**University of Baghdad**
**College of Engineering**
**Civil Engineering Department**



# Title: Lecture 4: Solved Problems: Calculation of Settlement from One-Dimensional Primary Consolidation-Solved Problems

Subject: Soil Mechanics

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

## Example 1

A soil layer of 9 m thickness having the initial void $e_o = 1.04$, after constructing a building, the final void ration $e_f$ is estimated to be 0.98. Calculate final settlement may be expected:

## Solution

H=9m $e_o = 1.04, e_f = 0.98$

$$\Delta e = e_o - e_f = 1.04 - 0.98 = 0.06$$

$$Sc = \frac{\Delta e}{1 + e_o} H$$

$$Sc = \frac{0.06}{1+1.04}(9) = 0.26 \text{ m} = 260 \text{ mm}$$

## Example 2

A recently completed fill was 32.8 ft thick and its initial average void ratio was 1.0. The fill was loaded on the surface by constructing an embankment covering a large area of the fill. Some months after the embankment was constructed, measurements of the fill indicated an average void ratio of 0.8. Estimate the compression of the fill.

## Solution

$H=32.8\,ft,\ e_o = 1.0, e_f = 0.8$

$\Delta e = e_o - e_f = 1.0 - 0.8 = 0.2$

$$Sc = \frac{\Delta e}{1 + e_o} H \qquad Sc = \frac{0.2}{1 + 1} 32.8 = 3.28\ ft$$

# Example 3

A sand layer of 2 m thickness is compacted at $\gamma$=19 kN/m$^3$ over a clay layer of 3 m depth. Calculate final settlement may be expected if coefficient of volume change is 0.007 m$^2$/ton

## Solution

$$m_v = 0.007\frac{m2}{ton} = 0.007\ \frac{m2}{1000kg}$$

$$= 0.007\ \frac{m2}{10\ kN} = 0.0007\ m^2/kN$$

1 kilogram =9.81N ≈ 10 N
1000 kilogram ≈ 10000N
1000 kilogram ≈ 10$k$N

$$Sc = m_v \Delta\sigma' H \qquad H = H_{clay} = 3m$$

$$\Delta\sigma' = h_{sand} * \gamma_{sand} = 2*19 = 38\ kN/m^2$$

$$Sc = 0.0007\ \frac{m^2}{kN} * 38\ \frac{kN}{m^2} * 3m = 0.0798\ m = 79.8\ mm = 7.98\ cm$$

# Example 4

For the soil Profile shown find the final consolidation settlement ?

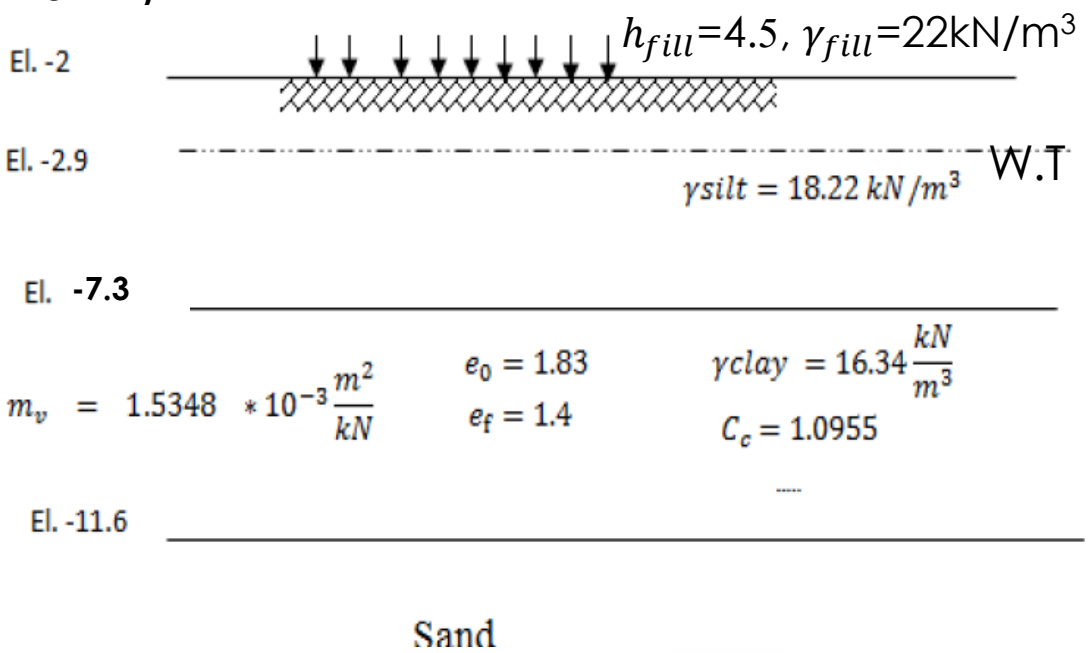
**Solution** $e_o = 1.83, e_f = 1.4$ , $\Delta e = e_o - e_f = 1.83 - 1.4 = 0.43$

