SUBSIDENCE MECHANICS: CONSOLIDATION (37)

I Main Topics

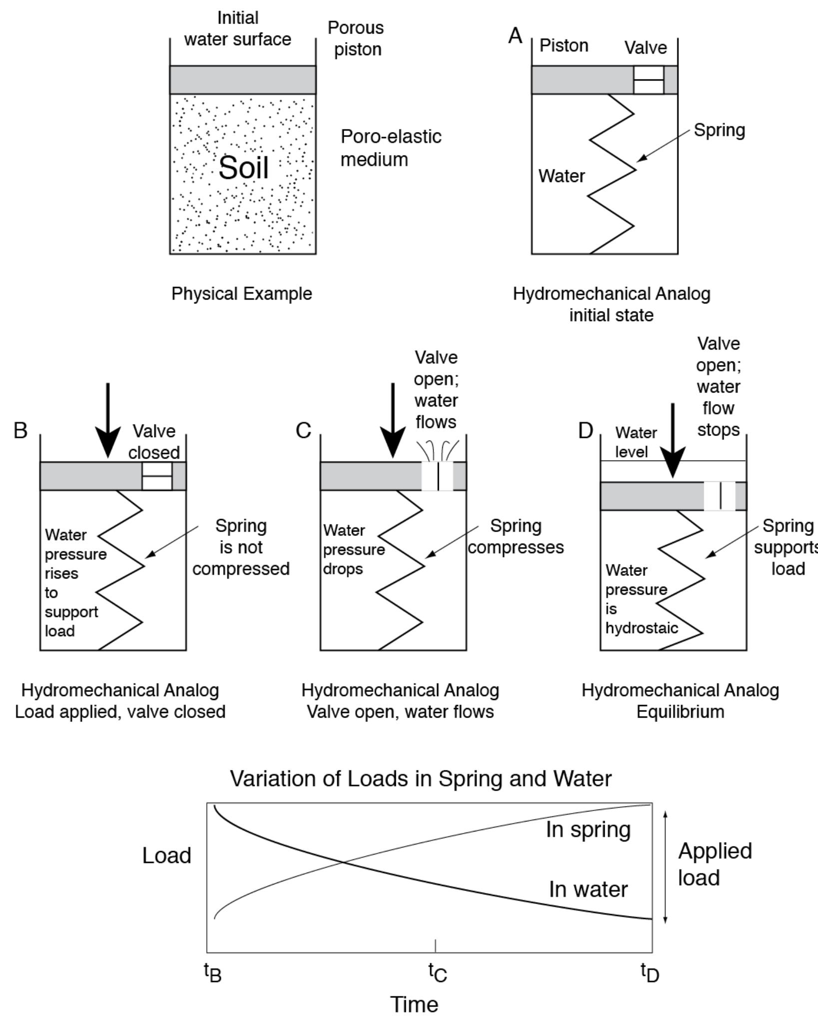
A Consolidation vs. compaction

B Mechanics of subsidence due to pore pressure changes

(Evaluation of subsidence)

II Consolidation vs. compaction
Definitions from Lambe and Whitman (1969)

A Consolidation: a decrease in volume resulting from dissipation of excess pore pressure.



II Consolidation vs. compaction

Definitions from Lambe and Whitman (1969)

B Compaction: a densification process involving mechanical equipment, usually a roller, and as distinguished from pre-loading and dewatering.

