Soil Mechanics I

4 – Compressibility

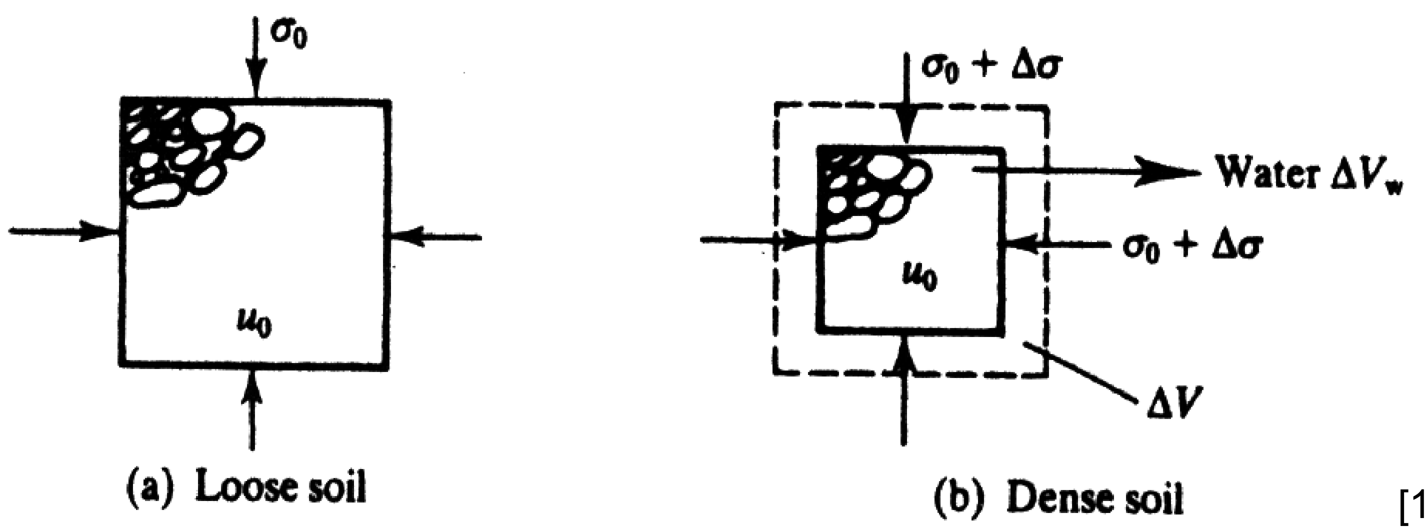
1. Isotropic compression
2. Nonlinearity
3. Overconsolidation; OC vs. creep
4. One-dimensional compression - parameters
5. Settlement (one-dimensional compressibility)
6. At-rest earth coefficient; E_{oed} vs E' for elastic material

Loading - isotropic $\Delta\sigma_1' = \Delta\sigma_2' = \Delta\sigma_3' = \Delta\sigma' = \Delta p'$; q = const.
- anisotropic $\Delta\sigma_1'$; $\Delta\sigma_2'$; $\Delta\sigma_3' \rightarrow \Delta p'$

$\Delta p' \neq 0 \rightarrow$ structural changes

(changes in position of soil grains) = compression

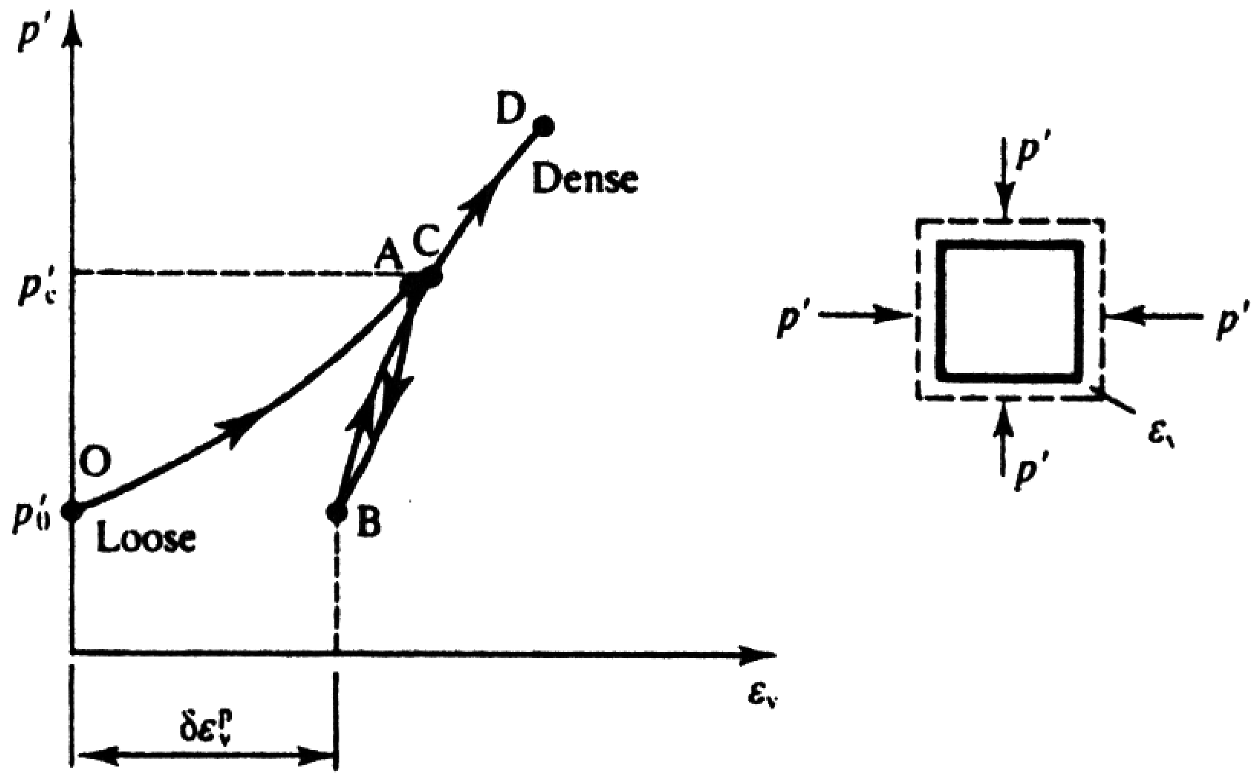
$\Delta p' > 0 \rightarrow$ loose soil $\rightarrow$ dense soil = change in porosity shown by (a) $\rightarrow$ (b):



