PERMEABILITY & SEEPAGE

Introduction

- Soil is a particular material consisting of solid grains and pores in between i.e. it is a porous media.
- The void in a soil mass are interconnected, under saturated conditions are filled with water and allow water to pass through them when subjected to differential head.
- **Permeability is the measure of the ease with which water can flows through the soils and rock.**
- A soil is said to be pervious if it offer minimum resistance to the flow of water.

Scope of Permeability Study

- The knowledge of permeability of soil is important for the following:

1. Evaluating the amount of seepage through or beneath dams and levees and into water wells.
2. Evaluating uplift or seepage pressure beneath hydraulic structures for stability analyses.
3. Providing control of seepage velocities, so that, fine particles are not eroded from the soil mass.
4. Rate of settlement (consolidation) studies where volume changes occur as water is expelled from the voids.
5. Evaluating the yield from wells as a source of water supply.
6. Designing the highways sub-drainage system.
7. Designing sub-drainage for water logging and salinity control.
8. Ground water lowering (Dewatering).
9. Design of landfill sites.

Darcy's Law Of Flow Through Soil

- According to Darcy's law, the velocity of flow (v) through soil is directly proportional to the hydraulic gradient (i).

$$v \infty i$$

$$v = k.i$$

$$v = k \frac{\mathrm{V}h}{\mathrm{V}L}$$

- Where:
- K = Constant of proportionality or Co – Efficient of Permeability
- Vh & V L = Head loss or difference in pressure head over a flow path of length VL
- Since

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

$$q = k\ i\ A$$

$$k = \frac{q}{i\ A}$$

Coefficient of Permeability may be defined as: Rate of flow per unit area of soil under unit Hydraulic Gradient. "i" is unit less, "k" has velocity unit

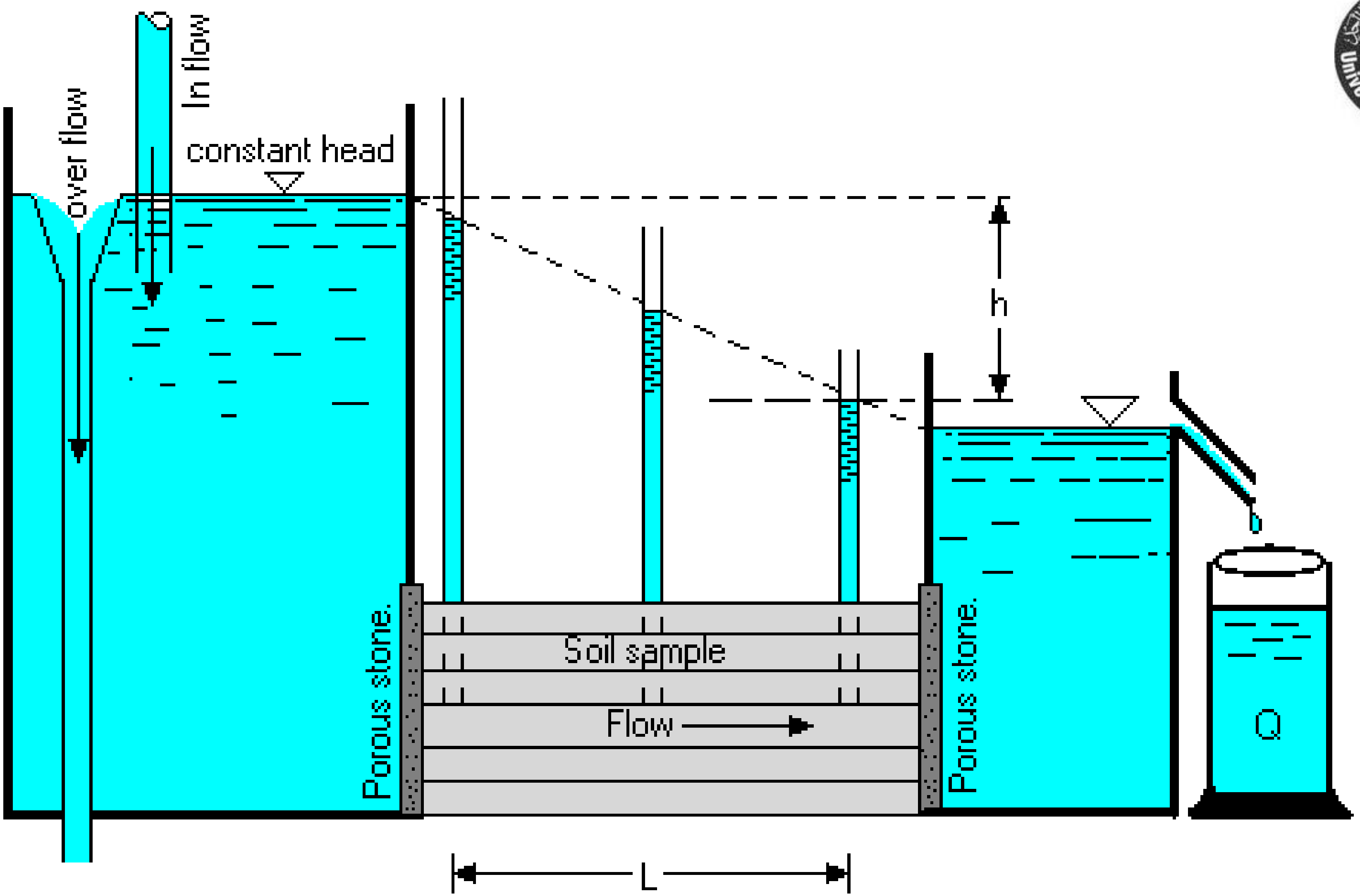


Fig: Loss of head, due to flow of water through soil.

Assumption of Darcy Law

1. The continuity of the flow condition in the soil mass must be satisfied with no velocity changes taking place during the flow.
2. The flow must be with voids saturated through out the flow and no compressible air present in the voids.
3. The flow must be in a steady state. i.e., the velocity of flow must be constant at any particular section with respect to time.
4. The flow must be laminar.

Factors Effecting Permeability

- Following are the factors that affect the permeability

1. Soil grain size
2. Properties of Liquid
3. Void ratio
4. Soil Structure
5. Degree of saturation
6. Entrapped air within soil

- **Soil grain size**
- Permeability depends mainly on the size of voids, which in turn depends on the size, shape and state of packing of the soil particles.
- Permeability appears to be proportional to the square of the effective grain size.

$$K \infty (D10)^2 \qquad \text{(Cm/Sec)}$$

- For sandy soil A. Hazen developed the following empirical equation.

$$K \infty C.(D10)^2$$

Factors Effecting Permeability

- Where,
- D_{10}, is the effective grain size in centimeters.
- K, is coefficient of permeability in centimeters per second.
- C, is a constant, according to Hazen, it varies from about 40 to 150 expressed as 1/cm.sec.

- Table: Values of coefficient C for different grades of sand.

C	Sand
40-80	Very fine, well graded or with appreciable fines
80-120	Medium coarse, poorly graded; clean, coarse but
120-150	Well graded very coarse, very poorly graded, gravelly, clean.

- Generally for sandy soil $K = 100.(D10)^2$ (C.G.S. units)

Factors Effecting Permeability

- **Properties of Soil**
- Permeability varies with density and viscosity of fluid flowing through the soil
- **a. Density of the fluid:**

$$K \infty \gamma$$

- Where, γ = Density of fluid.

- **b. Viscosity of the fluid:**

$$K \infty 1/\mu$$

- Where: μ = Absolute viscosity of fluid.
- Since viscosity changes with temperature following equation may be used to find 'K_1' for any temp.

K is co-efficient of permeability at standard temperature commonly 20^{o}C

K_1 is the co-efficient of permeability at any test temp.
μ is viscosity at standard temperature i.e., 20^{o}C.
μ_1 is viscosity at test temperature.

$$\frac{K}{K_1} = \frac{\mu_1}{\mu}$$

Factors Effecting Permeability

- **Void Ratio**
- a. For cohesive soil –

$$K \propto e^2$$

- b. For non cohesive soils –

$$K \propto \frac{e^3}{1+e}$$

- **Soil Structure**
- Stratified soil usually has greater permeability in the horizontal direction than in the vertical direction.
- **Degree of Saturation**
- Increase in the degree of saturation increases permeability.

$$K \propto S$$

Factors Effecting Permeability

- **Entrapped Air**
- Entrapped air/gases reduce the degree of saturation and permeability.
- Entrapped air/gases may be due to,
  - Chemical decomposition of soil.
  - Disintegration of rock and animal remains.
  - Dissolved air.