http://dot.ca.gov/hq/LandArch/webinars/images/optimizing_soil_compaction.jpg

III Mechanics of subsidence due to pore pressure changes

A Stages of consolidation

1 Initial consolidation: Void volume loss due to air loss

2 <u>Primary consolidation:</u> Void volume loss due to pore fluid loss

a Fluid "loss" requires fluid flow

b Flow reflects changes in pore pressure/effective stress

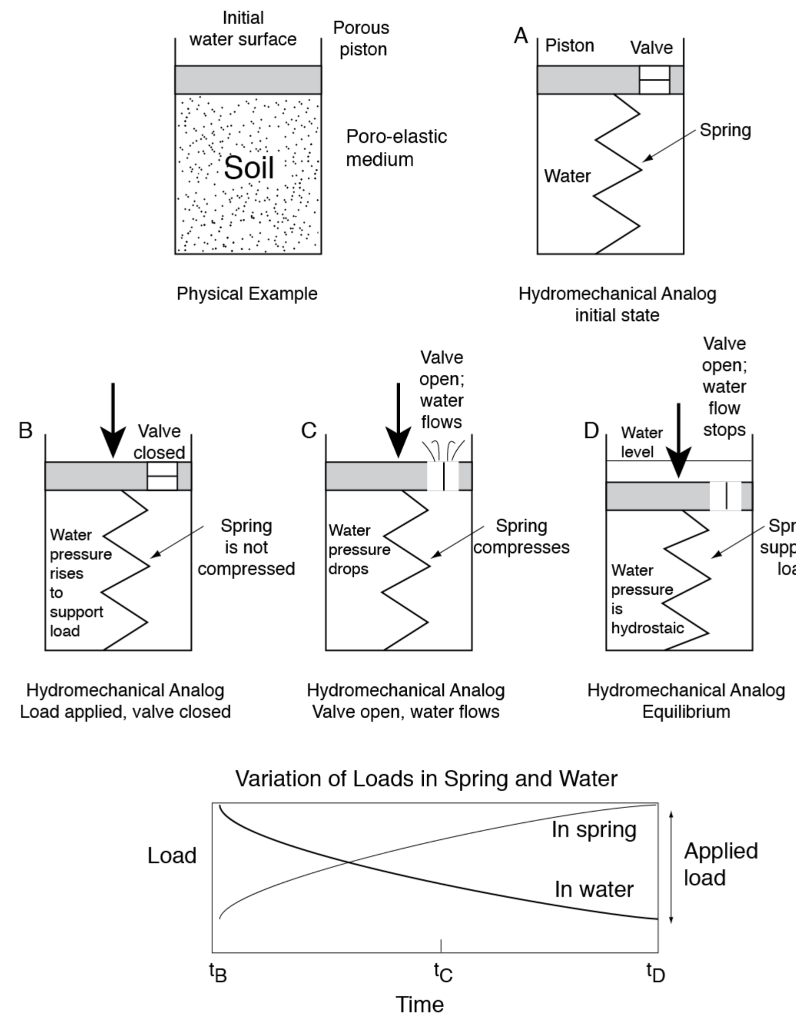
c Flow and pore pressure dissipation takes time, so primary consolidation is time-dependent

3 Secondary consolidation: due to decrease in solid volume

B Pressure here is considered to be <u>positive</u>

C Hydromechanical analog for consolidation

- Soils, sediments, and sedimentary rock consolidate as fluid volume (and pore volume) is lost
- As pore volume and pore pressure (u) decrease
  - Material column height decreases
  - Effective normal compressive stress increase



