Geotechnical Engineering–I

BSc Civil Engineering – 4th Semester

Lecture # 18

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by

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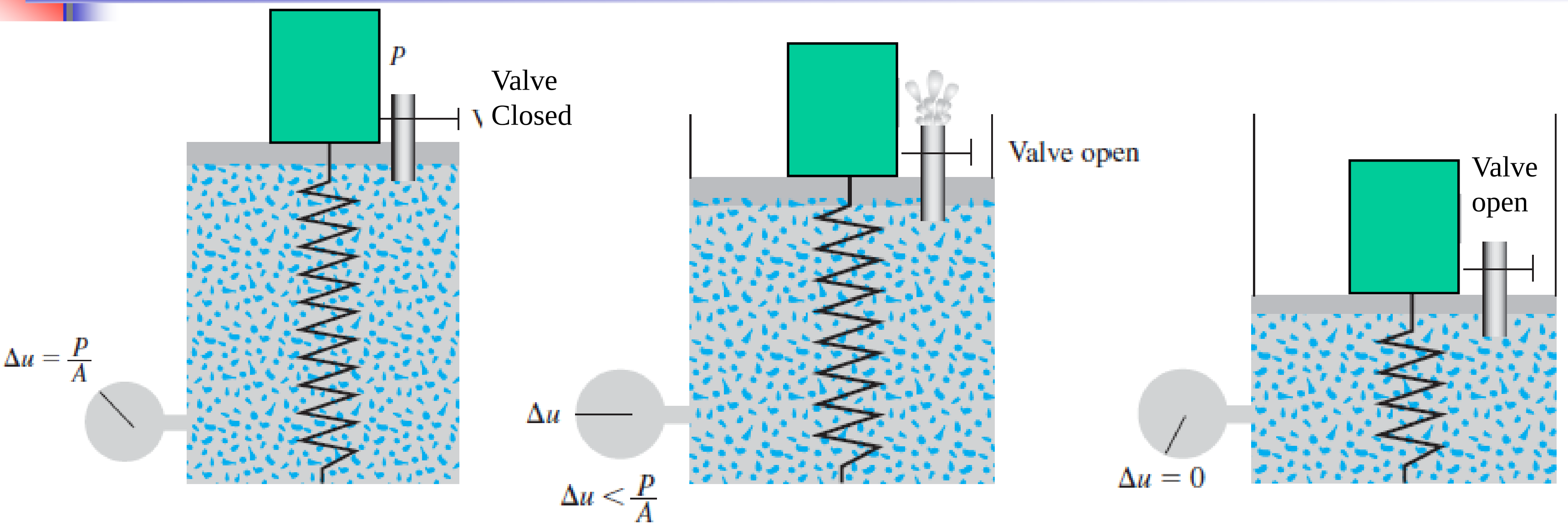
Lecture Handouts: https://groups.google.com/d/forum/geotec-1

Spring-Cylinder Model – Summary

Time dependent response of <u>*saturated*</u> *fine-grained soils*.



With the valve closed	With the valve opened	After $t >>> 0$
$P_S = 0$, &	$P_S > 0$, &	$P_W = 0$, &
$P_W = P$	$P_W < P$	$P_S = P$

Spring-cylinder assembly

Total load acting on the system = P

Load carried by water = P_W

Load carried by Spring = P_S

$$P = P_S + P_W \quad \text{OR} \quad P_S = P - P_W$$

In case of soil

Stress acting on soil mass → Total Stress = σ

Stress carried by water → Pore water pressure = u

Stress carried by soil particles → Effective stress = σ'

$$\sigma = \sigma' + u \quad \text{OR} \quad \sigma' = \sigma - u$$

Inferences from Spring-Cylinder Model

<u>Magnitude</u> of consolidation settlement

dependent on *compressibility of soil* (i.e. the stiffness of the spring)

expressed in term of *compression index (Cc)*

<u>Rate</u> of consolidation/settlement

dependent on

i. *permeability*, &
ii. *compressibility* of soil.

expressed in term of *co-efficient of consolidation (Cv)*

<u>Time</u> required for consolidation

dependent on

i. *permeability/velocity of flow through soil*, & → $t \, \alpha \left(1/v \right)$
ii. *Volume of water required to be squeezed out* → $t \, \alpha \, V$