[1]

For isotropic compression (i.e. for q=const.):

Bulk Modulus K = $dp' / d\varepsilon_V \neq$ const.



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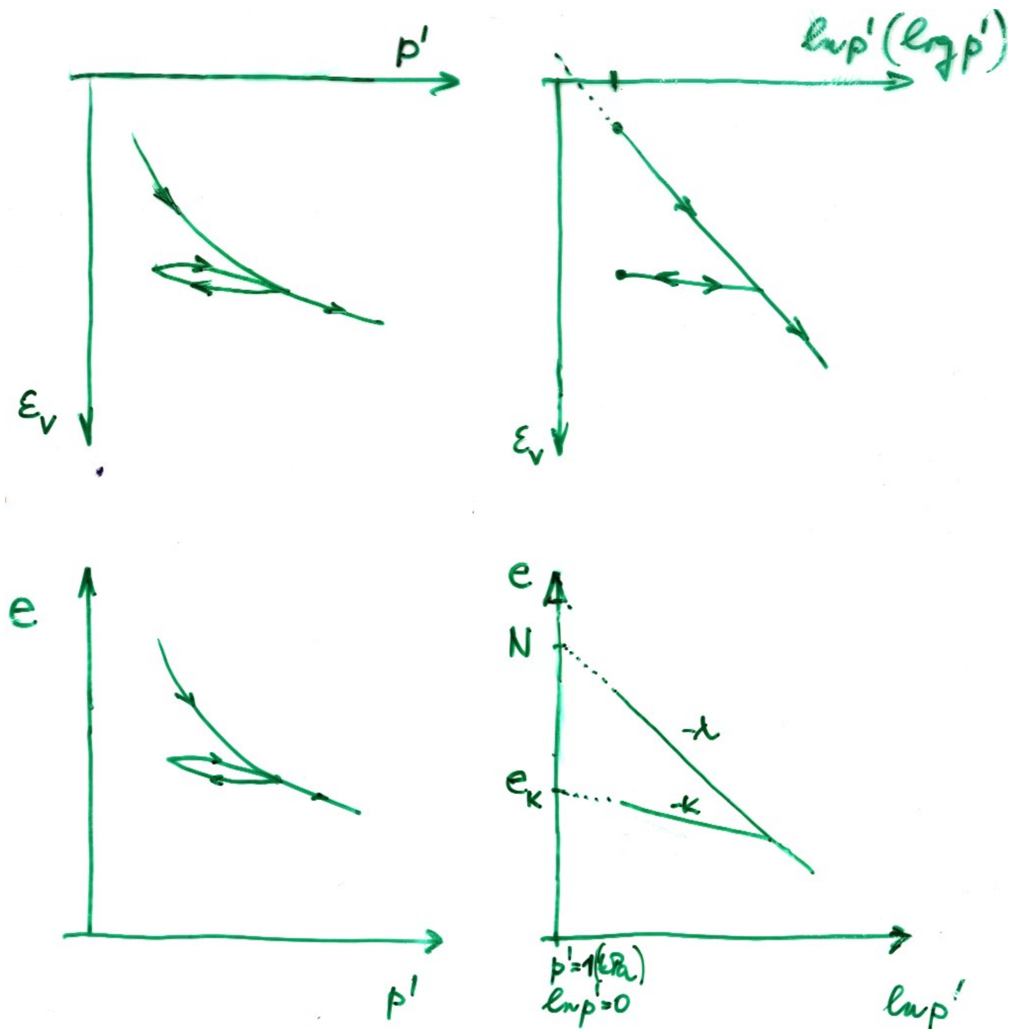


