

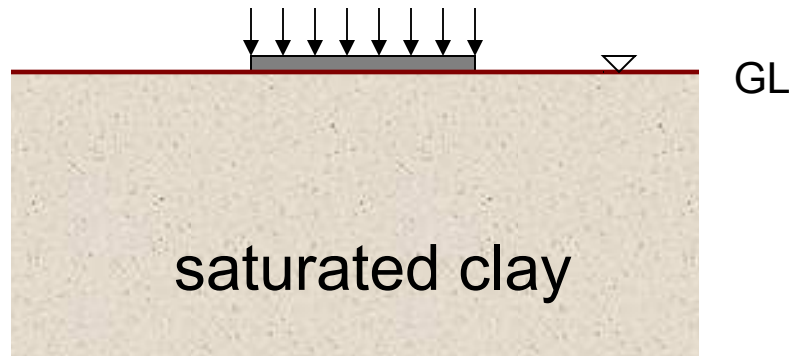


# Consolidation of Clays

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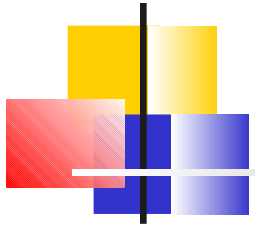
# What is Consolidation?

When a saturated clay is loaded externally,

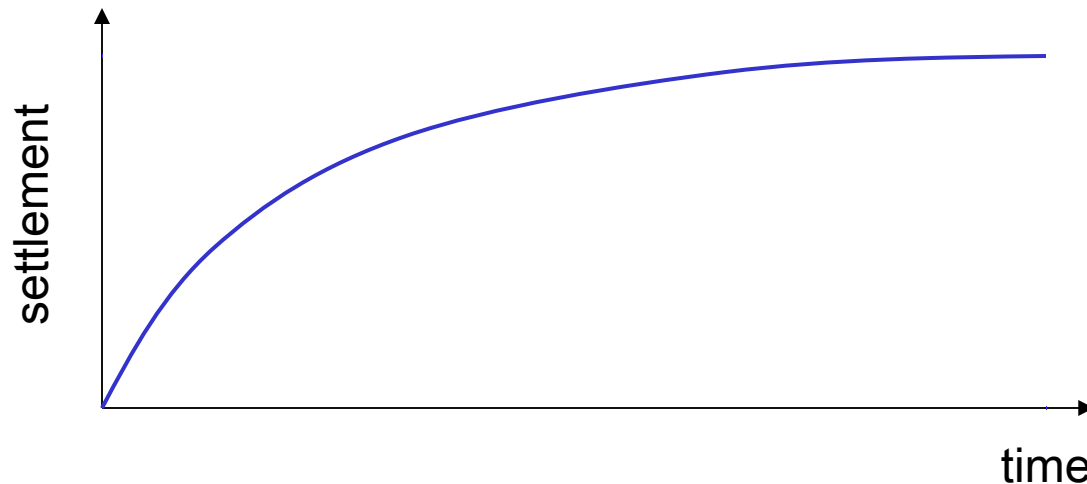


the water is squeezed out of the clay over a long time (due to low permeability of the clay).

# What is Consolidation?



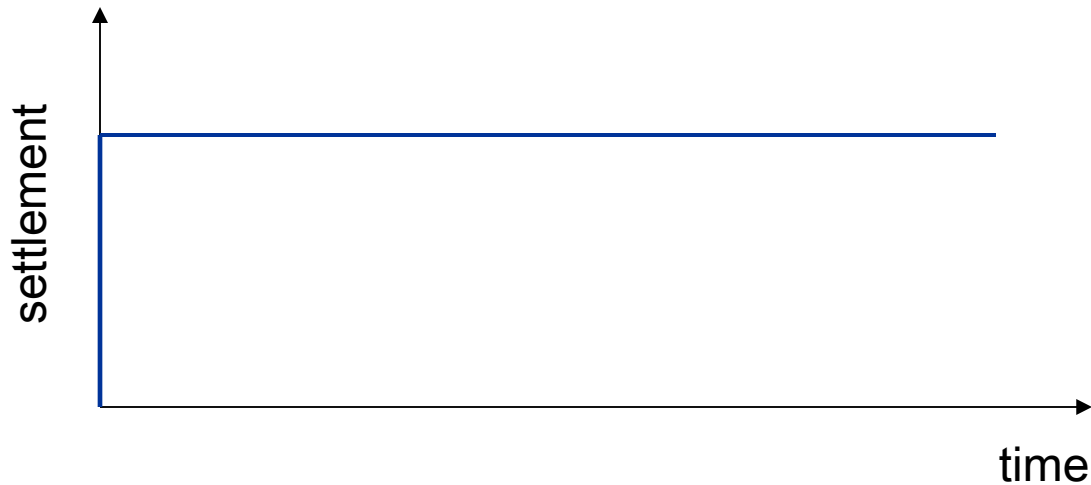
This leads to settlements occurring over a long time,



which could be several years.

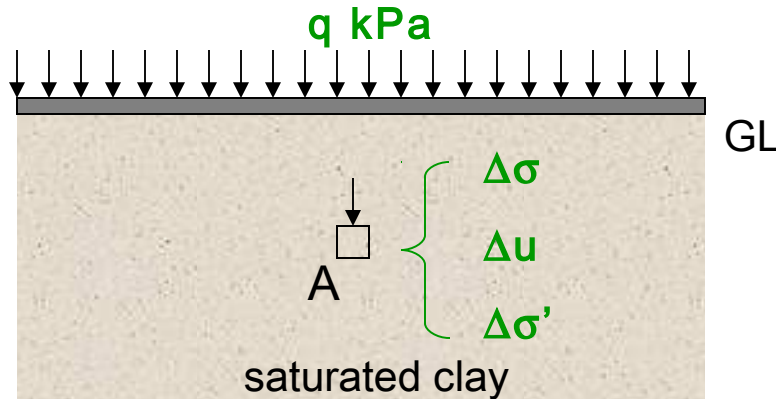
# In granular soils...

Granular soils are freely drained, and thus the settlement is instantaneous.



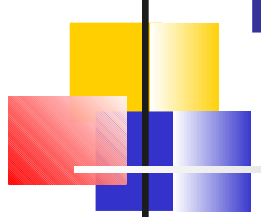
# During consolidation...

Due to a surcharge  $q$  applied at the GL,  
the stresses and pore pressures are increased at A.



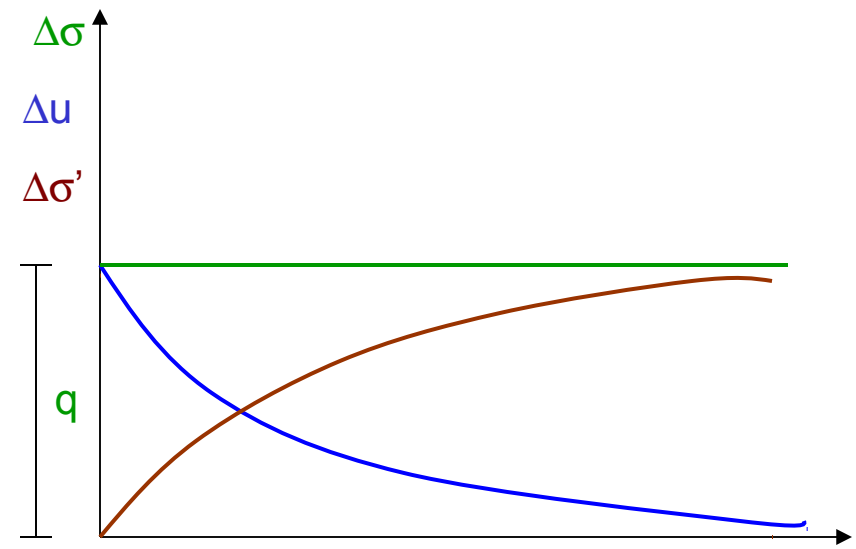
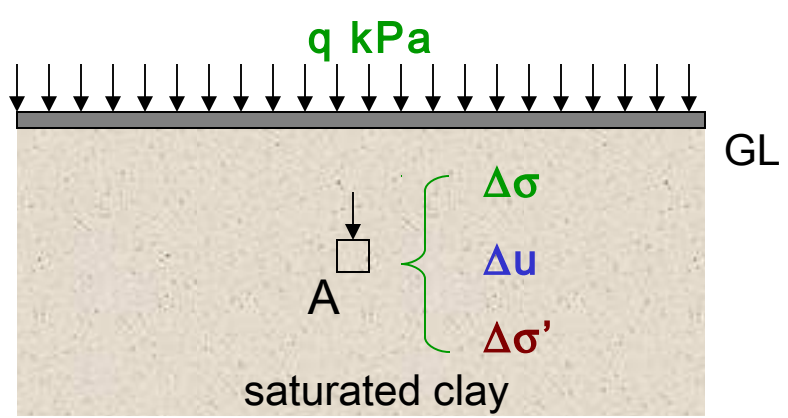
..and, they vary  
with time.

