Consolidation

Loaded Soil will Compress Due to:

- Deformation of soil grains (elastic)

Degree water saturation <1

- Compression of air and water in voids
- Squeezing water and air out of voids

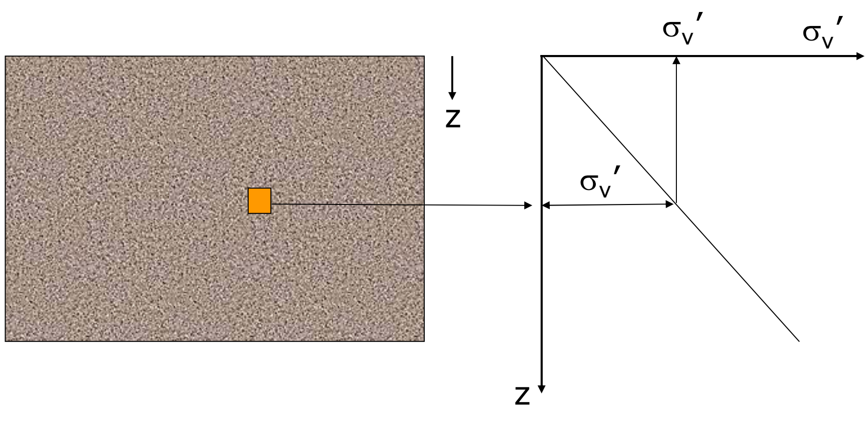
Degree water saturation =1

- Compression of water (very small)
- Squeezing water out of voids

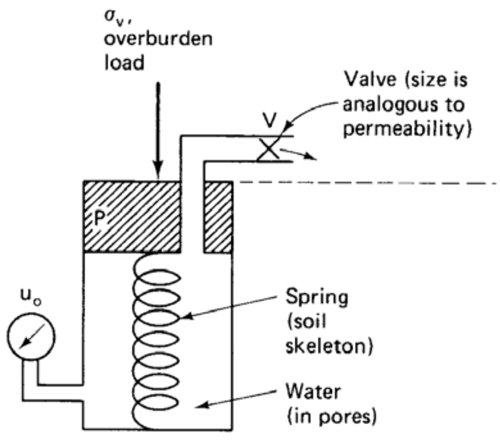
For Load Problems Need to Answer

1. How much settlement will occur due to an applied load?
   - Magnitude of settlement
2. How long will it take for settlement to occur?
   - Time rate of consolidation

