University of Baghdad
College of Engineering
Civil Engineering Department

Title: Lecture 3: Normally Consolidated & Overconsolidated Clay, Stresss -Void Ratio Curve

Subject: Soil Mechanics II

Year: Third

Semester: 2

Speaker: Prof. Dr. Nesreen Kurdy Al-Obaidy

References:

Principles of Geotechnical Engineering, Textbook by Das,2010

Fundamentals-of-Geotechnical-Engineering-Third-Edition, Textbook by Das

Maximum Effective Past Pressure in Soil Geologic History

Normally consolidated clay

Overconsolidated clay

Determination the preconsolidation pressure from the laboratory $e - \log\sigma^{`}$ plot

Empirical relationships to predict preconsolidation pressure

Factors Effect Void Ratio–Pressure Relationship

Calculation of Settlement from One-Dimensional Primary Consolidation

Maximum Effective Past Pressure in Soil Geologic History

The maximum effective past pressure is called the ***preconsolidation pressure*** (σ'_c)

At the time of sampling,
The **maximum effective past pressure** (σ'_c) **could be** $\leq$ the **existing effective overburden pressure** (σ'_o).

Why (σ'_c) **could be** $\leq (\sigma'_o)$**?**

The **reduction of effective pressure in the field** may be caused by **natural geologic processes** or **human processes**. **During the soil sampling**, the existing effective overburden pressure is also **released**, which results in some **expansion**.

When the specimen is subjected to a consolidation test,

the effective pressure applied < the maximum effective past overburden pressure (**Overconsolidated**

a small amount of compression (that is, a small change in void ratio) will occur

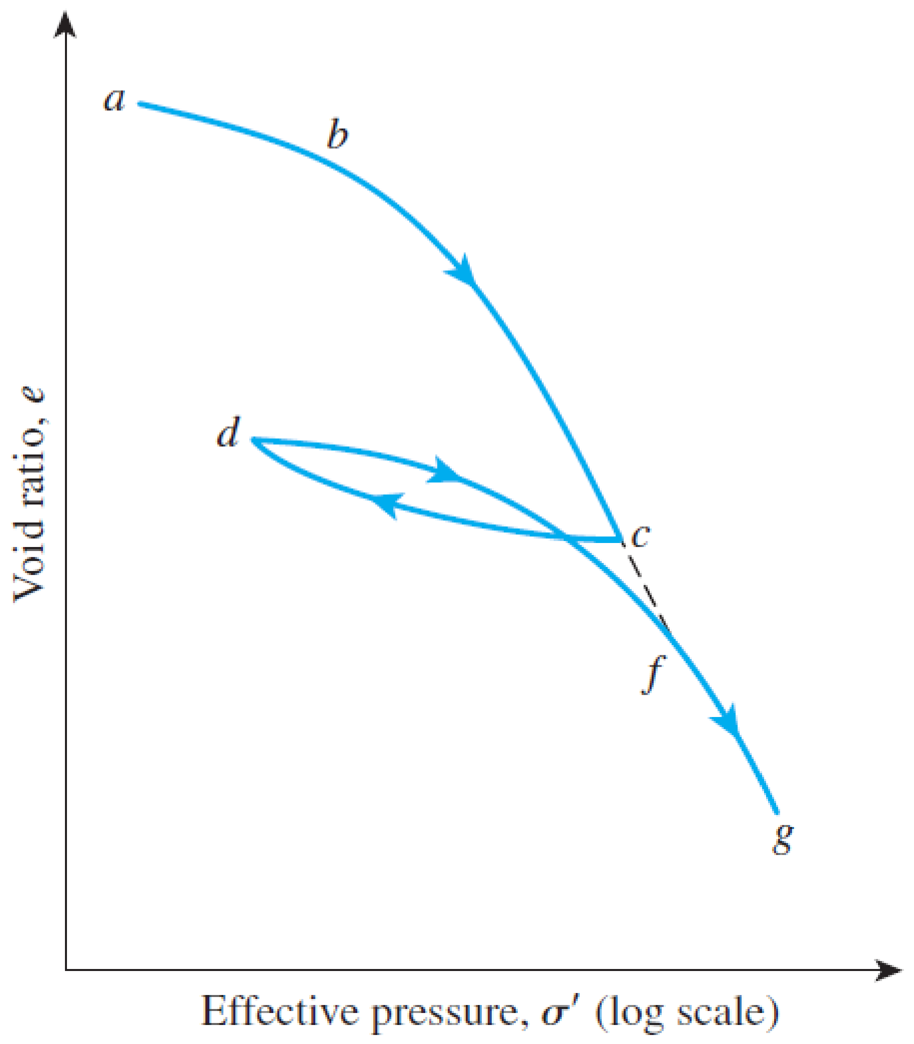
the effective pressure applied ≥ the maximum effective past overburden pressure (**Normally consolidated or Underconsolidated)**