Isotropic compression

(semi)logarithmic plot in working stress range is linear

loading

Normal Compression Line NCL:

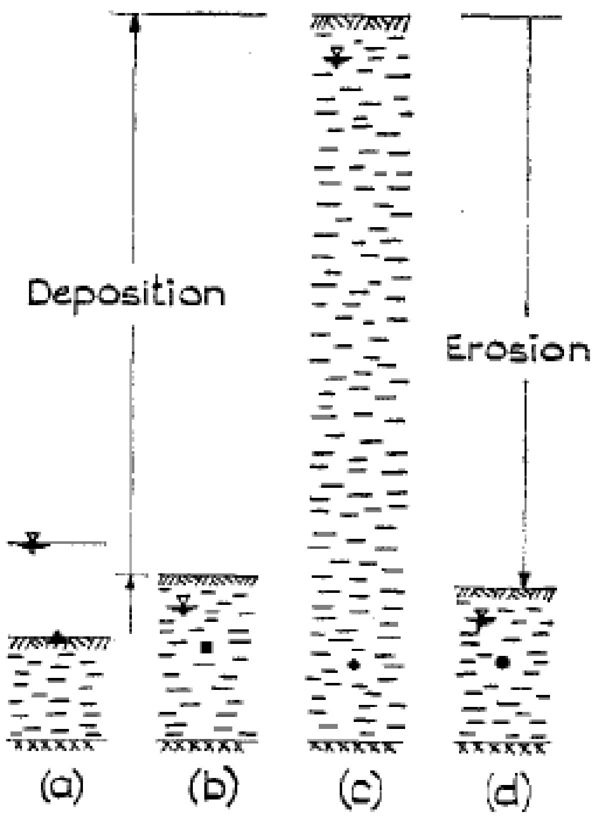
$$e = N - \lambda \ln p'$$

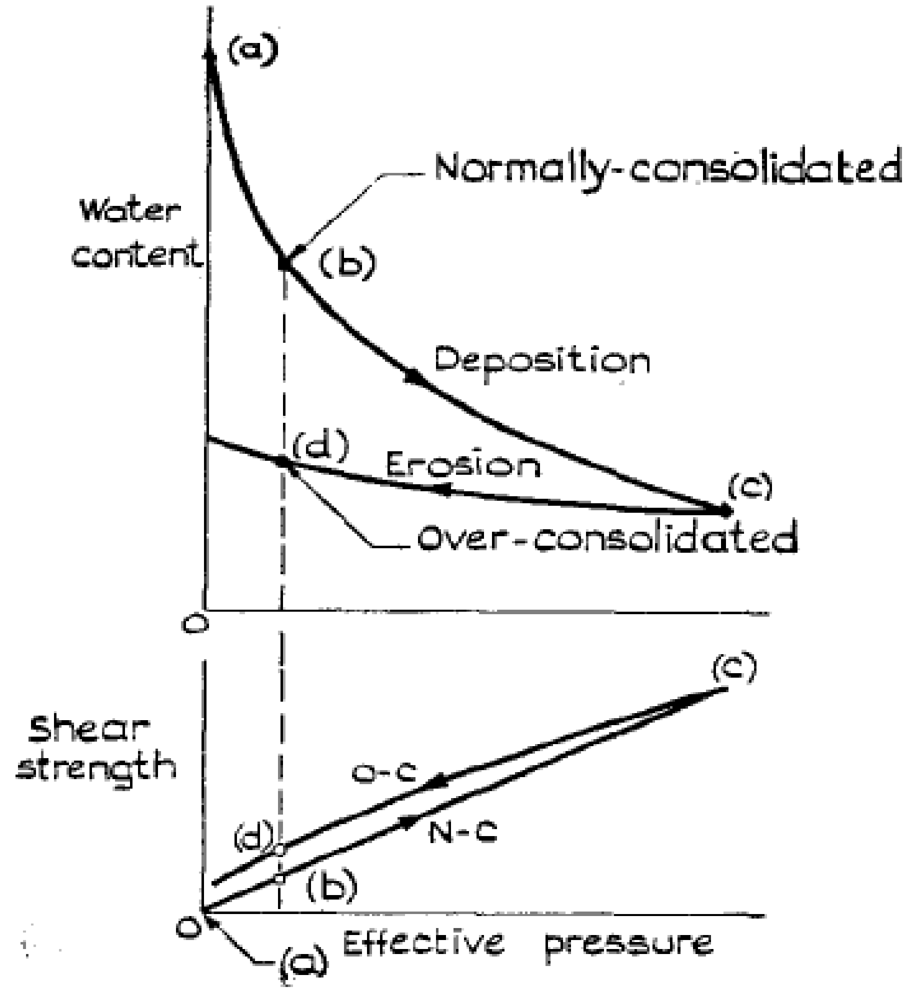
unloading – reloading

$$e = e_\kappa - \kappa \ln p'$$

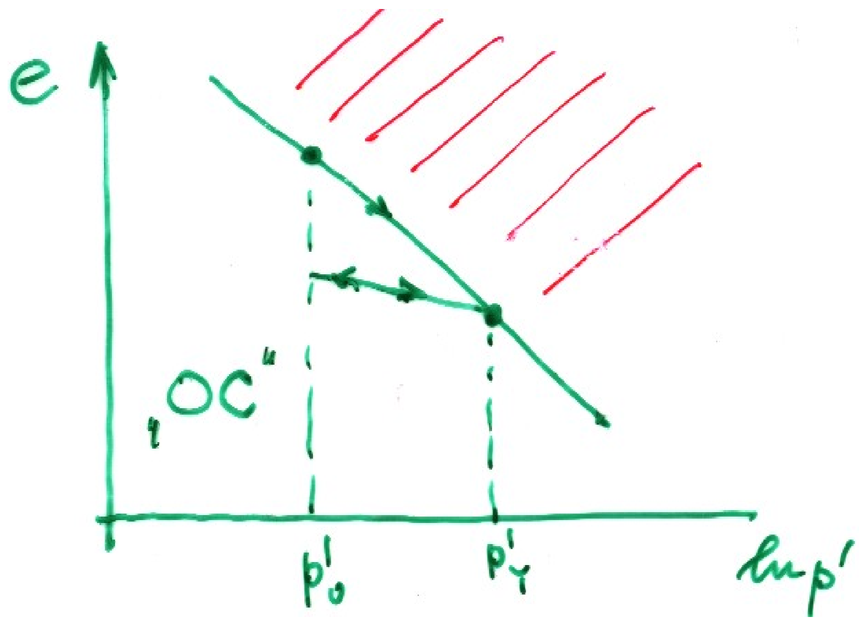
Parameters for isotropic compression: λ; κ; N