$$Sc = \frac{\Delta e}{1+e_o} H = \frac{0.43}{1+1.83}(11. \quad - 7.3) = \mathbf{0.653m}$$

$Sc = m_v \Delta\sigma' H, \Delta\sigma' = h_{fill} * \gamma_{fill} = 4. \ ? * 22 = 99\ kN/m^2$

$$Sc = 1.5348 * 10^{-3} * 99 * (11. \quad - 7.3)$$

$$Sc = \mathbf{0.653\ m}$$




$\sigma_o$`(at middle of clay layer) $= \sigma_o - u$

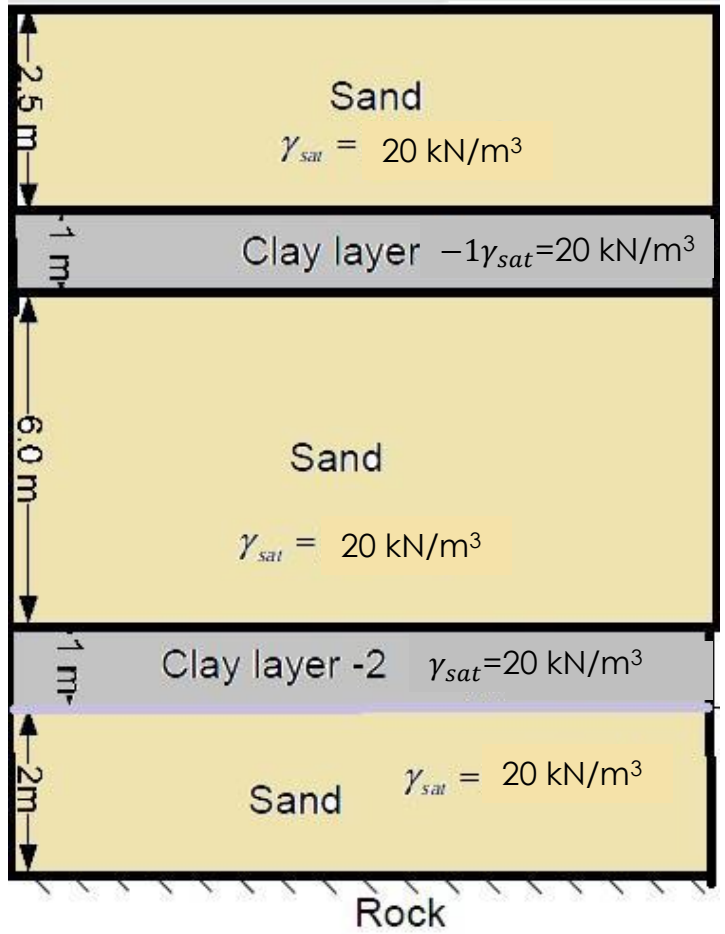
$$\sigma_o` = 0.9*18.22 + (7.3-2.9)18.22 - (7.3-2.9)9.81 + \left[\frac{11.6-7.3}{2} * 16.34\right] - \left[\frac{11.6-7.3}{2} * 9.81\right]$$

$$\sigma_o` = 67.46\ kN/m2$$

$$Sc = \frac{c_C H}{1+e_o} \log \frac{\sigma_o` + \Delta\sigma'}{\sigma_o`} \quad , Sc = \frac{1.0955}{1+1.83}(11. \quad - 7.3) \log \frac{67.46+99}{67.46} = \mathbf{0.653\ m}$$

# Example 5

The vertical soil profile shown below is loaded with a uniform surcharged pressure of 60 kPa on the ground surface. If the water table is at the ground surface, calculate the total consolidation settlement for clay layer-1? Note: Clay properties from laboratory consolidation on clay sample taken from these clay layers are: - $\sigma_c^{`}$=80 kPa, $\frac{c_C}{1+e_o}$=0.1, $\frac{c_s}{1+e_o}$ = 0.01