Seepage Velocity and Superficial Velocity

- Water moves through the soil pores.
- Area of flow is actually, the cumulative pore area, which is difficult to determine.
- Gross cross-sectional area of the soil cylinder is generally used for common permeability/ seepage calculations.
- Velocity in this case is known as superficial velocity (V_s) or approach velocity (V_a) or discharge velocity (V_d).
- Using the area of voids, velocity is known as seepage velocity. It is the actual velocity of flow through soil (pores)
- However for practical problems term velocity of flow is used which is based on total cross-sectional area of soil.
- Consider a soil Porosity

$$n = \frac{A_v}{A}$$

Seepage Velocity and Superficial Velocity

- For a given flow rate

$$q = V.A$$

- Where:
- A = Cross sectional area of the soil perpendicular to the flow direction
- A_v = Cross sectional area of the voids between the solid grains of soil

$$q = A_v.V_s = A.V$$

$$V_s = \left(\frac{A}{A_v}\right).V$$

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

$$V_s = \left(\frac{1+e}{e}\right).V$$

- Since “n” is always less than 1, $V_{s\ (\text{Seepage Velocity})}$ is always greater than V

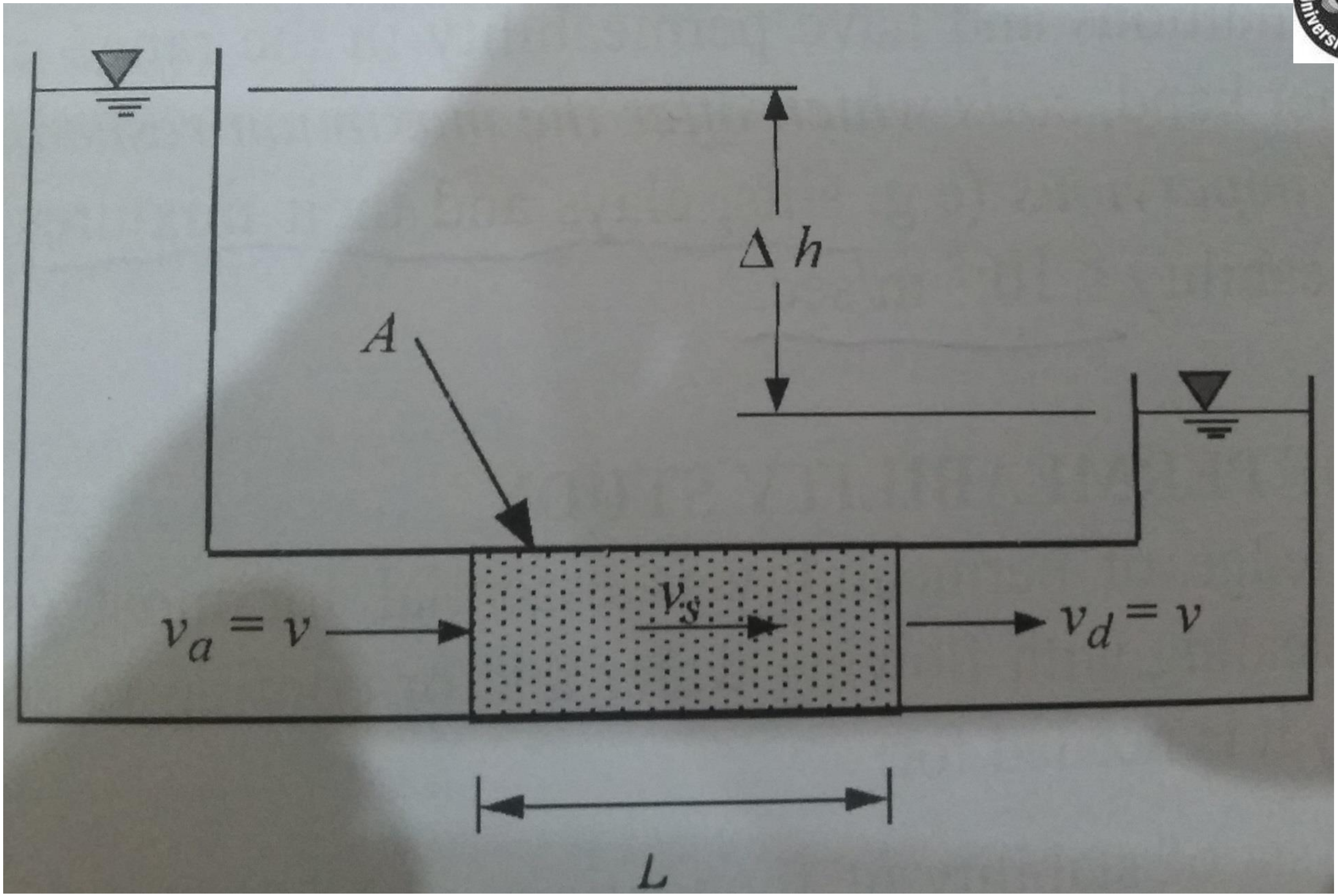


Fig: Superficial and seepage velocity in uniform flow

Measurement of Permeability

- Methods of measuring permeability is divided in two major groups

1. Direct Method **2. Indirect Method**

- **Indirect method**
  1. (Allen Hazen Method… Already Discussed)
  2. Permeability from consolidation test (Not important to discuss)
- **Direct Method**
  - **Laboratory Method**
    - Constant Head Permeameter.
    - Variable Head Permeameter.
  - **Field Method**
  1. Bore Hole Permeability Test
  2. Pumping Test (1. Confined Flow 2. Unconfined Flow)
  3. Packer's method also known as pressure head method
     - ❑ Bore Hole Permeability Test
       - ❖ Constant Head Method
       - ❖ Variable Head Method
         - ➢ Falling Water Level Method
         - ➢ Rising Water Level Method

Measurement of Permeability

- **Constant Permeameter**
- Following Figure represents a diagrammatic sketch of a constant head permeameter used for the determination of "k" for coarse grained soil in the laboratory.
- In this test water under a constant head "h" is allowed to percolate through a soil sample of length "L" and cross sectional area "A" until a steady state flow condition is reached. The quantity of water "Q" seeping through a sample in time "t" is then collected in a graduated cylinder and "k" is calculated
- Where:
- A = Cross-sectional area of soil sample
- L = Length of sample
- h = drop in head between the two piezometers
- l = distance between piezometers
- Vol. = Volume collected in time T.
- T = time of test