The change in the void ratio is much larger, and the $e - \log \sigma^{`}$ relationship is practically linear with a steeper slope.

Note: 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.

How to verify the relationship in the laboratory ?

- This **relationship** can be **verified** in the **laboratory** by ***loading*** the specimen to **exceed** the maximum effective overburden pressure, and then ***unloading*** and ***reloading*** again. The $e - \log \sigma`$ plot for such cases is shown in Figure below, in which *cd* represents unloading and *dfg* represents the reloading process.



What are the two types of clay based on stress history

1. **Normally consolidated clay NCC**, whose **present** effective overburden pressure **is the maximum pressure** that the soil was subjected to in the **past**. ($\sigma_o^` = \boldsymbol{\sigma_c^`}$)

2. **Overconsolidated clay, OCC** whose **present** effective overburden pressure is **less than (<**)that which the soil experienced in the **past**. **(**$\sigma_o^` < \boldsymbol{\sigma_c^`}$**)**

The overconsolidation ratio (OCR) for a soil can now be defined as

$$OCR = \frac{maximum\ overburden\ effective\ stress\ \boldsymbol{in\ past}}{\boldsymbol{current}\ overburden\ effective\ stres}$$

$$OCR = \frac{\sigma_c^`}{\sigma_o^`}$$

$OCR = 1$ *the soil is NCC*

$OCR > 1$ *the soil is OCC*

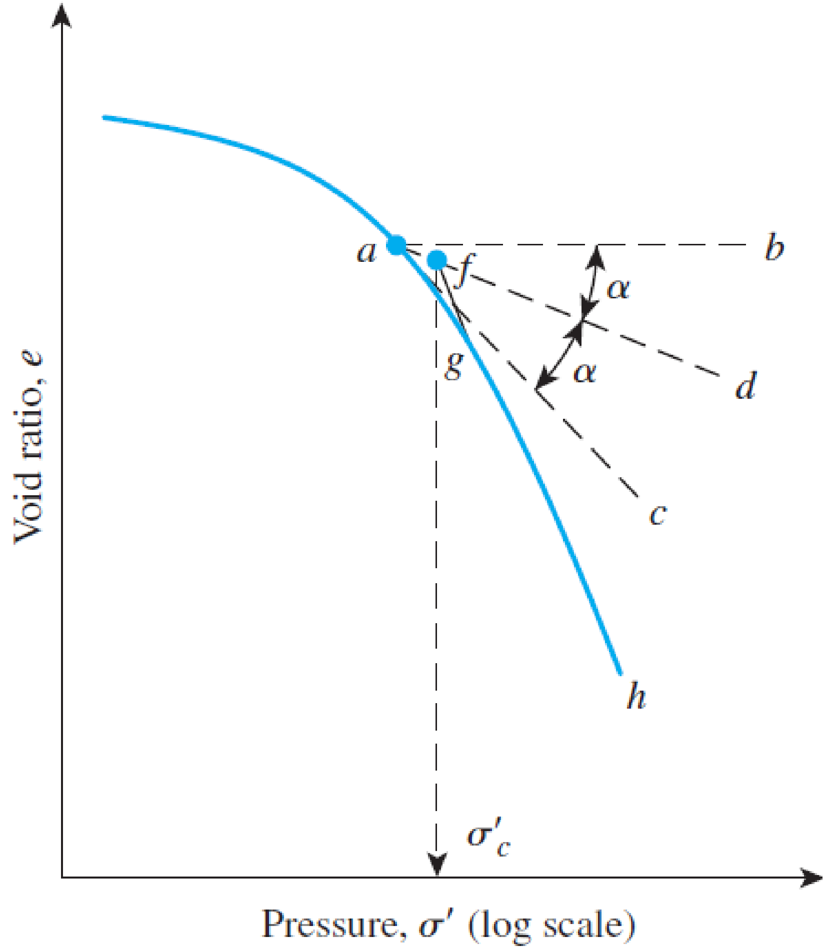
$OCR < 1$ *the soil is UCC*

UCC: Underconsolidated clay

Determination the preconsolidation pressure from the laboratory $e - \log\sigma`$ plot

Casagrande (1936) suggested a simple graphic construction

- 1. By visual observation, establish point ***a***, at which the $\boldsymbol{e - log\,\sigma`}$ plot has a minimum radius of curvature. 2. Draw a horizontal line ***ab***. 3. Draw the line ***ac*** tangent at ***a***.
- 4. Draw the line ***ad***, which is the bisector of the angle ***bac***. 5. Project the straight-line portion ***gh*** of the $\boldsymbol{e - log\,\sigma`}$ plot back to intersect line ***ad*** at ***f***. The abscissa of point *f* is the preconsolidation pressure $\boldsymbol{\sigma`_c}$



Empirical relationships to predict preconsolidation pressure

. • Stas and Kulhawy (1984): $\frac{\sigma_c^{`}}{P_a} = 10^{[1.11-1.62LI]}$

where P_a atmospheric pressure ≅ (100 kN/m^2), LI liquidity index

• Hansbo (1957) $\sigma_c^{`} = \alpha_{VST}\, C_{u\ VST}$

α_{VST}: an empirical coefficient= $\frac{222}{LL\%}$

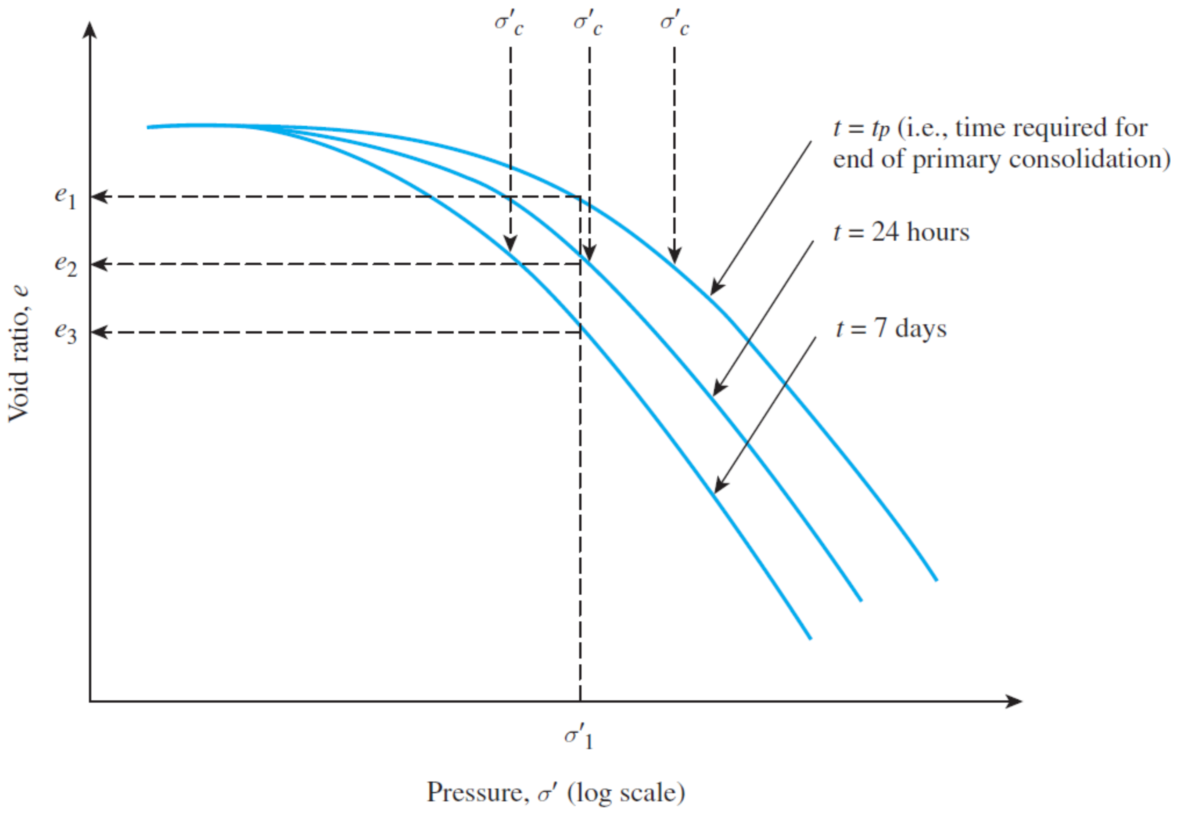
$C_{u\ VST}$:undrained shear strength obtained from vane shear test