D Consolidation: poro-elastic strain

$$\Delta H = H_0 \frac{\Delta H}{H_0}$$

<u>For 1-D consolidation</u>

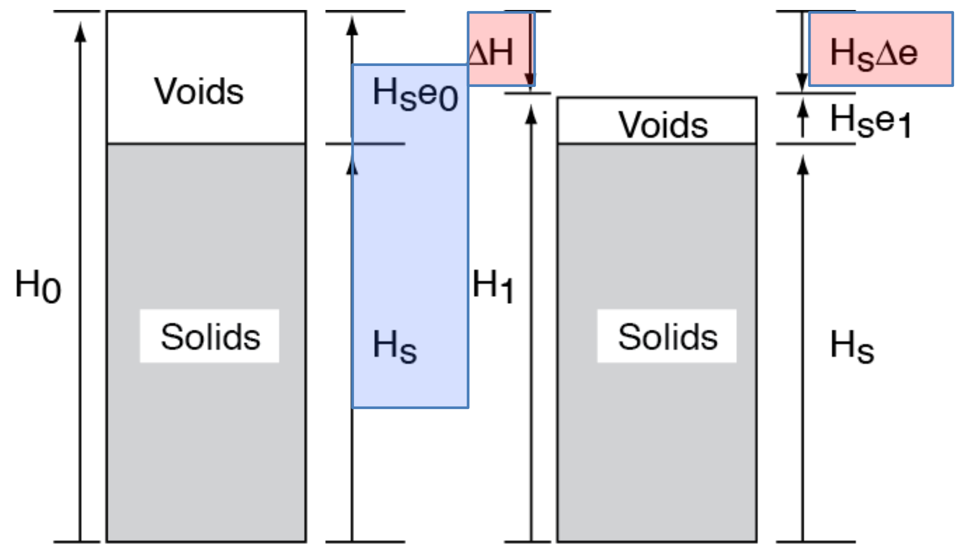
$$\Delta H = H_0 \frac{\Delta H}{H_0} = H_0 \frac{(\Delta e) H_s}{(1+e_0) H_s}$$

$$\Delta H = H_0 \frac{\Delta e}{1+e_0} = H_0 \varepsilon_{vert}$$

where

- e = void ratio;
- e_0 = initial void ratio
- Δe = change in void ratio
- ε_{vert} = vertical strain

Settlement = -ΔH



e = void ratio n = porosity

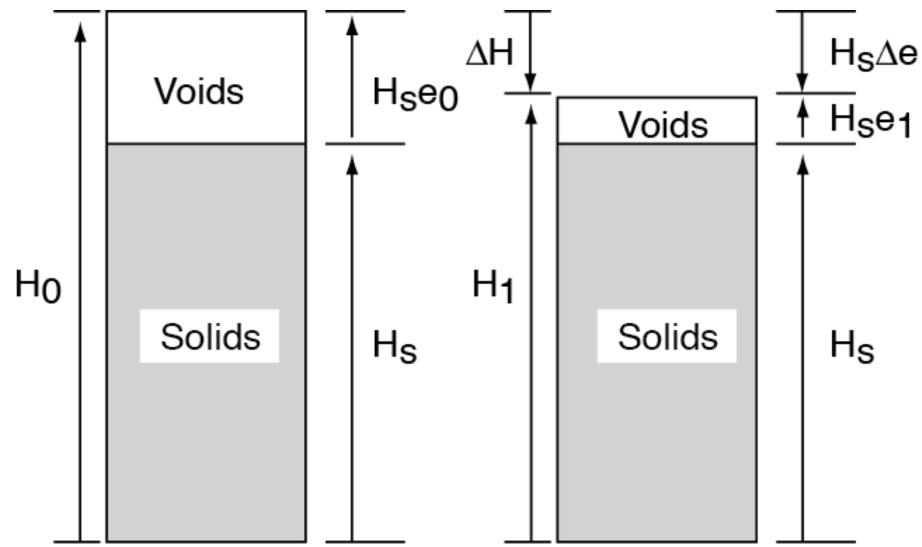
$$e = \frac{V_{voids}}{V_{solids}} = \frac{V_{voids}}{V_{total} - V_{voids}} = \frac{(V_{voids})/V_{total}}{(V_{total} - V_{voids})/V_{total}} = \frac{n}{1-n}$$

$$n = \frac{V_{voids}}{V_{total}} = \frac{V_{voids}}{V_{solids} + V_{voids}} = \frac{(V_{voids})/V_{solids}}{(V_{solids} + V_{voids})/V_{solids}} = \frac{e}{1+e}$$

D Consolidation: poro-elastic strain

Assumption: change in void ratio scales with the change in effective stress: $\Delta e \propto \Delta\sigma_z'$.