**Solution** 1- Clay layer -1 (consider mid depth) , $\Delta\sigma' = 60$ kPa

$\sigma_o^{`}$=2.5*20- 2.5*9.81+0.5*20- 0.5*9.81=30.6 kPa

$$OCR = \frac{\sigma_c^{`}}{\sigma_o^{`}} = \frac{80}{30.6} = \quad OCR > 1 \quad the\ soil\ is\ OCC$$

$\sigma_o^{`} + \Delta\sigma' = 30.6 + 60 = 90.6$ kPa $> 80$ kPa

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

$$Sc = 0.01(1)\log\frac{80}{30.6} + 0.1(1)\log\frac{30.6+60}{80} = 9.4\ mm$$

**Clay layer -2 (homework)**

## Example 6

The following are the results of a laboratory consolidation test,

**a.** Draw an *e*-log $\sigma'$ graph and determine the preconsolidation pressure, $\sigma_c^{`}$ .

**b.** Calculate the compression index and the ratio of *Cs* /*Cc*.

**c.** On the basis of the average *e*-log $\sigma'$ plot, calculate the void ratio at $\sigma' = 1000$ kN/m$^2$.

## Solution

**Part a/**The *e* versus log $\sigma'$ plot is shown. Casagrande's graphic procedure is used to determine the preconsolidation pressure:

$$\sigma_c^{`} = 120 \text{ kN/m}^2$$

**Part b/** From the average e-log$\sigma'$ plot, for the loading and unloading branches, the following values can be determined:

| Pressure $\sigma'$ (kN/m$^2$) | Void Ratio e | Remarks |
|---|---|---|
| 25 | 0.93 | Loading |
| 50 | 0.92 | |
| 100 | 0.88 | |
| 200 | 0.81 | |
| 400 | 0.69 | |
| 800 | 0.61 | |
| 1600 | 0.52 | |
| 800 | 0.535 | Unloading |
| 400 | 0.555 | |
| 200 | 0.57 | |

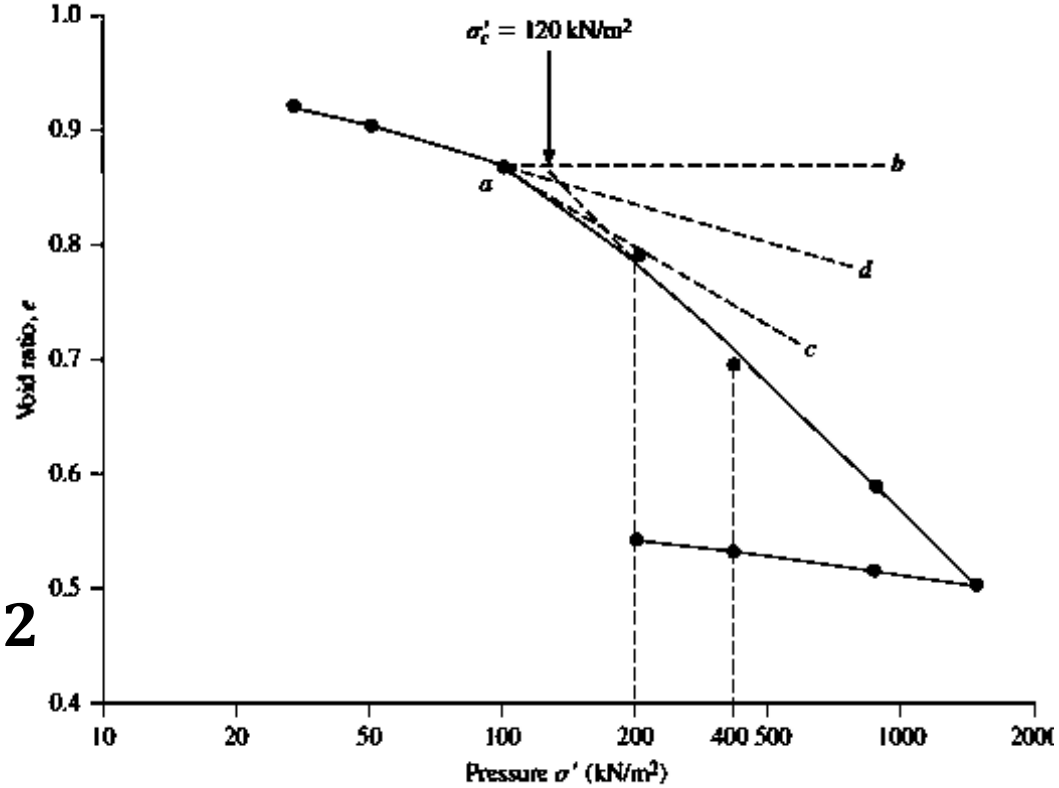
From the loading branch:

$$C_c = \frac{e_1 - e_2}{\log \frac{\sigma_2'}{\sigma_1'}} = \frac{0.8 - 0.7}{\log\left(\frac{400}{200}\right)} = 0.33$$

From the unloading branch:

$$C_s = \frac{e_1 - e_2}{\log \frac{\sigma_2'}{\sigma_1'}} = \frac{0.544 - 0.532}{\log\left(\frac{400}{200}\right)} = 0.04$$

$$\frac{C_s}{C_c} = \frac{0.04}{0.33} = 0.12$$




| Pressure $\sigma'$ (kN/m²) | Void Ratio e | Remarks |
|---|---|---|
| 200 | 0.8 | Loading |
| 400 | 0.7 | |
| 400 | 0.532 | Unloading |
| 200 | 0.544 | |

**Part c/**

$$C_c = \frac{e_1 - e_3}{\log \frac{\sigma_3'}{\sigma_1'}} = \frac{0.8 - e_3}{\log\left(\frac{1000}{200}\right)} = 0.33$$

$$e_3 = 0.8 - 0.33 \log\left(\frac{1000}{200}\right) \approx 0.57$$

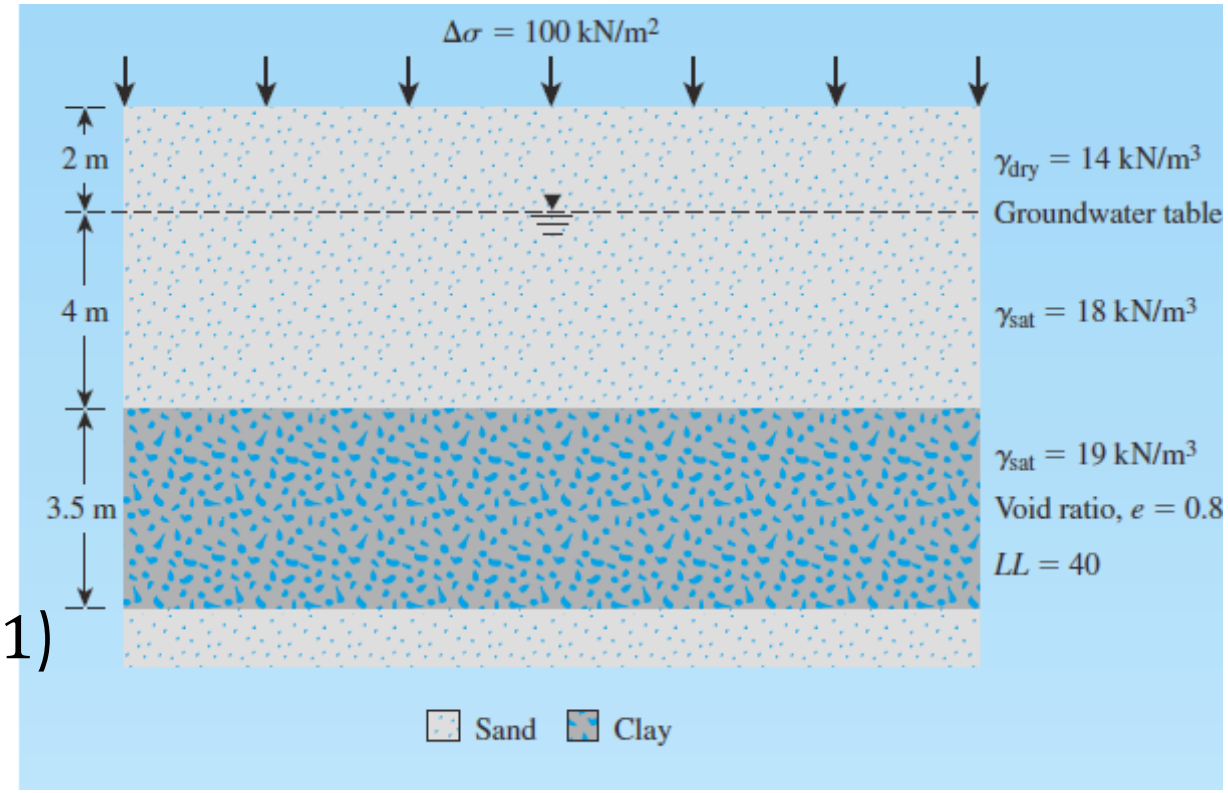
# Example 7

A soil profile is shown. If a uniformly distributed load, $\Delta\sigma$, is applied at the ground surface, what is the settlement of the clay layer caused by primary consolidation if:

a. The clay is normally consolidated

**b.** The preconsolidation pressure $\sigma_c^{`}$=200kN/m$^2$

**c.** $\sigma_c^{`}$=150kN/m$^2$,, Use $c_s \approx \frac{1}{5} c_c$




## Solution

**Part a/** The average effective stress at the middle of the clay layer is

$$\sigma_o^{`} = 2\gamma_{dry\ sand} + 4(\gamma_{sat\ sand} - \gamma_{water}) + 1.75(\gamma_{sat\ clay} - \gamma_{water})$$

$$\sigma_o^{`} = 2(14) + 4(18 - 9.81) + 1.75(19 - 9.81)$$

$$= 76.08\ \text{kN/m}^2$$

The clay NCC. $Sc = \frac{c_C H}{1+e_o} log \frac{\sigma_o` + \Delta\sigma`}{\sigma_o`}$ , $\Delta\sigma' = 100\ Kn/m^2, e_o$=0.8

$C_c$= 0.009(LL − 10) , $C_c$= 0.009(40 − 10) = 0.27

$$Sc = \frac{0.27(3.5)}{1+0.8} log \frac{76.08+100}{76.08} = 0.191 \text{ m} = \mathbf{191\ mm}$$

**Part b/**

$OCR = \frac{\sigma_c`}{\sigma_o`} = \frac{200}{76.08} =$ $OCR > 1$ the soil is OCC

$\sigma_o` + \Delta\sigma' = 76.08 + 100 = 176.08\ kPa < 200\ kPa$

$Sc = \frac{c_s H}{1+e_o} log \frac{\sigma_o` + \Delta\sigma`}{\sigma_o`}$ $c_s \approx \frac{1}{5} c_c = \frac{1}{5}(0.27) = 0.054$

$$Sc = \frac{0.054(3.5)}{1+0.8} log \frac{76.08+100}{76.08} = 0.038 \text{ m} = \mathbf{38\ mm}$$

## Part c/

$$OCR = \frac{\sigma_c`}{\sigma_o`} = \frac{150}{76.08.} \qquad OCR > 1 \quad the\ soil\ is\ OCC$$

