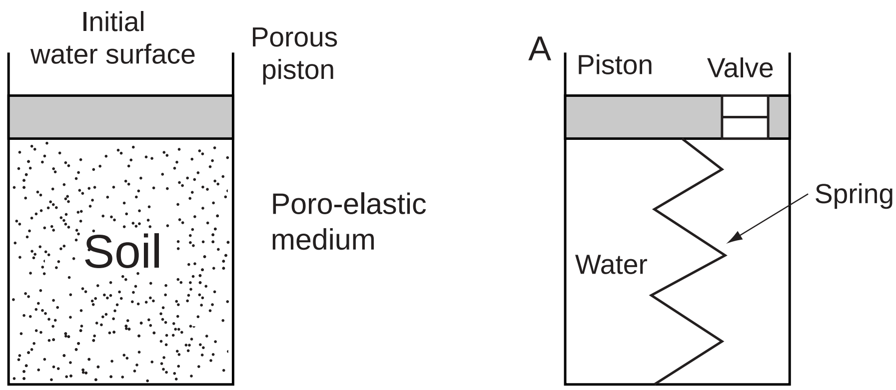
SUBSIDENCE MECHANICS: CONSOLIDATION (37)

I Main Topics
  A Consolidation vs. compaction
  B Mechanics of subsidence due to pore pressure changes
    (Evaluation of subsidence)

II Consolidation vs. compaction
  A Consolidation: Defined by Lambe and Whitman (1969) as a decrease in volume resulting from dissipation of excess pore pressure.
  B Compaction: Defined by Lambe and Whitman (1969) as a densification process involving mechanical equipment, usually a roller, and as distinguished from pre-loading and dewatering.

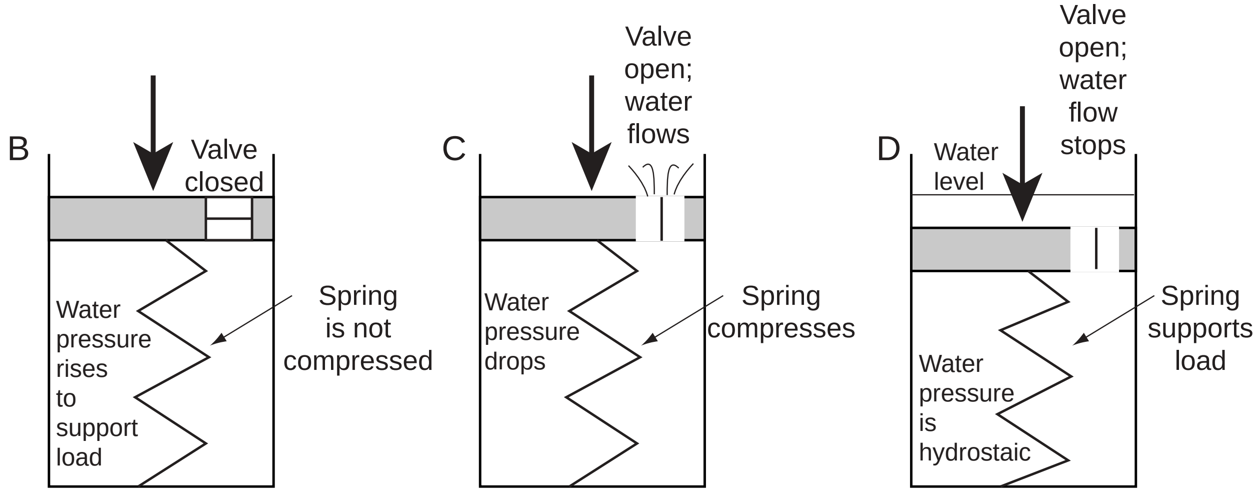
III Mechanics of subsidence due to pore pressure changes
  A Stages of consolidation
    1 Initial consolidation: Void volume loss due to air loss
    2 Primary consolidation: Void volume loss due to pore fluid loss
      a Fluid "loss" requires fluid flow
      b Flow reflects changes in pore pressure/effective 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 positive

C Hydromechanical analog for consolidation (from Lambe and Whitman, 1969)



