Subject Name: **Geotechnical Engineering-I**

Subject Code: **CE-6003**

Semester: **6th**

SYLLABUS

Soil Water and Consolidation: Soil water, Permeability Determination of permeability in laboratory and in field. Seepage and seepage pressure. Flow-nets, uses of a flow-net, Effective, neutral and total stresses. Compressibility and consolidation, Relationship between pressure and void ratio, Theory of one dimensional consolidation. Consolidation test, Fitting Time curves. Normally and over consolidated clays. Determination of pre-consolidation pressure, settlement analysis, Calculation of total settlement.

Soil water

Soil water is the term for water found in naturally occurring soil. Soil water is also called rhizic water. There are three main types of soil water - gravitational water, capillary water, and hygroscopic water - and these terms are defined based on the function of the water in the soil.

The following points highlight the four types of water available in the soil.

They are: (1) Gravitational Water or Ground Water

(2) Capillary Water

(3) Hygroscopic Water and

(4) Chemically Combined Water.

Gravitational Water

Gravitational water is free water moving through soil by the force of gravity. It is largely found in the macropores of soil and very little gravitational water is available to plants as it drains rapidly down the water table in all except the most compact of soils.

Capillary Water

Capillary water is water held in the microspores of the soil, and is the water that composes the soil solution. Capillary water is held in the soil because the surface tension properties (cohesion and adhesion) of the soil microspores are stronger than the force of gravity. However, as the soil dries out, the pore size increases and gravity starts to turn capillary water into gravitational water and it moves down.

Capillary water is the main water that is available to plants as it is trapped in the soil solution right next to the roots if the plant.

Hygroscopic Water

Hygroscopic water forms as a very thin film surrounding soil particles and is generally not available to the plant. This type of soil water is bound so tightly to the soil by adhesion properties that very little of it can be taken up by plant roots. Since hygroscopic water is found on the soil particles and not in the pores, certain types of soils with few pores (clays for example) will contain a higher percentage of it.

Permeability

The soil permeability is a measure indicating the capacity of the soil or rock to allow fluids to pass through it. It is often represented by the permeability coefficient (k) through the Darcy's equation:

$V=ki$

Where v is the apparent fluid velocity through the medium i is the hydraulic gradient , and K is the coefficient of permeability (hydraulic conductivity) often expressed in m/s

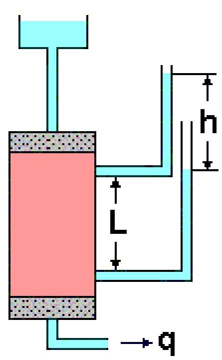
K depends on the relative permeability of the medium for fluid constituent (often water) and the dynamic viscosity of the fluid as follows.

Permeability (k) is an engineering property of soils and is a function of the soil type.Its value depends on the average size of the pores and is related to the distribution of particle sizes, particle shape and soil structure. The ratio of permeability's of typical sands/gravels to those of typical clays is of the order of 10^6. A small proportion of fine material in a coarse-grained soil can lead to a significant reduction in permeability.

Determination of permeability in laboratory and in field

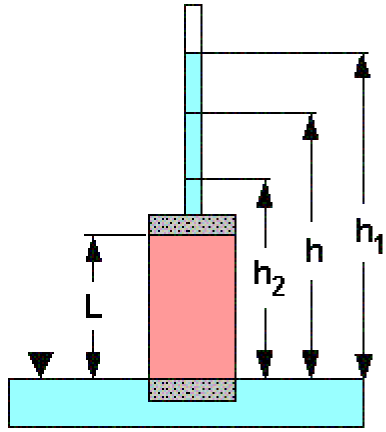
Constant Head Flow

Constant head permeameter is recommended for coarse-grained soils only since for such soils, flow rate is measurable with adequate precision. As water flows through a sample of cross-section area A, steady total head drop h is measured across length L.