# During consolidation...



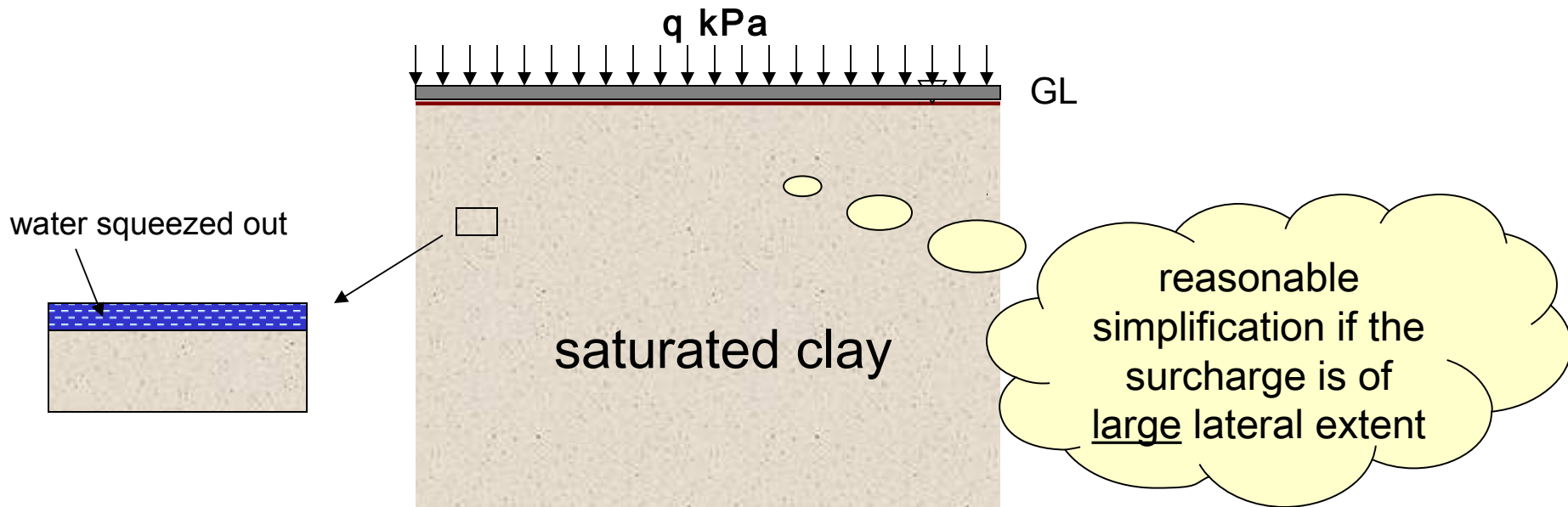
$\Delta\sigma$  remains the same ( $=q$ ) during consolidation.

$\Delta u$  decreases (due to drainage) while  $\Delta\sigma'$  increases, transferring the load from water to the soil.



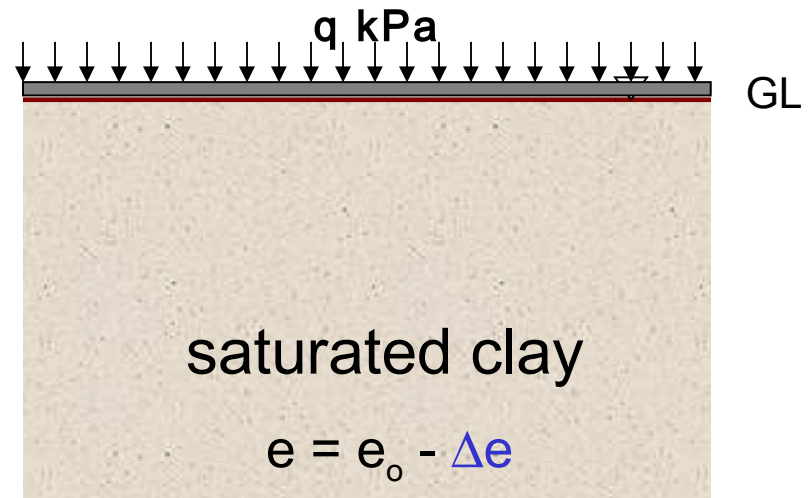
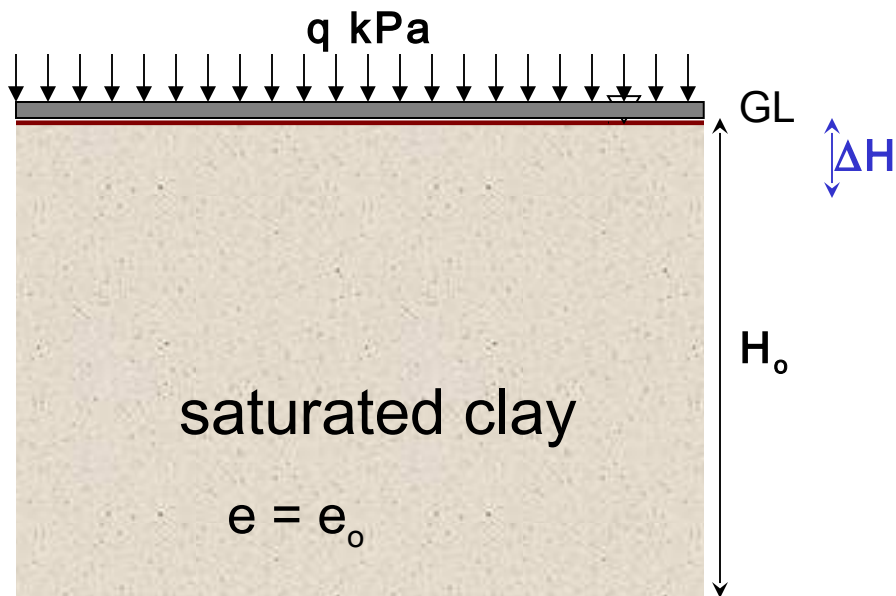
# One Dimensional Consolidation

- ~ drainage and deformations are vertical (none laterally)
- ~ a simplification for solving consolidation problems