Inferences from Spring-Cylinder Model

- *Magnitude of consolidation* → *compression index (Cc)*
- *Rate of consolidation* → *co-efficient of consolidation (Cv)*
- *Time required for consolidation*

Permeability / Velocity of flow through soil

$$t \;\alpha\; \left(1/v\right)$$

Darcy's equation → $v = ki$

$$i = h/H \qquad h = \Delta\sigma/\gamma_w$$

$$v = \frac{k \cdot \Delta\sigma}{\gamma_w \cdot H}$$

$$t \;\alpha\; \left(\frac{1}{k \cdot \Delta\sigma/\gamma_w \cdot H}\right) \cdots\cdots\cdots (1)$$

Volume of water required to be squeezed out

$$t \;\alpha\; V$$

$$t \;\alpha\; \Delta\sigma \cdot m_v \cdot H \cdots\cdots\cdots (2)$$

t = time required for any degree of consolidation
$\Delta\sigma$ = change in stress
m_V = coefficient of volume compressibility
H = length of the drainage path
($H = t$ → for one-way drainage
$H = t/2$ → for two-way drainage)
t = thickness of consolidating soil layer

Inferences from Spring-Cylinder Model

Magnitude of settlement → compression index (Cc)

Rate of consolidation → co-efficient of consolidation (Cv)

Time required for consolidation

$$t \;\alpha \left(\frac{1}{k \cdot \Delta\sigma / \gamma_w \cdot H} \right) \cdots\cdots\cdots (1)$$

$$t \;\alpha\; \Delta\sigma \cdot m_v \cdot H \cdots\cdots\cdots (2)$$

Combining (1) and (2).

$$t \;\alpha \left(\frac{m_v \cdot \gamma_w \cdot H^2}{k} \right) \cdots\cdots\cdots (3)$$

$$C_V = \left(\frac{k}{m_v \cdot \gamma_w} \right)$$

Replacing C_V in (3);

$$t \;\alpha \left(\frac{H^2}{C_V} \right)$$

$$t = \left(\frac{T \cdot H^2}{C_V} \right)$$

Inferences from Spring-Cylinder Model

Magnitude of settlement → compression index (Cc)

Rate of consolidation → co-efficient of consolidation (Cv)

Time required for consolidation

$$t = \left(\frac{T \cdot H^2}{C_V} \right)$$

where,

t = time required for any degree of consolidation

C_V = coefficient of consolidation

H = length of the drainage path

T = constant known as ‘Time Factor’

$$T = \frac{\pi}{4}\left(\frac{u}{100}\right)^2; \qquad for\ u \le 60\%$$

$$T = 1.781 - 0.933 \cdot \log_{10}(100 - u); \qquad for\ u > 60\%$$

$$T_{50} = 0.197; \qquad for\ u = 50\%$$

$$T_{90} = 0.848; \qquad for\ u = 90\%$$

Consolidation Time *(t)*

$$t = \left(\frac{T \cdot H^2}{C_V} \right) \quad \& \quad C_v = \left(\frac{k}{m_v \cdot \gamma_w} \right)$$

