LECTURE 21

CONSOLIDATION

Introduction

Civil Engineers build structures and the soil beneath these structures is loaded. This results in increase of stresses resulting in strain leading to settlement of stratum. The settlement is due to decrease in volume of soil mass. When water in the voids and soil particles are assumed as incompressible in a completely saturated soil system then - reduction in volume takes place due to expulsion of water from the voids. There will be rearrangement of soil particles in air voids created by the outflow of water from the voids. This rearrangement reflects as a volume change leading to compression of saturated fine grained soil resulting in settlement. The rate of volume change is related to the rate at which pore water moves out which in turn depends on the permeability of soil. Therefore the deformation due to increase of stress depends on the "Compressibility of soils"

As Civil Engineers we need to provide answers for

1. Total settlement (volume change)
2. Time required for the settlement of compressible layer

The total settlement consists of three components

1. Immediate settlement.
2. Primary consolidation settlement
3. Secondary consolidation settlement (Creep settlement)

St = Si + Sc + Ssc

Elastic Settlement or Immediate Settlement

This settlement occurs immediately after the load is applied. This is due to distortion (change in shape) at constant volume. There is negligible flow of water in less pervious soils. In case of pervious soils the flow of water is quick at constant volume. This is determined by elastic theory.

Primary Consolidation Settlement

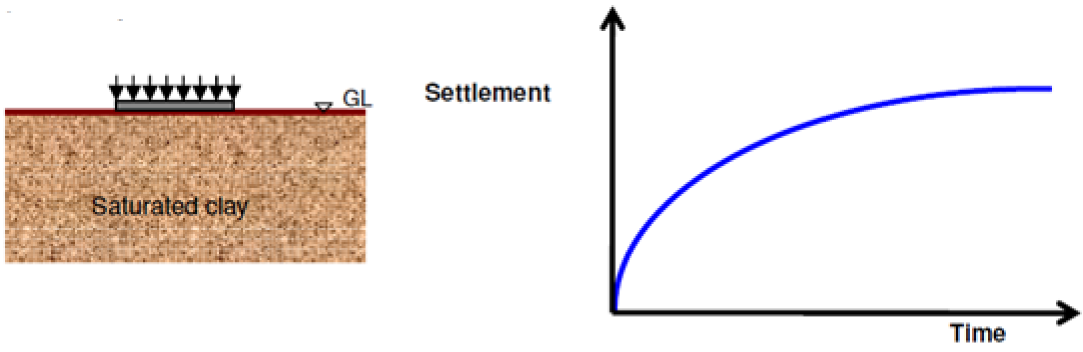


Figure Settlement versus Time

It occurs due to expulsion of pore water from the voids of a saturated soil. In case of saturated fine grained soils, the deformation is due to squeezing of water from the pores leading to rearrangement of soil particles. The movement of pore water depends on the permeability and dissipation of pore water pressure. With the passage of time the pore water pressure dissipates, the rate of flow decreases and finally the flow of water ceases. During this process there is gradual dissipation of pore water pressure and a simultaneous increase of effective stress as shown in the above Figure. The consolidation settlement occurs from the time water begins move out from the pores to the time at which flow ceases from the voids. This is also the time from which the excess pore water pressure starts reducing (effective stress increase) to the time at which complete dissipation of excess pore water pressure (total stress equal to effective stress). This time dependent compression is called “Consolidation settlement”.

Primary consolidation is a major component of settlement of fine grained saturated soils and this can be estimated from the theory of consolidation.