In any case, these above relationships may change from soil to soil. They may be taken as an **initial approximation.**

What will happen to the $e - \log \sigma`$ curve if a given load on a specimen is kept for a time t =24 hours?

Crawford (1964) has conducted several laboratory tests on Leda clay

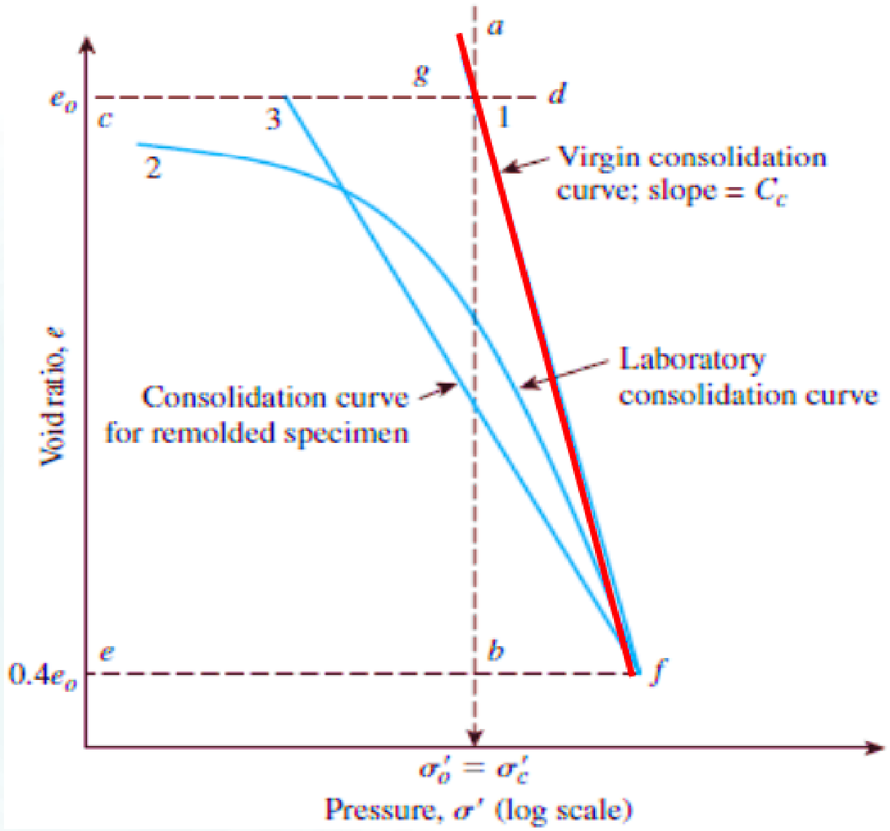
It may be seen that when the **duration** of load maintained on a specimen is **increased**, The $e - \log \sigma`$ curve gradually **moves** to the **left.** This means that, for a given load per unit area on the specimen the void ratio at the end of consolidation will decrease as time t is increased the amount of the secondary consolidation of the specimen is also increased