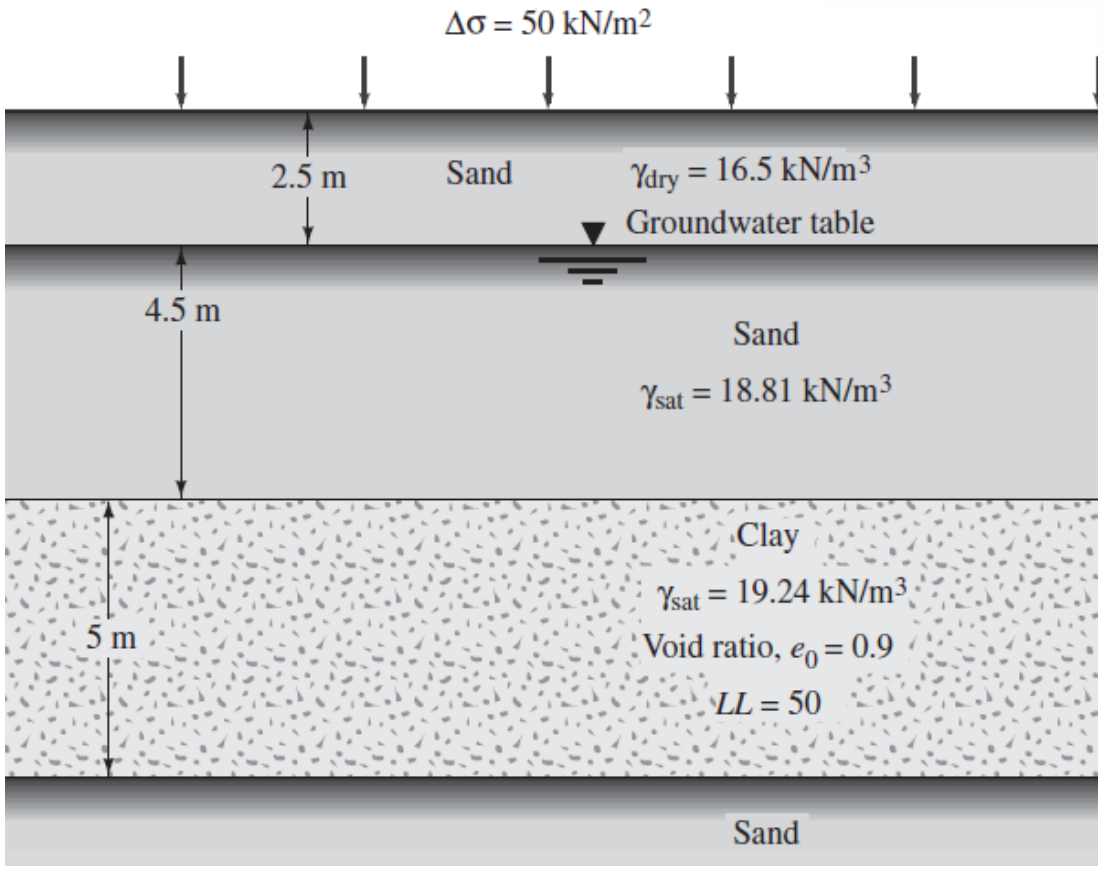
$$\sigma_o` + \Delta\sigma` = 76.08 + 100 = 176.08\ \text{kPa} > 150\ \text{kPa}$$

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

$$Sc = \frac{0.054(3.5)}{1+0.8}\log\frac{150}{76.08} + \frac{0.27(3.5)}{1+0.8}\log\frac{76.08+100}{150} = 0.0675\ \text{m} = \mathbf{67.5\ mm}$$