Soil Vertical Stress

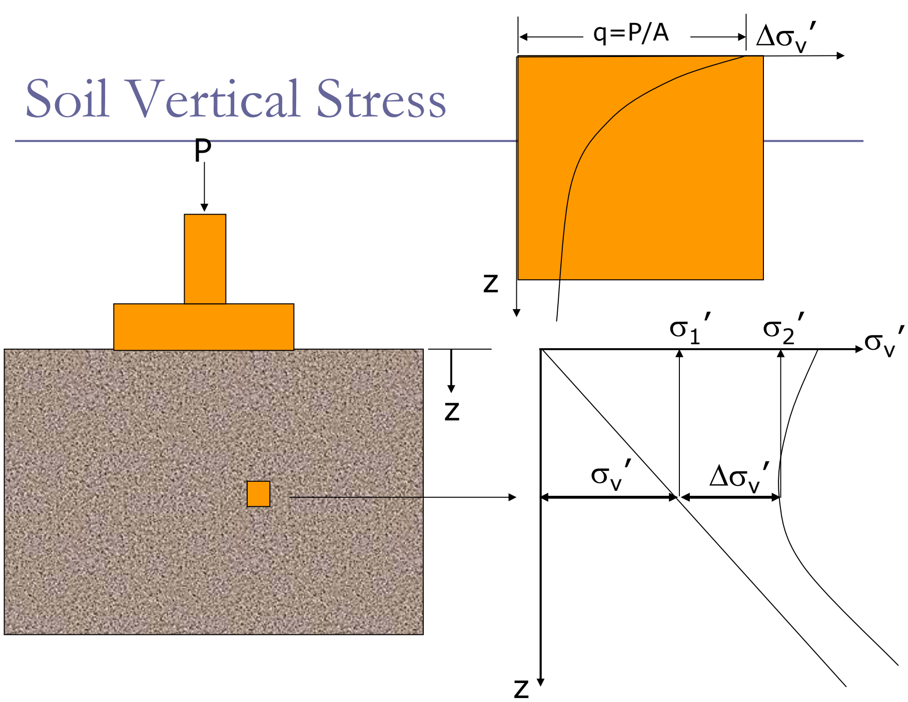


Spring Analogy to Soil Consolidation

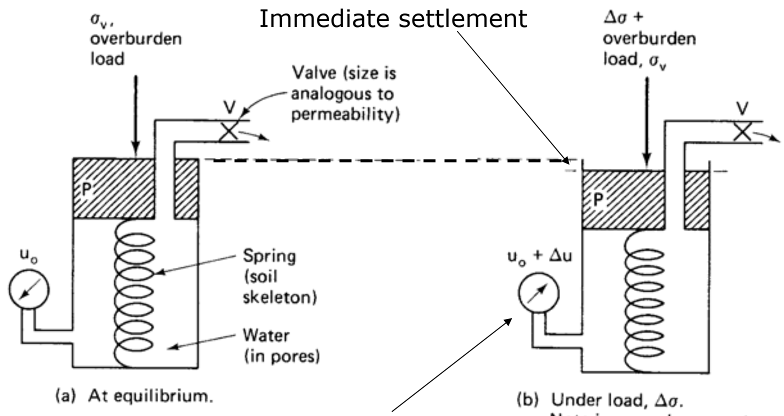


(a) At equilibrium.

Soil Vertical Stress



Spring Analogy to Soil Consolidation



Immediate settlement

Note: porewater pressure increased by $\Delta u = u_e$

Spring Analogy

S_{max} occurs when $\Delta u = 0$

Change in volume in container = volume of water removed if $Sr_w = 1$

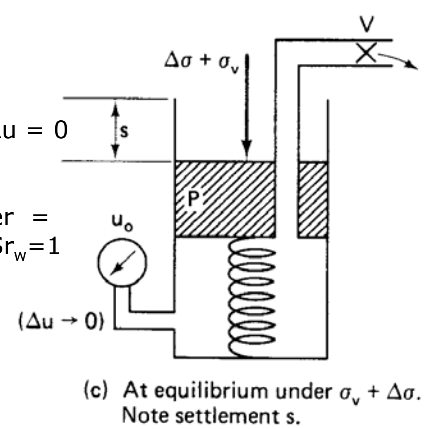


Fig. 8.2 Spring analogy as applied to consolidation.

