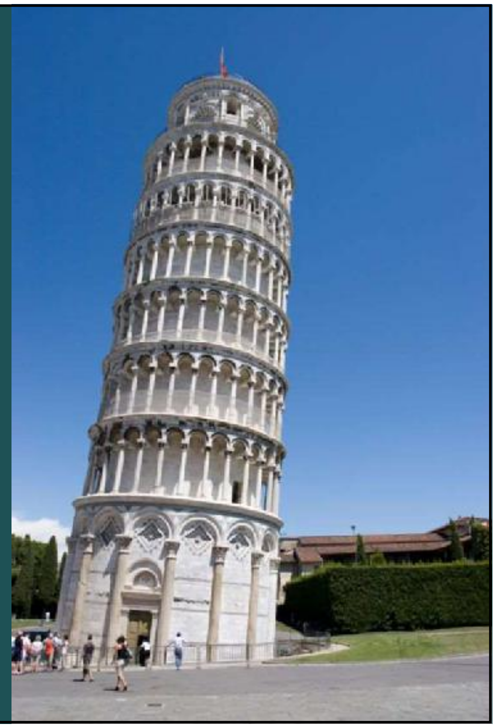
Consolidation Settlement

Structural Guide



Consolidation

- Occurs in Clay Soils
- When the application of additional load, pore water pressure in the saturated clay increases as the hydraulic conductivity of the clay is very small.
- Some time is required for excess pore water pressed to dissipate and increase the stress to be transferred to the soil skeleton.
- This gradual increase in the effective stress in the clay layer will cause settlement over a period of time and is referred to as consolidation settlement.

- Application of load tends to volumetric compression underlying soils. When the soil is saturated, pore water pressure increases immediately upon the application of loads.
- Consolidation is the process by which there is a reduction in volume due to the expulsion of water from the pores of the water.
- The dissipation of excess pore water pressure is accompanied by an increase in effective stress and volumetric strain. Cohesive soils have much lower hydraulic conductivity, and, as a result, consolidation required a far longer time to complete.

Consolidation Settlement

- Time dependence process
- Three-dimensional process, with water movement in any direction.
- However, with the soil confinement in the lateral direction, it could be considered as vertical
- Permeability of soil impacts on consolidation of soil

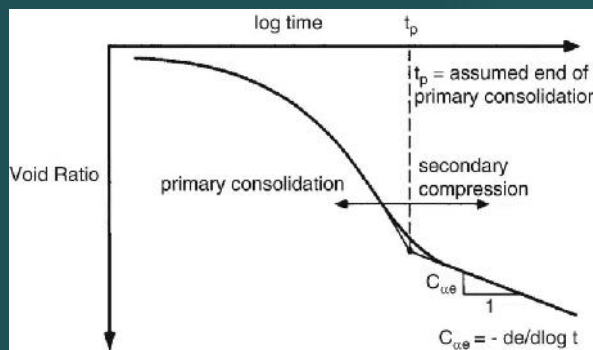
Stages of Consolidation

- Primary Consolidation Settlement
- Secondary Consolidation Settlement

Terminology

Primary Consolidation

- The process of dissipation of increased pour water pressure due to the application of loads on the soil layer and increase in the effective stress in the soil skeleton
- Settlement caused due to reduction of volume



Secondary Consolidation

- Occurs after the primary consolidation with the dissipation of the increased pore water pressure.
- Occurs with rearrangement of the soil skeleton with the dissipation of the pore water pressure and with the reduction of the volume.
- This is also called as creep Process

Primary Consolidation Settlement
Secondary Consolidation Settlement

Overconsolidation

- Comparison of stress acting on the soil in the current stage to its highest stress experienced by soil
- If the current stress is less than that applied in the past, the soil is overconsolidated.

Overconsolidation Ratio OCR

- Used to define the consolidation stage of the soil with respect to the past
- OCR = Highest stress experienced by soil / Current stress on soil
- It works like a factor of safety against further consolidation.

Normally Consolidated Soil

- A soil that is currently experiencing its highest stress is said to be "Normally Consolidated Soil" and has an OCR of one.
- Highest stress experience by soil = Current Stress on Soil
- The higher overburden pressure expense by the soil (weight or stress applied by the other layers on top) remains the same as now.

Preconsolidation Pressure

- The maximum effective vertical overburden stresses that a particular soil sample has sustained in the past.
- The preconsolidation pressure is also expressed in other terms such as pre-consolidation stress, precompression stress, pre-compaction stress, and preload stress.

Degree of Consolidation

Degree of Consolidation = Amount of consolidation at a given time with a soil mass / Total amount of Consolidation obtainable under the given stress condition.

Degree of Consolidation = Settlement of the clay layer at the time t after the load is applied / Maximum consolidation settlement that the clay layer will undergo under given loading.