$$\Delta H = H_0 \frac{\Delta e}{1+e_0}\left(\frac{-\Delta\sigma_z'}{-\Delta\sigma_z'}\right) = -H_0 m_v \Delta\sigma_z'$$



where

$$m_v = \frac{(-\Delta e)/(1+e_0)}{\Delta\sigma_z'}$$

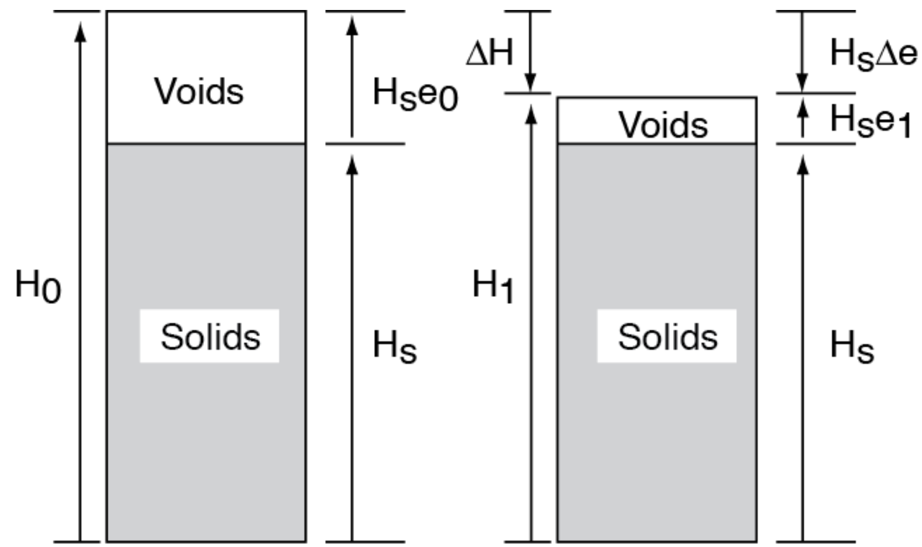
m_v = -vertical strain/change in effective stress

m_v = coefficient of volume change

D Consolidation: poro-elastic strain

Alternative expression

$$\Delta H = H_0 \frac{\Delta e}{1+e_0}\left(\frac{-\Delta\sigma_z'}{-\Delta\sigma_z'}\right) = \frac{-H_0}{1+e_0} a_v \Delta\sigma_z'$$



where

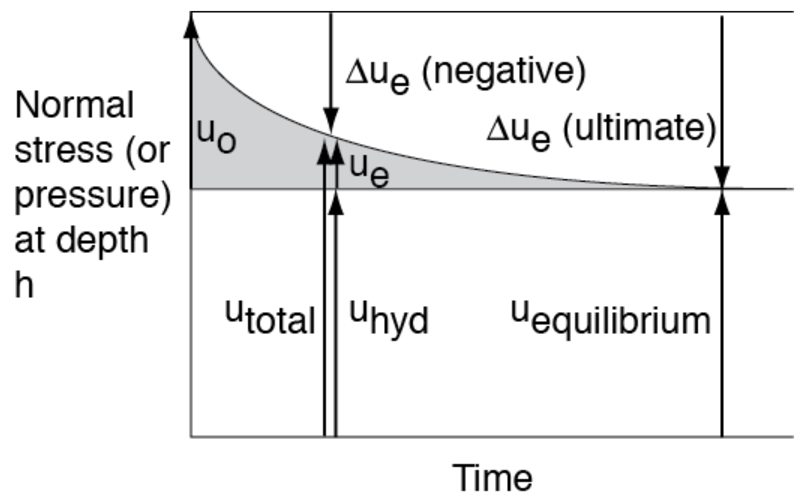
$$a_v = \frac{-\Delta e}{\Delta\sigma_z'}$$

a_v = -void ratio change/change in effective stress

a_v = coefficient of compressibility

E The consolidation ratio U

- Total pore pressure change (Δu_{total}) equals change in pore pressure in excess of hydrostatic pressure ($\Delta u_{excess} = \Delta u_e$)