Oedometer Test

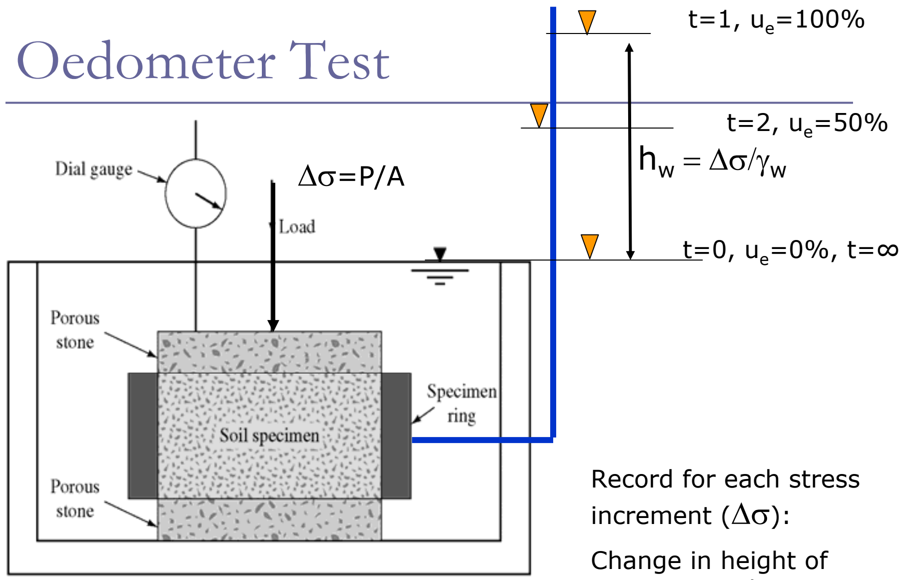


Figure 7.2 Consolidometer

Record for each stress increment ($\Delta\sigma$):

Change in height of specimen with time

Typical Stress Increment Test Data

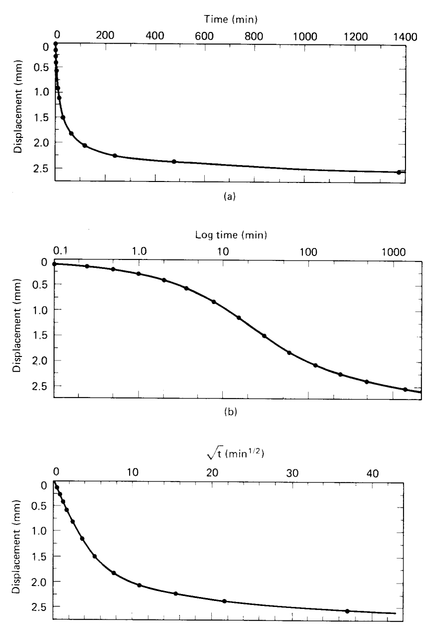


Fig. 9.6 Deformation-time curves for data from Table 9-2: (a) arithmetic scale; (b) log time scale; (c) square root of time scale.

Casagrande Log Time Method

U = degree of pore water pressure dissipated

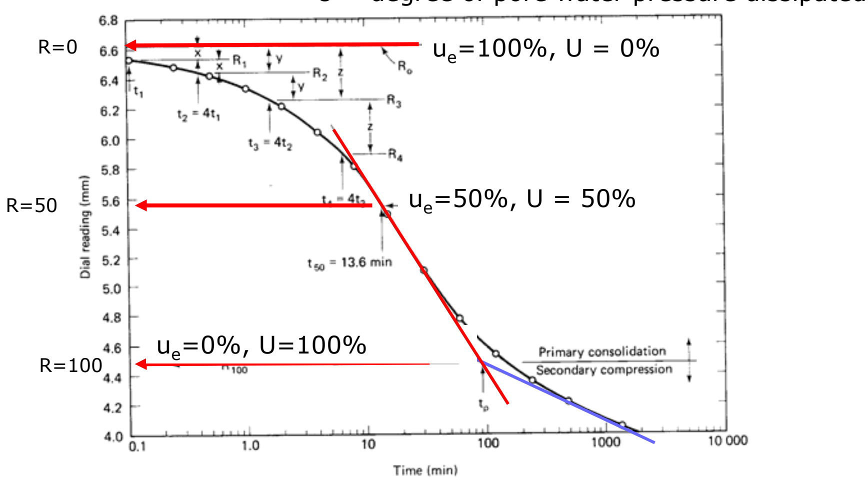


Fig. 9.7 Determination of t_{50} by the Casagrande method; data from Table 9-2.