Soil Type Undergo Consolidation

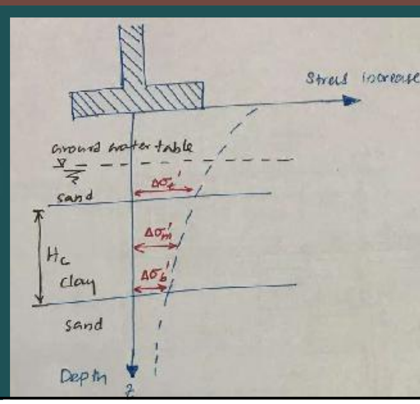
- Clay
- Organic Soils
- Silty Soils

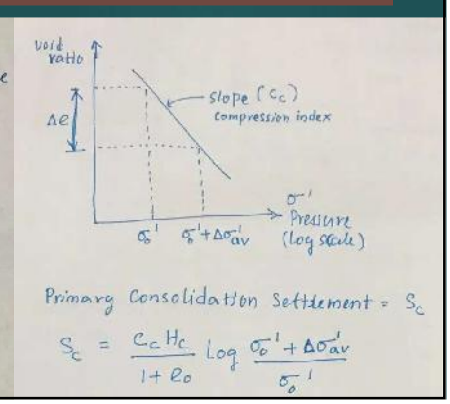
Primary Consolidation

- Two stages of soil are
  - Normally Consolidated Soil   - Current state same as past
  - Over Consolidated Soil – Previously higher load applied than now

Calculation of Consolidation Settlement of Normally Consolidated Soil

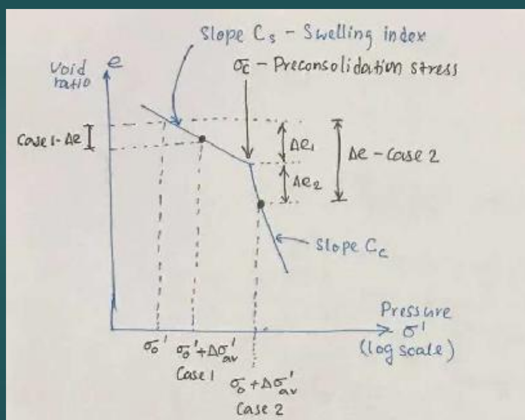
- Consider stress distribution under the foundation – on the clay layer
- Need to consider the average stress in the clay layer in settlement calculation.
- Average increase in the pressure in the clay layer can be calculated as
- $\Delta\sigma'_{av} = (1/6)[\Delta\sigma'_t + \Delta\sigma'_m + \Delta\sigma'_b]$





Calculation of Consolidation Settlement of Overconsolidated Consolidated Soil

- Case 01: Applied Stress is less than Preconsolidatioon Stress
- Case 02: Applied Stress is greater than Preconsolidation Stress



Case 01: Applied Stress less than Precompression Stress

$$\sigma_o' + \Delta\sigma_{av}' < \sigma_c'$$

$$S_c = \frac{C_s H_c}{1+e_o} \log \frac{\sigma_o' + \Delta\sigma_{av}'}{\sigma_o'}$$

Case 02: Applied Stress grater than Precompression Stress

$$\sigma_o' < \sigma_c' < \sigma_o' + \Delta\sigma_{av}'$$

$$S_c = \frac{C_s H_c}{1+e_o} \log \frac{\sigma_c'}{\sigma_o'} + \frac{C_c H_c}{1+e_o} \log \frac{\sigma_o' + \Delta\sigma_{av}'}{\sigma_c'}$$

Secondary Consolidation of Soil

- The settlement caused due to the plastic adjustment of the soil fabrics at the end of the primary consolidation is called secondary consolidation.
- Secondary Consolidation also can be explained as slippage and reorientation of soil particles under sustained loads.

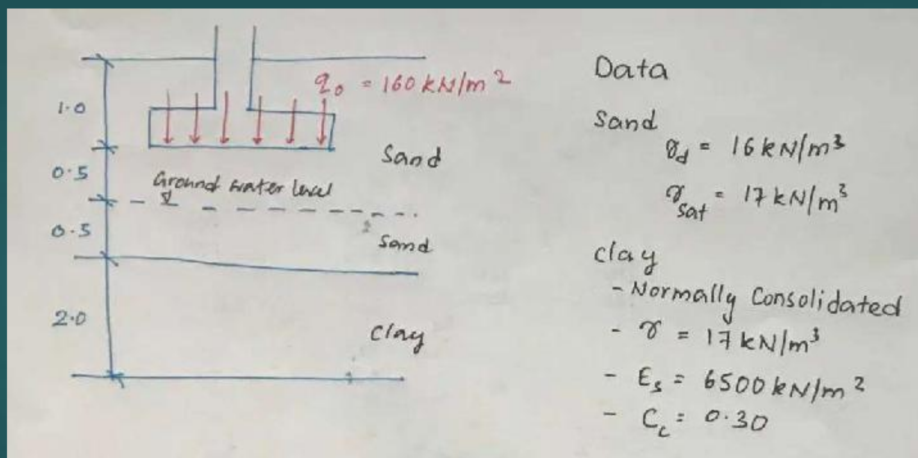
$$S_c = C_\alpha' H_c \log(t_2/t_1) \qquad C_\alpha' = C_\alpha / (1+e_p)$$

