نقابـــة المهندســــــين

الدورة التأهيلية لنيل مرتبة المهندس الاستشاري

في اختصاص هندسة الجيوتكنيك

Lecture

2

Settlement of Shallow Foundation

هبوط الأســــــاســــات الســطحية

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References

Bowles , J.,E.,(1996) "Foundation Analysis and Design" -5th ed. McGraw-Hill, ISBN 0-07-912247-7.
Das, B., M. (2012), " Principles of Foundation Engineering " Eighth Edition, CENGAGE Learning, ISBN-13: 978-1-305-08155-0.

Introduction

Foundation settlements must be estimated with great care for buildings, bridges, towers, power plants, and similar high-cost structures.
For structures such as fills, earth dams, levees, braced sheeting, and retaining walls a greater margin of error in the settlements can usually be tolerated.

Introduction

The settlement of a shallow foundation can be divided into two major categories: (a) elastic, or immediate, settlement and (b) consolidation settlement. Immediate, or elastic, settlement of a foundation takes place during or immediately after the construction of the structure.

Introduction

Consolidation settlement or those that are time-dependent and take months to years to develop.

Pore water is extruded from the void spaces of saturated clayey soils submerged in water.

The total settlement of a foundation is the sum of the elastic settlement and the consolidation settlement.

Introduction

Consolidation settlement comprises two phases: primary and secondary.
Secondary consolidation settlement occurs after the completion of primary consolidation caused by slippage and reorientation of soil particles under a sustained load.

Introduction

Primary consolidation settlement is more significant than secondary settlement in inorganic clays and silty soils. However, in organic soils, secondary consolidation settlement is more significant.

Immediate settlement

Immediate settlement analyses are used for all fine-grained soils including silts and clays with a degree of saturation $S \leq 90$ percent and for all coarse-grained soils with a large coefficient of permeability.

Immediate settlement

Settlement Based on the Theory of Elasticity

The elastic settlement of a shallow foundation can be estimated by using the theory of elasticity. From Hooke's law we obtain

$$S_e = \int_0^H \varepsilon_z \, d_z = \frac{1}{E_s} \int_0^H \left(\Delta\sigma_z - \mu_s \, \Delta\sigma_x - \mu_s \, \Delta\sigma_y \right) d\, z$$

Where: $S_e =$ elastic settlement $\quad H =$ thickness of soil layer

$E_s =$ modulus of elasticity of soil

$\mu_s =$ Poisson's ratio of the soil

$\Delta\sigma_z, \Delta\sigma_x, \Delta\sigma_y =$ stress increase due to *the net applied foundation load in the x, y, and z directions, respectively*

Immediate settlement

Settlement Based on the Theory of Elasticity

The settlement of the corner of a rectangular base of dimensions $B' * L'$ on the surface of an elastic half-space can be computed from an equation from the Theory of Elasticity as follows:

$$S_e = q_o \ B' \frac{1-\mu^2}{E_s} I_s I_f$$

Immediate settlement

Settlement Based on the Theory of Elasticity

$$S_e = q_o \ B' \frac{1-\mu^2}{E_s} I_s I_f$$

$q_o = intesity\ of\ contact\ pressure\ in\ units\ of\ E_s$

$E_s = average\ elasticity\ mudulus\ of\ soil$

$B' = least\ lateral\ dimensionof\ contributing\ base\ area$

$I_s = influence\ factor\ , which\ depend\ on\ \frac{L'}{B'}, thickness\ of\ stratum\ H, Poisson's\ ratio\ \mu. and\ foundation\ depth\ D_f$

$$I_s = I_1 + \frac{1-2\mu}{1-\mu} I_2$$

Immediate settlement

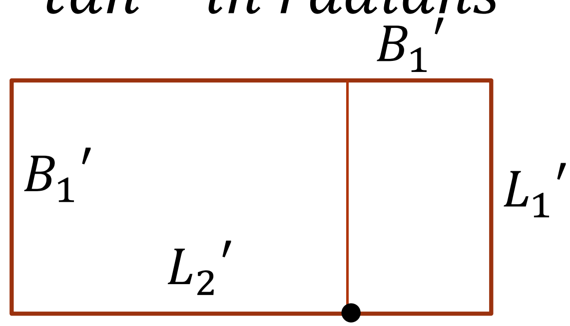
Settlement Based on the Theory of Elasticity