In case of saturated soil mass the applied stress is borne by pore water alone in the initial stages

$$\therefore \text{At } t = 0 \qquad \Delta\sigma = \Delta u \qquad \Delta\sigma' = 0$$

With passage of time water starts flowing out from the voids as a result the excess pore water pressure decreases and simultaneous increase in effective stress will takes place. The volume change is basically due to the change in effective stress After considerable amount of time (t =0) flow from the voids ceases the effective stress stabilizes and will be is equal to external applied total stress and this stage signifies the end of primary consolidation.

$$\text{At} \quad t = t_1 \qquad \Delta\sigma = \Delta\sigma' + \Delta u$$

$$\text{At} \quad t = \infty \qquad \Delta\sigma = \Delta\sigma' \qquad \Delta u = 0 \text{ (End of primary consolidation)}$$

Secondary Consolidation Settlement:-

This is also called Secondary compression (Creep). “It is the change in volume of a fine grained soil due to rearrangement of soil particles (fabric) at constant effective stress". The rate of secondary consolidation is very slow when compared with primary consolidation.

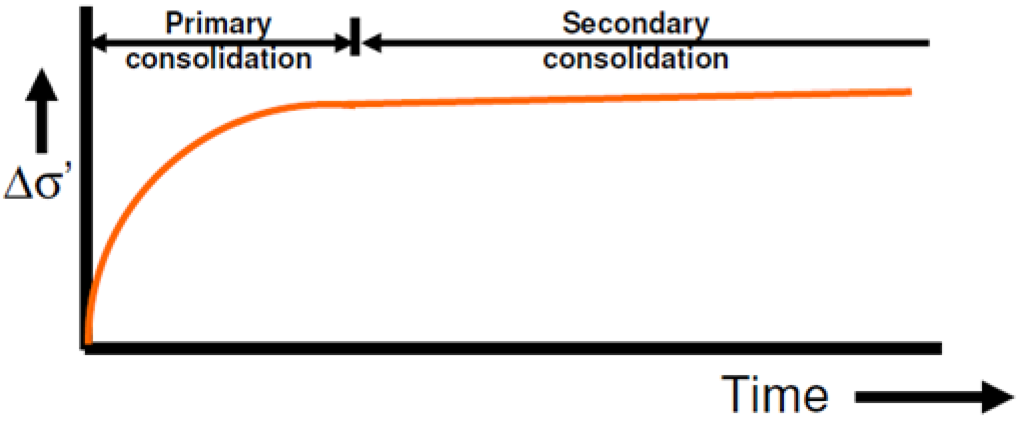


Figure Effective Stress versus Time

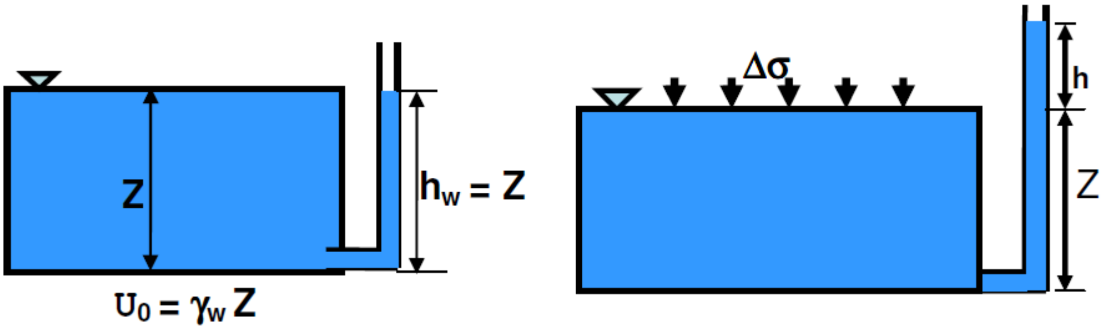
Excess Pore water Pressure (Δu)

"It is the pressure in excess of the equilibrium pore water pressure". It is represented as Δu.