Casagrande Log Time Method

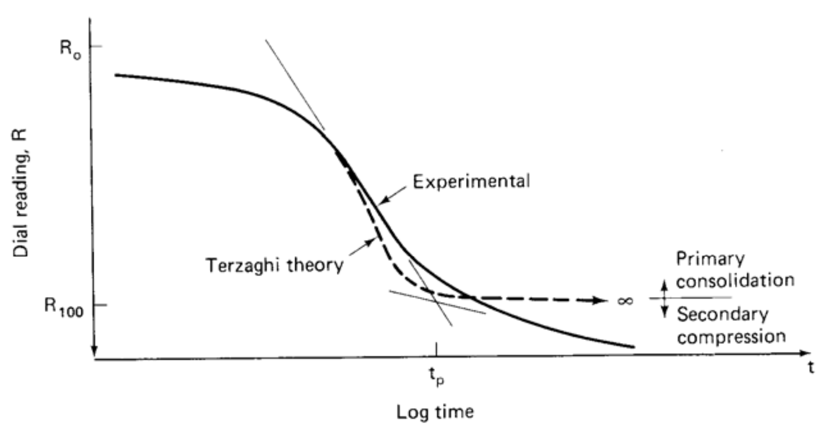


Fig. 9.8 Terzaghi consolidation theory and a typical experimental curve used to define t_p.

Root Time Method

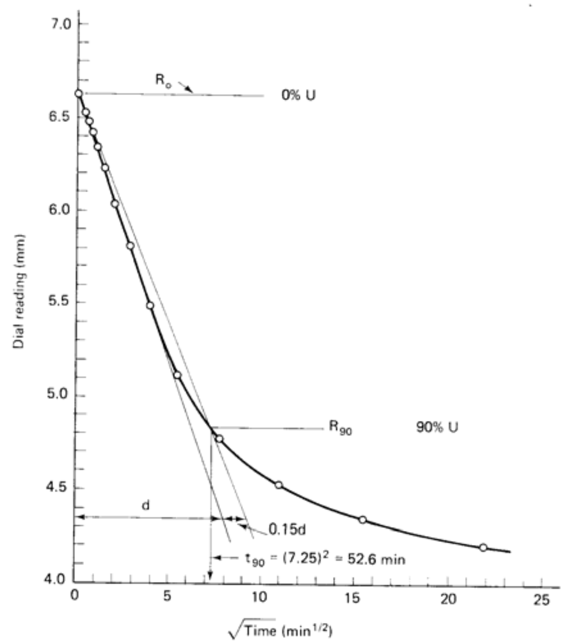
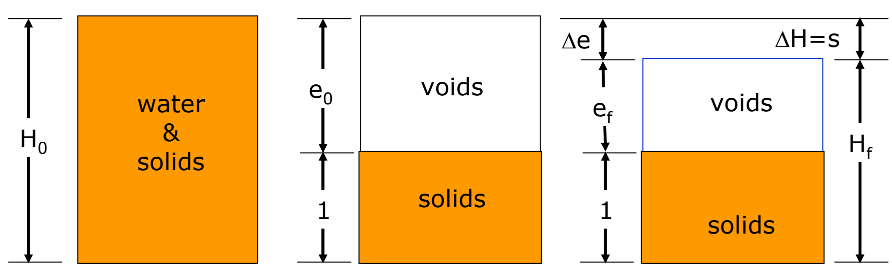


Fig. 9.9 Determination of c_v, using Taylor's square root of time method; data from Table 9-2.

Settlement Calculations



Consolidation Settlement Calculations

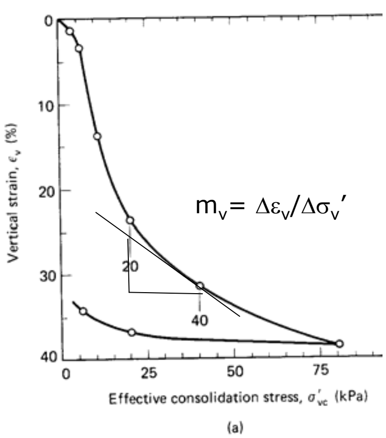
$$\varepsilon_v = \Delta H/H_0 = s/H_0 = \Delta e/1+e_0$$