The influence factors I1 and I2 can be computed using equations given by Steinbrenner as follows:

$$I_1 = \frac{1}{\pi}\left[M\ln\frac{\left(1+\sqrt{M^2+1}\right)\sqrt{M^2+N^2}}{M\left(1+\sqrt{M^2+N^2+1}\right)} + \ln\frac{\left(M+\sqrt{M^2+1}\right)\sqrt{1+N^2}}{\left(M+\sqrt{M^2+N^2+1}\right)}\right]$$

$$I_2 = \frac{N}{2\pi}\tan^{-1}\left(\frac{M}{N\sqrt{M^2+N^2+1}}\right) \qquad \tan^{-1} \text{in radians}$$

where $M = \frac{L'}{B'}$ $\quad N = \frac{H}{B'}$



Immediate settlement

Settlement Based on the Theory of Elasticity Theory

The influence factor I_f is from the Fox equations, which suggest that the settlement is reduced when it is placed at some depth in the ground, depending on Poisson's ratio and L/B.

$$I_f = 0.66\left(\frac{D_f}{B}\right)^{-0.19} + 0.025\,(\frac{L}{B} + 12\mu - 4.6)$$

Immediate settlement

Settlement Based on the Theory of Elasticity Theory

$$S_e = q_o \; B' \, \frac{1-\mu^2}{E_s} I_s I_f$$

This equation is strictly applicable to flexible bases on the half-space.

If your base is "rigid" you should reduce the Is factor by about 7 percent (that is, Isr = 0.931 Is).

Immediate settlement

Settlement Based on the Theory of Elasticity Theory

Note that the stratum depth actually causing settlement is not at $\frac{H}{B} = \rightarrow \infty$ *but is at either of the following:*

a. Depth z =5B where B = least total lateral dimension of base.

b. Depth to where a hard stratum is encountered.

$$E_{sav} = \frac{\sum_{i=1}^{z=H} E_{si} H_i}{H}$$

Immediate settlement

Settlement of Sandy Soil: Use of Strain Influence Factor

The settlement of granular soils can also be evaluated by the use of a semiempirical strain influence factor proposed by Schmertmann et al. (1978).

Immediate settlement

Settlement of Sandy Soil: Use of Strain Influence Factor

According to this method the settlement is

$$S = C_1 C_2 (\, q_o - q) \sum \frac{I_z}{E_s} \Delta z$$

where:

$$C_1 = 1 - 0.5 \left(\frac{q}{q_o - q} \right) = a\ corection\ factor\ for\ a\ depth\ of\ foundation$$

$$C_2 = 1 + 0.2\ log \frac{Time\ in\ years}{0.1} = a\ correction\ factor\ for\ a\ creep\ in\ soil$$

$q_o = stress\ at\ the\ level\ of\ foundation,$ $\quad E_s = \ elasticity\ mudulus\ of\ soil$

$q = \gamma\ D_f = effective\ stress\ at\ the\ level\ of\ foundation$

$I_z = strain\ influence\ factor$

Immediate settlement

Settlement of Sandy Soil: Use of Strain Influence Factor

The following relations are suggested to determine the strain influence factor

I_z at $Z = 0$ $$I_z = 0.1 + \frac{0.1}{9}\left(\frac{L}{B} - 1\right) \leq 0.2$$

Variation of Z_1 for I_{zm} $$z_1 = 0.5B + \frac{0.5B}{9}\left(\frac{L}{B} - 1\right) \leq B$$