$$\Downarrow$$

$$t = \left(\frac{T \cdot H^2 \cdot m_v \cdot \gamma_w}{k} \right)$$

where,

t = time required for any degree of consolidation

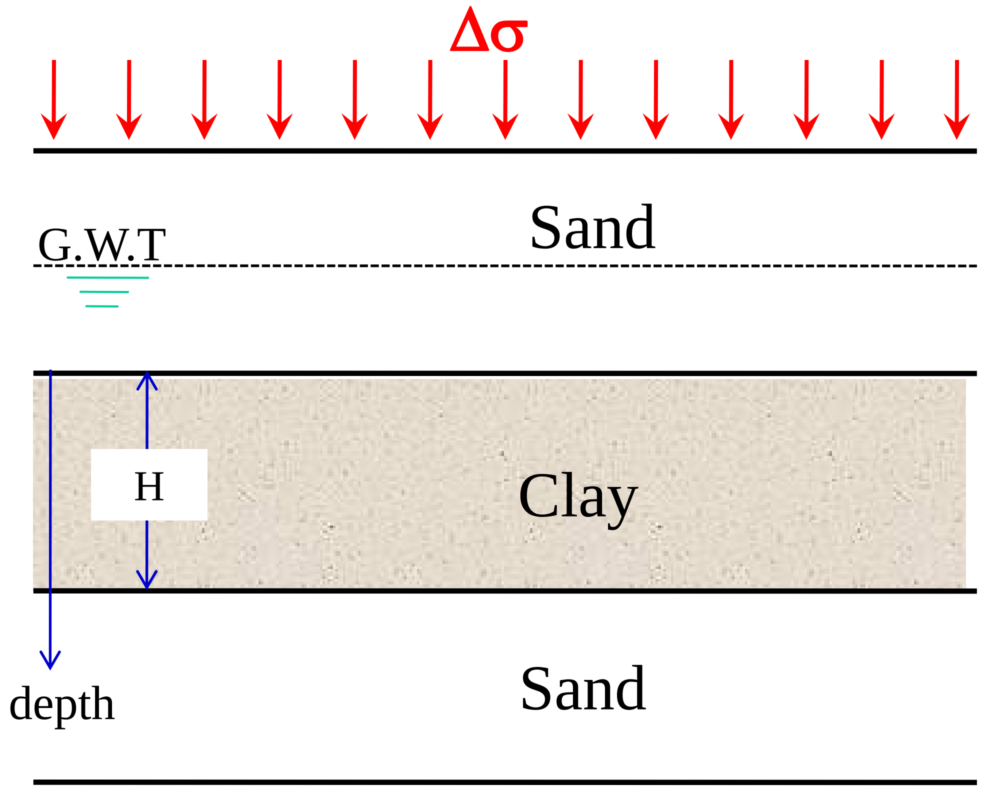
C_V = coefficient of consolidation

H = length of the drainage path

T = constant known as 'Time Factor'

Time required for consolidation (consolidation time) is independent of the magnitude of stress change ($\Delta\sigma$).

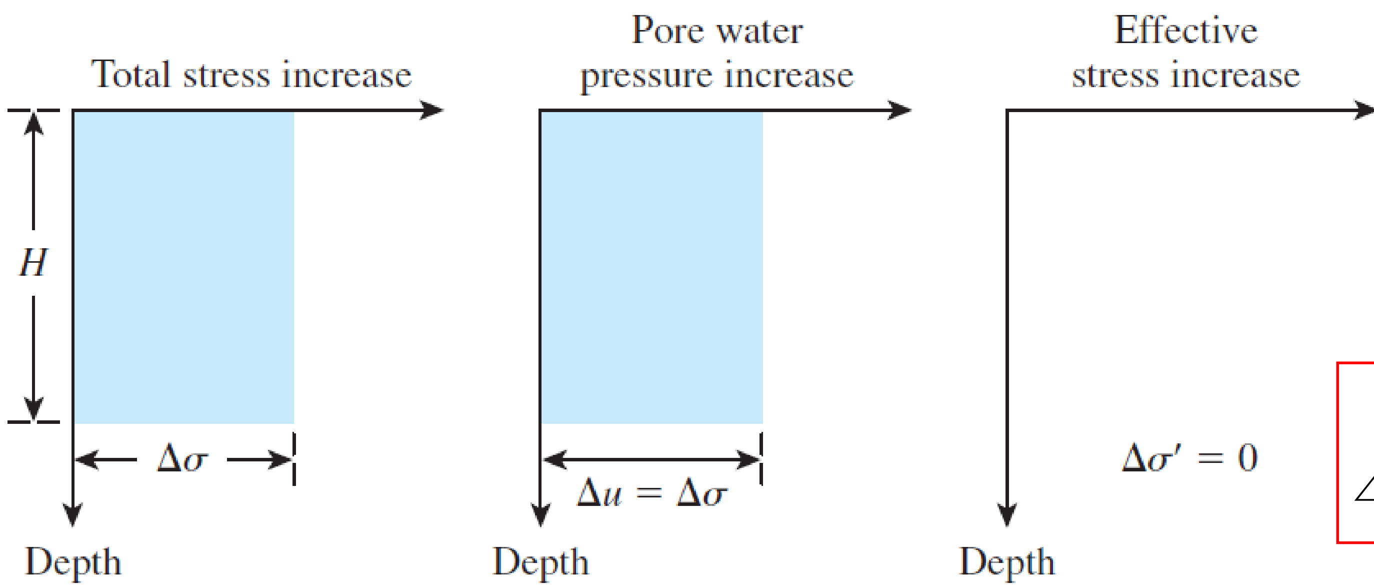
Consolidation Settlement in the Field



External stress *(Δσ)* applied on a soil stratum in the field.