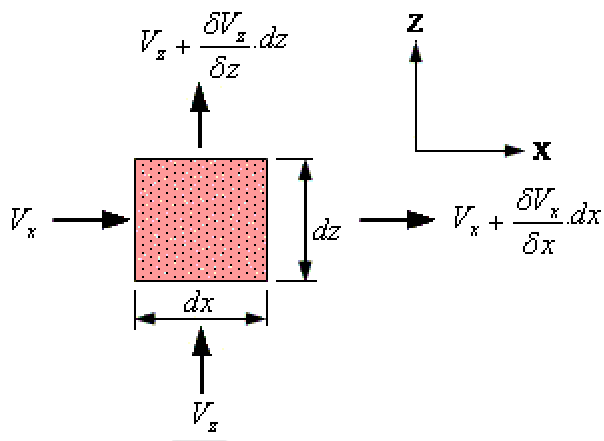


Falling Head Flow

Falling head permeameter is recommended for fine-grained soils.



Seepage and seepage pressure



A rectangular soil element is shown with dimensions *dx* and *dz* in the plane, and thickness *dy* perpendicular to this plane. Consider planar flow into the rectangular soil element.

In the x-direction, the net amount of the water entering and leaving the element is

$$\frac{\delta V_x}{\delta x}.dx.dy.dz$$

Similarly in the z-direction, the difference between the water inflow and outflow is

$$\frac{\delta V_z}{\delta z}.dz.dx.dy$$

For a two-dimensional steady flow of pore water, any imbalance in flows into and out of an element in the z-direction must be compensated by a corresponding opposite imbalance in the x-direction. Combining the above, and dividing by *dx.dy.dz* , the continuity equation is expressed as

$$\frac{\delta V_x}{\delta x} + \frac{\delta V_z}{\delta z} = 0$$

From Darcy's law

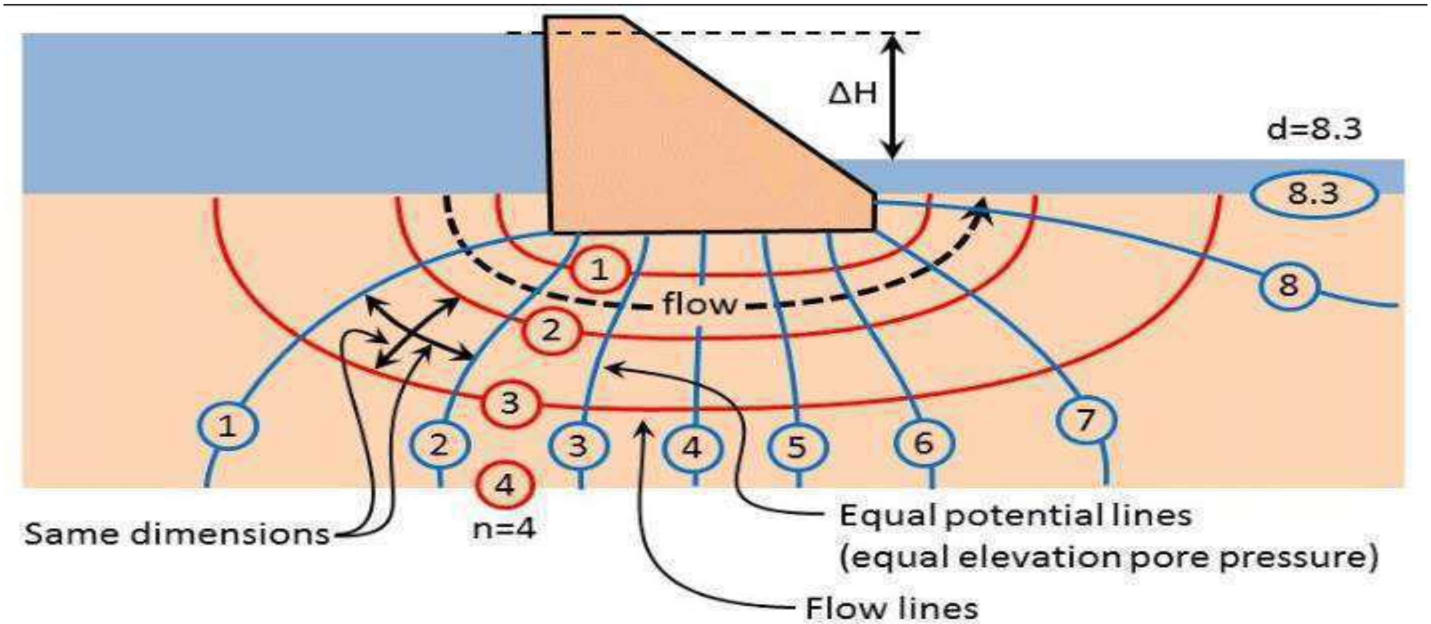
$$V_x = k_x \cdot \frac{\delta h}{\delta x}$$

$$V_z = k_z \cdot \frac{\delta h}{\delta z}$$

where h is the head causing flow.