They are constants



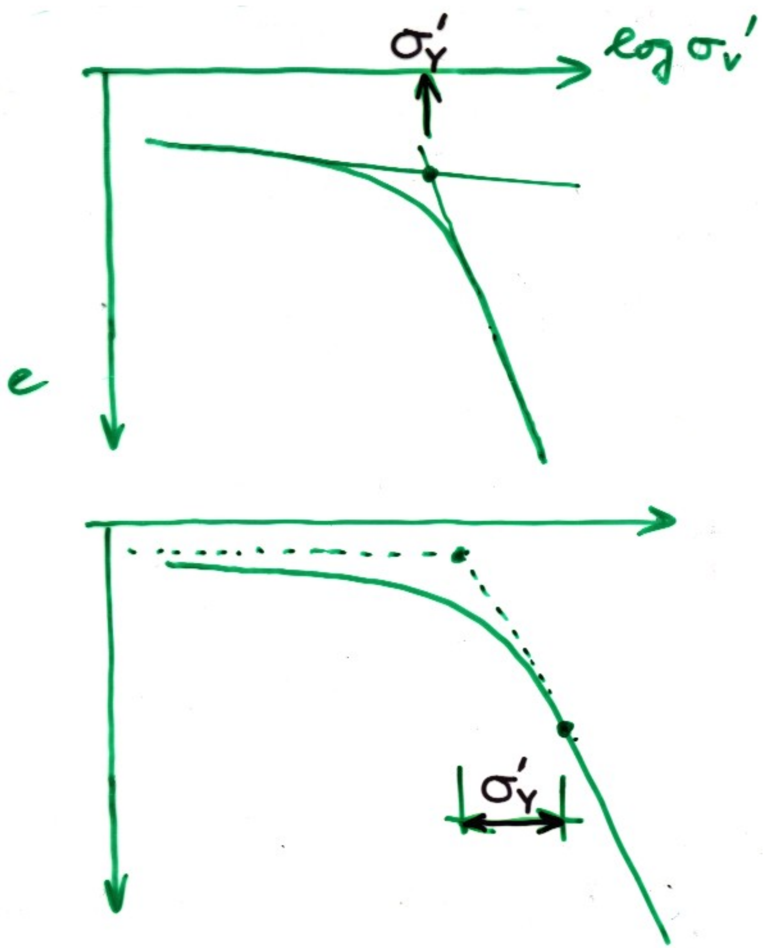


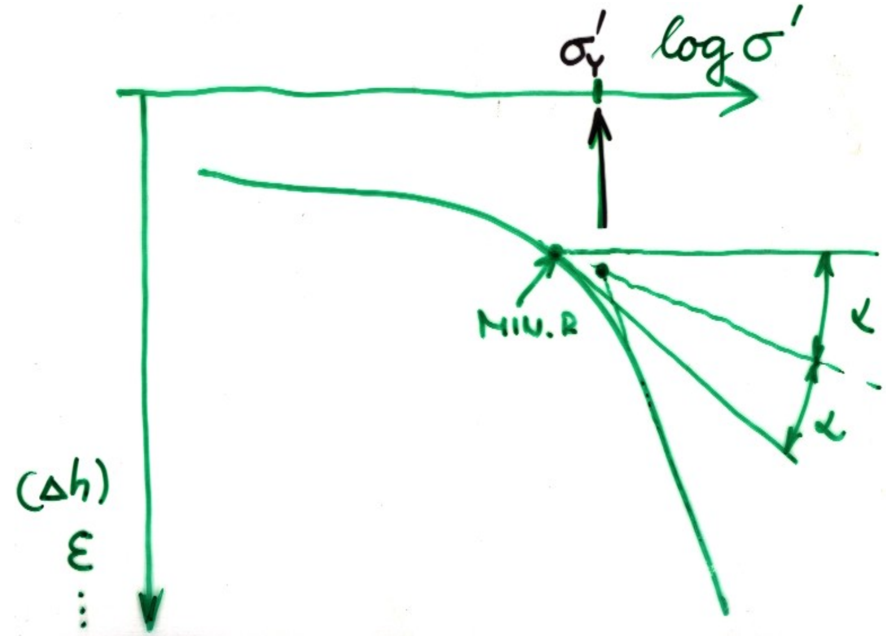
Skempton (1964)


e
„OC"
p'_0