This will give slightly different values for the preconsolidation pressure

Effect of Disturbance on Void Ratio–Pressure Relationship

A soil specimen will be **remolded** when it is subjected to some degree of **disturbance**. This **remolding** will result in some **deviation** of $e - \log \sigma'$ plot as observed in the laboratory from the actual behavior in the field. The field $e - \log \sigma'$ plot can be reconstructed from the laboratory test results in the manner described by (Terzaghi and Peck, 1967).



Normally Consolidated Clay of Low to Medium Plasticity

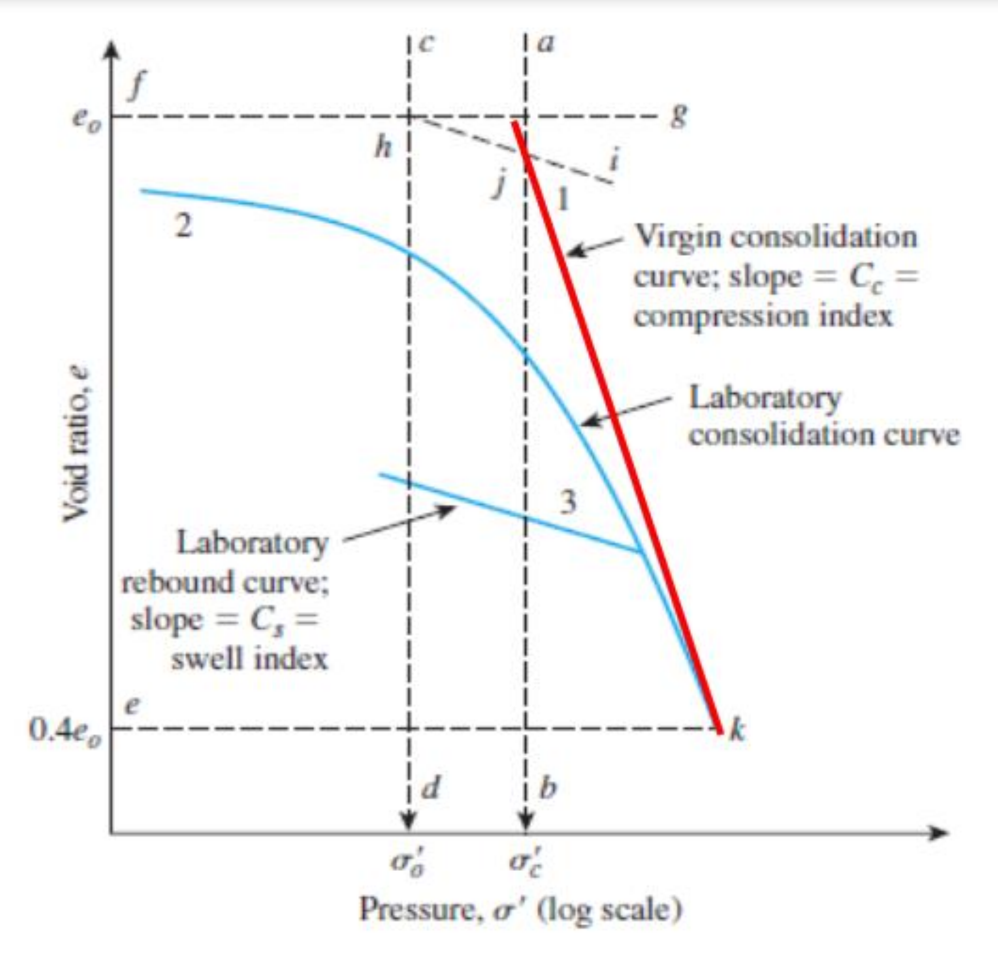
- **Determine from Curve 2 (Laboratory test) the preconsolidation pressure $\sigma'_c = \sigma'_o$**
- **Draw a vertical line *ab***
- **Calculate the void ratio in the field e_o**