$$s = \varepsilon_v H_0 = (\Delta e/1+e_0)\, H_0$$

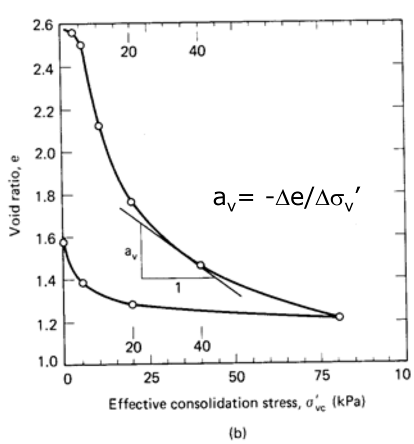
Note: Want settlement @ U=100%

100% dissipation of excess porewater pressure

U_{100} Data for Stress Increments

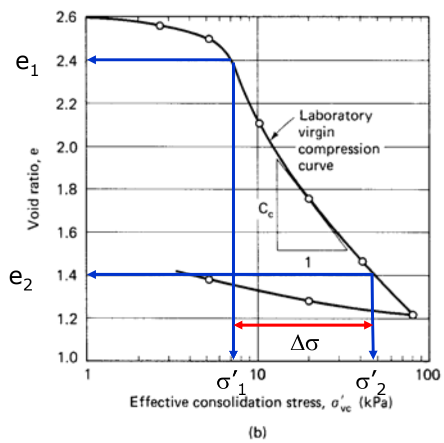


Coef. of Volume change (m_v)



Coef. of compressibility (a_v)

U_{100} Data for Stress Increments



Compression Index (C_c)

$c_c = \Delta e / (\log\sigma_2' - \log\sigma_1')$

$c_c = (e_1 - e_2)/\log(\sigma_2'/\sigma_1')$

If $\sigma_2' = \sigma_1' + \Delta\sigma$

$c_c = \Delta e / \log[(\sigma_1' + \Delta\sigma)/\sigma_1']$

$\mathbf{e}_1 = 2.4$, $\mathbf{e}_2 = 1.4$ $\Delta e = 1.0$

$\sigma'_1 = 7.1$, $\sigma'_2 = 49$

$c_c = 1.0/(\log 49 - \log 7.1) = 1.19$

Settlement Equation in Terms of m_v

$$S = \varepsilon_v H_o$$

$$m_v = \frac{\Delta\varepsilon_v}{\Delta\sigma'} \qquad (1/\mathrm{kPa} = \mathrm{m}^2/\mathrm{kN})$$

$$\mathrm{S} = \int_0^{\mathrm{H}} \mathrm{m_v} \Delta\sigma' dz$$

if $\mathrm{m_v}$ and $\Delta\sigma'$ are assumed constant with depth then

$$\mathrm{S} = \mathrm{m_v} \Delta\sigma' H$$

Settlement Equation in Terms of a_v

$$S = \varepsilon_v H_o = \frac{\Delta e}{1+e_o} H$$

$$a_v = \frac{\Delta e}{\Delta \sigma'} \qquad (1/\text{kPa} = \text{m}^2/\text{kN})$$