p'_Y
ln p'

„overconsolidation stress" = yield stress σ_Y'

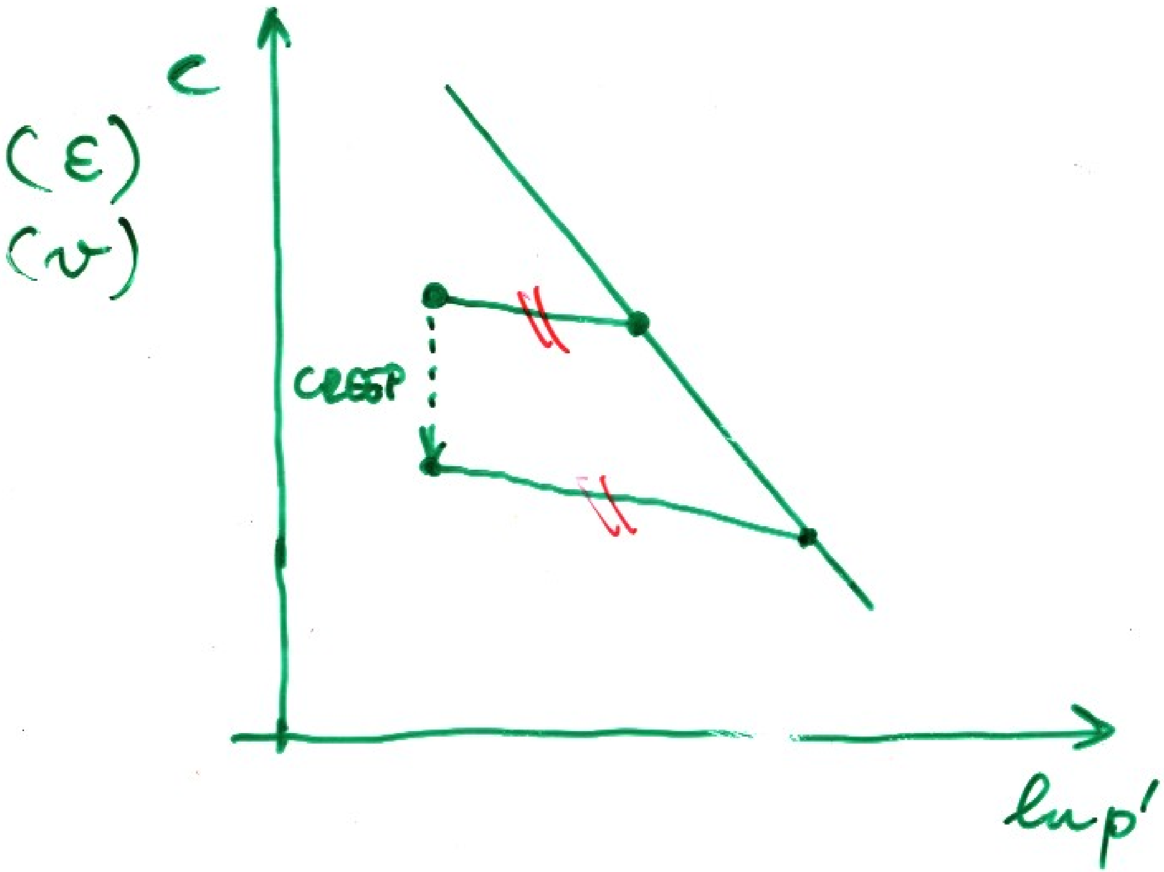
determination (from oedometer data)