# $\Delta H - \Delta e$ Relation

average vertical strain =  $\frac{\Delta H}{H_0}$



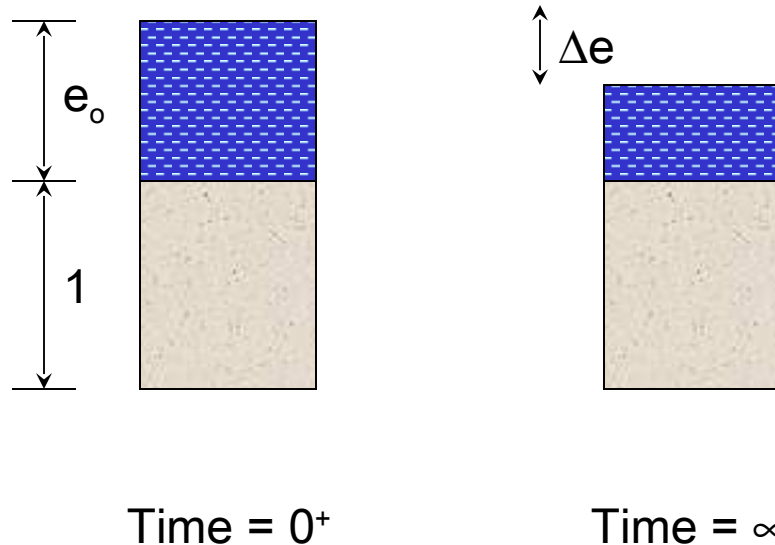
Time =  $0^+$

Time =  $\infty$



# $\Delta H - \Delta e$ Relation

Consider an element where  $V_s = 1$  initially.



$$\therefore \text{average vertical strain} = \frac{\Delta e}{1 + e_0}$$

# $\Delta H$ - $\Delta e$ Relation

Equating the two expressions for average vertical strain,

consolidation  
settlement

change in void ratio

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

initial thickness of  
clay layer

initial void ratio



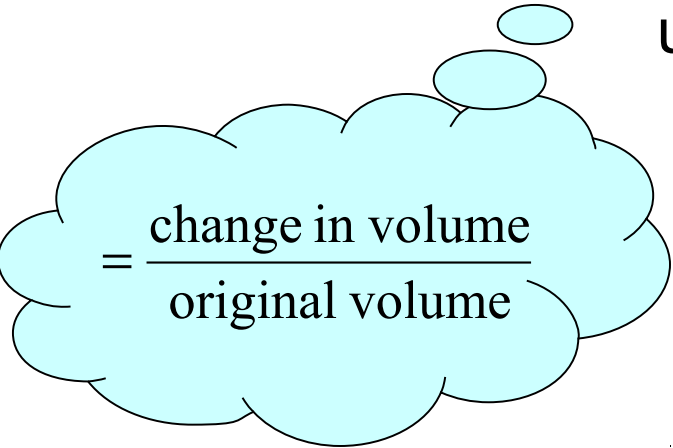
# Coefficient of volume compressibility

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~ denoted by  $m_v$

~ is the **volumetric strain** in a clay element per unit increase in stress

no units


$$= \frac{\text{change in volume}}{\text{original volume}}$$

i.e.,

$$m_v =$$

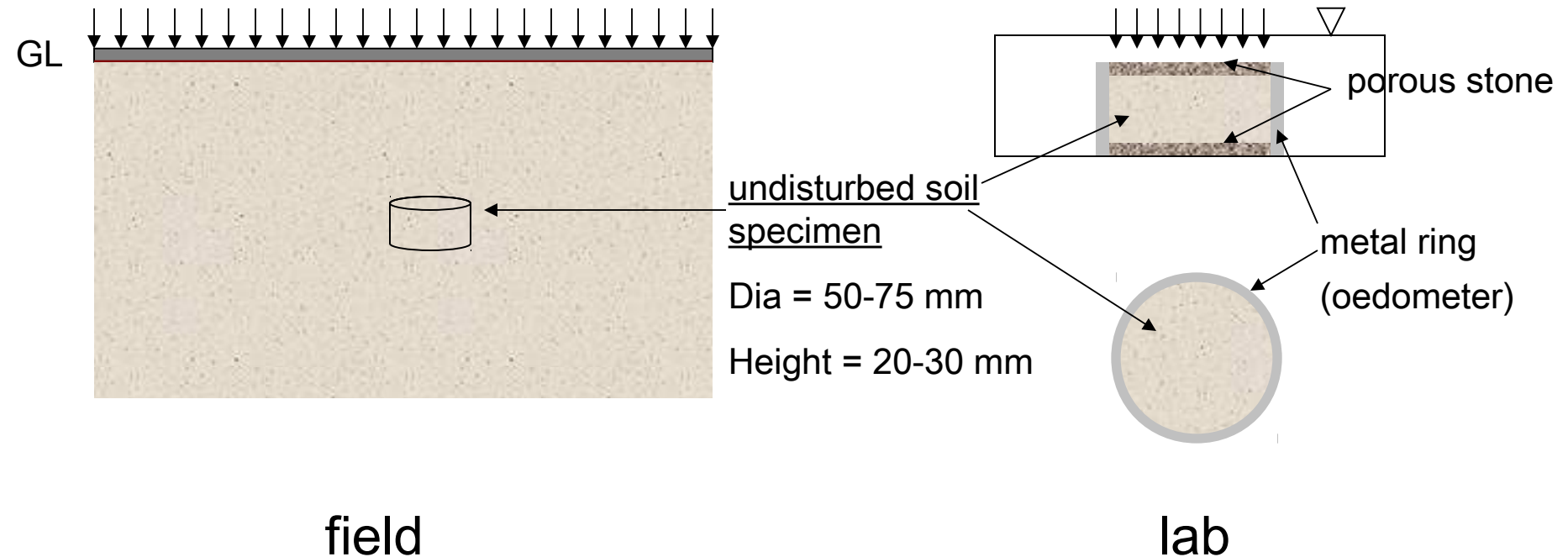
kPa<sup>-1</sup> or MPa<sup>-1</sup>

$$= \frac{\Delta V / V}{\Delta \sigma}$$

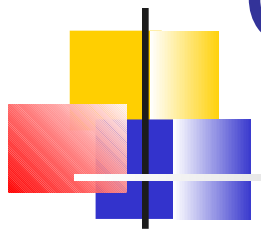
kPa or MPa

# Consolidation Test

~ simulation of 1-D field consolidation in lab.

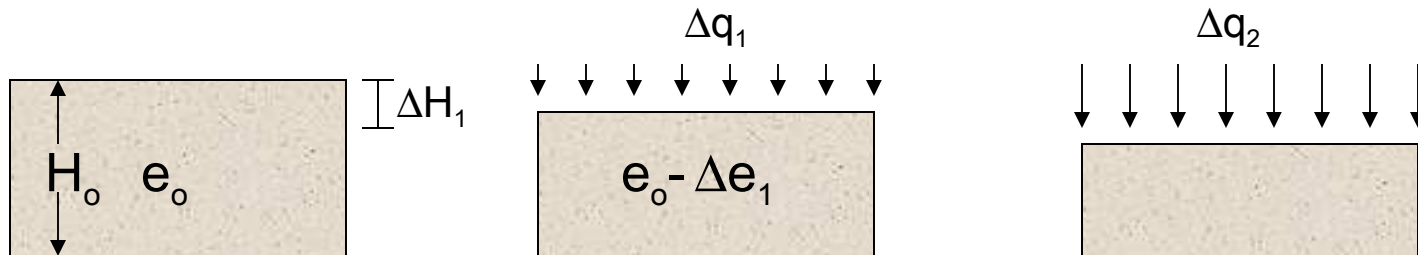


# Consolidation Test



loading in increments

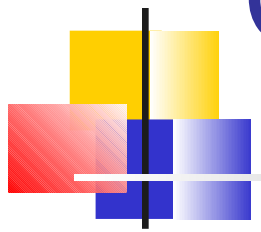
allowing full consolidation before next increment