Flow-nets &uses of a flow-net

A flow-net is a graphical representation of two-dimensional steady-state groundwater flow through aquifers. Construction of a flow-net is often used for solving groundwater flow problems where the geometry makes analytical solutions impractical. The method is often used in civil engineering, hydrogeology or soil mechanics as a first check for problems of flow under hydraulic structures like dams or sheet pile walls. As such, a grid obtained by drawing a series of equipotential lines is called a flow-net. The flow-net is an important tool in analyzing two-dimensional ir-rotational flow problems. Flow net technique is a graphical representation method.



Effective, neutral and total stresses.

As mention before, the soil consist of the solid particles which distributed randomly with void spaces in between, the void spaces are occupied by water and/or air. We need to known the cross section of soil profile.Under Ground Surface (GS) or (G.L) ground level to calculate the stresses on the element. It means the column of the soil weight in the nature case as shown in fig. (1).There are many types of stresses the total stress, natural stress and effective stress.

At point (A) in fig(1).

$s_T = \gamma h$

s_T : Total stress at point A

γ : Unit weight of soil

h : The high of the soil column

For Multi layer soil

In this case as shown in Fig (2)

$s_T = \gamma_1 h_1 + \gamma_2 h_2 + \gamma_3 h_3$

The stress has two components. The stress due to pore pressure (u) ; u = h γw ? γw = density of water

Stress due to the weight of the rectangle; σ = h γw

The principle effective stress is σ' = σ – u The principle of effective stress is the most important principle in soil mechanics. Deformations of soils are a function of effective stresses not total stresses. The principle of effective stresses applies only to normal stresses and not shear stresses.

Total stress (σ) is equal to the sum of effective stress (σ') and pore water pressure (u) or, alternatively, effective stress is equal to total stress minus pore water pressure.

Now assume the block is sand, what if the ground water level is at a depth hw below the ground level, σ = γhw + γSAT (h – hw)

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The pore pressure is u = γw(h – hw)

So the effective stress is; σ' = σ – u = γhw + γSAT(h – hw) - γw(h– hw) compressibility and Consolidation

Consolidation is a process by which soils decrease in volume. According to Karl von Terzaghi "consolidation is any process which involves a decrease in water content of saturated soil without replacement of water by air." In general it is the process in which reduction in volume takes place by expulsion of water under long term static loads. It occurs when stress is applied to a soil that causes the soil particles to pack together more tightly, therefore reducing its bulk volume. When this occurs in a soil that is saturated with water, water will be squeezed out of the soil. The magnitude of consolidation can be predicted by many different methods. In the Classical Method, developed by Terzaghi, soils are tested with an odometer test to determine their compression index. This can be used to predict the amount of consolidation.