# H.W

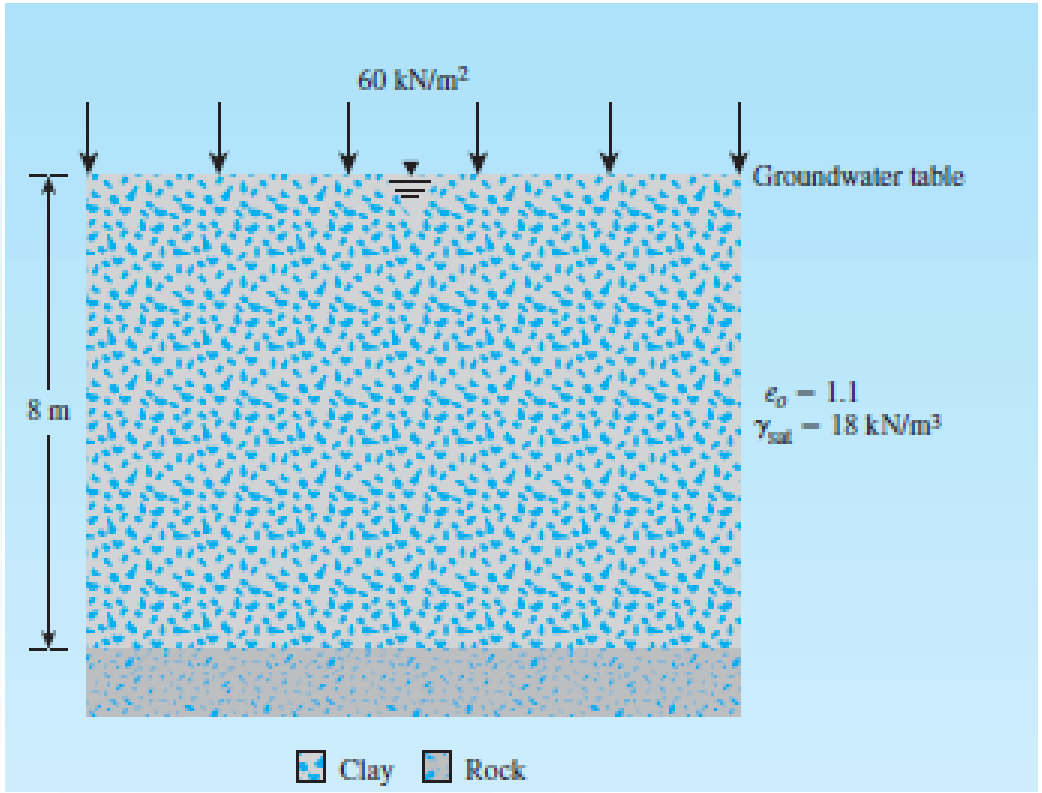
A soil profile is shown. If a uniformly distributed load, $\Delta\sigma$, is applied at the ground surface, what is the settlement of the clay layer caused by primary consolidation. We are given that $\sigma_c^{`}$=125 kN/m$^2$ and $c_s \approx \frac{1}{6} c_c$