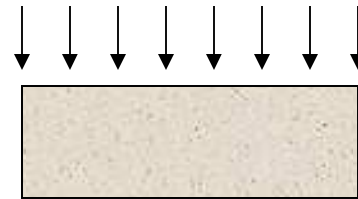
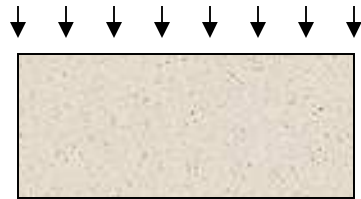
$$\Delta e_1 = \frac{\Delta H_1}{H_o} (1 + e_o)$$

$$\Delta e_2 =$$

# Consolidation Test

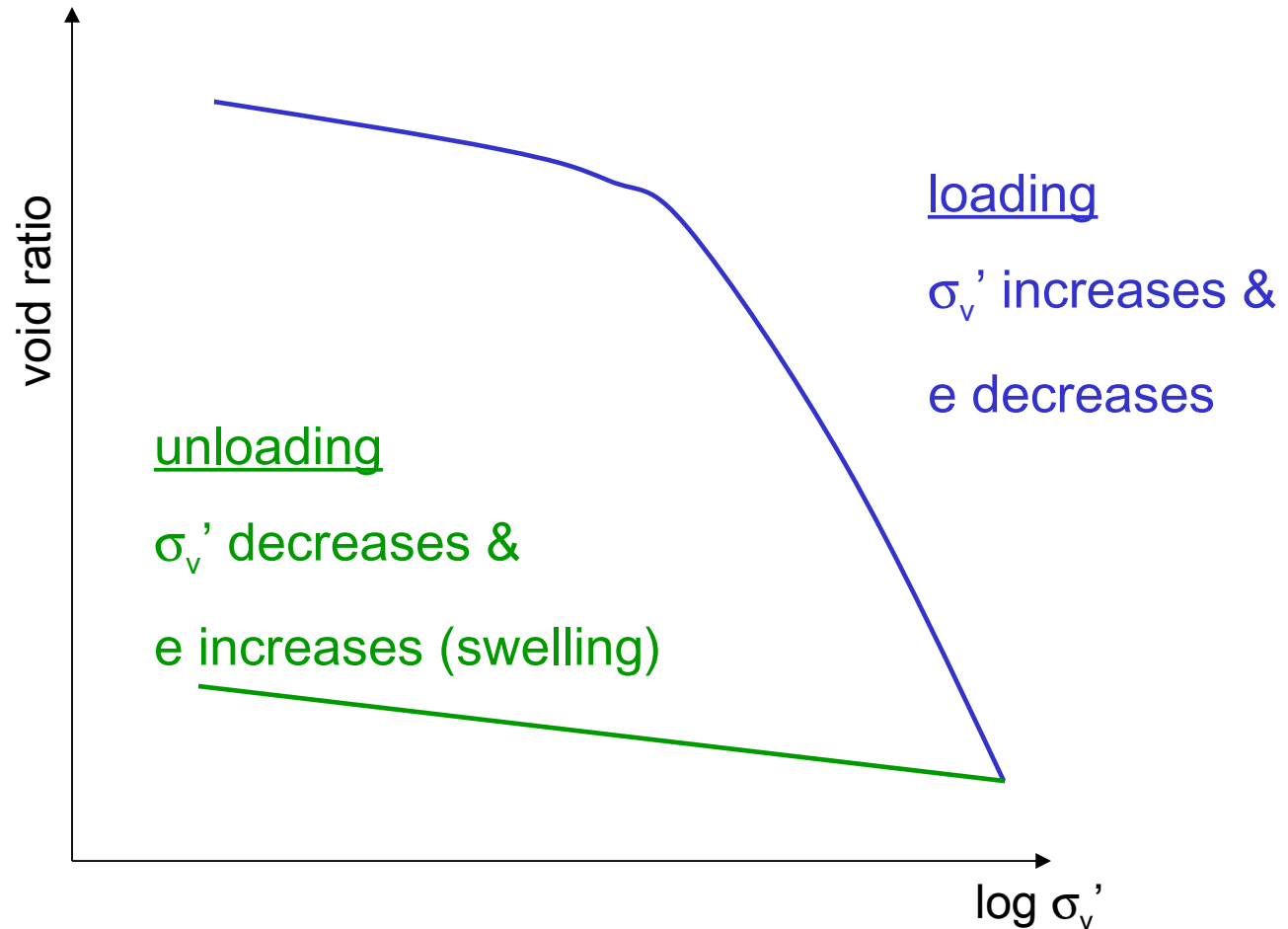


← unloading →

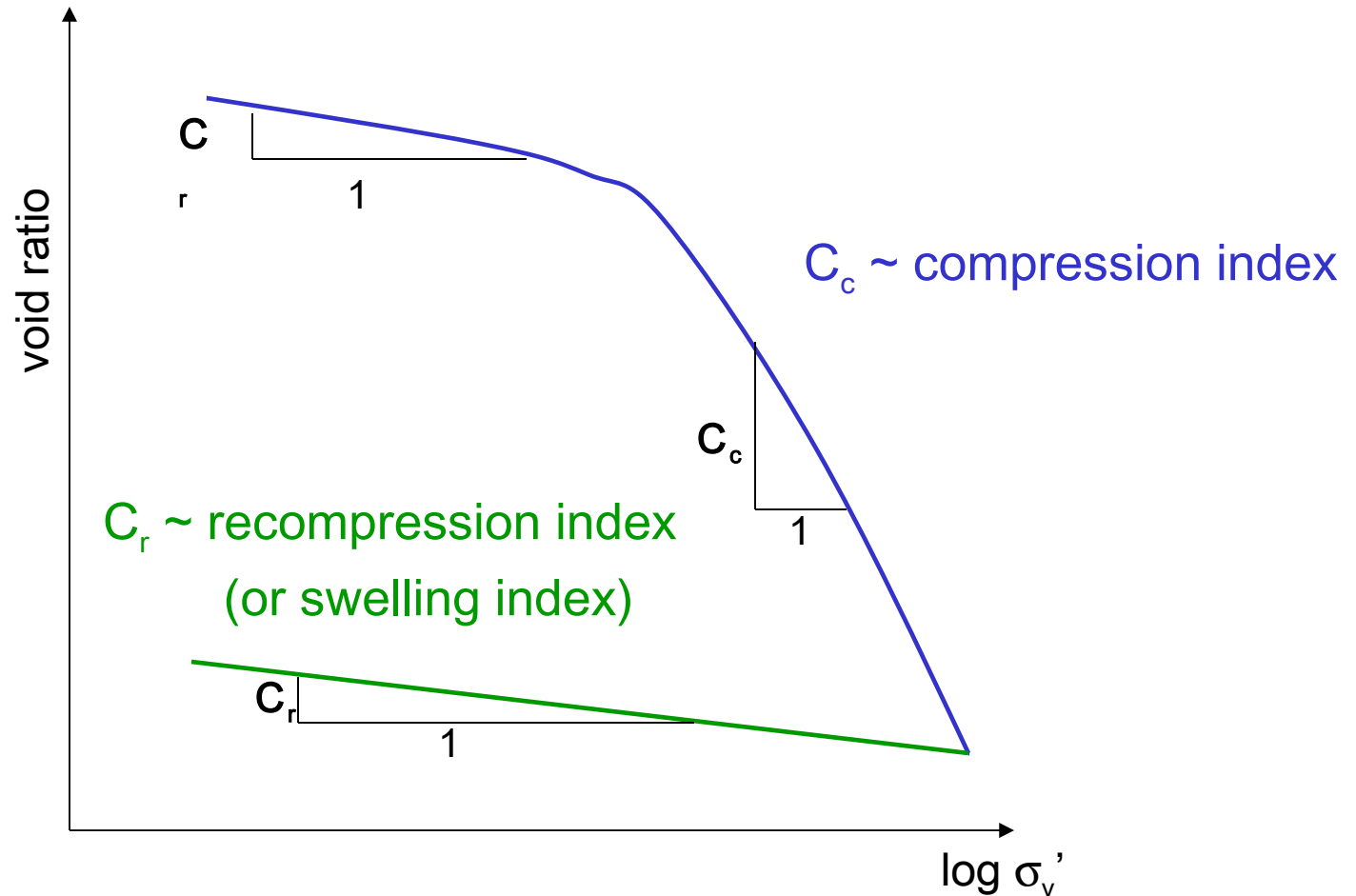
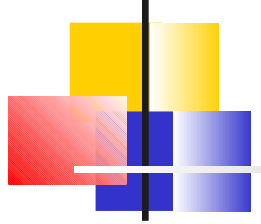