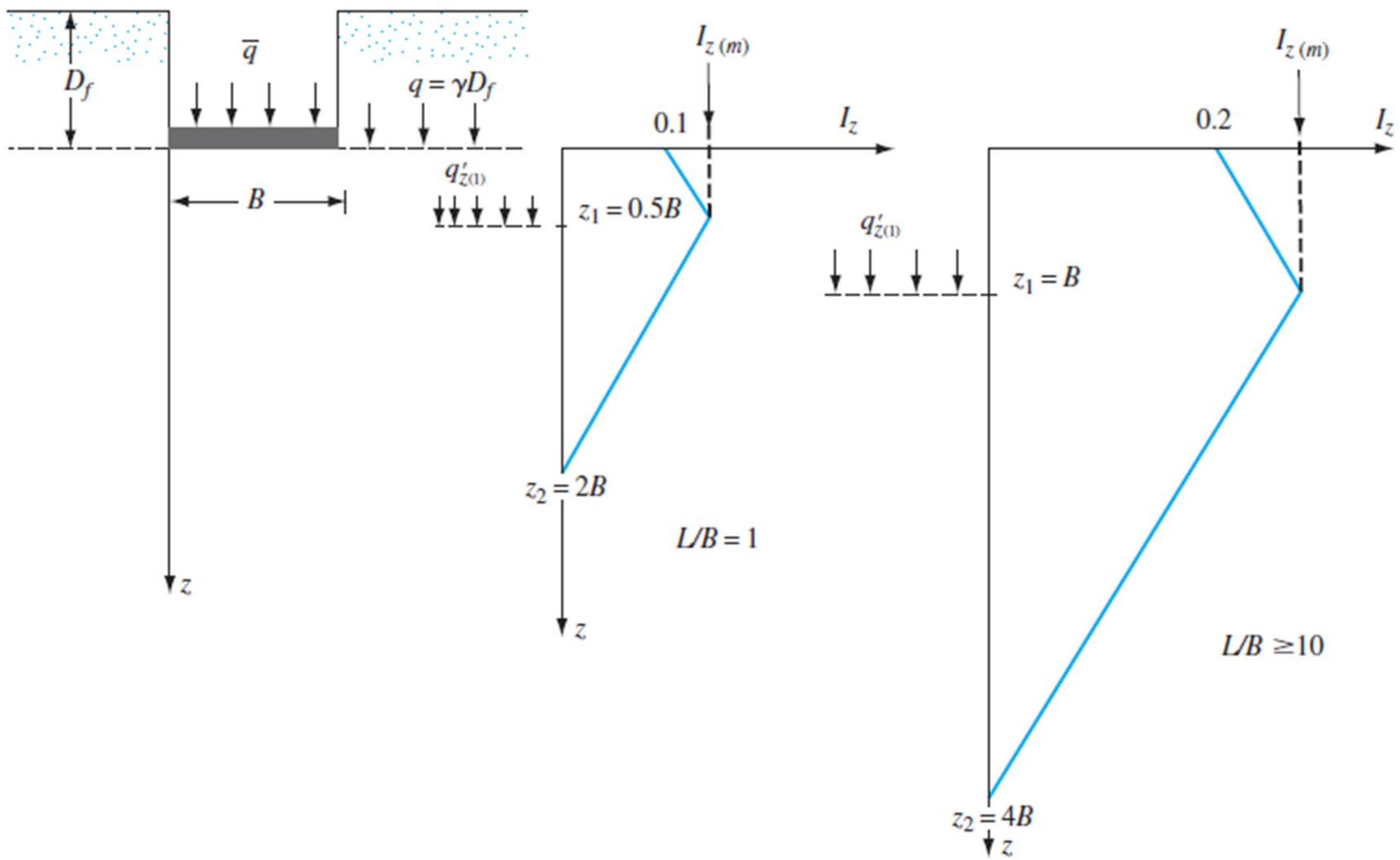
Variation of Z_2 for $I_z = 0$ $$z_2 = 2B + \frac{2B}{9}\left(\frac{L}{B} - 1\right) \leq 4B$$

The maximum value of Iz can be calculated as $$I_{zm} = 0.5 + 0.1\sqrt{\frac{q_o - q}{q_{z1}}}$$

q_{z1} = effective stress at a depth Z_1

Immediate settlement

Settlement of Sandy Soil: Use of Strain Influence Factor



Primary Consolidation Settlement

On the basis of the one-dimensional consolidation settlement equations we write

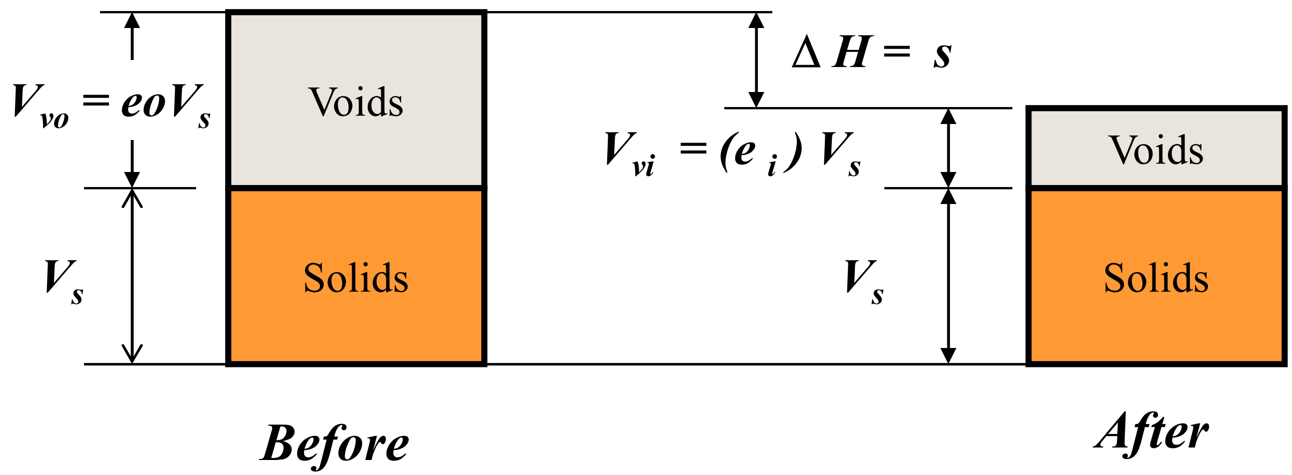
$$S_{c(p)} = \int_0^H \varepsilon_z \, d_z$$