- SAND→ *Quick drainage* of water → *Immediate settlement*
- CLAY → *Slow drainage* → *Consolidation settlement* (time dependent)

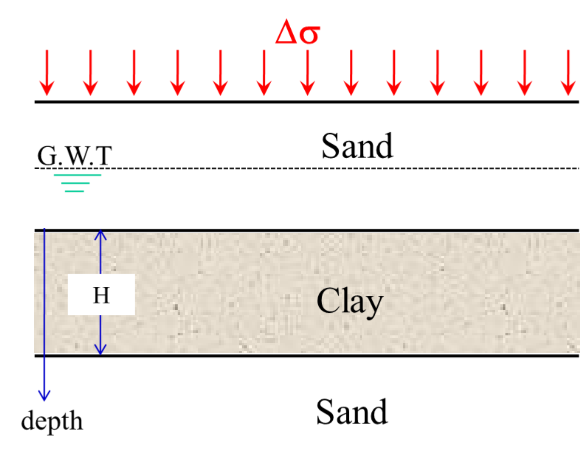
Consolidation Settlement in the Field



At time $t = 0$

Remember

$\Delta\sigma = \Delta u + \Delta\sigma'$

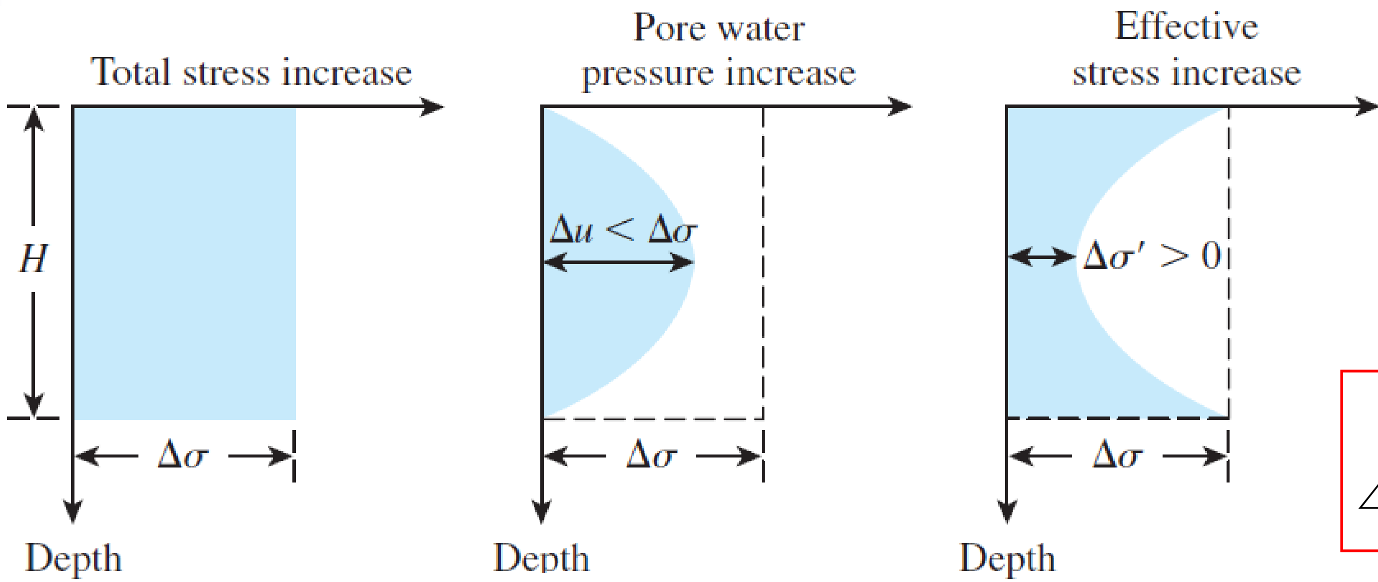


Immediately after load application $(t = 0)$

All the applied stress carried by pore water only, $\Delta u = \Delta\sigma$