$$u_{total} = u_{hydrostatic} + u_{excess}$$

$$\Delta u_{total} = \Delta u_{excess}$$

u = pore pressure

u_e = excess pore pressure

u_0 = initial excess pore pressure

u_{hyd} = hydrostatic pore pressure

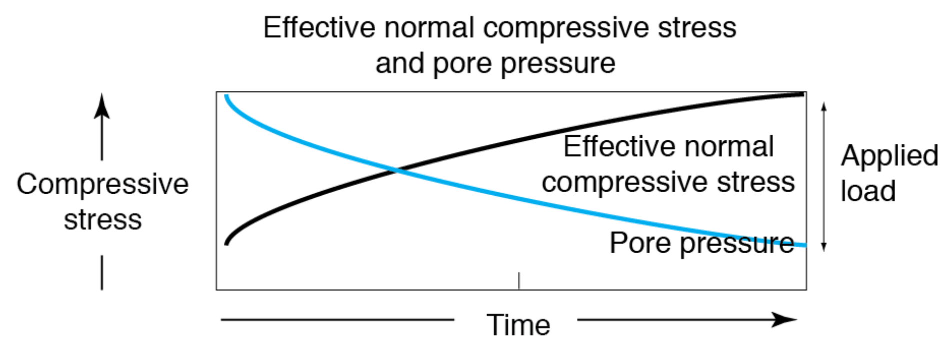
E The consolidation ratio U

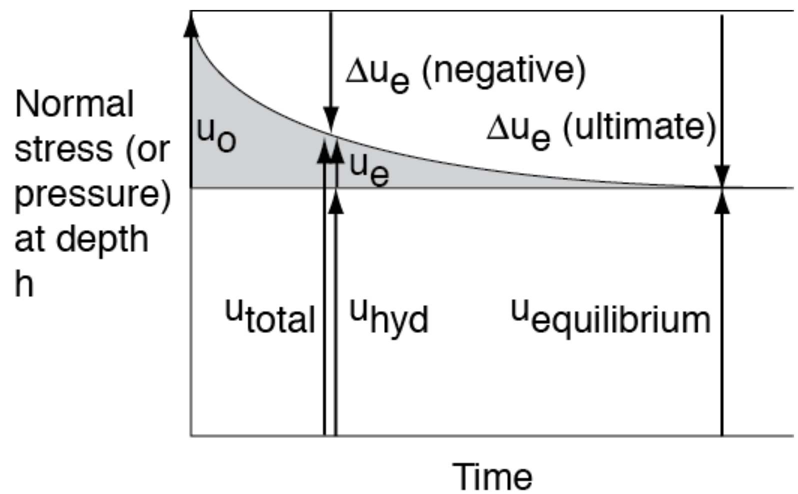
- Increase in effective normal compress stress (Δu_{total}) equals decrease in excess hydrostatic pressure ($\Delta u_{excess} = \Delta u_e$)