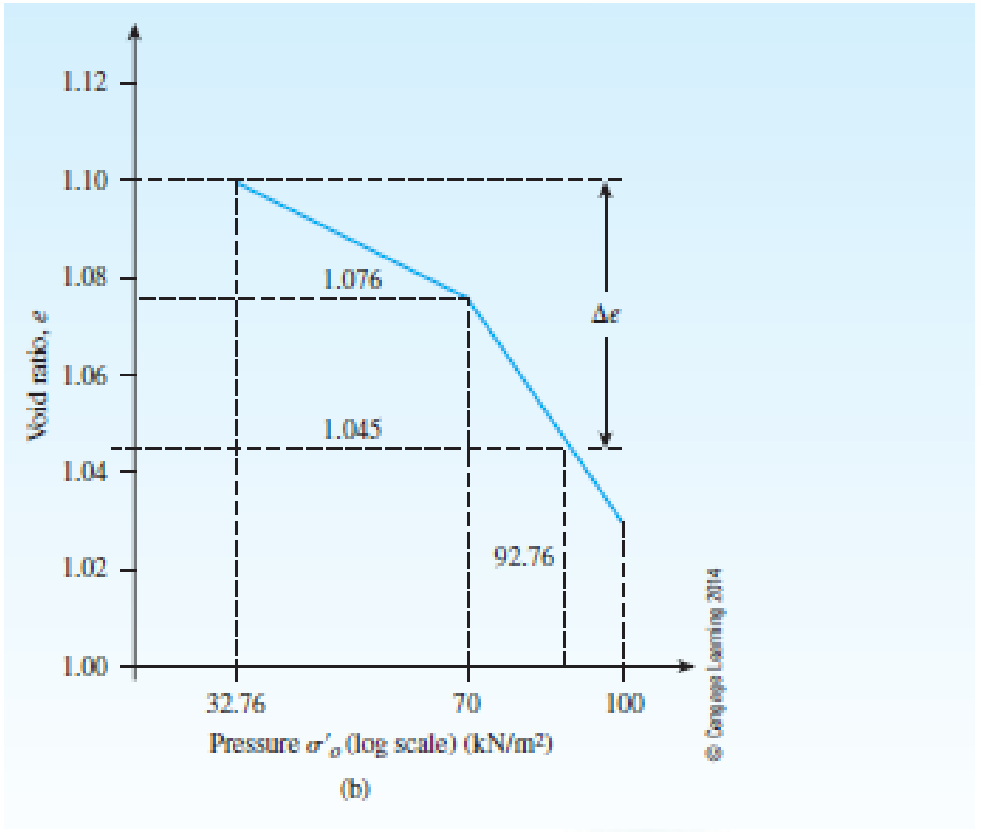



**Ans. $Sc$ =101 mm**

## Example 8

A soil profile is shown. Laboratory consolidation tests were conducted on a specimen collected from the middle of the clay layer. The field consolidation curve interpolated from the laboratory test results as shown. Calculate the settlement in the field caused by primary consolidation for a surcharge of 60 kN/m$^2$ applied at the ground surface.



## Solution

$\sigma_o^{`} = 4(\gamma_{sat} - \gamma_w) = 4(18.0\text{-}9.81) = 32.76$ kN/m$^2$

$\Delta\sigma^{`} = \mathbf{60\ Kn/m^2}$ $\sigma_o^{`} + \Delta\sigma^{`} = 32.76 + \mathbf{60 = 92.}76$ kN/m$^2$

$e_o = 1.1$

$e_f$ corresponding to stress of **92.**76 kN/m$^2$ is 1.045.

