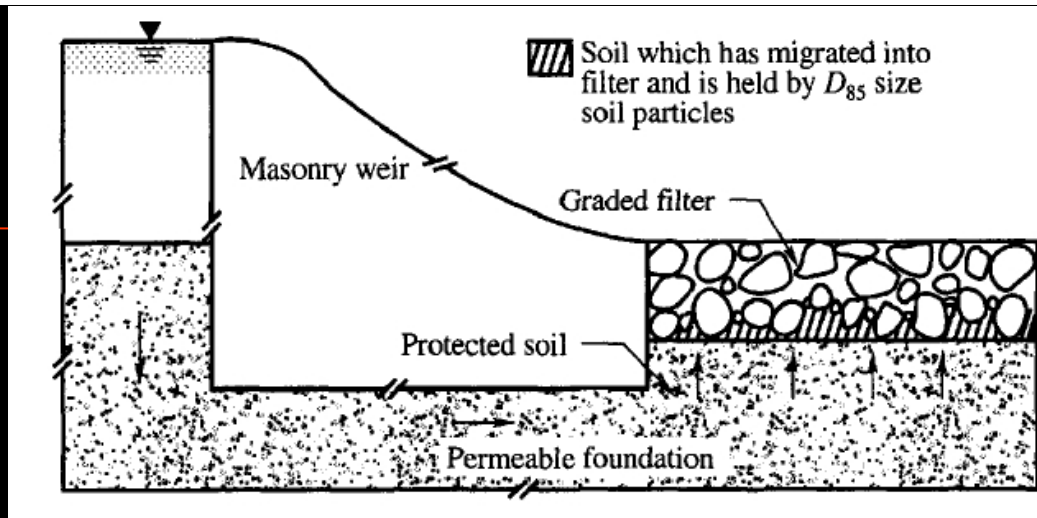| Soil No. | Void ratio | $i_c$ |
|----------|------------|-------|
| 1 | 0.5 | 1.10 |
| 2 | 0.6 | 1.03 |
| 3 | 0.7 | 0.97 |
| 4 | 0.8 | 0.92 |
| 5 | 1.0 | 0.83 |

- Quick conditions are common in excavations below the ground water table. This can be prevented by lowering the ground water elevation by pumping before excavation.

- Quick conditions occur most often in fine sands or silts and cannot occur in coarse soils.

- The larger the particle size, the greater is the porosity. To maintain a critical gradient of unity, the velocity at which water must be supplied at the point of inflow varies as the permeability.

- Therefore a quick condition cannot occur in a coarse soil unless a large quantity of water can be supplied.

## How Quicksand Forms

- Sand Particles
- Underground Water Source
- Water Droplets

Water liquifies surrounding loose sand

Underground Spring

WARNING
NO ONE ALLOWED
BEYOND THIS POINT
SOFT AND UNSTABLE
SOIL HAS BEEN REPORTED
SEMINOLE COUNTY
PARKS AND RECREATION
407-788-0405

HONDA

# Filter Requirements to Control Piping.

- Filter drains are required on the downstream sides of hydraulic structures and around drainage pipes.

- A properly graded filter prevents the erosion of soil in contact with it due to seepage forces.

- To prevent the movement of erodible soils into or through filters, the pore spaces between the filter particles should be small enough to hold some of the protected materials in place.

- Taylor (1948) shows that if three perfect spheres have diameters greater than 6.5 times the diameter of a small sphere, the small spheres can move through the larger as shown in Fig

Soil which has migrated into filter and is held by $D_{85}$ size soil particles

Masonry weir

Graded filter

Protected soil

Permeable foundation

- Soils and aggregates are always composed of ranges of particle sizes, and if pore spaces in filters are small enough to hold the 85 per cent size (D85) of the protected soil in place, the finer particles will also be held in place as shown in Fig.

# Problem

A sand deposit contains three distinct horizontal layers of equal thickness (Fig below.). The hydraulic conductivity of the upper and lower layers is $10^3$ cm/sec and that of the middle is $10^2$ cm/sec. What are the equivalent values of the horizontal and vertical hydraulic conductivities of the three layers, and what is their ratio?
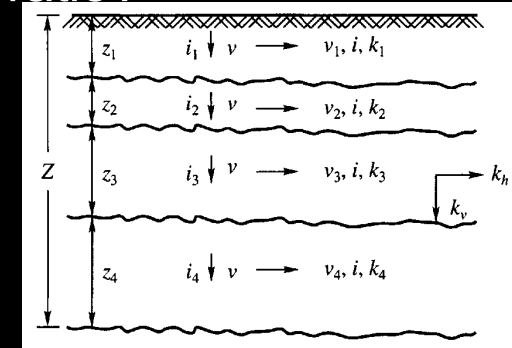
$$k_h = \frac{1}{Z}(k_1 z_1 + k_2 z_2 + k_3 z_3) = \frac{1}{3}(k_1 + k_2 + k_3) \quad \text{since} \quad z_1 = z_2 = z_3$$

$$k_h = \frac{1}{3}(10^{-3} + 10^{-2} + 10^{-3}) = \frac{1}{3}(2 \times 10^{-3} + 10^{-2}) = 4 \times 10^{-3} \text{ cm/sec}$$

*Vertical flow*

$$k_v = \frac{Z}{\dfrac{z_1}{k_1} + \dfrac{z_2}{k_2} + \dfrac{z_3}{k_3}} = \frac{3}{\dfrac{1}{k_1} + \dfrac{1}{k_2} + \dfrac{1}{k_3}} = \frac{3}{\dfrac{2}{k_1} + \dfrac{1}{k_2}}$$

$$= \frac{3 k_1 k_2}{2 k_2 + k_1} = \frac{3 \times 10^{-3} \times 10^{-2}}{2 \times 10^{-2} + 10^{-3}} = 1.43 \times 10^{-3} \text{ cm/sec}$$

$$\frac{k_h}{k_v} = \frac{4 \times 10^{-3}}{1.43 \times 10^{-3}} = 2.8$$