where :

$$\varepsilon_z = \frac{\Delta e}{1 + e_o}$$

$$\frac{\Delta h}{h} = \frac{e_o - e_i}{1 + e_o}$$

Primary Consolidation Settlement



$$V_s = \frac{V_{To}}{1 + e_o}$$

$$V_s = \frac{V_{Ti}}{1 + e_i}$$

$$\frac{V_{Ti}}{V_o} = \frac{1 + e_i}{1 + e_o}$$

$$e_i = e_o - (1 + e_o)\frac{\Delta h}{h}$$

Primary Consolidation Settlement

The consolidation settlement Sc due to this average stress increase can be calculated as follows:

For normally consolidated clay

$$S = \frac{c_c\ h}{1 + e_o} log\left(\frac{\sigma'_{vo} +\ \Delta\sigma_v}{\sigma'_{vo}}\right)$$

For overconsolidated clay with $\sigma'_{vo} +\ \Delta\sigma_v \leq P'_c$

$$S = \frac{c_s\ h}{1 + e_o} log\left(\frac{\sigma'_{vo} +\ \Delta\sigma_v}{\sigma'_{vo}}\right)$$

Primary Consolidation Settlement

$$\textit{For overconsolidated clay with}$$

$$\sigma'_{vo} \leq P'_c \leq \sigma'_{vo} + \Delta\sigma_v$$

$$S = \frac{c_s\ h}{1+e_o} log\left(\frac{P'_c}{\sigma'_{vo}}\right) + \frac{c_c\ h}{1+e_o} log\left(\frac{\sigma'_{vo} + \Delta\sigma_v}{P'_c}\right)$$

where

$C_c = \textit{compression index}$

$C_s = \textit{swelling index}$

$e_o = \textit{initial void ratio of the clay layer}$

$P'_c = \textit{preconsolidation pressure}$

$h = \textit{thickness of the clay layer}$

$\sigma'_{vo} = \textit{overburden effective pressure at the middle of the clay layer}$

Primary Consolidation Settlement

$\Delta\sigma_v = average\ increase\ in\ pressure\ on\ the\ clay$
$layer\ caused\ by\ the\ construction\ of\ foundation$

Note that the increase in effective pressure, $\Delta\sigma_v$*, on the clay layer is not constant with depth: The magnitude of* $\Delta\sigma_v$ *will decrease with the increase in depth measured from the bottom of the foundation. However, the average increase in pressure may be approximated by*