# $e - \log \sigma_v'$ plot

- from the above data

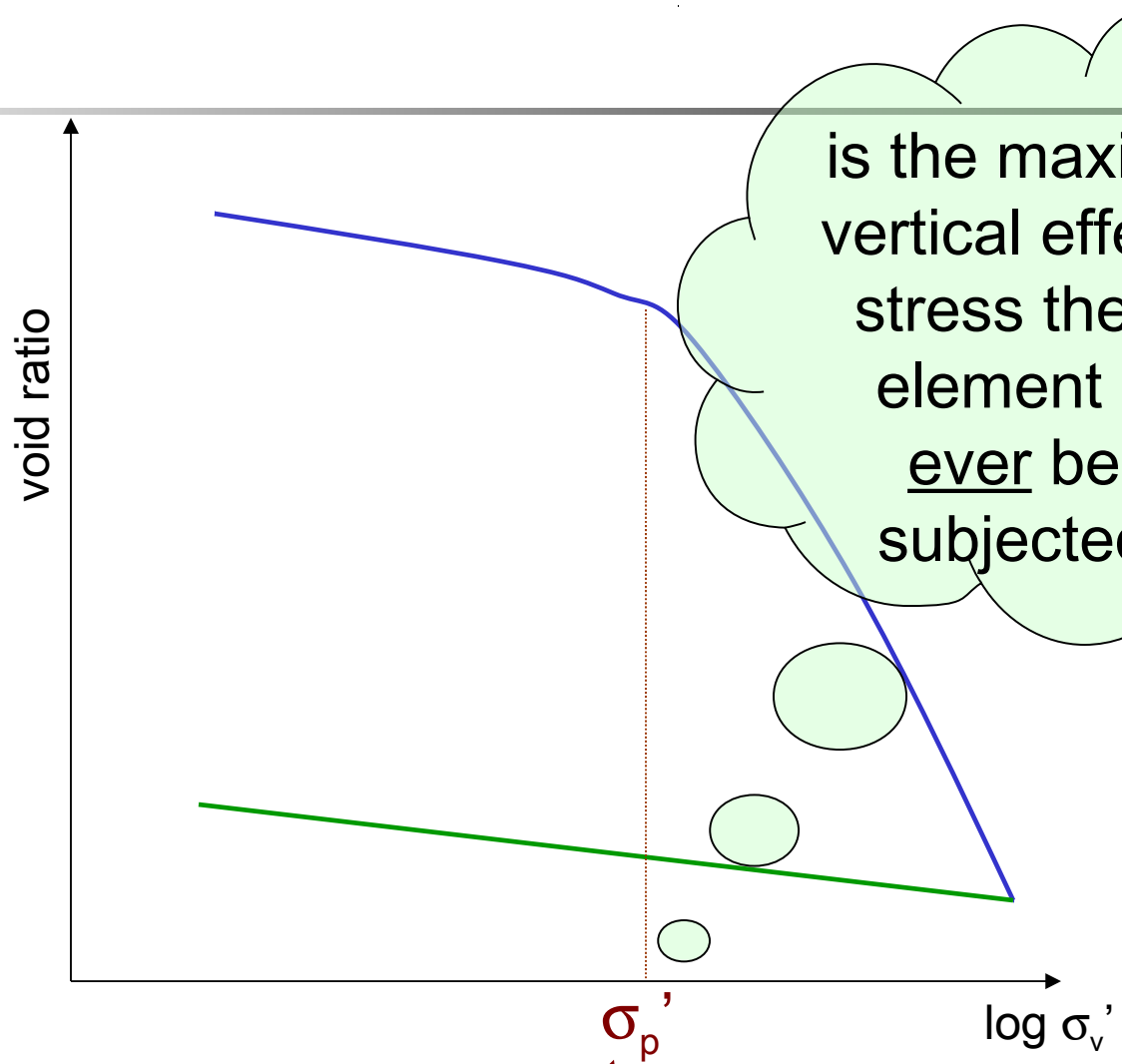
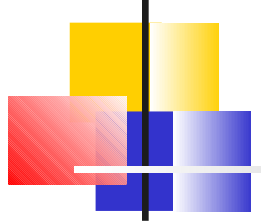


# Compression and recompression indices



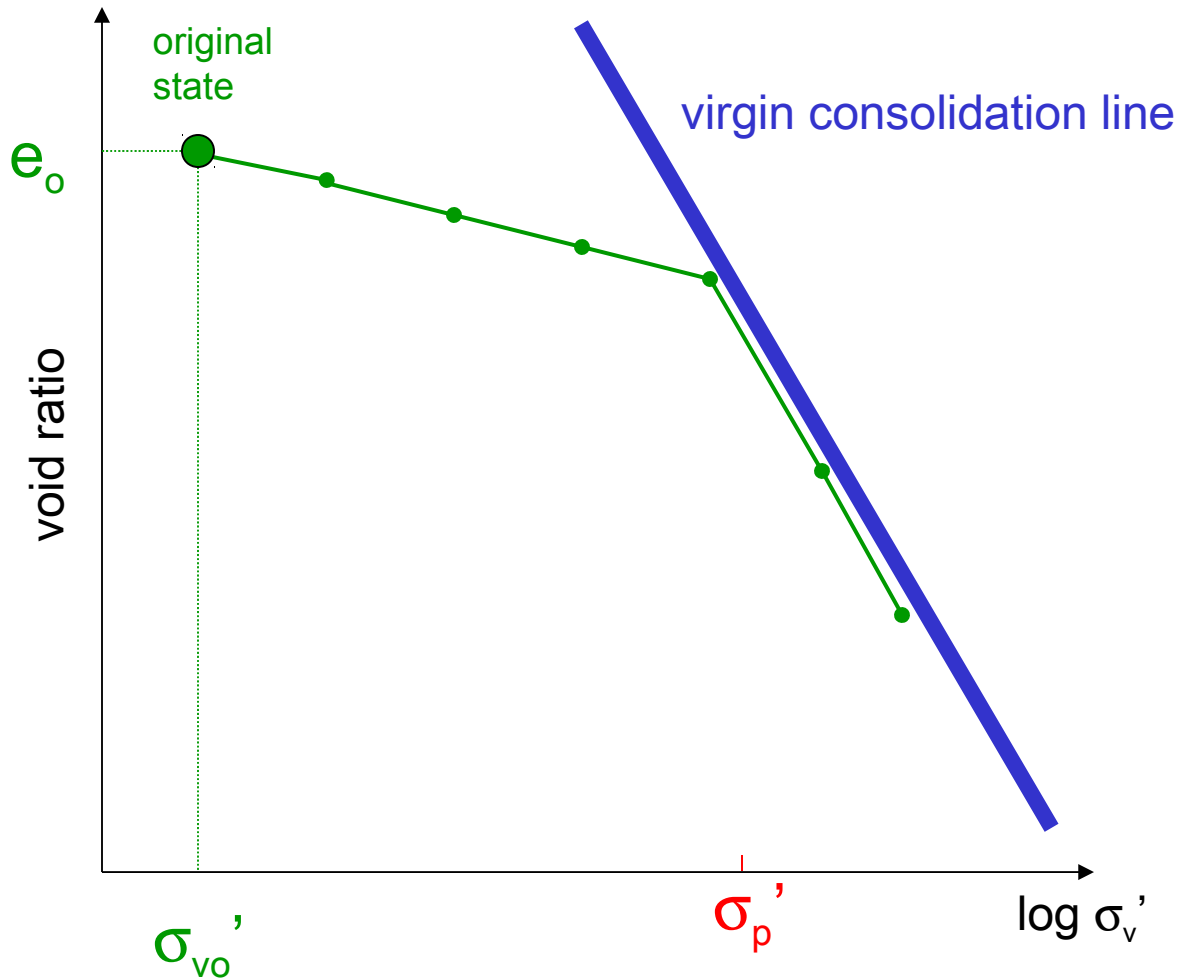
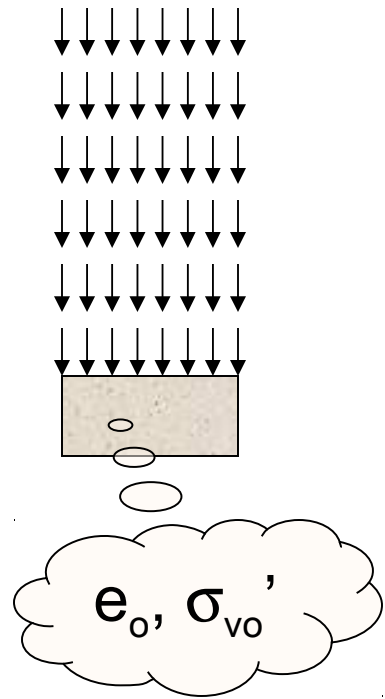
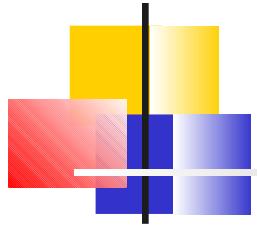