$$e_o = \frac{V_v}{V_s} = \frac{H_v\,A}{H_s\,A} = \frac{H_v}{H_s} \qquad H_s = \frac{W_s}{A G_s \gamma_w} \qquad H_v = H - H_s$$

- **Draw a horizontal line *cd***
- **Calculate $0.4e_o$ Draw a horizontal line *ef***
- **Join Points *f* and *g***

This is the virgin compression curve

Effect of Disturbance on Void Ratio–Pressure Relationship



Over-consolidated Clay of Low to Medium Plasticity

- **Determine from Curve 2 (Laboratory test) the preconsolidation pressure σ'_c**
- **Draw a vertical line *ab***
- **Determine the field effective overburden pressure σ'_o Draw a vertical line *cd***
- **Calculate the void ratio in the field e_o**

$$e_o = \frac{V_v}{V_s} = \frac{H_v A}{H_s A} = \frac{H_v}{H_s}$$ $$H_s = \frac{W_s}{AG_s\gamma_w}$$ $$H_v = H - H_s$$

- **Draw a horizontal line *fg***
- **Calculate *0.4*e_o Draw a horizontal line *ek***
- **Draw a line *hi* parallel to curve 3**
- **Join Points *k* and *j***

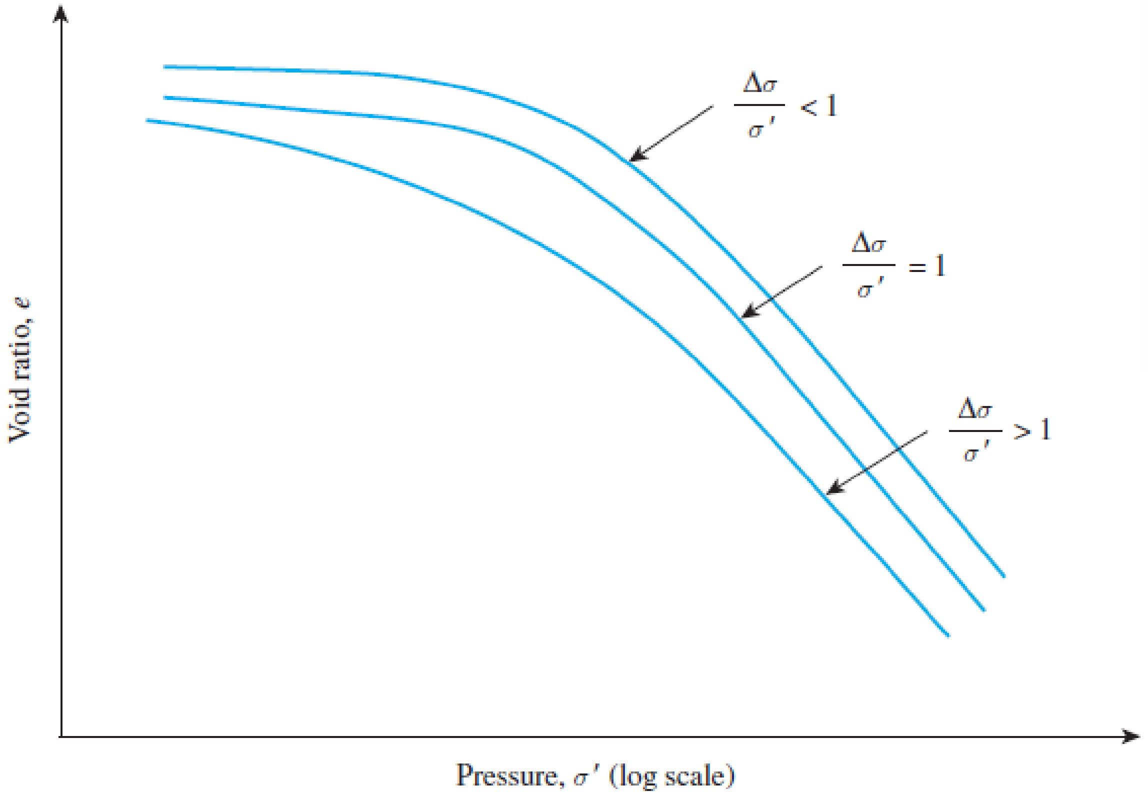
This is the virgin compression curve

What will happen to the the $e - \log \sigma'$ curve if other factors remaining the same, the load increment ratio $\Delta\sigma/\sigma'$ on the specimen is kept at values other than one?

Based on Leonards and Altschaeffl (1964).

When $\frac{\Delta\sigma}{\sigma'}$ is increased,

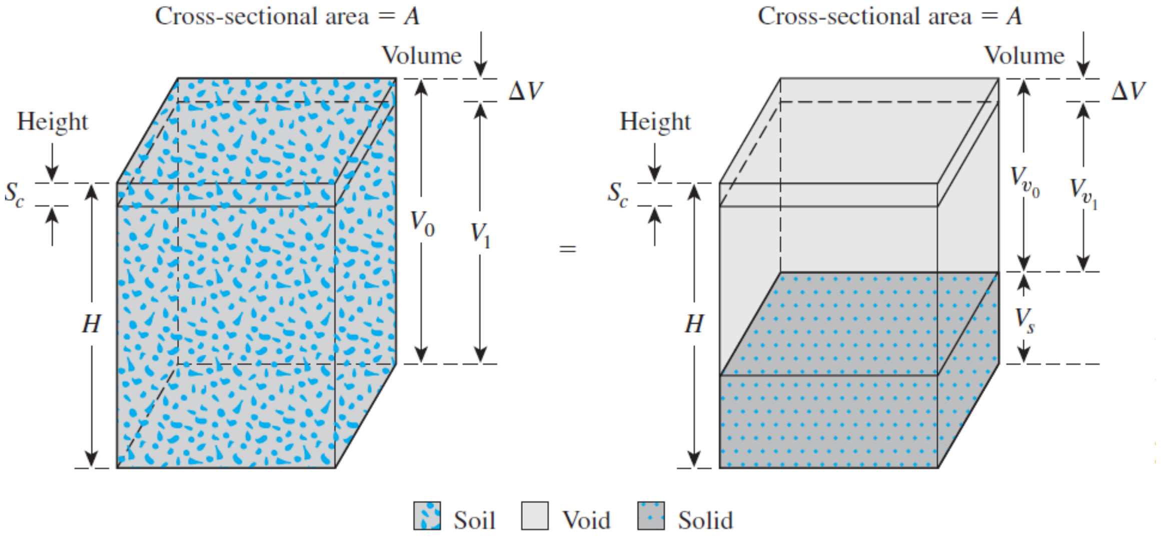
the e log σ' curve gradually moves **down**.



Calculation of Settlement from One-Dimensional Primary Consolidation

If the primary settlement be *Sc*, *the change of volume for* saturated clay layer of thickness *H* and cross-sectional area *A* under an existing average effective overburden pressure

- $\Delta V = V_o - V_f = HA - (H - Sc)A = Sc\ A$
- $\Delta V = Sc\ A = V_{vo} - V_{vf} = \Delta V_v$
- $\Delta V_v = \Delta e V_s$
- $V_s = \frac{V_o}{1+e_o} = \frac{HA}{1+e_o}$
- $\Delta V = Sc\ A = \Delta V_v = \Delta e V_s = \frac{\Delta e}{1+e_o} HA$