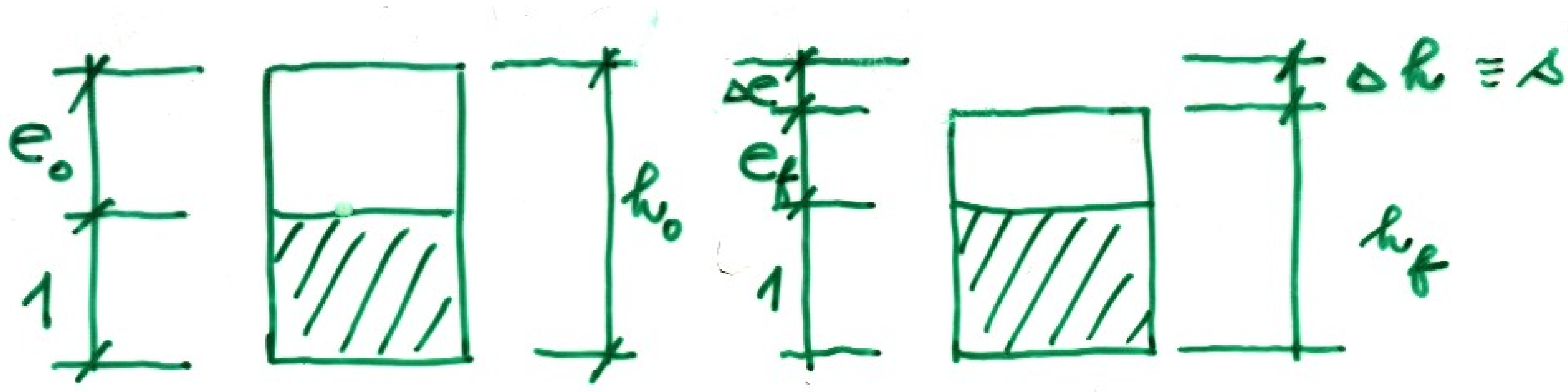


„Overconsolidation Stress“ vs Creep

→ the meaning of „overconsolidation stress“ - ???



One-dimensional compression (oedometer)

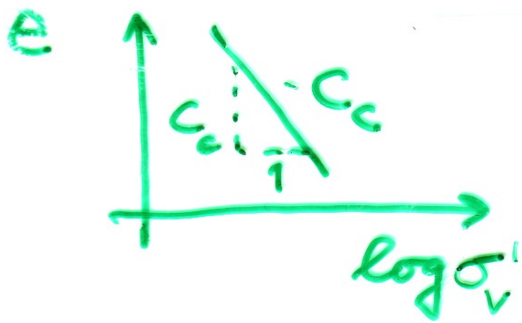


$\varepsilon_V = - \Delta h / h_0 = - \Delta e / (1+e_0) \equiv s / h_0$

s – settlement

Settlement calculation:

$s = - \Delta e / (1+e_0)\, h_0 = \varepsilon_V\, h_0$



semi-logarithmic plot of stress vs e:

compressibility index $C_c = - \Delta e / \Delta \log \sigma_v'$

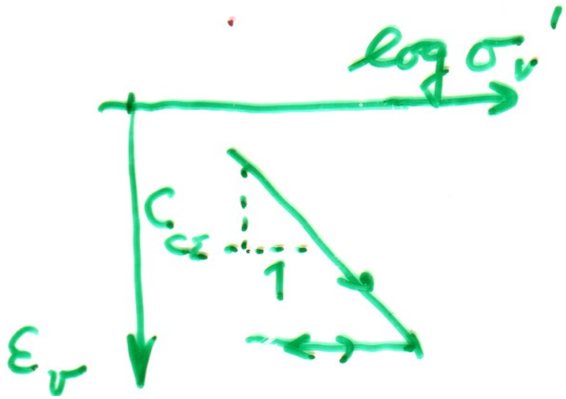
unloading: C_{cr} (or C_s ← 'swelling')

C_c is a real parameter – constant (for working stress range)

NB:

In determining C_c, NCL must be measured (not the compressibility at OC...)