$$C_\alpha = \Delta e / \log(t_2/t_1)$$

e_p - void ratio at the end of Primary consolidation

- Organic and highly compressible soils are more susceptible to higher secondary consolidation
- The secondary consolidation is less significant in overconsolidated inorganic clays as the secondary compression index is very small.

Work Example: Primary Consolidation Settlement on Normally Consolidated Clay



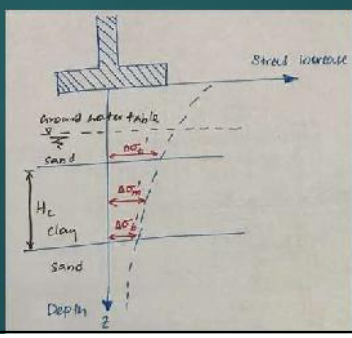
Work Example: Conti…

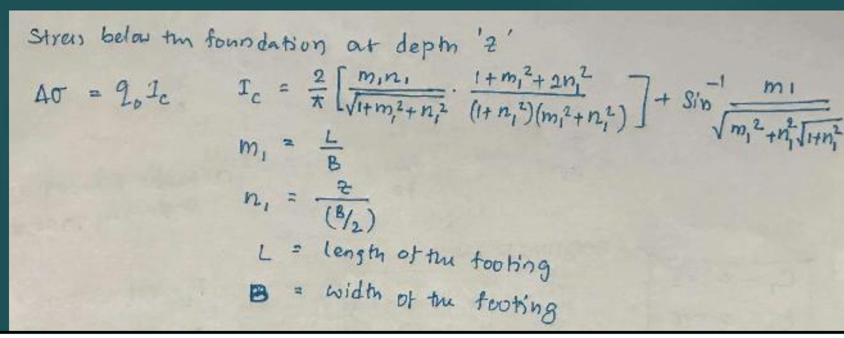
- Settlement can be calculated in normally consolidated soil from
- $S_c = C_c H_c/(1+e_0) \log[(\sigma'_0+\Delta\sigma'_{av})/\sigma'_0]$

- S_c – consolidation settlement in the normally consolidated clay
- C_c – Compression index – to be evaluated from the laboratory testing
- H_c – Height of the clay layer
- e_0 – Initial void ratio of the clay layer – to be obtained from the laboratory testing of undisturbed sample
- σ'_0 – Soil stress at mid-height of the clay layer
- $\Delta\sigma'_{av}$ – Average increase in the stress in the clay layer due to the foundation load

Work Example: Conti…

- Calculate soil stress (σ'_0) at mid-height of the clay layer
  - σ'_0 = 1.5×16 + 0.5(17-9.81) + 1x(17-9.81) = 34.785 kN/m^2
- Calculate Increase in the Soil Stress due to Foundation load at Mid Height of the Clay Layer
  - $\Delta\sigma'_{av} = (1/6)[\ \Delta\sigma'_t + 4\Delta\sigma'_m + \Delta\sigma'_b\ ]$
- We may refer to book Principles in Foundation Engineering for easy method





Work Example: Conti…

- Consider the width and length of the foundation as (BxL = 1mx2m). The depth"z" is measured from the bottom of the foundation.
- q_0 = 150 kN/m^2 e_0 – 0.8

Stress	m_1	z	n_1	I_c	q_0I_c
$\Delta\sigma'_t$	2	1	1	0.800	120
$\Delta\sigma'_m$	2	2	4	0.190	28.5
$\Delta\sigma'_b$	2	3	6	0.095	14.25

- $\Delta\sigma'_{av} = (1/6)[\ \Delta\sigma'_t + 4\Delta\sigma'_m + \Delta\sigma'_b\ ]$
- $\Delta\sigma'_{av}$ = (1/6)[120 + 4×28.5 + 14.25] = 41.375 kN/m^2

Calculate Settlement

- $S_c = C_cH_c/(1+e_0)\ \log[(\sigma'_0+\Delta\sigma'_{av})/\sigma'_0]$
- S_c = 0.3×2/(1+0.8) log[(34.785+41.375)/34.785] = 0.113 m = 113 mm

Thank you

Structural Guide

Civil & Structural Engineering Knowledge Base