$Sc = \frac{\Delta e}{1+e_o} H$ from oedometer $Sc = m_v \Delta\sigma' H$ $\quad m_v = \frac{a_v}{1+e_o}$

where m_v = coefficient of volume compressibility; a_v = coefficient of compressibility of soil $= \frac{\Delta e}{\Delta\sigma'}$ **Coefficient of consolidation** $C_v = \frac{k}{m_v \gamma_w}$

Calculation of Settlement from One-Dimensional Primary Consolidation

For NCC

$$Sc = \frac{c_c H}{1 + e_o} \log \frac{\sigma_o^{`} + \Delta\sigma'}{\sigma_o^{`}}$$

c_C: Compression Index

For OCC

When $\sigma_o^{`} + \Delta\sigma' \leq \sigma_c^{`}$

$$Sc = \frac{c_s H}{1 + e_o} \log \frac{\sigma_o^{`} + \Delta\sigma'}{\sigma_o^{`}}$$

c_s: Swelling Index

When $\sigma_o^{`} + \Delta\sigma' > \sigma_c^{`}$

$$Sc = \frac{c_s H}{1 + e_o} \log \frac{\sigma_c^{`}}{\sigma_o^{`}} + \frac{c_c H}{1 + e_o} \log \frac{\sigma_o^{`} + \Delta\sigma'}{\sigma_c^{`}}$$

Note: primary settlement be *Sc can be also denoted by Sp*

Correlations for Compression Index (Cc)

- Skempton (1944) $C_c = 0.009(LL - 10)$ For undisturbed low to medium sensitivity soils
- $C_c = 0.007(LL - 10)$ For disturbed (remolded) low to medium sensitivity soils

Rendon-Herrero (1983) $C_c = 0.141\, Gs^{1.2} \left(\frac{1 + e_o}{Gs}\right)^{2.38}$

Nagaraj and Murty (1985) $C_c = 0.2343 \left[\frac{LL\%}{100}\right] Gs$

Wroth and Wood (1978) $C_c \approx 0.5 \left[\frac{PI\%}{100}\right] Gs$

If an average value of *Gs* is taken to be about 2.7 (Kulhawy and Mayne, 1990) $C_c \approx \frac{PI}{74}$

Park and Koumoto (2004) expressed the compression index as a function to the insitu porosity

$$C_c = \frac{n_o}{371.747 - 4.275 n_o}$$

Table Correlations for Compression Index, C_c^*

Equation	Reference	Region of applicability
$C_c = 0.007(LL - 7)$	Skempton (1944)	Remolded clays
$C_c = 0.01w_N$		Chicago clays
$C_c = 1.15(e_o - 0.27)$	Nishida (1956)	All clays
$C_c = 0.30(e_o - 0.27)$	Hough (1957)	Inorganic cohesive soil: silt, silty clay, clay
$C_c = 0.0115w_N$		Organic soils, peats, organic silt, and clay
$C_c = 0.0046(LL - 9)$		Brazilian clays
$C_c = 0.75(e_o - 0.5)$		Soils with low plasticity
$C_c = 0.208e_o + 0.0083$		Chicago clays
$C_c = 0.156e_o + 0.0107$		All clays

After Rendon-Herrero, 1980. With permission from ASCE.

Note: e_o = *in situ* void ratio; w_N = *in situ* water content.

Important /Compression index **normally varies between 0.30 for highly plastic clays and 0.075 for low plastic clays.**

Correlations for Swelling Index (Cs)

The swell index is appreciably **smaller in magnitude** than the compression index and generally can be determined from laboratory tests. In most cases,

$$C_s \approx \frac{1}{5} to \frac{1}{10} C_c$$

The swell index was expressed by Nagaraj and Murty (1985) as

$$C_s = 0.0463 \left[\frac{LL\%}{100}\right] Gs$$

Based on the modified Cam clay model, Kulhawy and Mayne (1990) have shown that

$$C_s \approx \frac{PI}{370}$$

Thank you