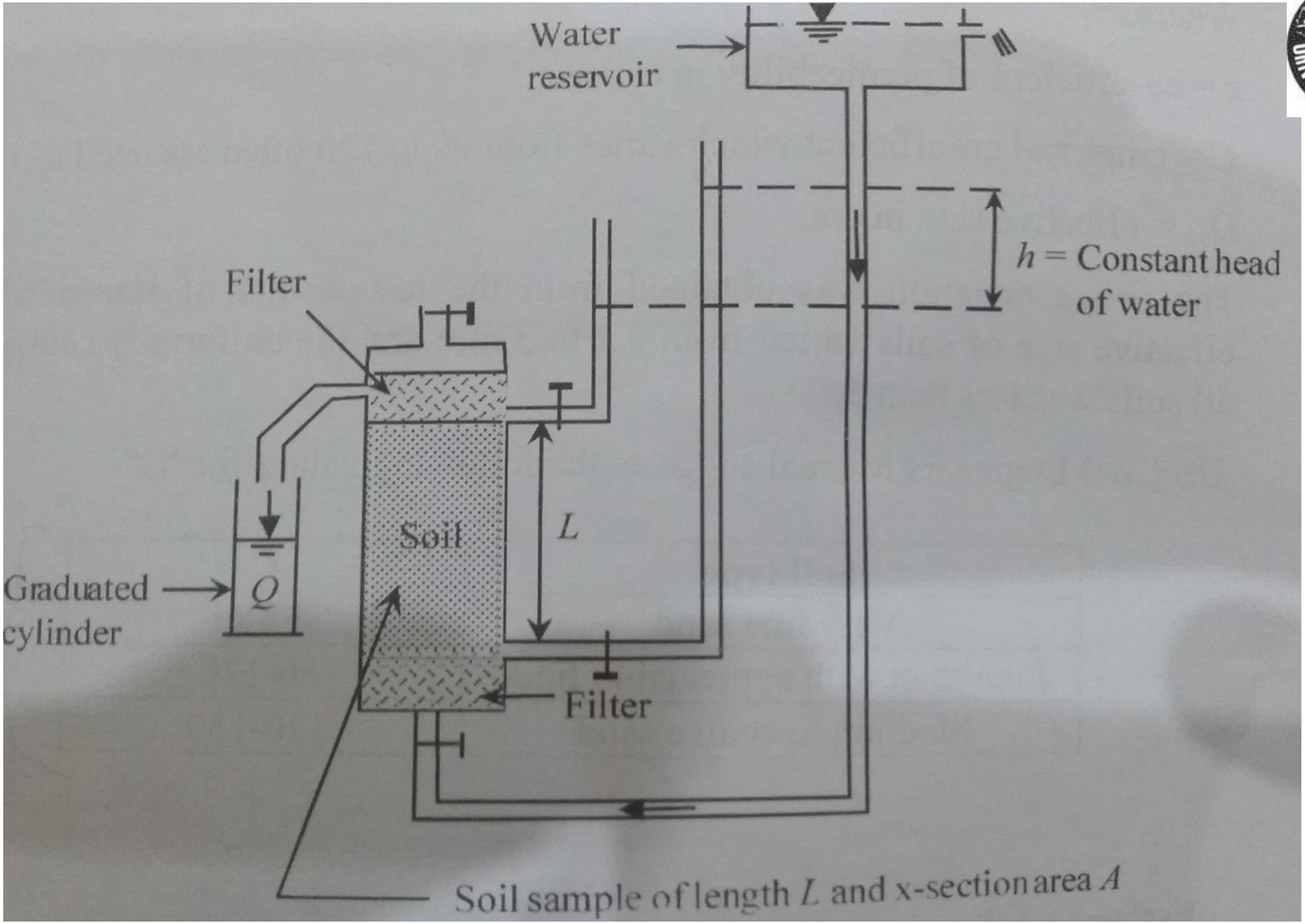


Fig: Constant Head Permeameter

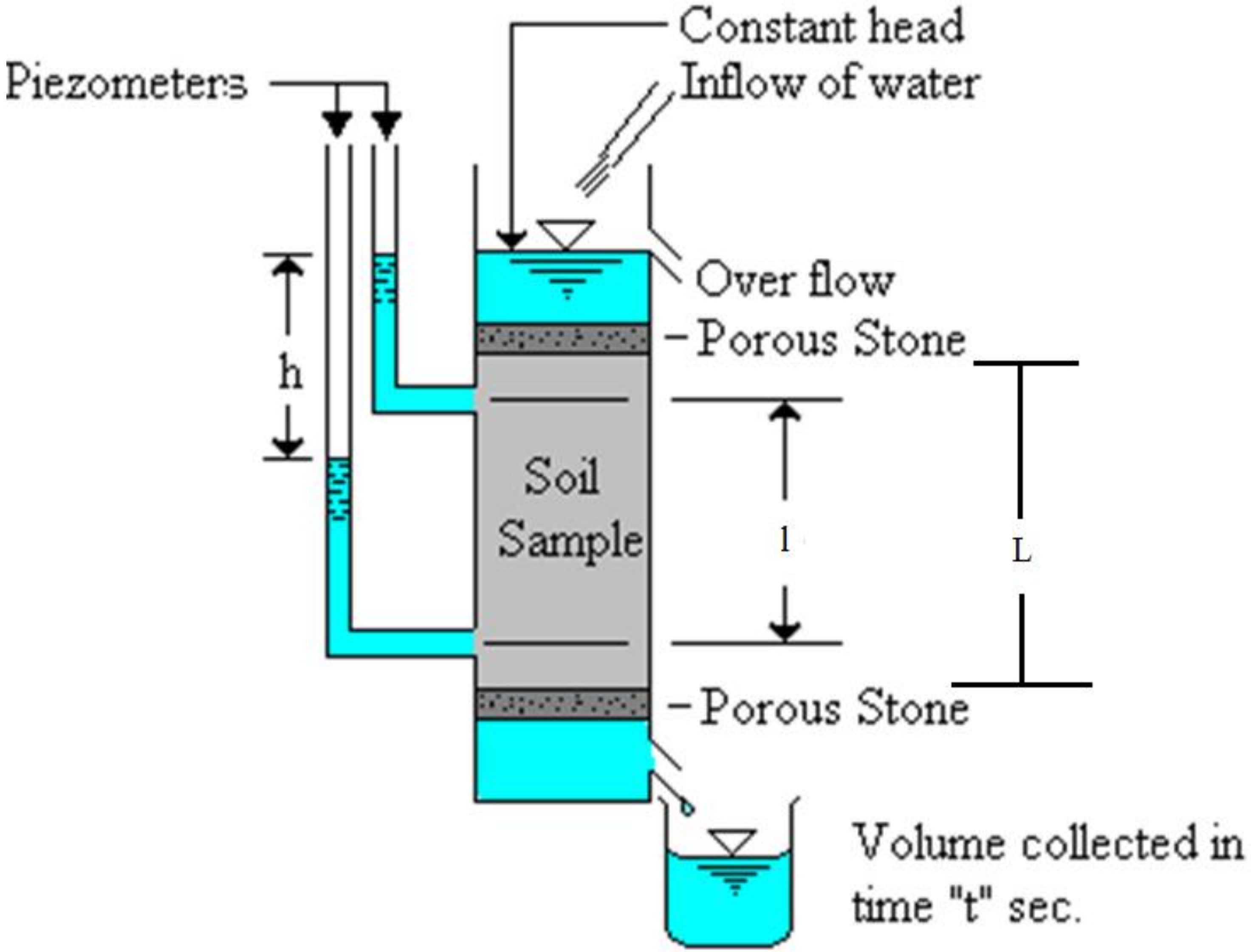


Fig: Constant Head Permeameter

Measurement of Permeability

- According to DARCY'S law,

$$v \propto i$$

$$v = k.i$$

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

$$V = K \times \frac{h}{L}$$

- Multiplying by "A" on Both side

$$AV = KA\frac{h}{L}$$

$$Q = KA\frac{h}{L}$$

$$Since \quad Q = \frac{Vol.}{Time}$$

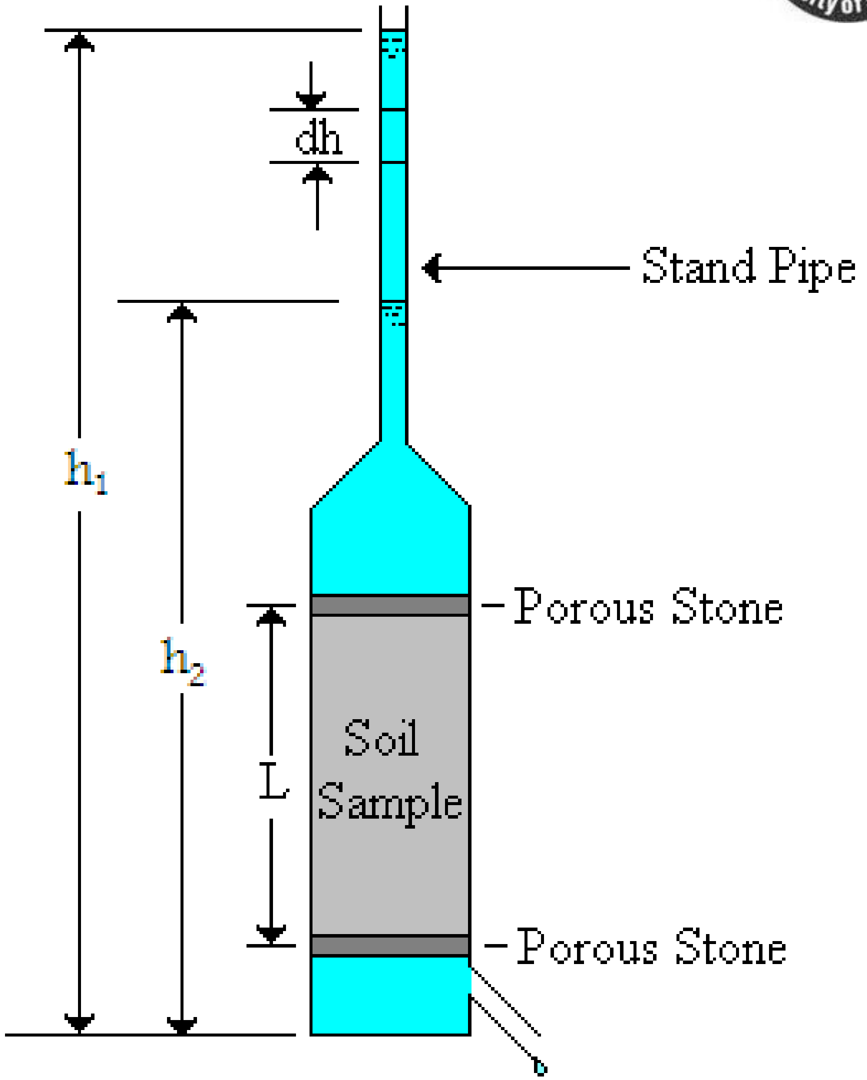
$$\frac{Vol.}{T} = KA\frac{h}{L}$$

$$K = \frac{Vol. \times L}{AhT} \quad k = \frac{Q.L}{A.h}$$

In highly impervious soil, quantity of flow is small and accurate measurement of its value is not possible. Therefore the constant head permeameter is mainly applicable to relatively previous soil such as sands and gravel.