Effective stress, $\Delta\sigma' = 0$

Consolidation Settlement in the Field



At time $0 < t < \infty$

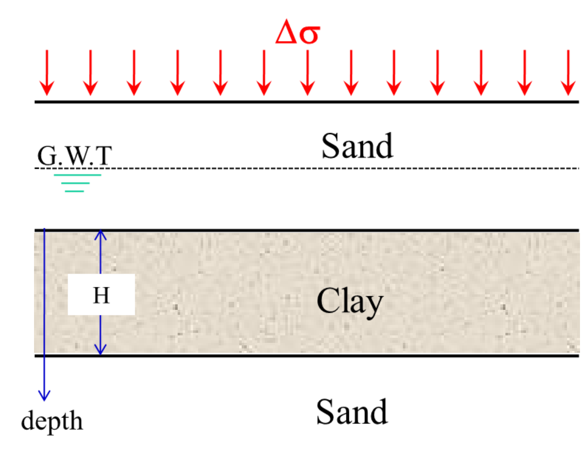
Remember

$$\Delta\sigma = \Delta u + \Delta\sigma'$$

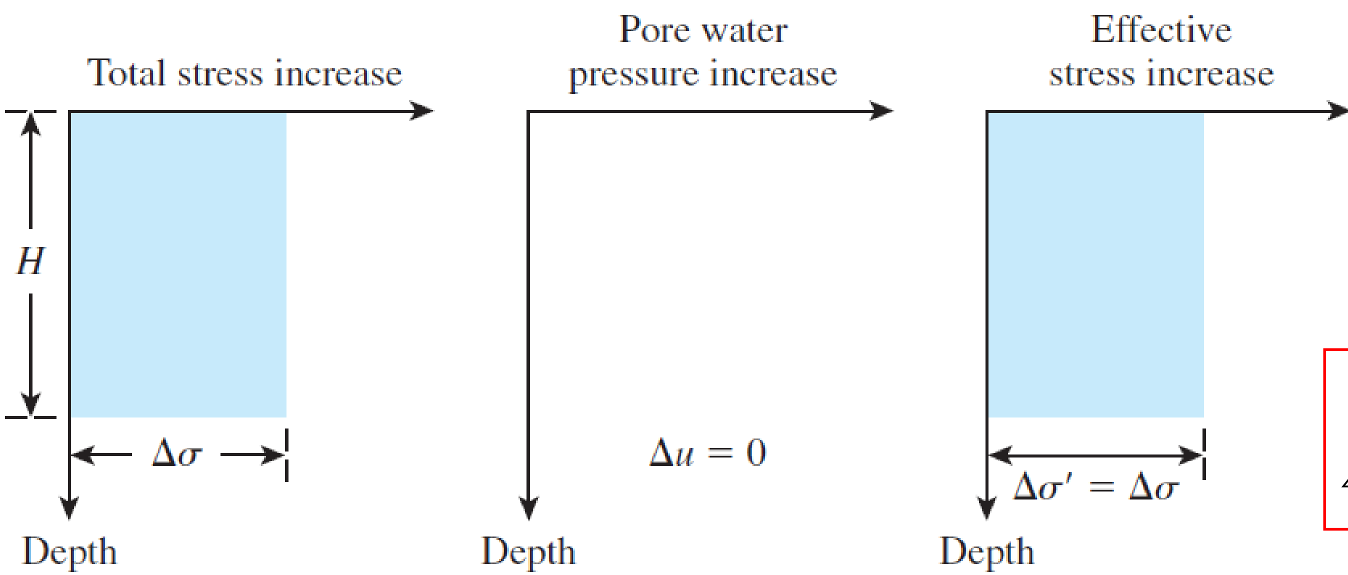
Some time after load application $(0 < t < \infty)$

Pore water pressure starts dissipating, $\Delta u < \Delta\sigma$

Additional stress start getting transferred to soil particles, $\Delta\sigma' > 0$