$$\sigma_{z(total)} = \sigma_z' + u$$

$$\sigma_z' = \sigma_{z(total)} - u$$

$$\Delta\sigma_z' = -\Delta u = -\Delta u_{excess}$$





u = pore pressure

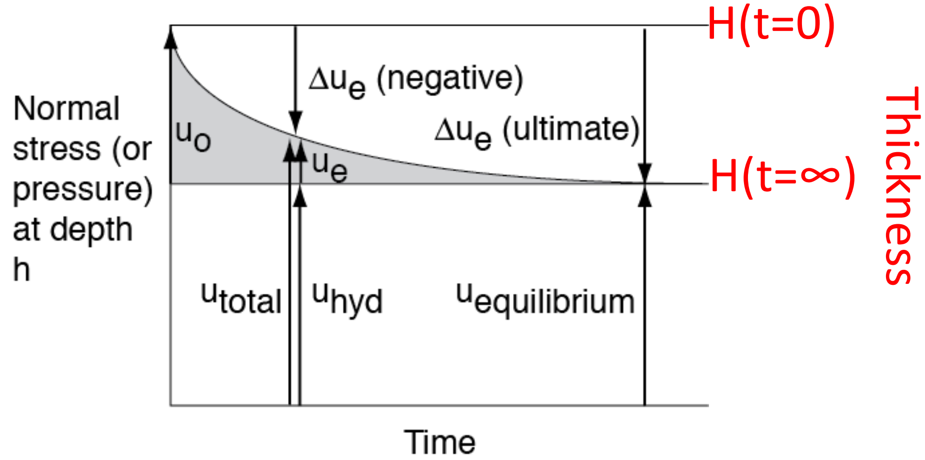
u_e = excess pore pressure

u_0 = initial excess pore pressure

u_{hyd} = hydrostatic pore pressure

E The consolidation ratio U

- Primary consolidation ratio U(t) varies with time as fluid flows, pore pressure (u) drops, and effective normal compressive stress ($\Delta\sigma'_z$) increases



$$U(t) \equiv \frac{\Delta H(t)}{\Delta H_{\max}} = \frac{\Delta e(t)}{\Delta e_{\max}}$$

$$U = \frac{\Delta H}{\Delta H_{\max}} = \frac{-H_0 m_v \Delta\sigma'_z}{-H_0 m_v \Delta\sigma'_{z(\max)}} = \frac{\Delta\sigma'_z}{\Delta\sigma'_{z(\max)}}$$

$$U = \frac{-\Delta u}{-\Delta u_{\max}} = \frac{-\Delta u_e}{-\Delta u_{e(\max)}} = \frac{\Delta u_e}{\Delta u_{e(\max)}}$$

u = pore pressure

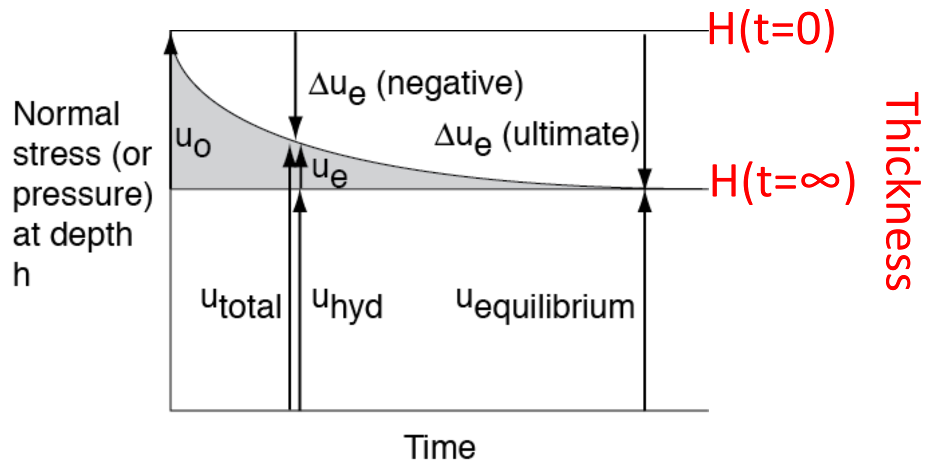
u_e = excess pore pressure

u_0 = initial excess pore pressure

u_{hyd} = hydrostatic pore pressure

E The consolidation ratio U

- Primary consolidation ratio U(t) depends on the ratio of the excess pore pressure (u_e) to the initial excess pore pressure (u_0)



u = pore pressure

u_e = excess pore pressure

u_0 = initial excess pore pressure

u_{hyd} = hydrostatic pore pressure

$$U(t) \equiv \frac{\Delta H(t)}{\Delta H_{\max}} = \frac{\Delta u_e}{\Delta u_{e(\max)}}$$

$$\Delta u_e = u_e - u_0$$

$$\Delta u_{e(\max)} = -u_0$$

$$U(t) = 1 - \frac{u_e}{u_0}$$

Note: U usually varies with position. One can use the **average** consolidation ratio in a column of material to find the height change for the column.

References

- Lambe, T.W., and Whitman, R.V., 1969, Soil mechanics, 1969: Wiley, New York, 553 p.