Measurement of Permeability

- **Variable Head Permeameter**
- It is used to find the permeability of relatively less permeable soil (fine grained soil, silt and clay).
- it is also known as falling head permeameter.
- Fig Show Variable Head Permeameter
- Where:
- a = cross-sectional area of the stand pipe.
- A = cross-sectional area of soil sample.
- L = Length of sample.
- h_1= Initial head at time t_1.
- h_2= Final head at time t_2.
- dh = the drop in head in time dt



Measurement of Permeability

- -ev sign indicates head decreases with time

$$Q = -a.\frac{dh}{dt}$$

$$-adh = k.A.\frac{h}{L}.dt$$

$$dt = -\frac{aL}{Ak}.\frac{dh}{h}$$

- Integrating between 0 to "t" and h_1 to h_2

$$-t = \frac{-aL}{Ak}.\ln\frac{h_1}{h_2}$$

$$k = 2.3(\frac{a}{A}).\frac{L}{t}.Log.\frac{h_1}{h_2}$$

Measurement of Permeability

- **Field Pumping Test**
- The most reliable value of “k” of pervious soils below GWT can be found by performing pumping test.
- This test is very costly and time consuming and usually justified only for large projects such as dams, large building complex or bridge.
- “k” can be calculated for
- Unconfined Flow
- Confined Flow
- **Unconfined Flow**
- Following Fig represents a field pumping set up for unconfined flow case.
- In this test water is pumped out continuously at a uniform rate from the main well till the water level in the observation wells and in the main well remain constant for a considerable time.
- Under this condition, the flow is stabilized and the inflow and the outflow become equal.
- The draw down resulted from continuous pumping is known as “ Cone of Depression (R)

Measurement of Permeability

- The maximum draw down (drawdown is the change in hydraulic hea observed at a well in an aquifer, typically due to pumping a well as part of an aquifer test or well test) is in the main well and gradually dies out forming a theoretical circle around the main well. This circle is Known as the circle of influence, and radius of which is known as radius of influence of depression cone.
- **Test Assumptions**
- The soil is homogeneous
- The flow towards the main well is assumed to be steady, radial, horizontal and laminar
- The velocity in the horizontal direction is independent of depth
- GWT is assumed to be horizontal
- The hydraulic gradient at a point along the depression curve is equal to the slope of the curve