# Preconsolidation pressure

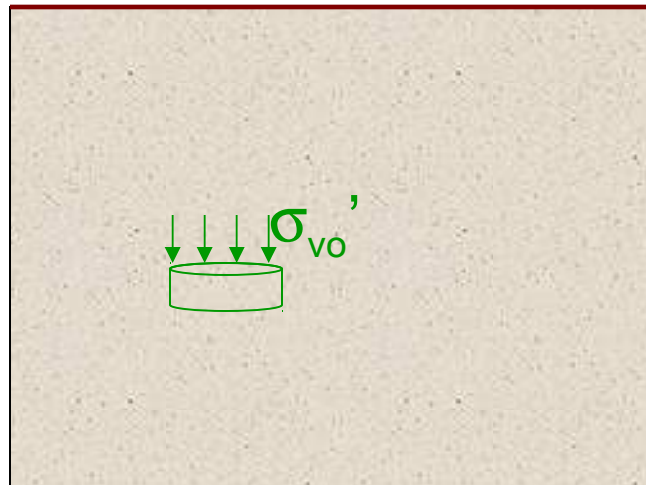
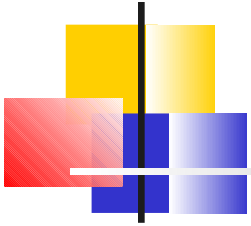


is the maximum vertical effective stress the soil element has ever been subjected to

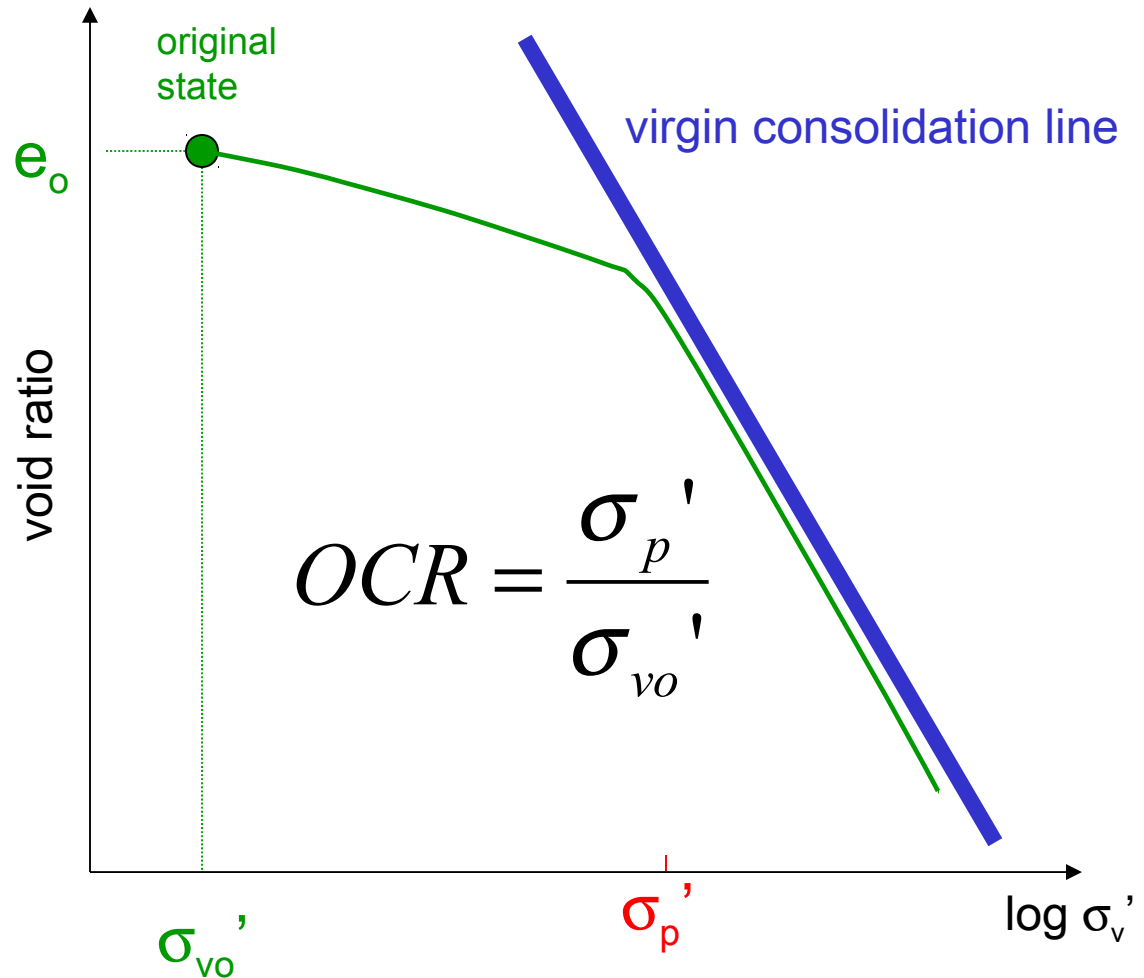
# Virgin Consolidation Line



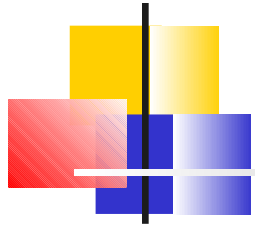
# Overconsolidation ratio (OCR)