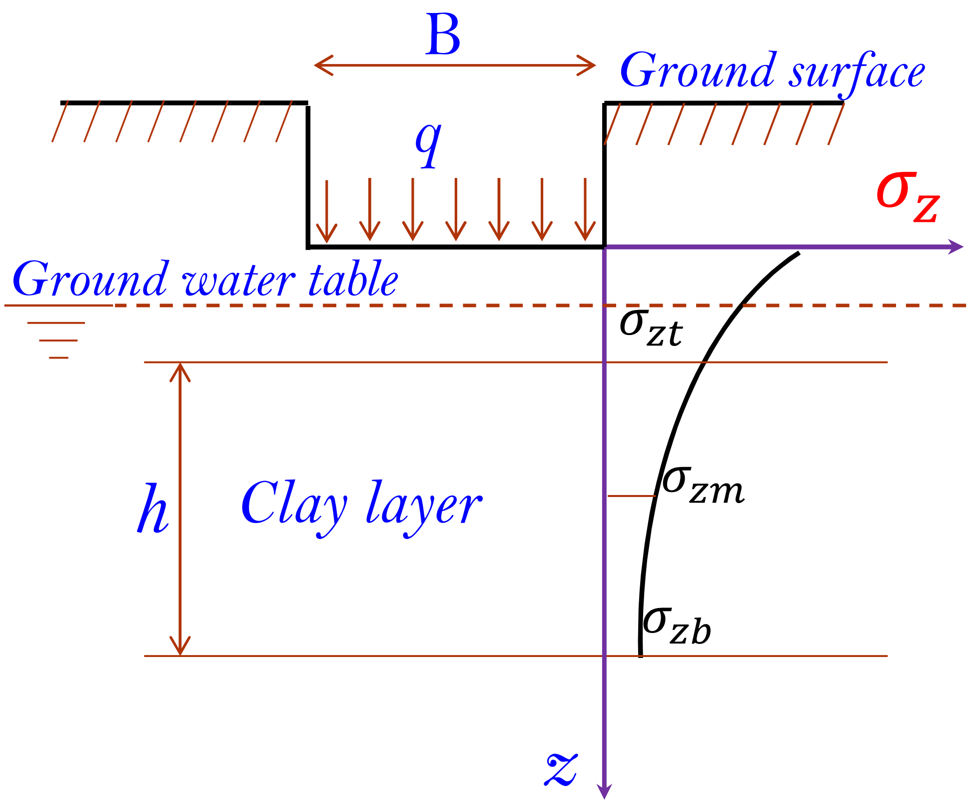
$$\Delta\sigma_v = \frac{1}{6}(\sigma_{zt} + 4\sigma_{zm} + \sigma_{zb})$$

Primary Consolidation Settlement

Primary consolidation settlement calculation

where :

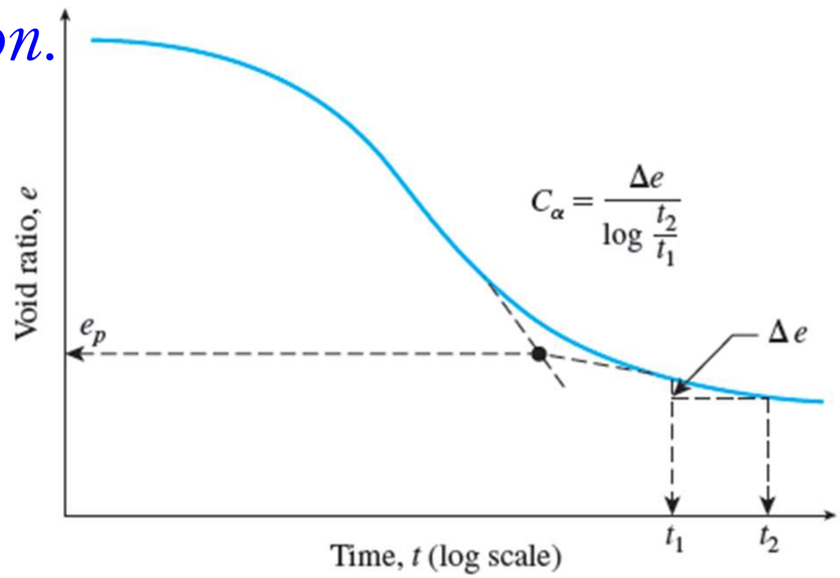
σ_{zt}, σ_{zm}, *and* σ_{zb} *are, respectively, the pressure increases at the top, middle, and bottom of the clay layer that are caused by the construction of the foundation.*



Secondary Consolidation Settlement

At the end of primary consolidation (i.e., after the complete dissipation of excess pore water pressure) some settlement is observed that is due to the plastic adjustment of soil fabrics. This stage of consolidation is called secondary consolidation.

A plot of deformation against the logarithm of time during secondary consolidation is practically linear as shown in Figure.