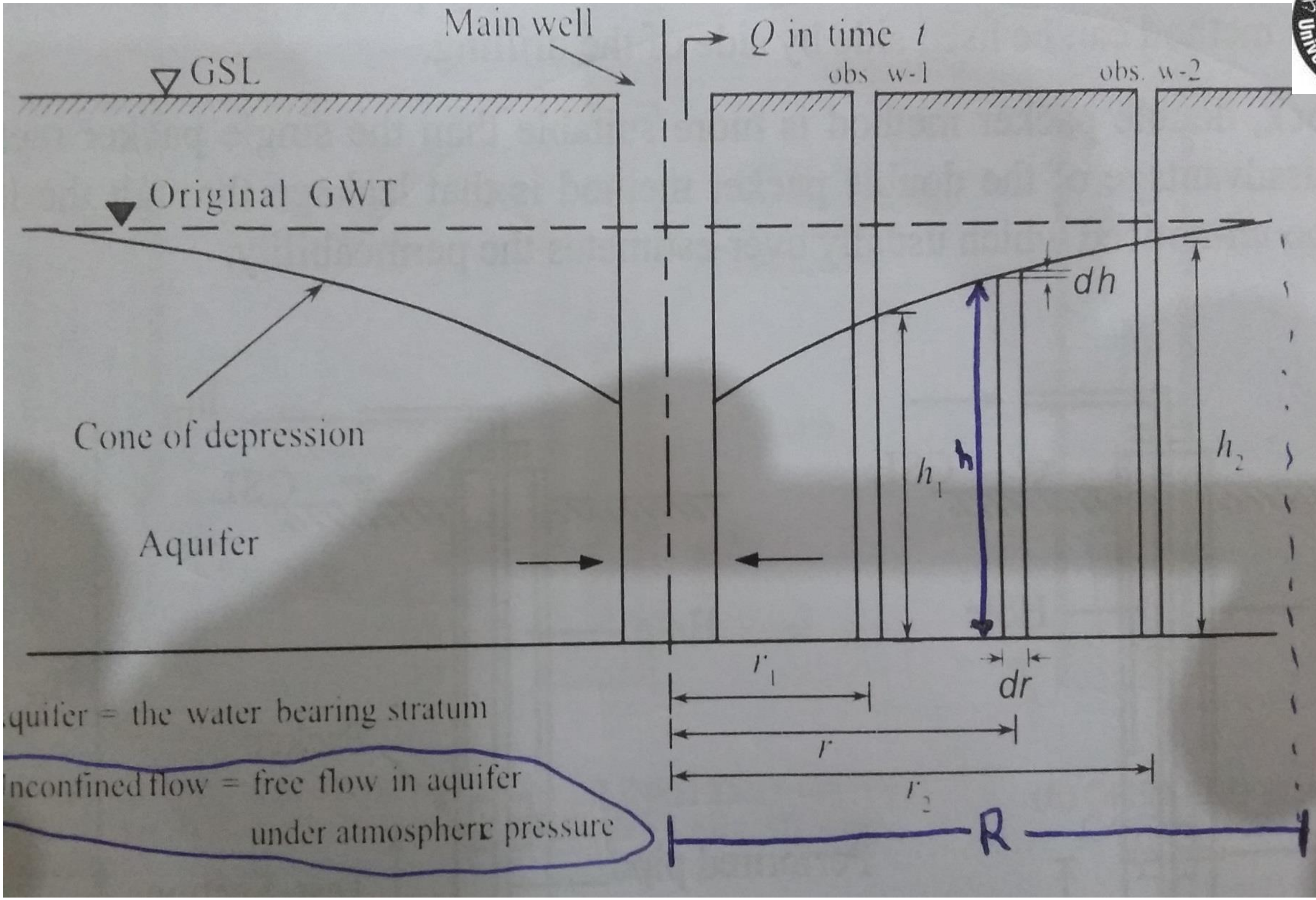


Fig: Field pumping Test for unconfined Flow

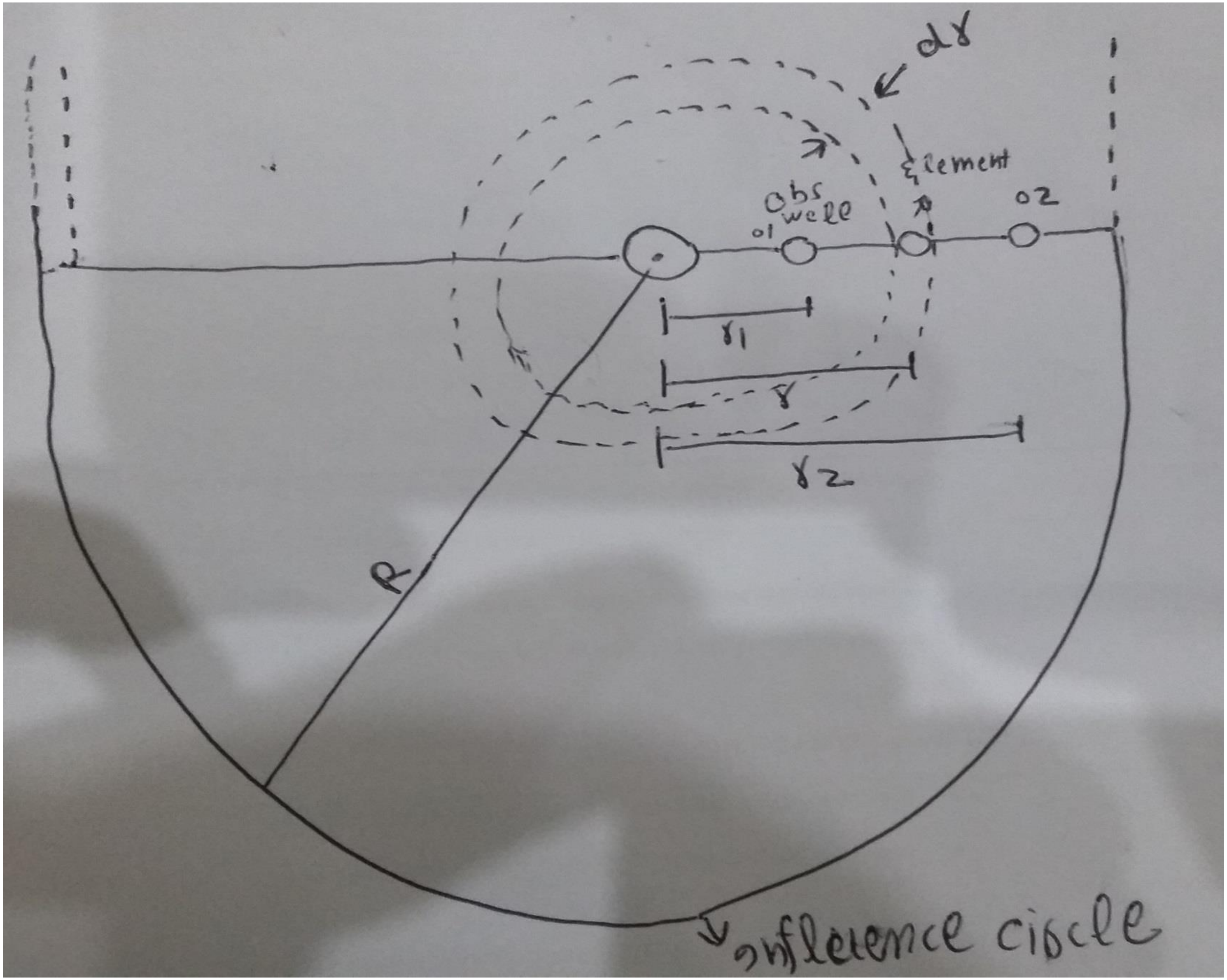


Fig: Field pumping Test for unconfined Flow

Measurement of Permeability

- Let "Q/t" is the steady rate of flow in the pumping test. Consider a soil element od width "d_r" at a distance "r" from the main well (Fig).
- The surface area of the soil through which water flows out is that of the cylinder of radius "r" and height "h" and is given by:

$$A = Area\ of\ flow = 2\pi rh$$

$$i = hydraulic\ gradient = head\ loss\ per\ unit\ length = \frac{d_h}{d_r}$$

$$\frac{Q}{t} = kiA = 2\pi krh.\frac{d_h}{d_r}$$

$$\frac{d_r}{r} = \frac{2\pi k}{Q/t}.h.d_h$$

Integrating between the limits r_2 to r_1 and corresponding heads h_2 to h_1

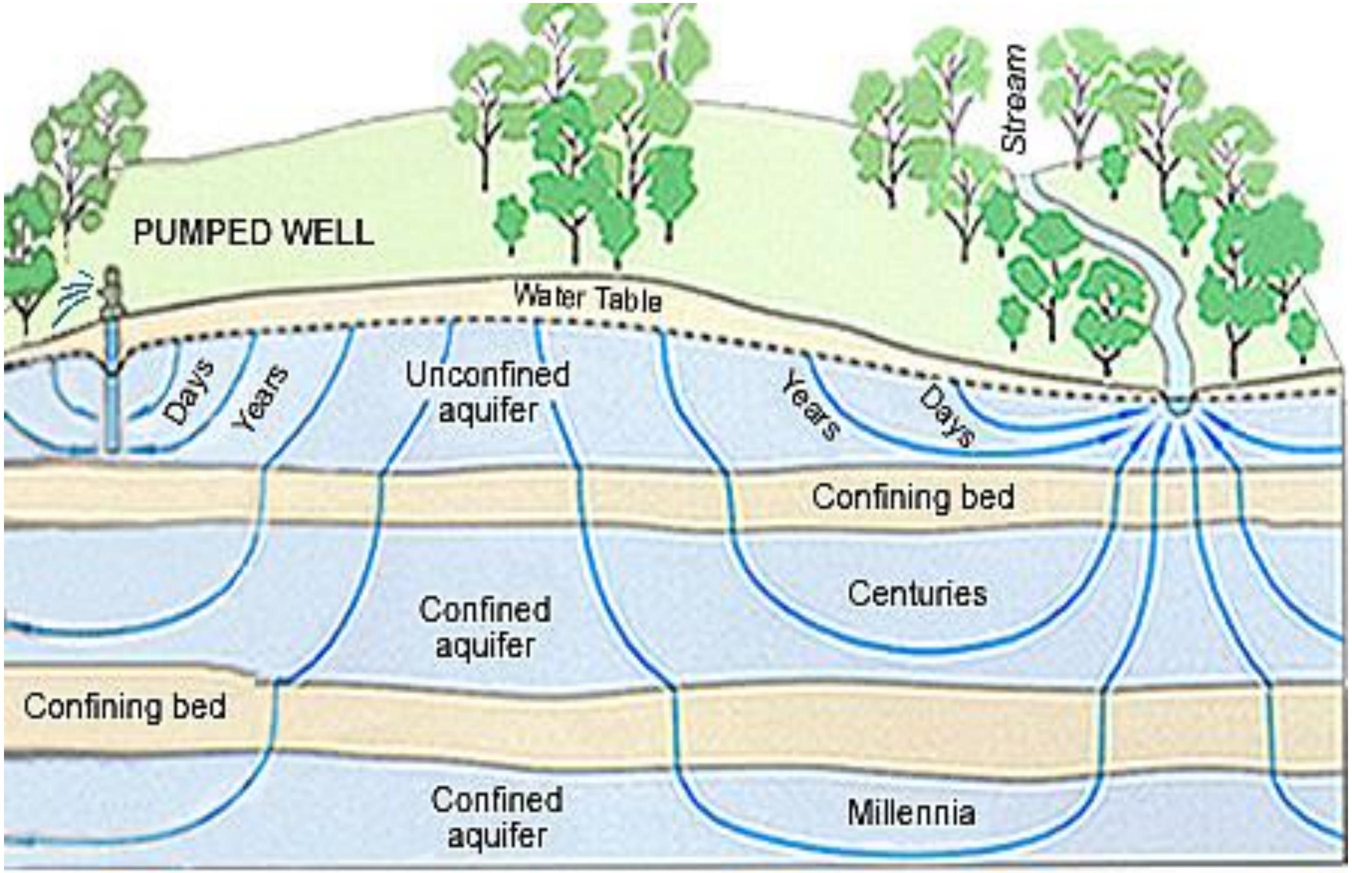
$$\ln(r_2 - r_1) = \frac{2\pi k}{Q/t}.(\frac{h_2^2 - h_1^2}{2})$$

$$k = \frac{2.3.q}{\pi(h_2^2 - h_1^2)}.log(\frac{r_2}{r_1})$$

- Where q = Q/t = Rate of flow out of the main well

Measurement of Permeability

- **Confined Flow**
- When the flow is confined between two impervious layers, the flow is under pressure and is called confined flow



Courtesy of U.S.Geological Survey

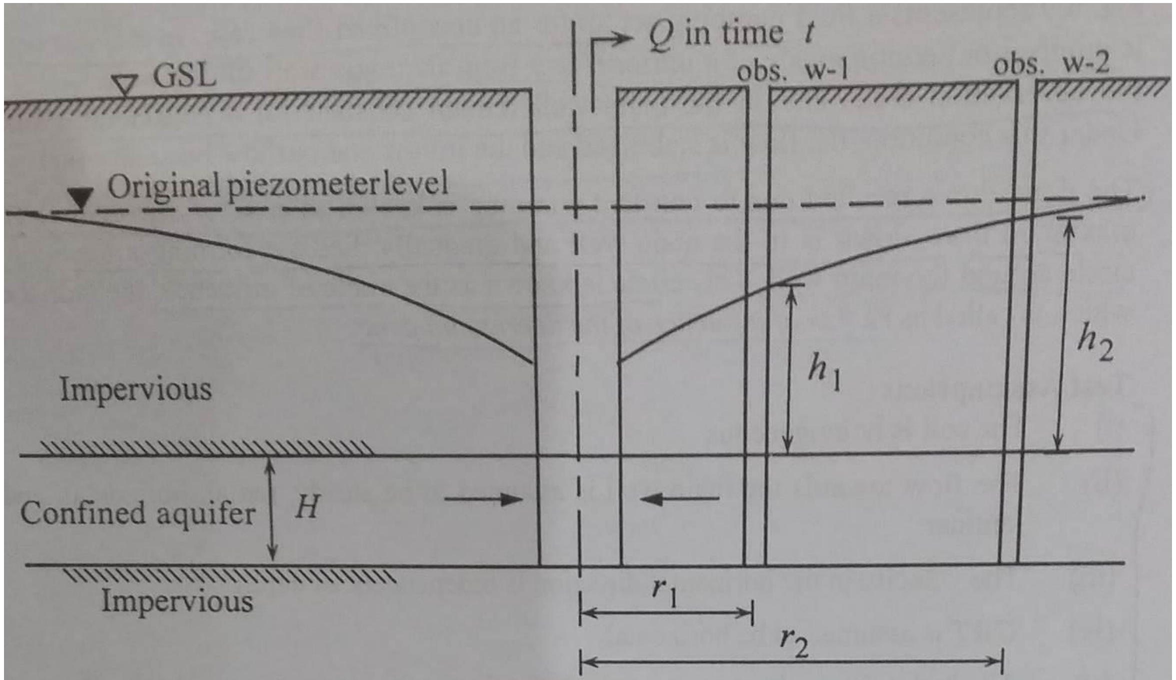


Figure 5.10 Pumping test set up for confined flow.