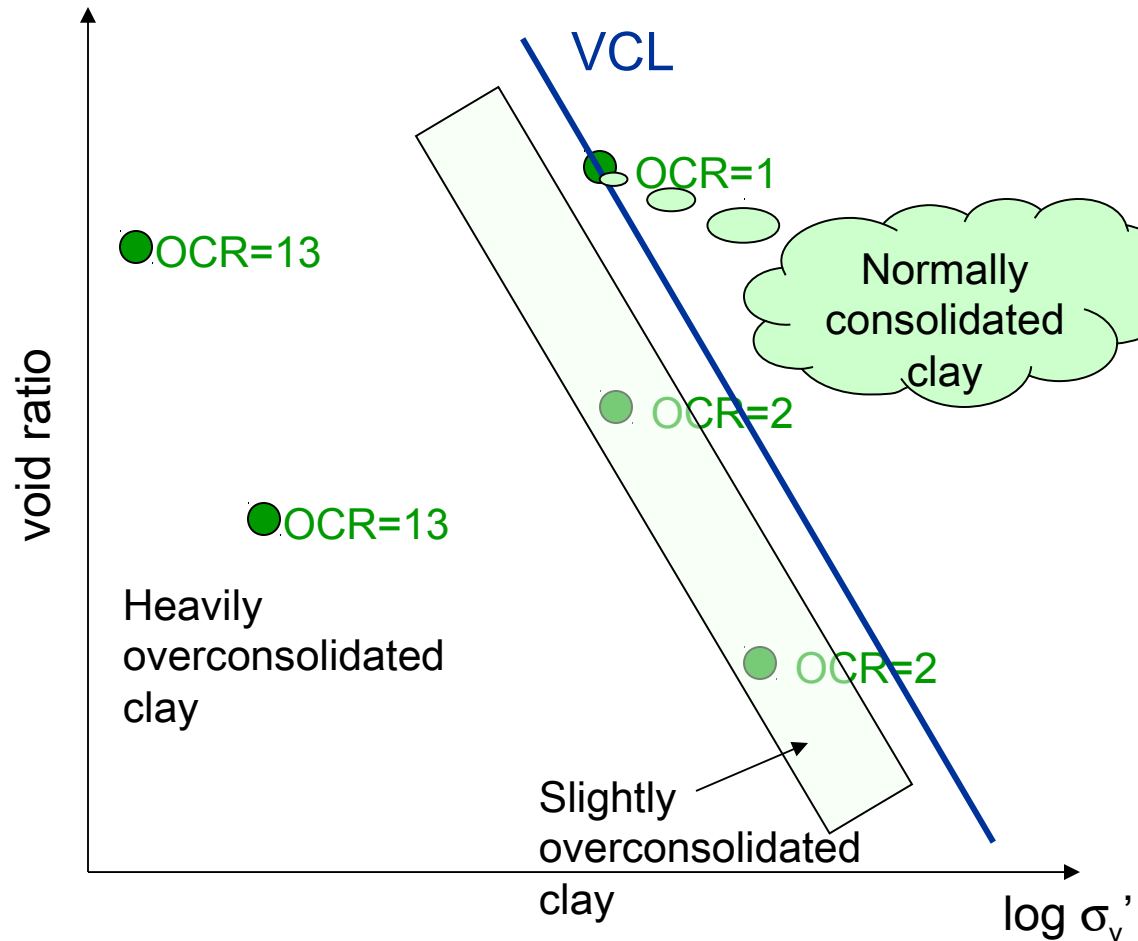
Field



# Overconsolidation ratio (OCR)



● ~current state





# More to come...

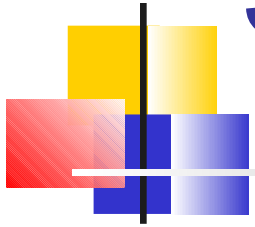
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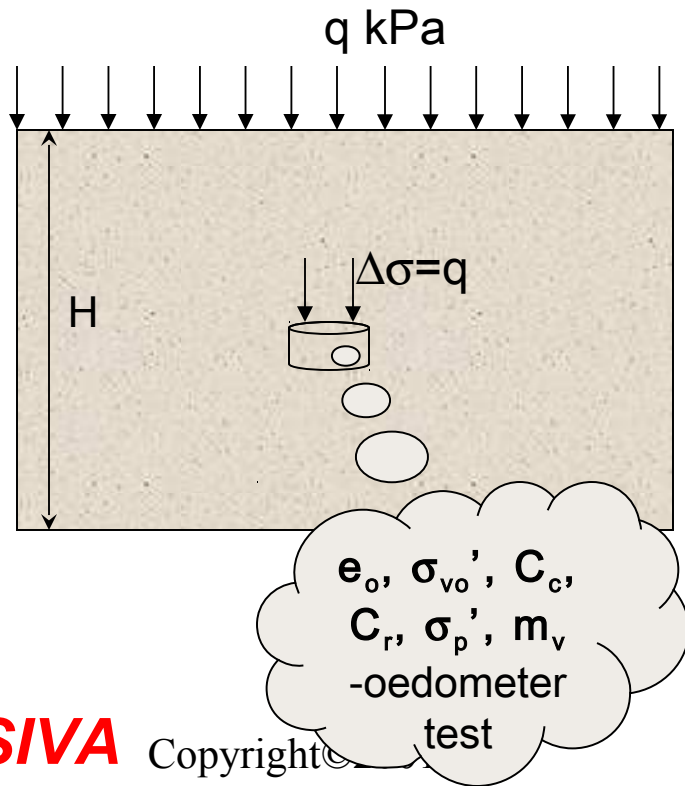
**AM I  
GETTING  
THROUGH  
TO YOU?**

©MATTHEWS

# Settlement computations



Two different ways to estimate the consolidation settlement:



(a) using  $m_v$

$$\text{settlement} = m_v \Delta\sigma H$$

(b) using  $e$ - $\log \sigma_v'$  plot

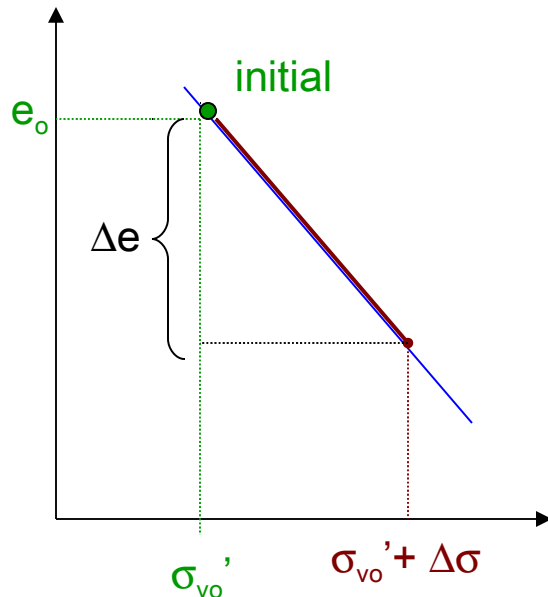
$$\text{settlement} = \frac{\Delta e}{1 + e_o} H$$

next slide

# Settlement computations

~ computing  $\Delta e$  using  $e$ - $\log \sigma_v'$  plot

If the clay is normally consolidated,  
the entire loading path is along the **VCL**.