One Dimensional Compression

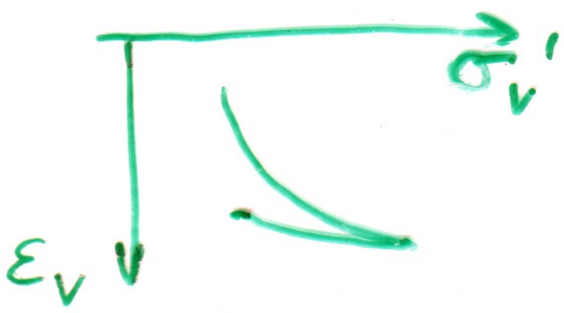


semi-logarithmic plot of stress vs ε:

modified compressibility index $C_{c\varepsilon} = \Delta\varepsilon \,/\, \Delta\log\sigma_v'$

unloading $C_{r\varepsilon}$ (or $C_{s\varepsilon}$ ← 'swelling')

$\varepsilon_V = -\,\Delta e \,/\, (1+e_0) \rightarrow C_{c\varepsilon} = C_c \,/ (1+e_0)$

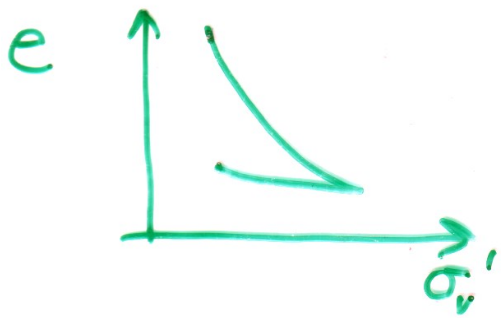


arithmetic plot of stress vs ε:

oedometer modulus $E_{oed} = \Delta\sigma_v' / \Delta\varepsilon$

coefficient of volume change $m_v = 1 / E_{oed}$

Not a real parameter – not a constant – depends on stress level



arithmetic plot of stress vs e:

coefficient of compressibility $a_v = -\ \Delta e / \Delta\sigma_v'$

Not a real parameter – not a constant – depends on stress level

Settlement computation

$s = -\Delta e / (1+e_0)\, h_0 = \varepsilon_V\, h_0$

summing over layers: $s = \sum s_i$

using different „parameters“:

$s = C_c\, h_0\ / (1+e_0)\ \log ((\sigma_{v0}' + \Delta\sigma_v') / \sigma_{v0}')$

$s = C_{c\varepsilon}\, h_0 \log ((\sigma_{v0}' + \Delta\sigma_v') / \sigma_{v0}')$

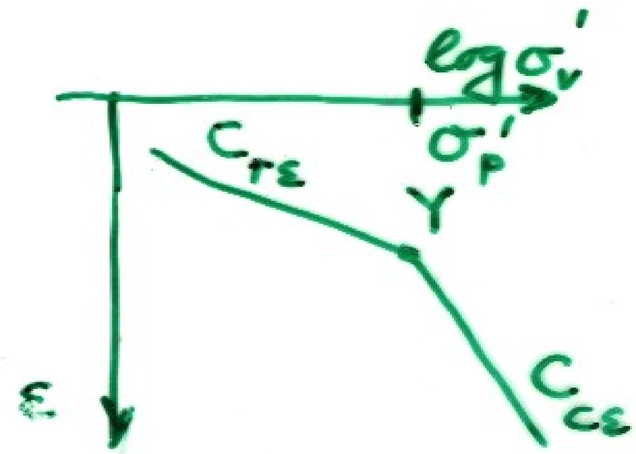
$s = m_v\ h_0\ \Delta\sigma_v'$ (m_v not a constant)

$s = h_0\ \Delta\sigma_v' / E_{oed}$ (E_{oed} not a constant)

$\Delta\sigma_v'$ change in effective stress

Settlement computation – OC soil

for example with $C_{c\varepsilon}$



$$s = C_{r\varepsilon}\, h_0 \log(\sigma_p' / \sigma_{v0}') + C_{c\varepsilon}\, h_0 \log((\sigma_{v0}' + \Delta\sigma_v') / \sigma_p')$$

One-dimensional compression – „at rest“ coefficient K_0

$\varepsilon_h \equiv 0$

$\varepsilon_h = 1 / E' (\sigma_h' - v' (\sigma_h' + \sigma_v')) = 0$

$\sigma_h' - v' \sigma_h' - v' \sigma_v' = 0$

$\sigma_h' / \sigma_v' = v' / (1 - v') = K_0$ = at rest coefficient

NB:

1 The above definition of K_0 is valid for elastic material only (Hooke's law used);

With soils: v' not a constant

2 Effective stress ratio K_0 constant for NC soil only (while NC soil is not elastic at all)

Elastic relationship between Oedometer a Young's Moduli

Oedometer ($\Delta\sigma_v$; $\sigma_h' = \sigma_v' K_0$; $\varepsilon_h = 0$):

$$\varepsilon_v = \sigma_v' / E_{oed}'$$

Hooke's Law for a specimen in the oedometer:

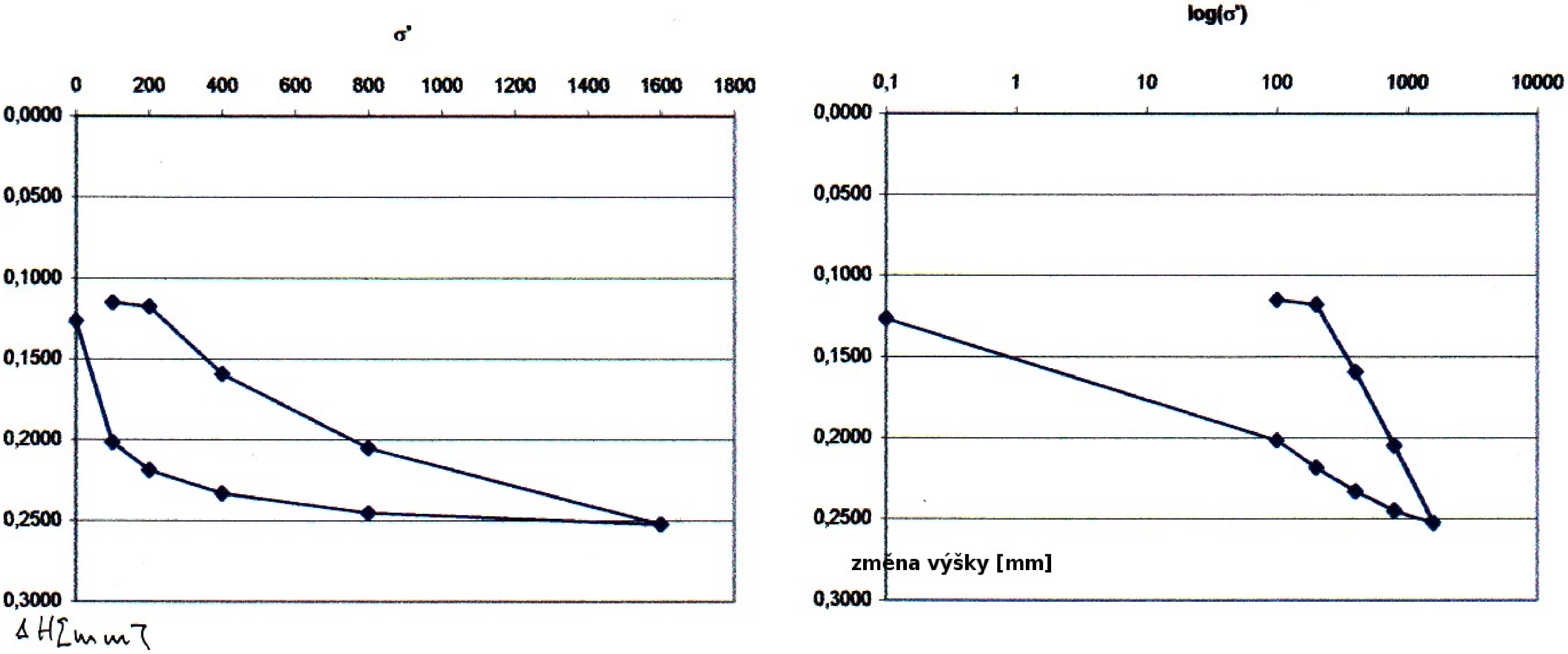
$$\varepsilon_v = 1 / E' (\sigma_v' - v' (\sigma_h' + \sigma_h')) = \sigma_v' / E' (1 - v' (2v' / (1 - v'))$$

$$\varepsilon_v = \sigma_v' / E' (1 - 2v'^2 / (1 - v'))$$

$$\rightarrow 1 / E_{oed}' = 1 / E' \; (1 - 2v'^2 / (1 - v'))$$

$$\rightarrow E_{oed}' = E' / (1 - 2v'^2 / (1 - v'))$$ for an elastic material only

Kaolin Clay - Lab class No 7



Typical values of „parameters“

C_c; $C_{cr} \approx C_c / 5$

clay	$C_c = 0,2 – 0,5$
silt, silty clay	$C_c = 0,15 – 0,3$
sensitive clay	$C_c > 1$; $C_c = 7\text{-}10$
peat	$C_c = 10 – 15$

E_{oed}

fine-grained soil	$E_{oed} = 1 – 30$ MPa
kaolin – Lab Class	$E_{oed} = 3 – 8$ MPa
sand	$E_{oed} = 5 – 100$ MPa
gravel	$E_{oed} = 20 – 500$ MPa

Oedometer modulus is stress dependent – not a parameter

Literature for the course Soil Mechanics I
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http://labmz1.natur.cuni.cz/~bhc/s/sm1/

Atkinson, J.H. (2007) The mechanics of soils and foundations. 2nd ed. Taylor & Francis.

Further reading:

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- Mitchell, J.K. and Soga, K (2005) Fundamentals of soil behaviour. J Wiley.
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[1] Atkinson, J.H. (2007) The mechanics of soils and foundations. 2nd ed. Taylor & Francis.