In this case the flow is confined within the aquifer of depth H as shown in Figure 5.10.

$\therefore A = 2\pi rH$ and

$$q = Q/t = kiA = k\left(\frac{dh}{dr}\right)(2\pi rH)$$

$\therefore dr/r = \dfrac{2\pi k}{q} H\, dh$ and integrating between the limits r_2 to r_1 and corresponding heads h_2 and h_1

$$k = \frac{2.3q \log(r_2/r_1)}{2\pi H(h_2 - h_1)}$$

$$= \frac{0.366q \log(r_2/r_1)}{H(h_2 - h_1)} \qquad 5.23$$

YIELD OF WELL

Yield of a well means, the maximum discharge capacity of the well installed in any water bearing strata. The yield depends on the permeability of water bearing strata.

Specific Yield

The specific yield of the well, q, is defined as it's yield per unit length (1m) of draw down in the well.

RADIUS OF INFLUENCE

The radius of influence of the depression cone, R, is to be estimated from experience or it is to be determined from observation in several bore holes (observation wells) made at different distances from the test well. It can also be determined from any of the above equation, which contain the term R.

According to Sichardt, for stabilized flow, R is given by an empirical equation as follows.

$$R = 3000\ S\sqrt{K} \quad (in\ meters\ units)$$

Where:

S = Maximum draw down in meters
K = Coefficient of permeability of soil in m/sec.

Kozeny gave an expression for the calculation of the radius of influence, R, in terms of time, t, during which yield from the well of Q (m^3/sec) has been attained.

$$R = \sqrt{\frac{12t}{n}\sqrt{\frac{QK}{\pi}}} \qquad (in\ meters\ units)$$

Where:

n = Porosity of soil in decimal fractions.
K = coefficient of permeability of soil (m/sec).

The radius of influence increases with the fourth root of discharge, Q, and permeability K.

Seepage

Seepage

- Quantity of water passing through a porous media such as soil is known as seepage. The process by which a liquid leaks through a porous substance;
- The study of seepage is essential for Engineers involving in the design and construction of all projects related to hydraulics, water retaining.
- Seepage has great influence on
- The stability of foundation and slopes as it may causes:
  - Surface erosion
  - Internal erosion known as piping
  - Instability of excavation
  - Quicksand Condition
- Loss for precious water stored for the use of irrigation purpose and electricity generation
- **Seepage Force**
- The flowing water generates a force which acts on the soil grain and known as Seepage Force

Seepage

- **Quicksand**
- Quicksand is a colloid hydrogel consisting of fine granular material (such as sand, silt or clay), and water.
- Quicksand forms in saturated loose sand when the sand is suddenly agitated.
- When water in the sand cannot escape, it creates a liquefied soil that loses strength and cannot support weight.

Seepage

- As stated already the flowing water exert a seepage force on soil grains w effects the inter granular pressure or effective stress in soil mass
- Consider a soil sample of length "b" with water flowing upward under a head "h" as shown in Following fig

$$Hydraulic\ gradient\ \text{“}i\text{”} = head\ loss\ per\ unit\ length\ = h/b$$

$$Total\ downward\ force\ at\ the\ sample\ base\ = \gamma_{sat}.b + \gamma_w.a$$

$$Pore\ pressure\ or\ neutral\ stress\ at\ the\ base\ = \gamma_w(h + a + b)$$

$$Inter\ granular\ or\ effective\ stress\ = \sigma = Total\ stress - Pore\ water\ pressure\ at\ the\ base$$

$$\sigma = (\gamma_{sat}.b + \gamma_w.a) - \gamma_w(h + a + b)$$

$$\sigma = (\gamma_{sat} - \gamma_w).b - \gamma_w.h = \gamma'.b - \gamma_w.h$$

$$(As\ assumed\ unit\ weight\ of\ soil, = \gamma' = \gamma_{sat} - \gamma_w)$$

- Thus the effect of upward seepage is to reduce the effective pressure in soil
- When the effective stress become zero the inter granular pressure between the soil grains is lost completely and if the soil in non- cohesive, the soil start moving with flowing water giving the impression of boiling, i.e. soil become active or alive or quick and this particular condition is called "QuickSand"
- Critical hydraulic gradient (i_c) is given by:

Seepage

$$\gamma_{sub}.b = \gamma_w.h$$

$$i_c = h/b = \gamma'/\gamma_w$$

$$\frac{\gamma_{sub}}{\gamma_w} = \frac{\gamma_{sat} - \gamma_w}{\gamma_w} = \frac{(\frac{G_s + e}{1+e}).\gamma_w - \gamma_w}{\gamma_w} = \frac{G_s + e}{1+e} - 1$$

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

- At critical hydraulic gradient, the soil will be unstable and upward force (seepage force) acting on the particle will overcome their downward gravitational force (Weight) resulting in boiling of soil particle.
- This may cause internal erosion of soil particles which is generally called piping.
- Piping has caused failure of many earth structures.