$$S = \int_0^H \frac{a_v}{1+e_o} \Delta \sigma' dz$$

if a_v and $\Delta\sigma'$ are assumed constant with depth then

$$S = \frac{a_v}{1+e_o} \Delta \sigma' H = m_v \Delta \sigma' H$$

therefore $m_v = \dfrac{a_v}{1+e_o}$

Settlement Equation in Terms of c_c

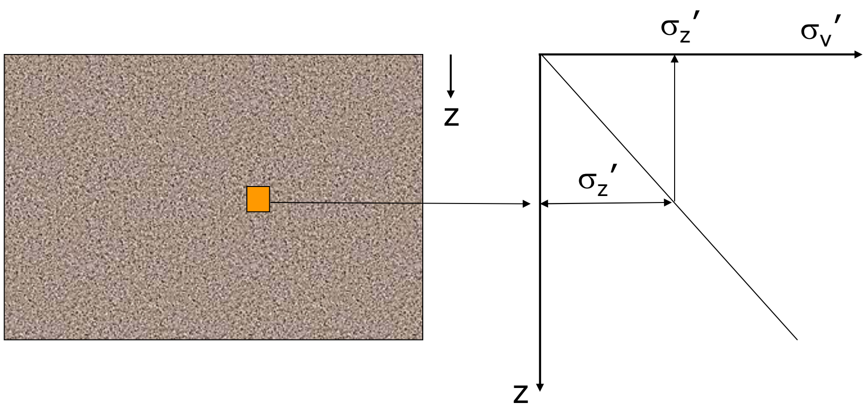
$$S = \varepsilon_v H_o = \frac{\Delta e}{1+e_o} H$$

$$c_c = \frac{\Delta e}{\log \dfrac{\sigma_2'}{\sigma_1'}}$$

Note: c_c = 0.009(LL-10)

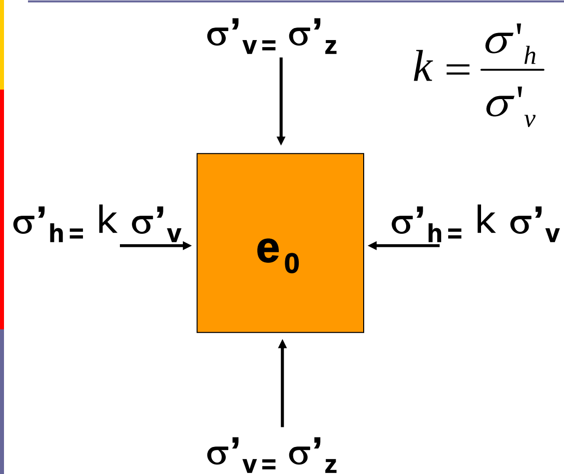
$$S = \frac{c_c}{1+e_o} H \log \frac{\sigma_2'}{\sigma_1'} = \frac{c_c}{1+e_o} H \log\left(\frac{\sigma_1' + \Delta\sigma}{\sigma_1'}\right)$$