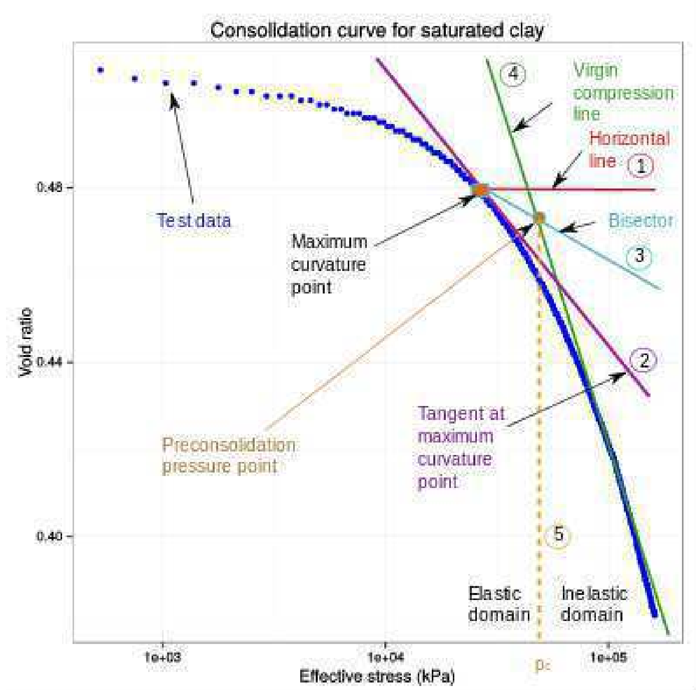
When stress is removed from a consolidated soil, the soil will rebound, regaining some of the volume it had lost in the consolidation process. If the stress is reapplied, the soil will consolidate again along a recompression curve, defined by the recompression index. The soil which had its load removed is considered to be *over consolidated*. This is the case for soils which have previously had glaciers on them. The highest stress that it has been subjected to is termed the *pre consolidation stress*. The *over consolidation ratio* or OCR is defined as the highest stress experienced divided by the current stress. A soil which is currently experiencing its highest stress is said to be *normally consolidated* and to have an OCR of one. A soil could be considered *under consolidated* immediately after a new load is applied but before the excess pore water pressure has had time to dissipate.

When a soil layer is subjected to vertical stress, volume change can take place through rearrangement of soil grains, and some amount of grain fracture may also take place. The volume of soil grains remains constant, so change in total volume is due to change in volume of water. In saturated soils, this can happen only if water is pushed out of the voids. The movement of water takes time and is controlled by the permeability of the soil and the locations of free draining boundary surfaces.

It is necessary to determine both the magnitude of volume change (or the settlement) and the time required for the volume change to occur. The magnitude of settlement is dependent on the magnitude of applied stress, thickness of the soil layer, and the compressibility of the soil.

When soil is loaded undrained, the pore pressure increases. As the excess pore pressure dissipates and water leaves the soil, settlement takes place. This process takes time, and the rate of settlement decreases over time. In coarse soils (sands and gravels), volume change occurs immediately as pore pressures are dissipated rapidly due to high permeability. In fine soils (silts and clays), slow seepage occurs due to low permeability.

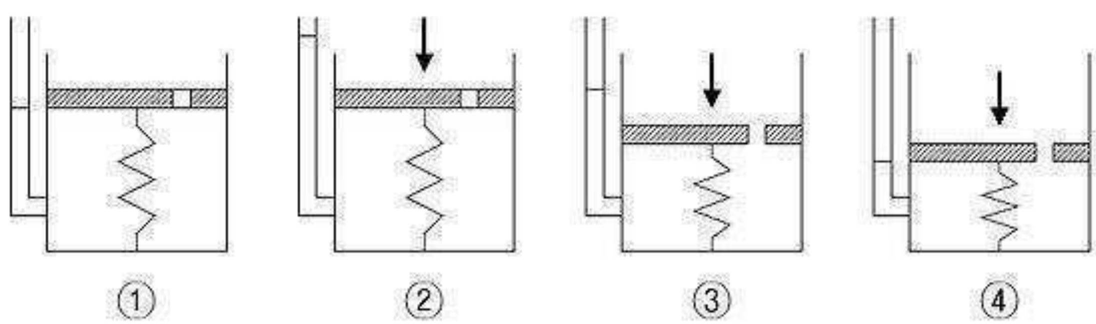
Relationship between pressure and void ratio