Seepage

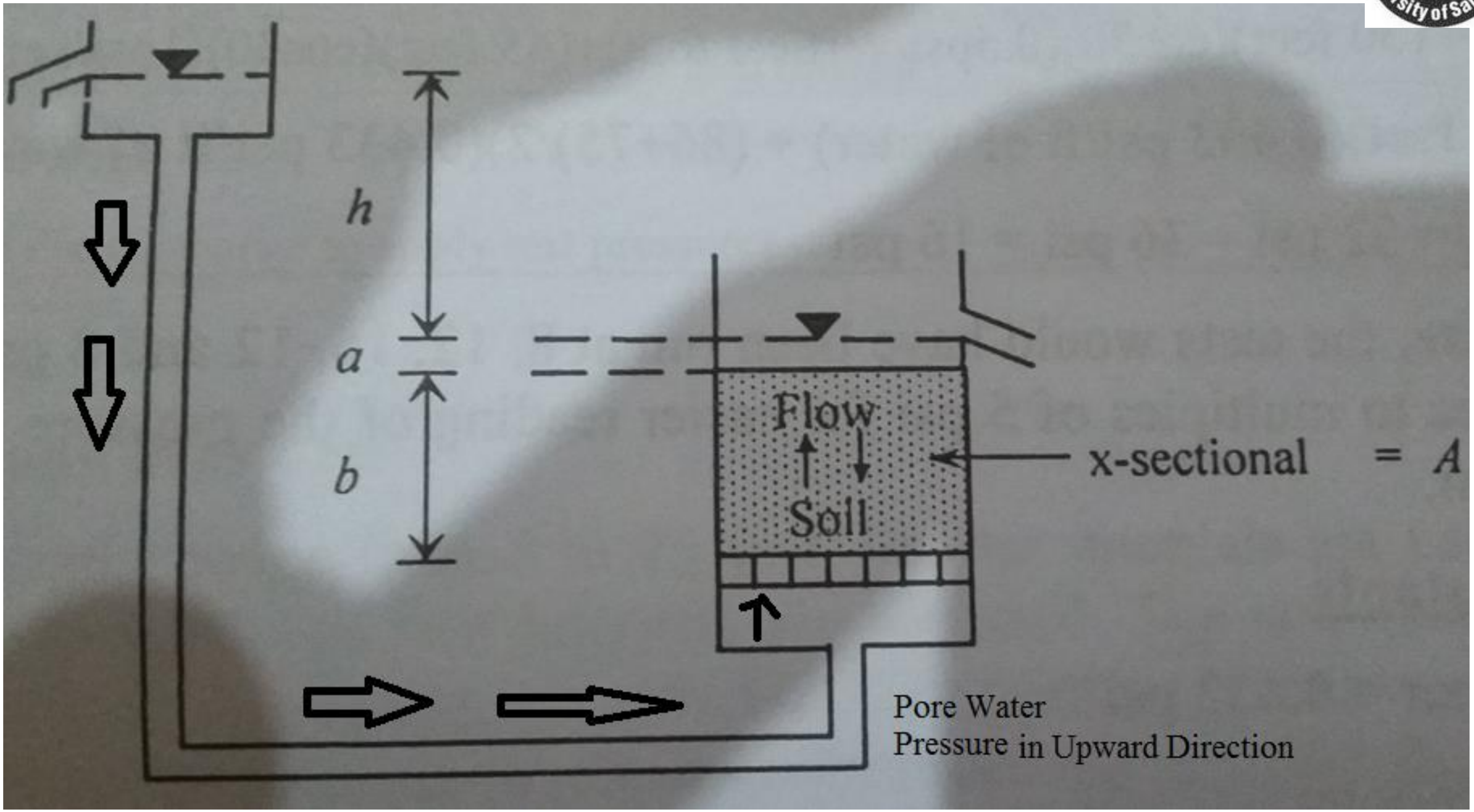


Fig: Seepage in Soil

Seepage

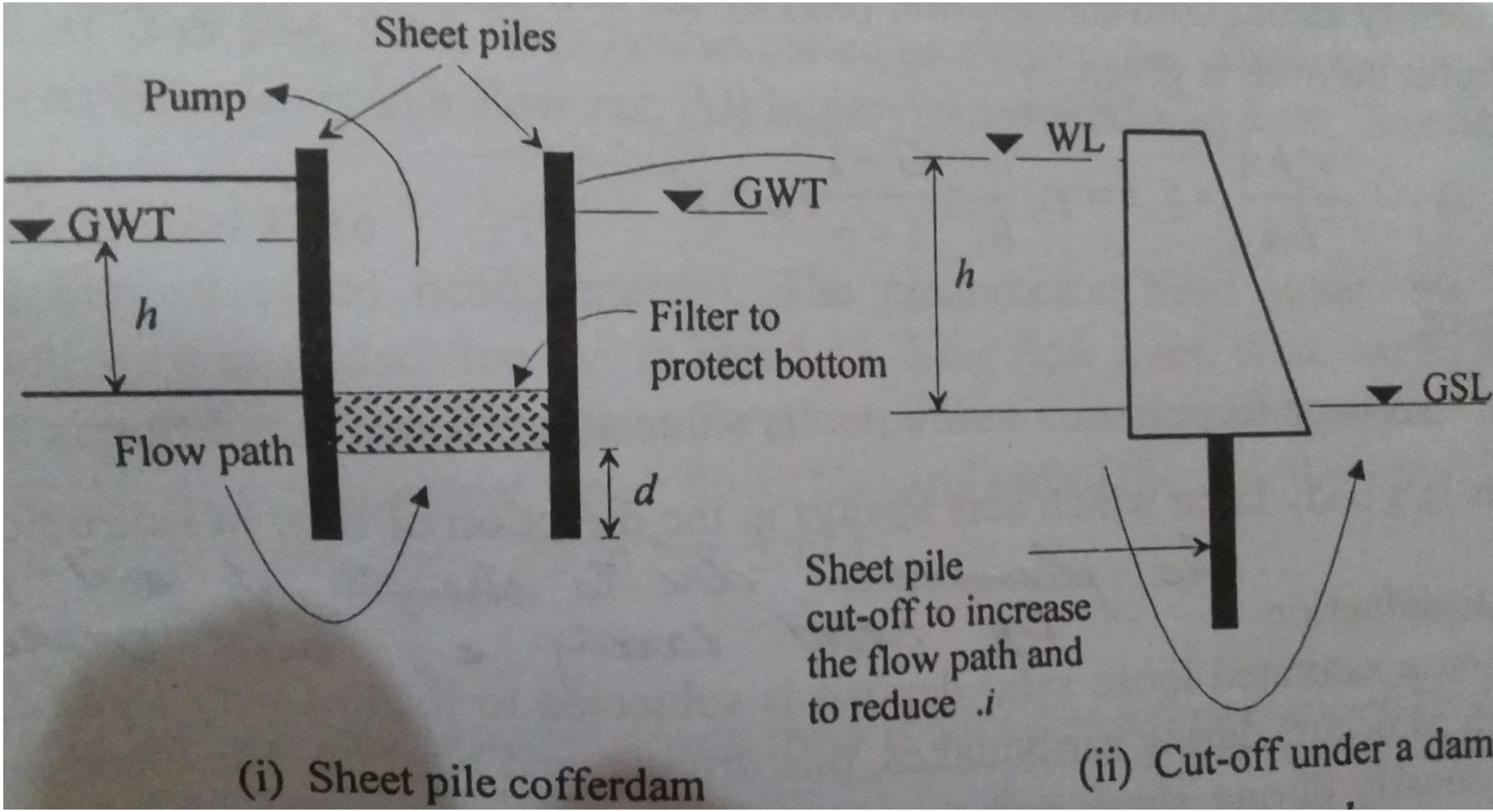


Fig: Quicksand Condition in Engineering Works

Seepage

- When there is a gradient, there is a seepage force
- These force affects sands more than clays, because clay has some initial cohesion which holds the particles together.
- Let “A” be the cross sectional area of the cylinder containing soil sample in Fig
- For just equilibrium condition

Effective downward force = Total upward force

Or

Submerged weight = Seepage force (Uplift force)

$$(\gamma_{sub}).(bA) = (\gamma_w).(hA)$$

- In uniform flow the upward force $(\gamma_w).(hA)$, is distributed uniformly throughout the volume (b.A) of the soil column. Thus the seepage force per unit volume is:

Seepage

- Thus the Seepage force per unit volume is given by

$$(\gamma_{sub}).(bA) = (\gamma_w).(hA)$$

$$\frac{(\gamma_w).(hA)}{(bA)} = (\gamma_w).i$$

$$(\gamma_w).i = \frac{(\gamma_w).(h)}{(b)}$$

$$(\gamma_w).i = (\frac{G_s - 1}{1+e}).(\gamma_w)$$

$$\gamma_{sub}.b = \gamma_w.h$$

$$\gamma_{sub} = \frac{\gamma_w.h}{b} = \gamma_w.i$$

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

- Where:
- $(\gamma_w).i$ = Seepage force per unit volume. It's value at quicksand condition is $(\gamma_w).i_c$
- This is body force which is always acts in the direction of flow.

Seepage

- **Liquefaction**
- When a saturated loose sand deposit is subjected to load of very short duration such as during earth quake, pile driving and blasting. The sand is then try to densify during shear and this tend to squeeze water out of the pores .
- As the loading time is very short the water does not have time to escape the pores and the pore water pressure increases, Since the total stresses have not increased during loading , the effective stress then tend towards to zero, and soil looses spontaneously all strength and bearing capacity.

Seepage

- **Seepage Control**
- Thus seepage can be controlled by:
- Reduction in flow head (h) or
- Increasing the flow path (L)
- Increasing the downward force to resist the water pressure.
- **Reduction in flow head (h)**
- It is achieved by
- Reducing permeability through good compaction, grouting of granular soils and mixing some clay in the granular materials during construction
- **Increasing the seepage path** , which will reduce the seepage quantity and seepage force will be decreased due to reduction in "i". In practice seepage path is can be increased by using different types of cutoff, seepage blankets as shown in the following Fig
- Excessive water pressure (seepage force) can be controlled by drainage that short circuits the flow and bleed off the excessive neutral stress at a point where it can do no harm to the structure. It is done by providing different types of drains and filters relief wells. As shown in following Fig