Soil Vertical Stress



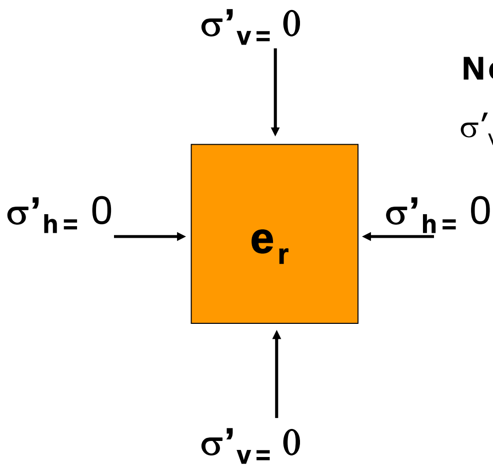
Stress on Soil @ depth z

$$k = \frac{\sigma'_h}{\sigma'_v} \qquad \sigma'_h = k\sigma'_v$$



At depth z

Stress on Soil at depth z=0



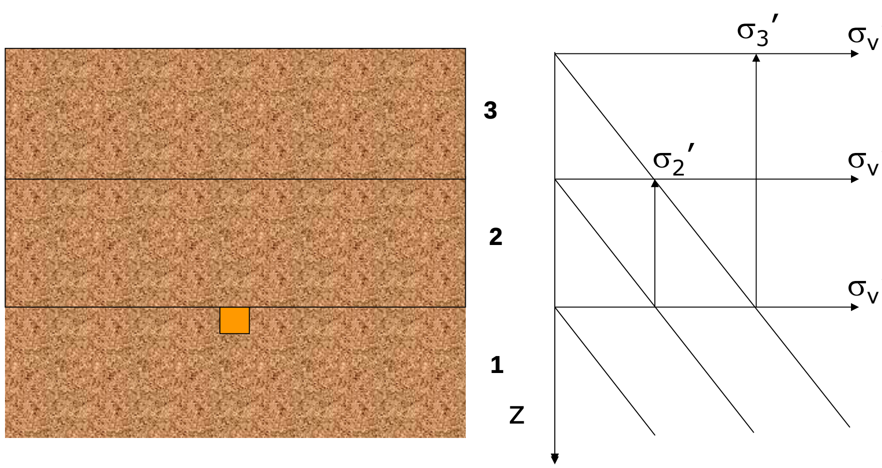
Note: soil unloaded from

$\sigma'_v = \sigma'_z$ to $\sigma'_z = 0$

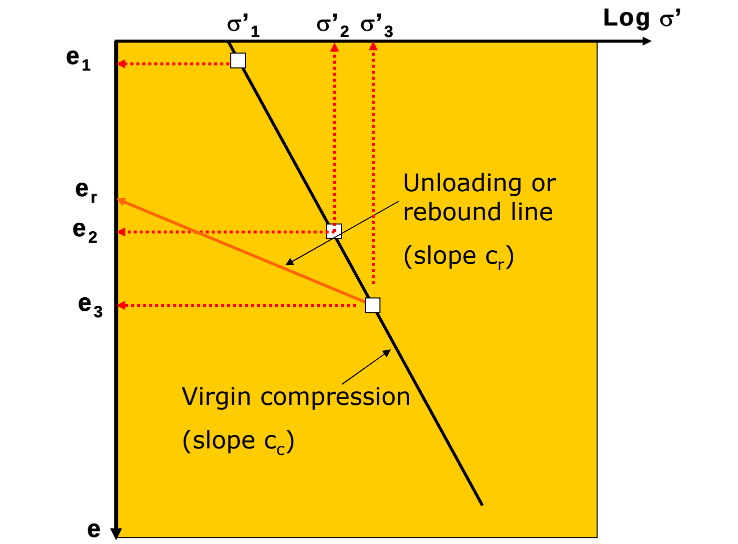
$\mathbf{e_r > e_0}$

At ground surface

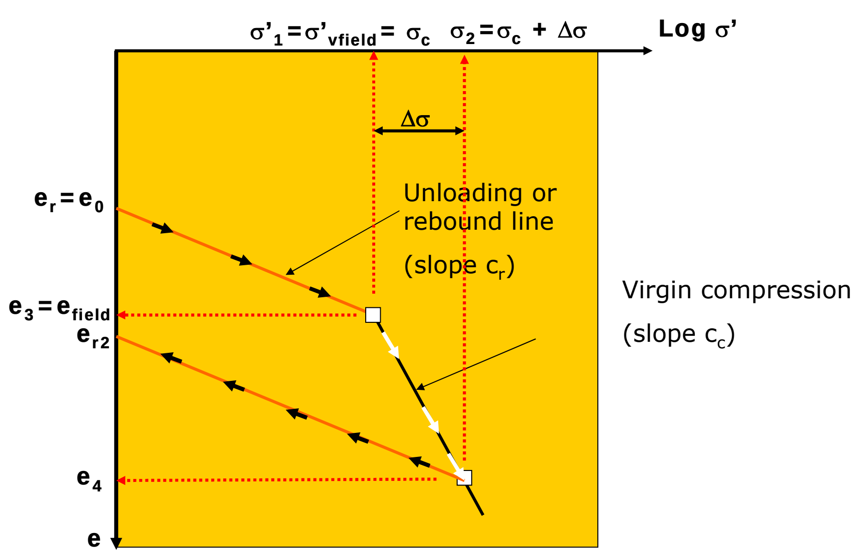
Soil Formation



Soil Consolidation Curve



Oedometer Test on Soil Sample



Settlement due to Δσ

$$S_{total} = S_r + S_c$$

$$S_r = S_{rebound} = \frac{C_r}{1+e_0} \mathrm{H}_0 \log(\frac{\sigma'_2}{\sigma'_1}) = \frac{C_r}{1+e_0} \mathrm{H}_0 \log(\frac{\sigma'_c}{\sigma'_1})$$

note : for this case $\sigma'_1 = 0$

$$\mathrm{S_c} = \frac{C_c}{1+e_0} \mathrm{H}_0 \log(\frac{\sigma'_2}{\sigma'_1}) = \frac{C_c}{1+e_0} \mathrm{H}_0 \log(\frac{\sigma'_c + \Delta\sigma}{\sigma'_c})$$