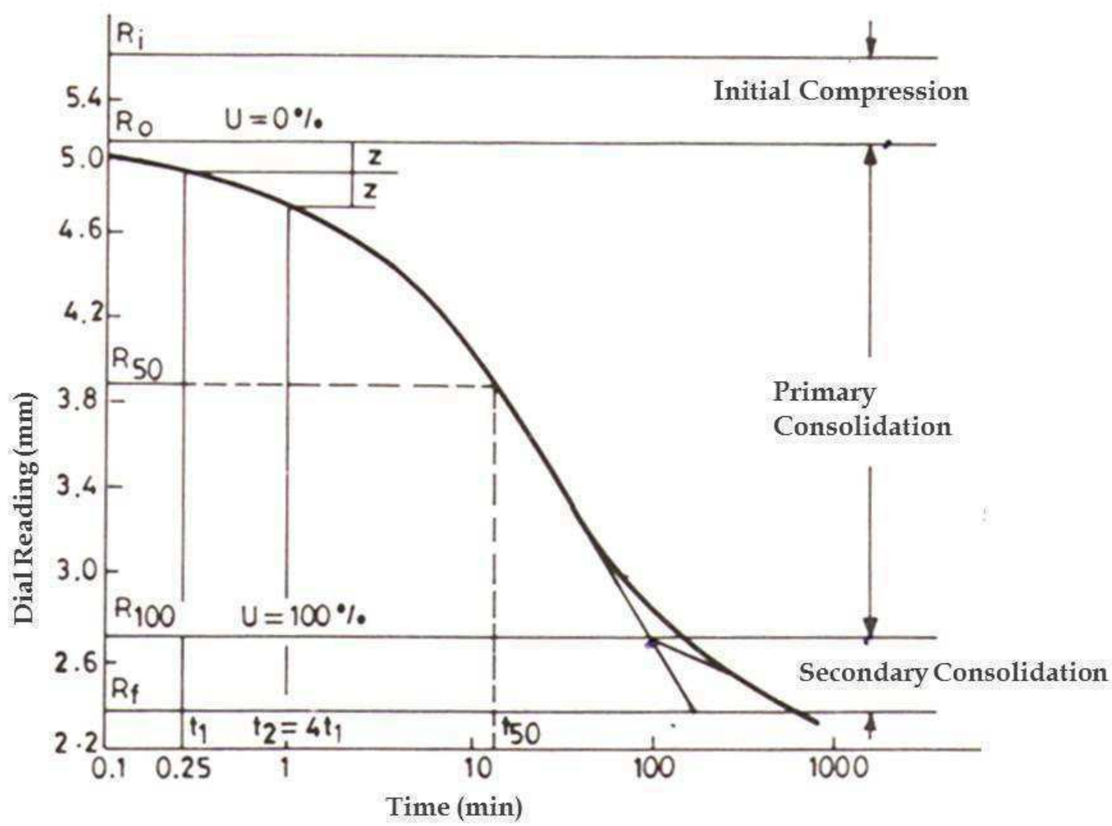
Theory of one dimensional consolidation

The process of consolidation is often explained with an idealized system composed of a spring, a container with a hole in its cover, and water. In this system, the spring represents the compressibility or the structure of the soil itself, and the water which fills the container represents the pore water in the soil.

1. **The container is completely filled with water, and the hole is closed. (Fully saturated soil)**
2. **A load is applied onto the cover, while the hole is still unopened. At this stage, only the water resists the applied load. (Development of excess pore water pressure)**
3. **As soon as the hole is opened, water starts to drain out through the hole and the spring shortens. (Drainage of excess pore water pressure)**
4. **After some time, the drainage of water no longer occurs. Now, the spring alone resists the applied load. (Full dissipation of excess pore water pressure. End of consolidation)**



Consolidation test & Fitting Time curves



After the coefficient of consolidation (c_v) has been determined from laboratory data calculations are possible for site settlements. It is important to note that c_v is *not a constant*, but varies with both the level of stress and degree of consolidation. For practical site settlement calculations, however, it is sufficiently accurate to measure c_v relative to the loading range applicable on site and then assume this value to be approximately constant for all degrees of consolidation

The basic equation used is:

$$c_v = \frac{T_v d^2}{t}$$

Normally and over consolidated clays

OP corresponds to initial loading of the soil. PQ corresponds to unloading of the soil. QFR corresponds to a reloading of the soil. Upon reloading beyond P, the soil continues along the path that it would have followed if loaded from O to R continuously.

The pre-consolidation stress, s'_{pc}, is defined to be the maximum effective stress experienced by the soil. This stress is identified in comparison with the effective stress in its present state. For soil at state Q or F, this would correspond to the effective stress at point P.

If the current effective stress, s', is equal (note that it cannot be greater than) to the pre-consolidation stress, then the deposit is said to be normally consolidated(NC). If the current effective stress is less than the pre-consolidation stress, then the soil is said to be over-consolidated (OC).