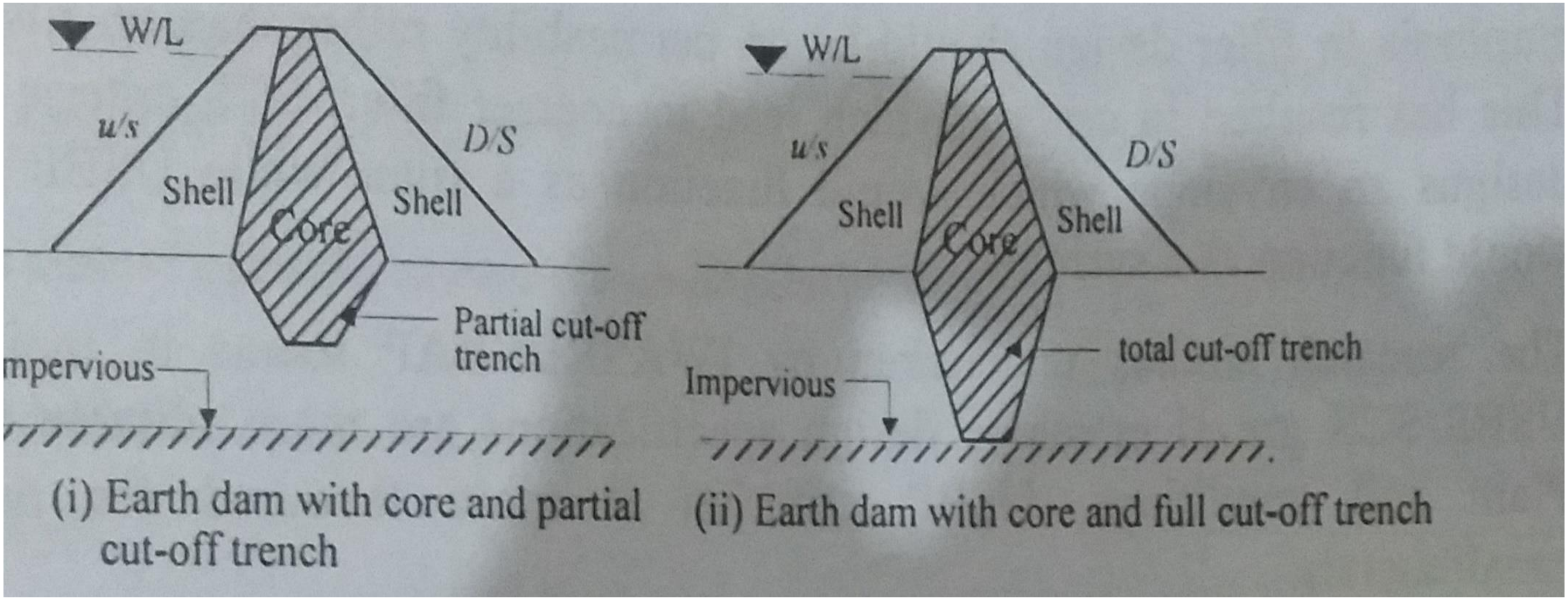


Fig: Different Seepage Control Measure

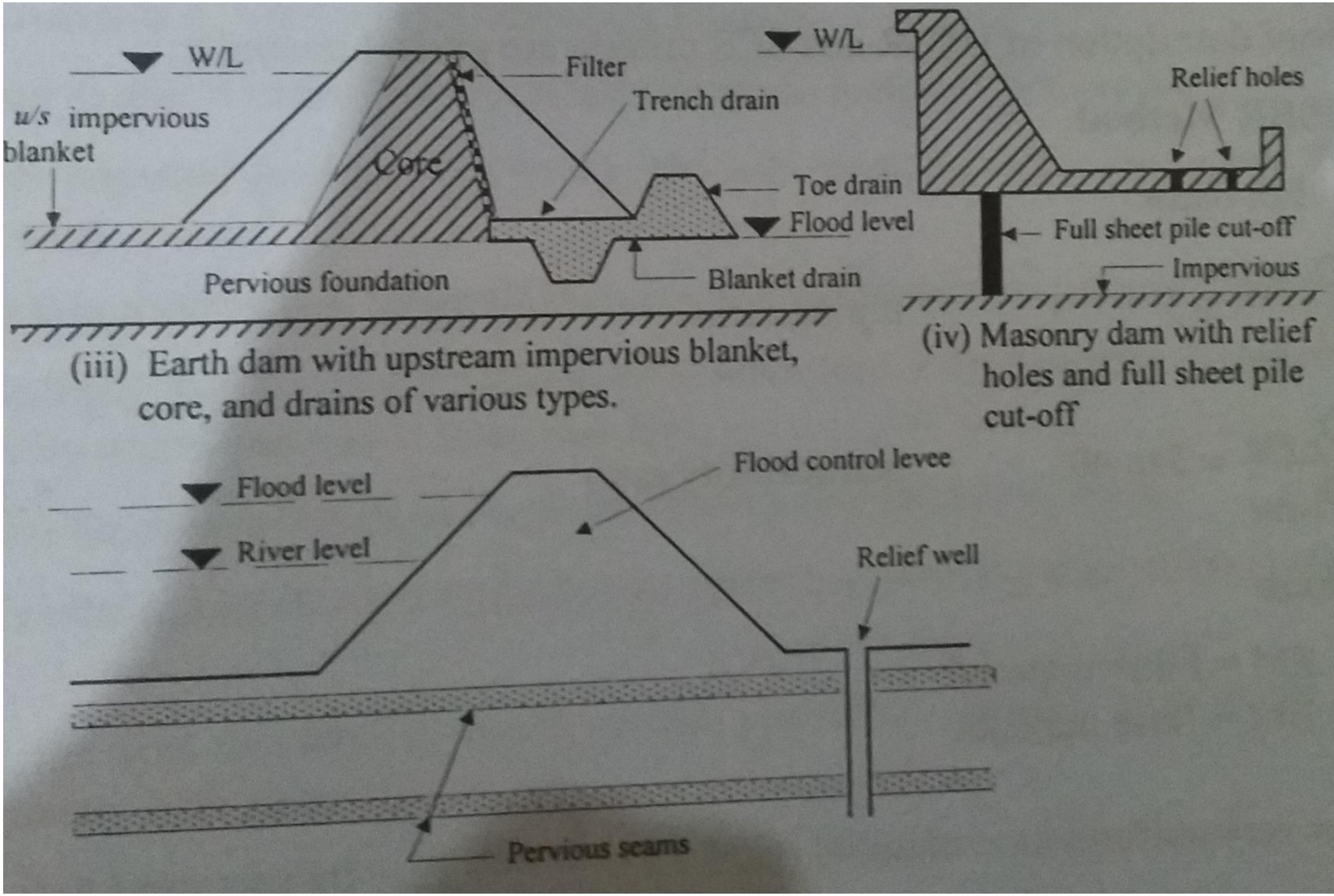
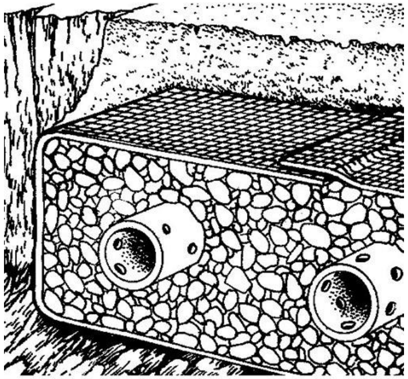
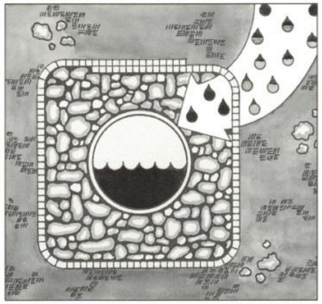


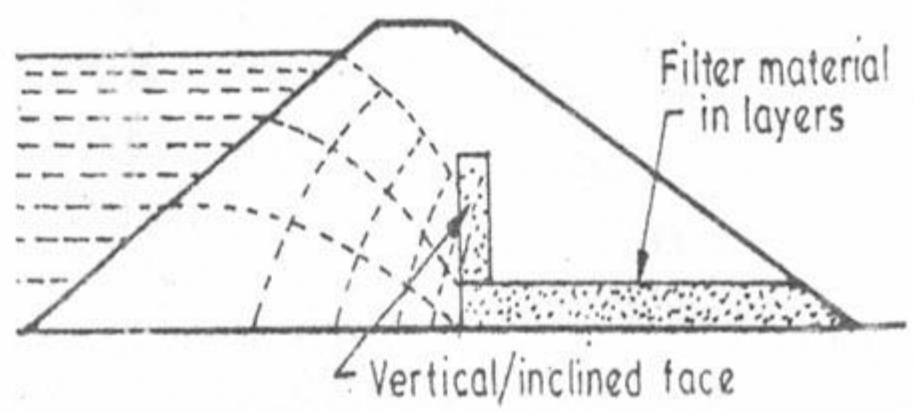
Fig: Different Seepage Control Measure

Seepage

- **Filter Design**
- A filter consist of one or more layers of free draining granular materials placed in less pervious foundation or base materials to prevent internal erosion (piping) of base soil particles and at the same time allowing seeping water to escape with little head loss. Thus the seepage force within the filter are reduced
- Some times a filter may be constructed in several layers, each about 150 mm thick, and each layer design to protect the layer below it. This type of filter is called "Reversed or Inverted or Granular Filter"







THANK YOU!