H=8m $e_o = 1.1, e_f = 1.045.$

$$\Delta e = e_o - e_f = 1.1 - 1.045 = 0.055$$

$$Sc = \frac{\Delta e}{1 + e_o} H$$

$$Sc = \frac{0.055}{1 + 1.1} * 8 = 0.21\ m = 210\ mm$$

## Example 9

The laboratory consolidation data for an undisturbed clay sample are as follows:

$e_1 = 1.1$, $\sigma_1' = 95\ kN/m^2$

$e_2 = 0.9$, $\sigma_2'$ =475 kN/m$^2$

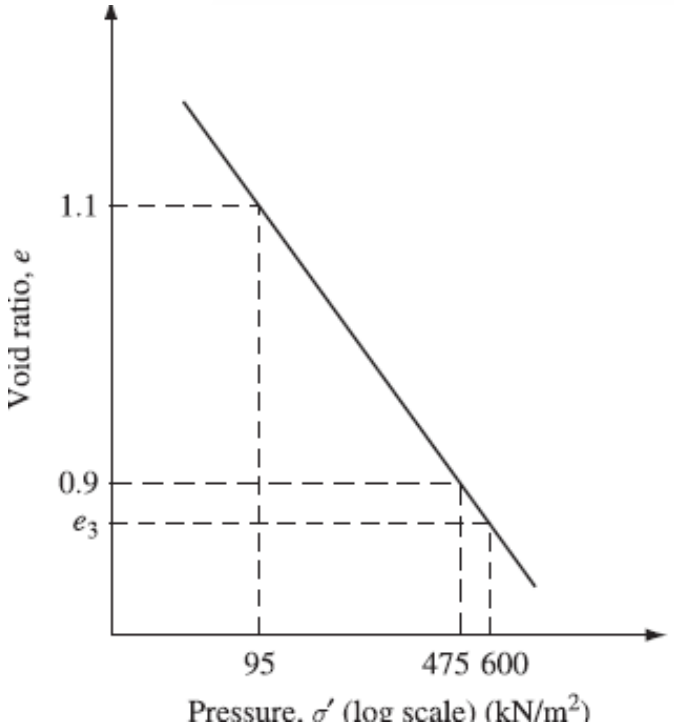
What will be the void ratio for a pressure of 600 kN/m$^2$? (Note: , $\sigma_c'$ =95 kN/m$^2$)

## Solution

$$C_c = \frac{e_1 - e_2}{\log \frac{\sigma_2'}{\sigma_1'}} = \frac{1.1 - 0.9}{\log\left(\frac{475}{95}\right)} = 0.286$$

$$C_c = \frac{e_1 - e_3}{\log \frac{\sigma_3'}{\sigma_1'}} = \frac{1.1 - e_3}{\log\left(\frac{600}{95}\right)} = 0.286$$

$$e_3 = 1.1 - 0.286 \log\left(\frac{600}{95}\right) = 0.87$$



## Example 10

Two points on a curve for normally consolidated clay have the following Coordinates: Point 1: $e_1 = 0.7$, $\sigma_1^{`} = 2089$ lb/ft$^2$, Point 2: $e_2 = 0.6$, $\sigma_2^{`} = 6266$ lb/ft$^2$. If the average overburden pressure on a 20 ft thick clay layer is 3133 lb/ft$^2$, how much settlement will the clay layer experience due to an induced stress of 3340 Ib/ft$^2$ at its mid depth?

## Solution

$$C_c = \frac{e_1 - e_2}{\log \frac{\sigma_2^{'}}{\sigma_1^{'}}} = \frac{0.7 - 0.6}{\log\left(\frac{6266}{2089}\right)} = 0.21$$

We need the initial void ratio $e_o$ at an overburden pressure of 3133 lb/ft$^2$.

$$C_c = \frac{e_0 - e_2}{\log \frac{\sigma_2^{'}}{\sigma_0^{'}}} = \frac{e_0 - 0.6}{\log\left(\frac{6266}{3133}\right)} = 0.21$$

$e_0$=0.663

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

$$Sc = \frac{0.21(20)}{1 + 0.663} \log \frac{3133 + 3340}{3133}$$

$$= \mathbf{0}.\,796\ \boldsymbol{ft} = \mathbf{9}.\,55\ \boldsymbol{inch}$$

# Thank you