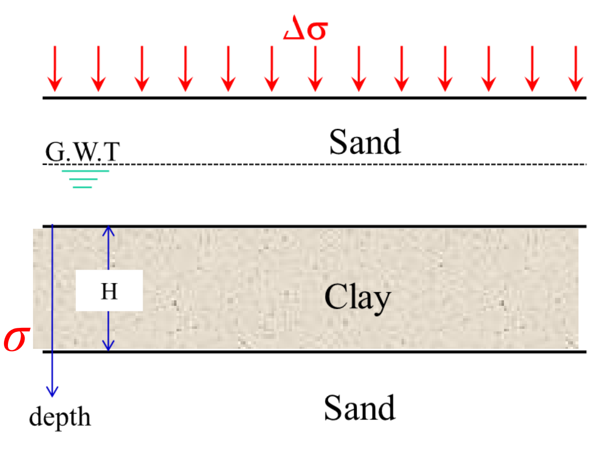
Consolidation Settlement in the Field



At time $t = \infty$

Remember

$\Delta\sigma = \Delta u + \Delta\sigma'$

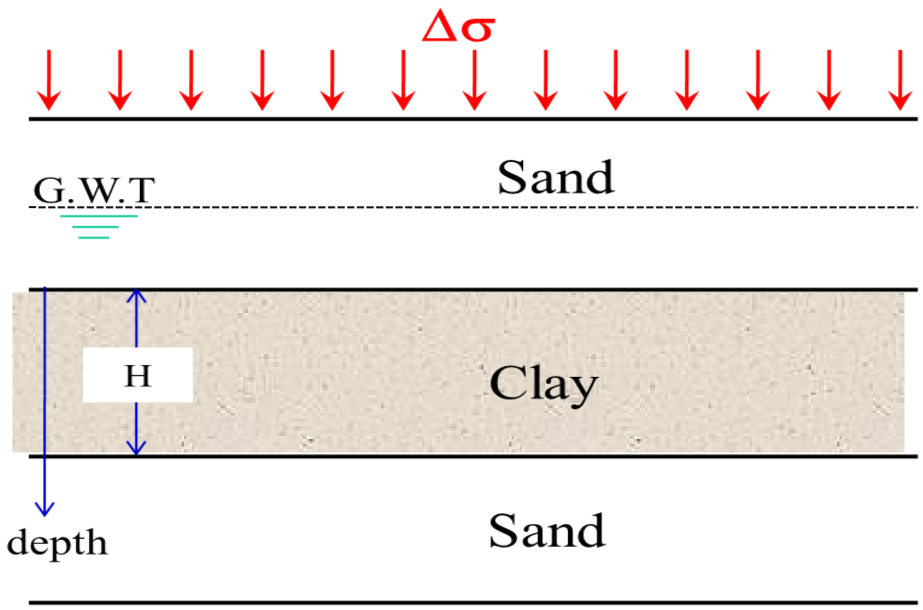


Long time after load application $(t = \infty)$

Pore water pressure dissipated completely, $\Delta u = 0$

All the applied stress being taken by soil particles, $\Delta\sigma' = \Delta\sigma$

One-Dimensional Consolidation



Drainage and *deformations* occur in *vertical direction only*.

(none laterally)