$$\Delta u = h\,\gamma_w$$

Where h --- Piezometric head

γ_w --- Unit weight of water



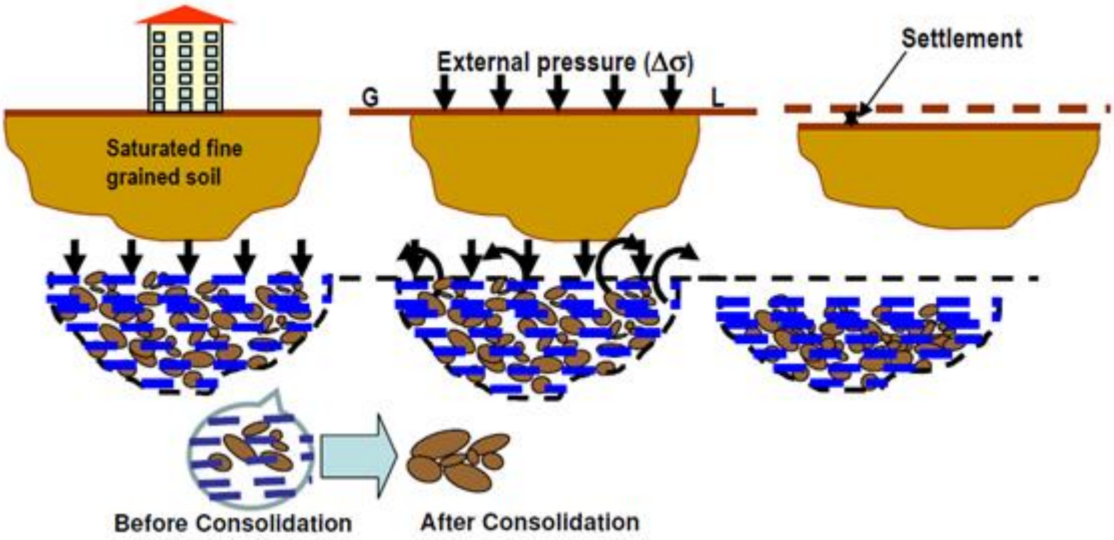


Figure Mechanism of volume change in saturated fine grained soil under external loading

When saturated soil mass is subjected to external load decrease in volume takes place due to rearrangement of soil particles. Reduction in volume is due to expulsion of water from the voids. The volume change depends on the rate at which water is expelled and it is a function of permeability.

The total vertical deformation (Consolidation settlement) depends on

1. Magnitude of applied pressure
2. Thickness of the saturated deposit

We are concerned with

_ Measurement of volume change

_ The time duration required for the volume change

Spring Analogy

The consolidation process 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 itself of the soil, and the water which fills the container represents the pore water in the soil.

On figure , the tube on the left of the container shows the water pressure in the container.

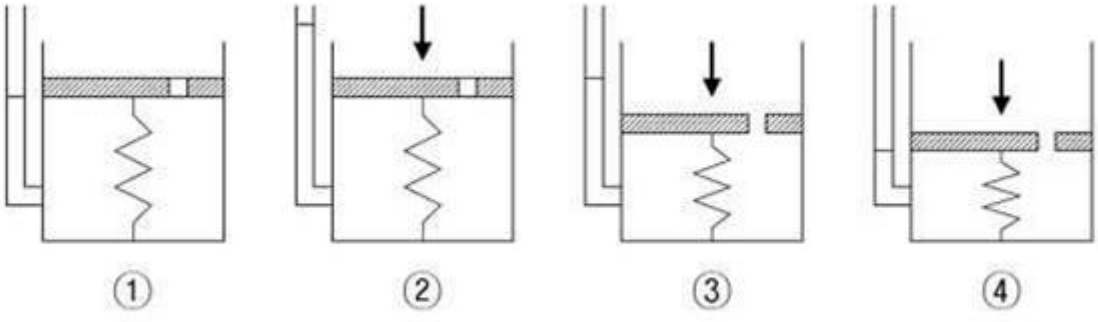


Figure: process of consolidation

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 excessive 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 excessive pore water)
4. After some time, the drainage of water no longer occurs. Now, the spring alone resists the applied load. (Full dissipation of excessive pore water pressure. End of consolidation)