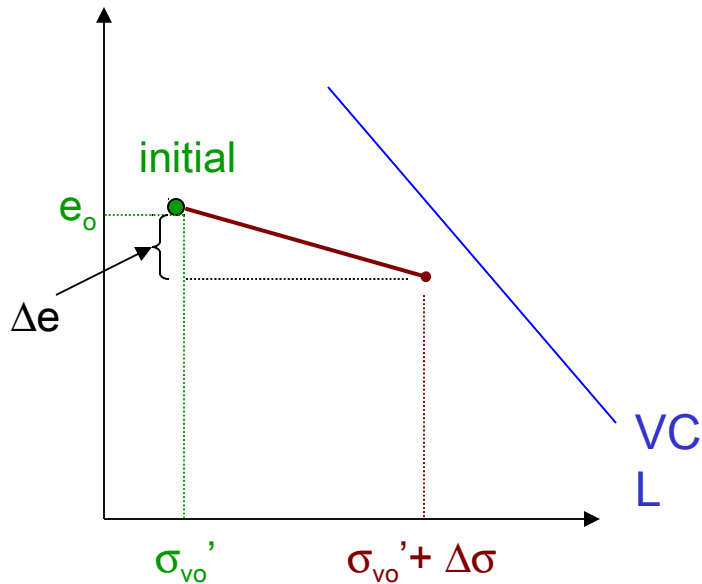


$$\Delta e = C_c \log \frac{\sigma_{vo}' + \Delta\sigma'}{\sigma_{vo}'}$$

# Settlement computations

~ computing  $\Delta e$  using  $e$ - $\log \sigma_v'$  plot

If the clay is overconsolidated, and remains so by the end of consolidation,



$$\Delta e = C_r \log \frac{\sigma_{v0}' + \Delta\sigma'}{\sigma_{v0}'}$$

note the use of  $C_r$

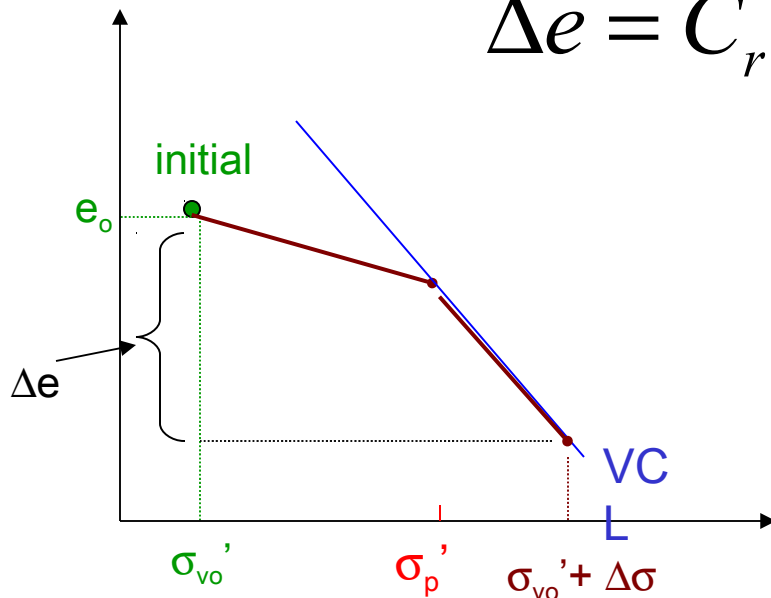


# Settlement computations

~ computing  $\Delta e$  using  $e$ -log  $\sigma_v'$  plot

If an overconsolidated clay becomes normally consolidated by the end of consolidation,

$$\Delta e = C_r \log \frac{\sigma_p'}{\sigma_{vo}'} + C_c \log \frac{\sigma_{vo}' + \Delta \sigma'}{\sigma_p'}$$



# Preloading

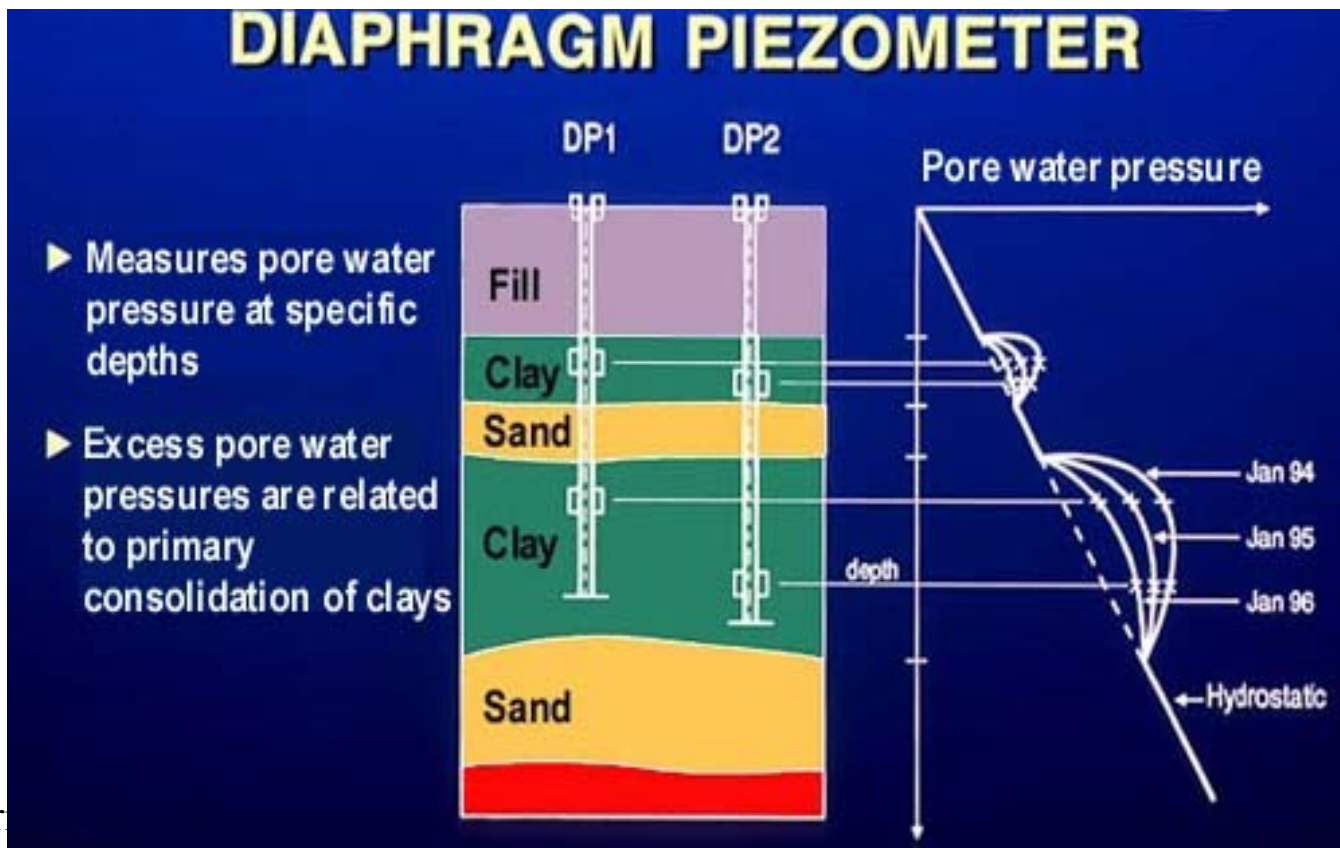
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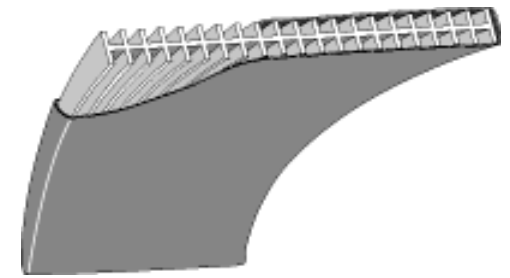
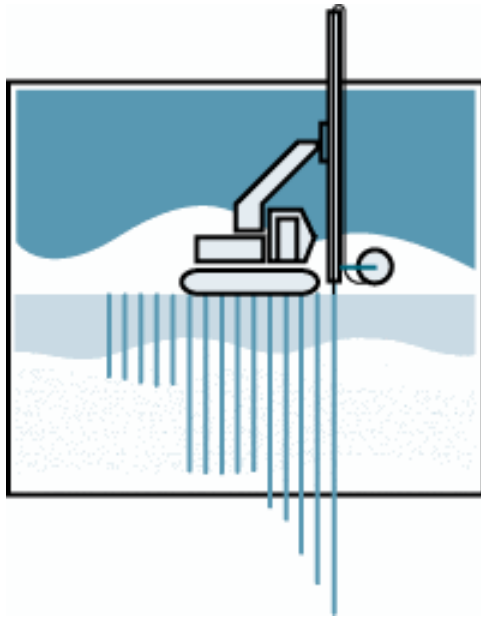
Preloading at West Kowloon Expressway, Hong Kong.  
(5-10 m embankments for 2-5 months)

# Preloading

Piezometers measure pore pressures and thus indicate when the consolidation is over.



# Preloading



Cross section of PVD

Installation

Prefabricated Vertical Drains to Accelerate Consolidation

# Prefabricated Vertical Drains

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Installation of PVDs