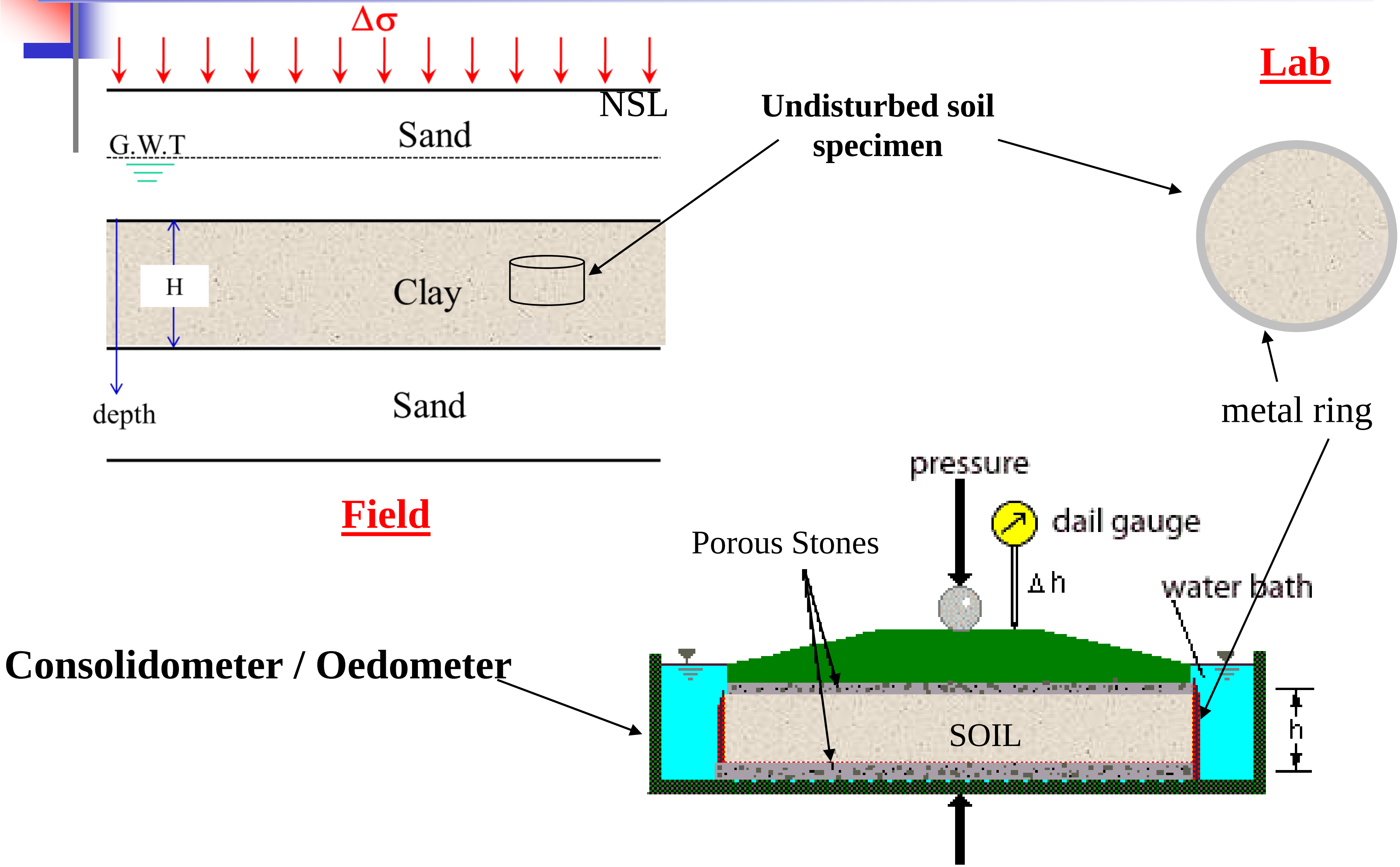
A reasonable simplification for solving consolidation problems

1-D Consolidation Theory

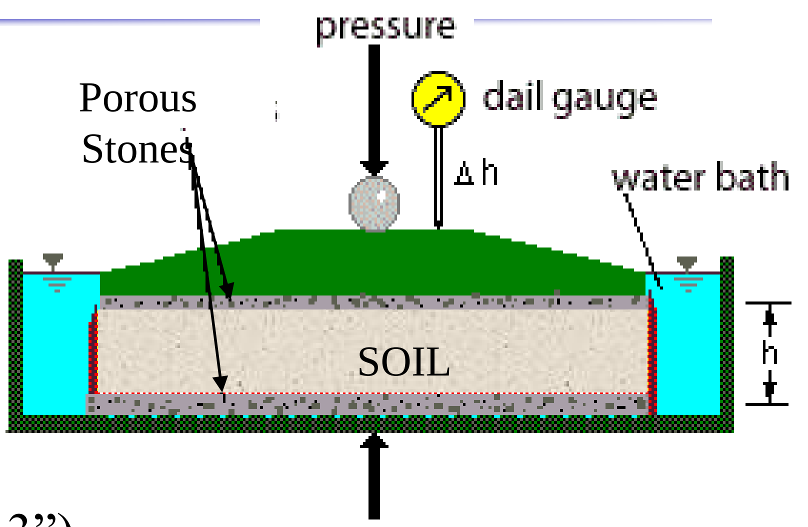
Assumptions of one-dimensional consolidation theory

1. Soil is *homogenous*.
2. Soil is *fully saturated*.
3. Coefficient of consolidation *(C_V) remains constant* throughout the soil mass and also remains constant with time.
4. Coefficient of permeability *(k) is constant* throughout.
5. *Darcy's law* for flow of water through the soil mass is valid, i.e., $v = k.i$
6. Consolidation is a *one-dimensional* problem i.e., *water flows in only one direction* and the *resulting settlement* also occur *in one direction only*.
7. *Soil particles* are assumed to be *incompressible* i.e., all the settlement is due to the expulsion of water.