Secondary Consolidation Settlement

From the figure , the secondary compression index can be defined as

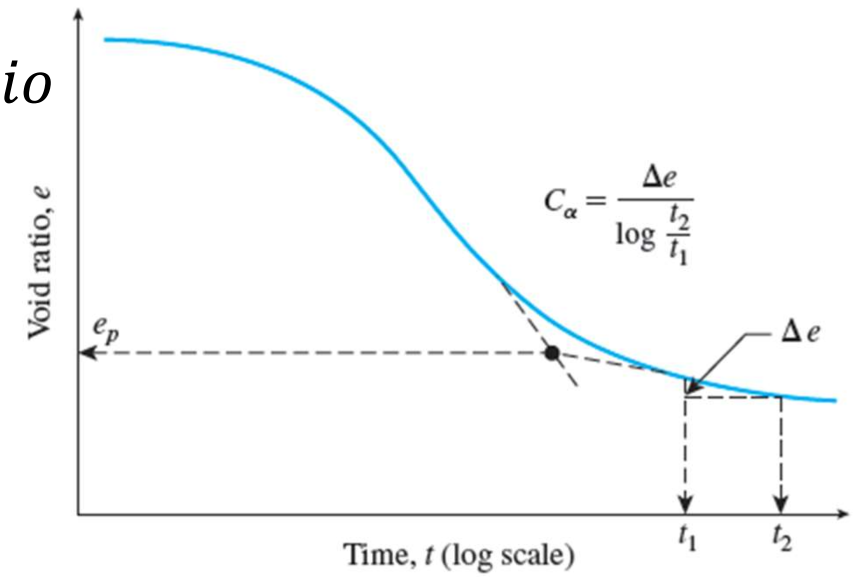
where

$$C_\alpha = \frac{\Delta e}{log t_2 - log t_1}$$

$C_\alpha = secondary\ compression\ index$

$\Delta e = change\ of\ void\ ratio$

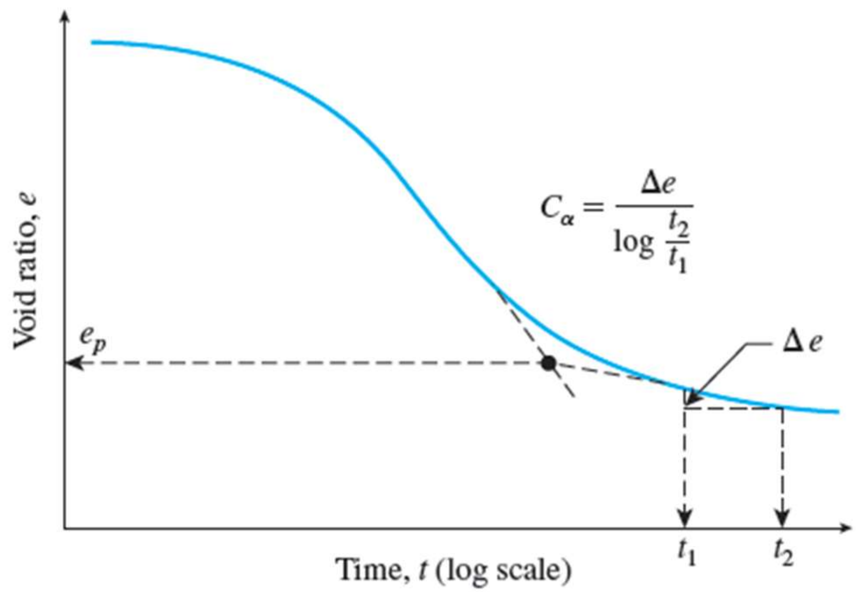
$t_1 and\ t_2 = time$



Secondary Consolidation Settlement

The magnitude of the secondary consolidation can be calculated as

$$S_{cs} = C'_{\alpha} h \log(t_2/t_1)$$



where

$$C'_{\alpha} = \frac{C_{\alpha}}{1 + e_p}$$

$e_p = \textit{void ratio at the end of primary consolidation}$

$h = \textit{thickness of the clay layer}$

Secondary Consolidation Settlement

Secondary consolidation settlement is more important in the case of all organic and highly compressible inorganic soils.
In overconsolidated inorganic clays, the secondary compression index is very small and of less practical significance.

Time Rate of Consolidation

Degree of consolidation

The average degree of consolidation for the entire depth of the clay layer at any time t can be expressed as

$$U = \frac{S_t}{S_f} = 1 - \frac{\left(\frac{1}{2H_{dr}}\right)\int_0^{2H_{dr}} u_z\, dz}{u_o}$$

where

$U =$ *average degree of consolidation*

$S_t =$ *settlement of the layer at time t*

$S_f =$ *final settlement of the layer from primary consolidation*

Time Rate of Consolidation

Degree of consolidation

The values of the time factor and their corresponding average degrees of consolidation for the case presented in may also be approximated by the following simple relationship:

$$For\ U = 0\ to\ 60\%,\ \ T_v = \frac{\pi}{4}\left(\frac{U\%}{100}\right)^2$$

$$For\ U > 60\%,\ \ T_v = 1.781 - 0.933 log(100 - U\%)$$

$$T_v = \frac{C_v\, t}{H_{dr}^2}$$

End of the Lecture

Let Learning Continue