Physical Example

Hydromechanical Analog
initial state

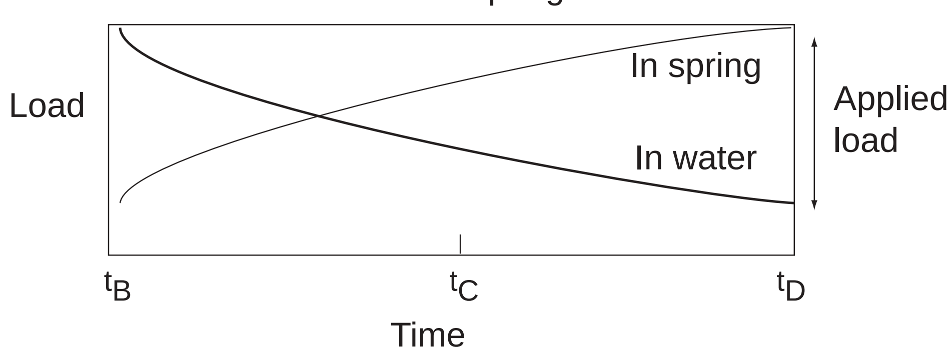


Hydromechanical Analog
Load applied, valve closed

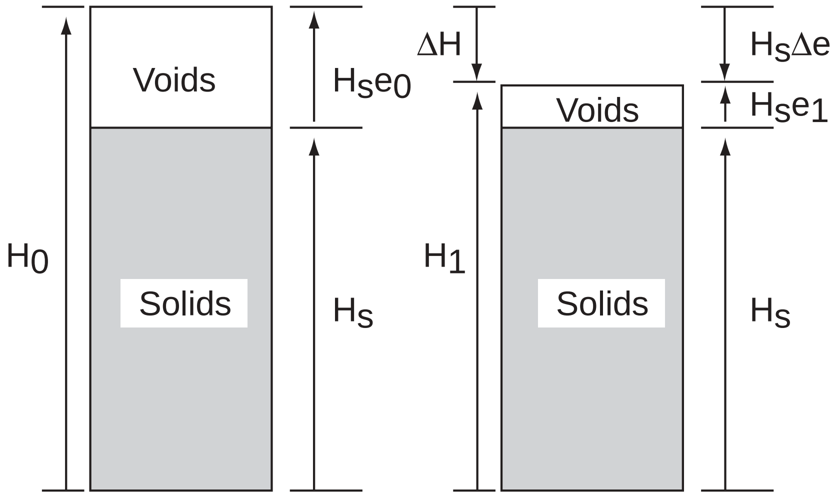
Hydromechanical Analog
Valve open, water flows

Hydromechanical Analog
Equilibrium

Variation of Loads in Spring and Water



D Consolidation as a reflection of poro-elastic strain



Initial state Final state

$$\frac{H_1 - H_0}{H_0} = \frac{\Delta H}{H_0} = \varepsilon$$

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

$$\frac{\Delta H}{H_1} = \frac{\Delta e}{1+e_0}$$

ΔH = final height - initial height = $H_1 - H_o$ ΔH is negative here

Settlement = $-\Delta H$ Settlement is positive here

$\Delta H = (H_o)$ (vertical strain) = H_o $(\Delta H/H_o)$ (37.1)

For 1-D consolidation

$\Delta H = (H_o)$ (vertical strain) = H_o $(\Delta e/[1+e_o])$ (37.2)

where e = void ratio; $\Delta e < 0$

<u>The change in void ratio scales approximately with the change in effective stress, or the change in excess pore pressure:</u> $\Delta e \propto \Delta\sigma_z'$ or $\Delta e \propto \Delta u_e$

Two similar approaches relate Δe to $\Delta\sigma_z'$; both utilize the following

$\Delta H = H_o$ $(\Delta e/\{1+e_o\})$ $[\Delta\sigma_z' / \Delta\sigma_z']$. (37.3)