1-D Lab Consolidation



1-D Lab Consolidation



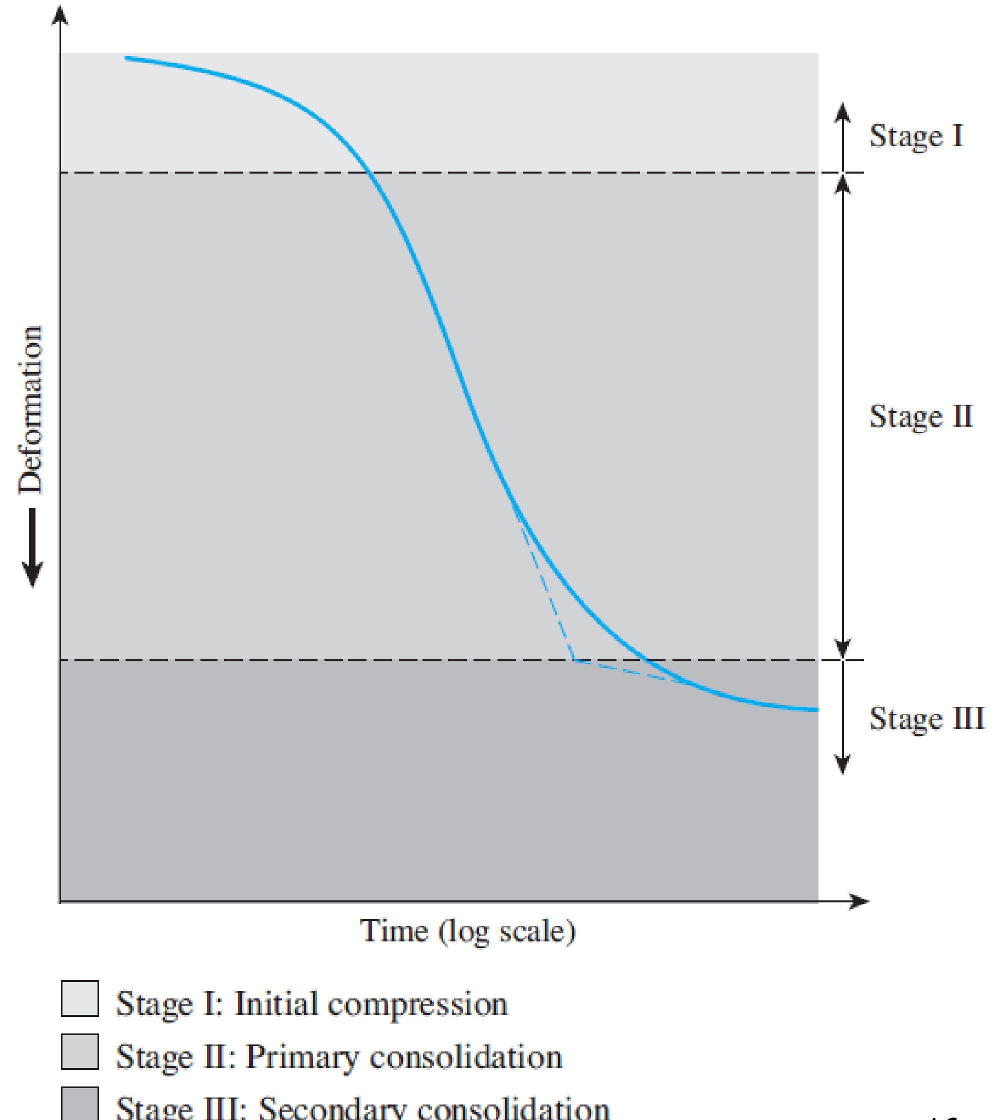
- Devised by *Carl Terzaghi.*
- The apparatus is called *Consolidometer / Oedometer*
- Soil specimen placed inside a *metal ring*
- Two *porous stones*, one at the top and other at the bottom of specimen
- *Diameter* of specimen = 50-75 mm (2”-3”)
- *Diameter/Height: between 2.5 & 5*
- Specimen kept *submerged in water* throughout the test
- Load is applied through a *lever arm*
- Each load is usually applied for 24hrs (or till deformations become negligible)
- Each loading increment is usually double the previous load.
- After complete loading, *unloading* is done in steps.

Deformation ~ Time Plot

Stage–I: Initial compression → mainly due to *preloading*.

Stage–II: Primary Consolidation → due to dissipation of pore water pressure (*expulsion of water*)

Stage–III: Secondary Consolidation → due to *plastic readjustment* of soil fabric.



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