Over Consolidation Ratio (OCR)

$$OCR = \frac{\sigma'_c}{\sigma'}$$

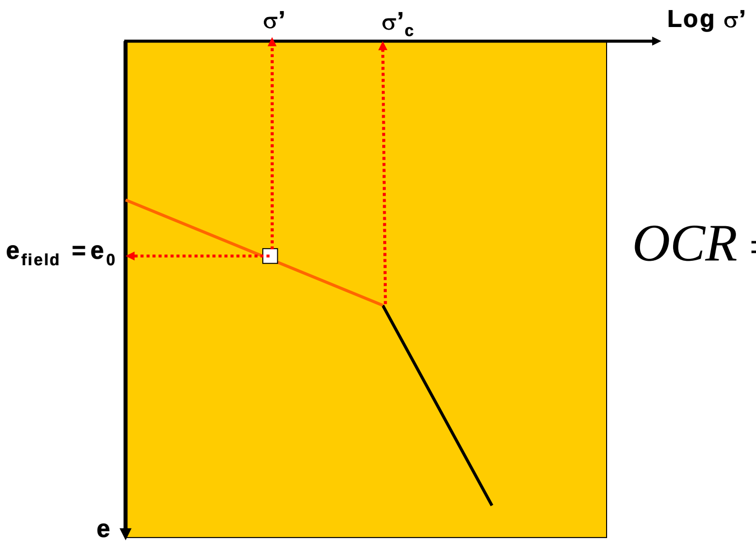
where :

OCR = Over Consolidation Ratio

σ'_c = preconsolidation pressure of a specimen

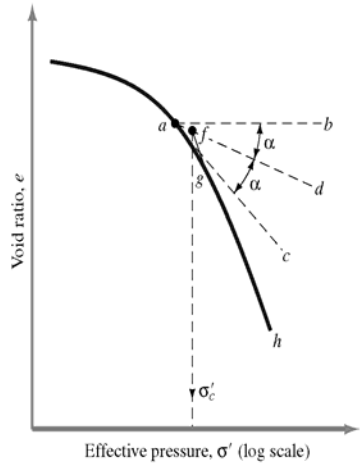
σ' = present (field) effective overburben pressure

Over Consolidation Ratio (OCR)



$$OCR = \frac{\sigma'_c}{\sigma'}$$

Determination of σ_c'



See Das for procedure

Note σ_c' is not a distinct point

Figure 7.8
Graphic procedure for determining preconsolidation pressure

Over Consolidation Ratio (OCR)

- If OCR ≤ 1.2 $\sigma'_c \sim \sigma'$ then soil is normally consolidated
- If OCR ≥ 1.2 then soil is over consolidated

Settlement Analysis

$$S_{total} = S_r + S_c$$

$$S_r = \frac{C_r}{1+e_0} \mathrm{H_0} \log\left(\frac{\sigma'_2}{\sigma'_1}\right) = \frac{C_r}{1+e_0} \mathrm{H_0} \log\left(\frac{\sigma'_c}{\sigma'}\right)$$

$$\mathrm{S_c} = \frac{C_c}{1+e_0} \mathrm{H_0} \log\left(\frac{\sigma'_2}{\sigma'_1}\right) = \frac{C_c}{1+e_0} \mathrm{H_0} \log\left(\frac{\sigma'_c + \Delta\sigma}{\sigma'_c}\right)$$

If OCR=1 then $\mathrm{S_r} = 0$