$\Delta H = [-H_o$ $\mathbf{(-\Delta e/\{1+e_o\})\ /\Delta\sigma_z'}]$ $\Delta\sigma_z' = -H_o$ (m_v) $\Delta\sigma_z'$ (37.4)

where

$m_v = -(\Delta e/\{1+e_o\}) / \Delta\sigma_z'$ = -vertical strain: change in effective stress

m_v = coefficient of volume change

$\Delta H = (-H_o$ $/\{1+e_o\})$ $\mathbf{(-\Delta e/\Delta\sigma_z')}$ $\Delta\sigma_z' = (-H_o$ $/\{1+e_o\})$ (a_v) $\Delta\sigma_z'$ (37.5)

$a_v = -\Delta e/ \Delta\sigma_z'$ = -void ratio change: change in effective stress

a_v = coefficient of compressibility

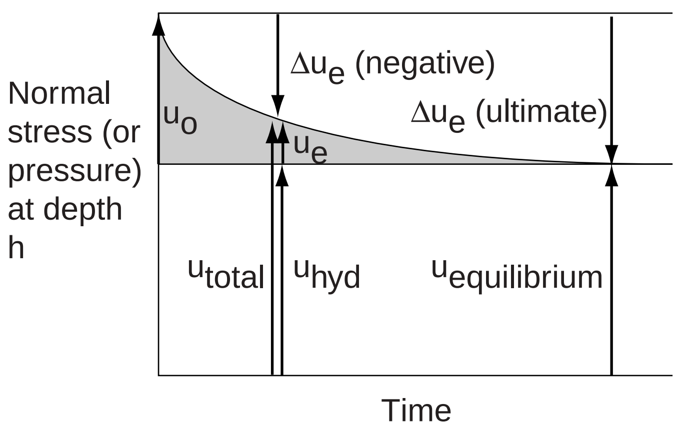
E The consolidation ratio U

$$U(t) = \Delta H(t)/\Delta H_{max} = \Delta e/\Delta e_{max} \quad (37.6)$$

Solving for ΔH using (37.4), but using Δu_e in place of $-\Delta\sigma_z'$, yields

$$U = \Delta H/\Delta H_{max} = (H_o\ m_v\ \Delta u_e) / (H_o\ m_v\ \Delta u_{e\ max}) \quad (37.7)$$

$$U = \Delta H/\Delta H_{max} = \Delta u_e/\Delta u_{e\ max} \quad (37.8)$$



The excess pore pressure $\mathbf{u_e}$ is what must be bled off for the water pressure to return to an equilibrium (hydrostatic) case. The hydrostatic pressure is $\rho_{water}gh$; h is the depth below the water table. The term $\mathbf{u_o}$ is the <u>initial e</u>xcess pore pressure. The **change** in excess pore pressure $\Delta\mathbf{u_e}$ is measured relative to u_o and can be defined in three ways.

$$\Delta u_e = u_e|_t - u_e|_{t=0}. \quad (37.9a)$$

$$\Delta u_e = (u|_t - u_{hyd}) - (u|_{t=0} - u_{hyd}) = (u|_t - u|_{t=0}) = \Delta u \quad (37.9b)$$

$$\Delta u_e = (u|_t - u|_{t=0}) = (\sigma_{total}|_t - \sigma'|_t) - (\sigma_{total}|_{t=0} - \sigma'|_{t=0}) = -\Delta\sigma' \quad (37.9c)$$

As the pore pressure drops, Δu_e is negative and $\Delta\sigma'$ (the change in effective stress) is positive. Also, Δu_e is a maximum when u_e is zero, so the maximum change in u_e is $-u_o$: the negative of the initial excess pore pressure.

$$\Delta u_{e\ max} = -u_o \quad (37.10)$$

Substituting (37.9a) and (37.10) into (37.8)

$$U = \Delta u_e/\Delta u_{e\ max} = (u_e - u_o)/(-u_o) \quad (37.11)$$

This reduces to

$$U = 1 - (u_e / u_o) \quad (37.12)$$

Equating (37.7) and (37.12),

$$U = \Delta H / \Delta H_{max} = 1 - (u_e / u_o) \quad (37.13)$$

Note: U does not need to be constant throughout a consolidating column of material; U usually varies with position. Use the **average** consolidation ratio in a column of material to find the height change for the column.