It may be seen that for the same increase in effective stress, the change in void ratio is much less for an over consolidated soil (from e_0 to e_f), than it would have been for a normally consolidated soil as in path OP. In unloading, the soil swells but the increase in volume is much less than the initial decrease in volume for the same stress difference.

The distance from the normal consolidation line has an important influence on soil behavior. This is described numerically by the over consolidation ratio (OCR), which is defined as the ratio of the reconsolidation stress to the current effective stress.

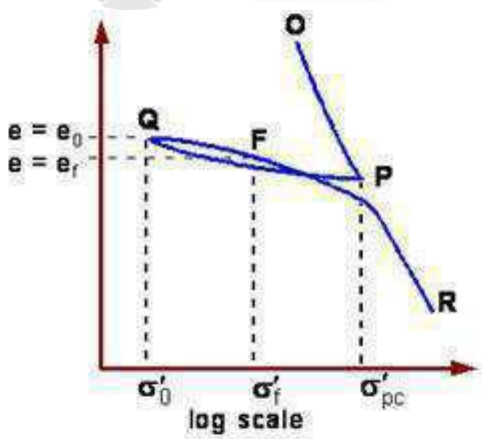
$$OCR = \frac{\sigma'_{pc}}{\sigma'}$$

Note that when the soil is normally consolidated, OCR = 1

Settlements will generally be much smaller for structures built on over consolidated soils. Most soils are overconsolidated to some degree. This can be due to shrinking and swelling of the soil on drying and rewetting, changes in ground water levels, and unloading due to erosion of overlying strata.

For NC clays, the plot of void ratio versus log of effective stress can be approximated to a straight line, and the slope of this line is indicated by a parameter termed as compression index, C_c.

$$C_c = \frac{\Delta e}{\log_{10}\left(\frac{\sigma'_2}{\sigma'_1}\right)}$$



Settlementanalysis &Calculation of total settlement

The total settlement of a loaded soil has three components: Elastic settlement, primary consolidation, and secondary compression.

Elastic settlement is on account of change in shape at constant volume, i.e. due to vertical compression and lateral expansion. Primary consolidation(or simply consolidation) is on account of flow of water from the voids, and is a function of the permeability and compressibility of soil. Secondary compression is on account of creep-like behavior.

Primary consolidation is the major component and it can be reasonably estimated. A general theory for consolidation, incorporating three-dimensional flow is complicated and only applicable to a very limited range of problems in geotechnical engineering. For the vast majority of practical settlement problems, it is sufficient to consider that both seepage and strain take place in one direction only, as one-dimensional consolidation in the vertical direction.

The components of settlement of a foundation are:

1. Immediate settlement
2. Consolidation Settlement, and
3. Secondary compression (creep)

$\Delta H = \Delta Hi + U\, \Delta Hc + \Delta Hs$

ΔH = total settlement, ΔHc = consolidation settlement, ΔH = secondary compression, U = average degree of consolidation. Generally, the final settlement of a foundation is of interest and U is considered equal to 1 (i.e. 100% consolidation)

1. Immediate Settlement

- Immediate settlement takes place as the load is applied or within a time period of about 7 days.
- Predominates in cohesion less soils and unsaturated clay
- Immediate settlement analysis are used for all fine-grained soils including silts and clays with a degree of saturation < 90% and for all coarse grained soils with large co-efficient of permeability (say above 10.2 m/s)

2. Consolidation Settlement (ΔHc)

- Consolidation settlements are time dependent and take months to years to develop. The leaning tower of Pisa in Italy has been undergoing consolidation settlement for over 700 years. The lean is caused by consolidation settlement being greater on one side. This, however, is an extreme case. The principal settlements for most projects occur in 3 to 10 years.
- Dominates in saturated/nearly saturated fine grained soils where consolidation theory applies. Here we are interested to estimate both consolidation settlement and how long a time it will take or most of the settlement to occur.

3. Secondary Settlement/Creep (ΔHc)

- Occurs under constant effective stress due to continuous rearrangement of clay particles into a more stable configuration.
- Predominates in highly plastic clays and organic clays.