INS 3121
SOIL MECHANICS

In-Situ Stresses

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8.1 Stresses in Saturated Soil without Seepage

- The nature of the distribution of stress in the soil profile. At point A,

$$\sigma = H \times \gamma_w + (H_A - H) \times \gamma_{sat}$$

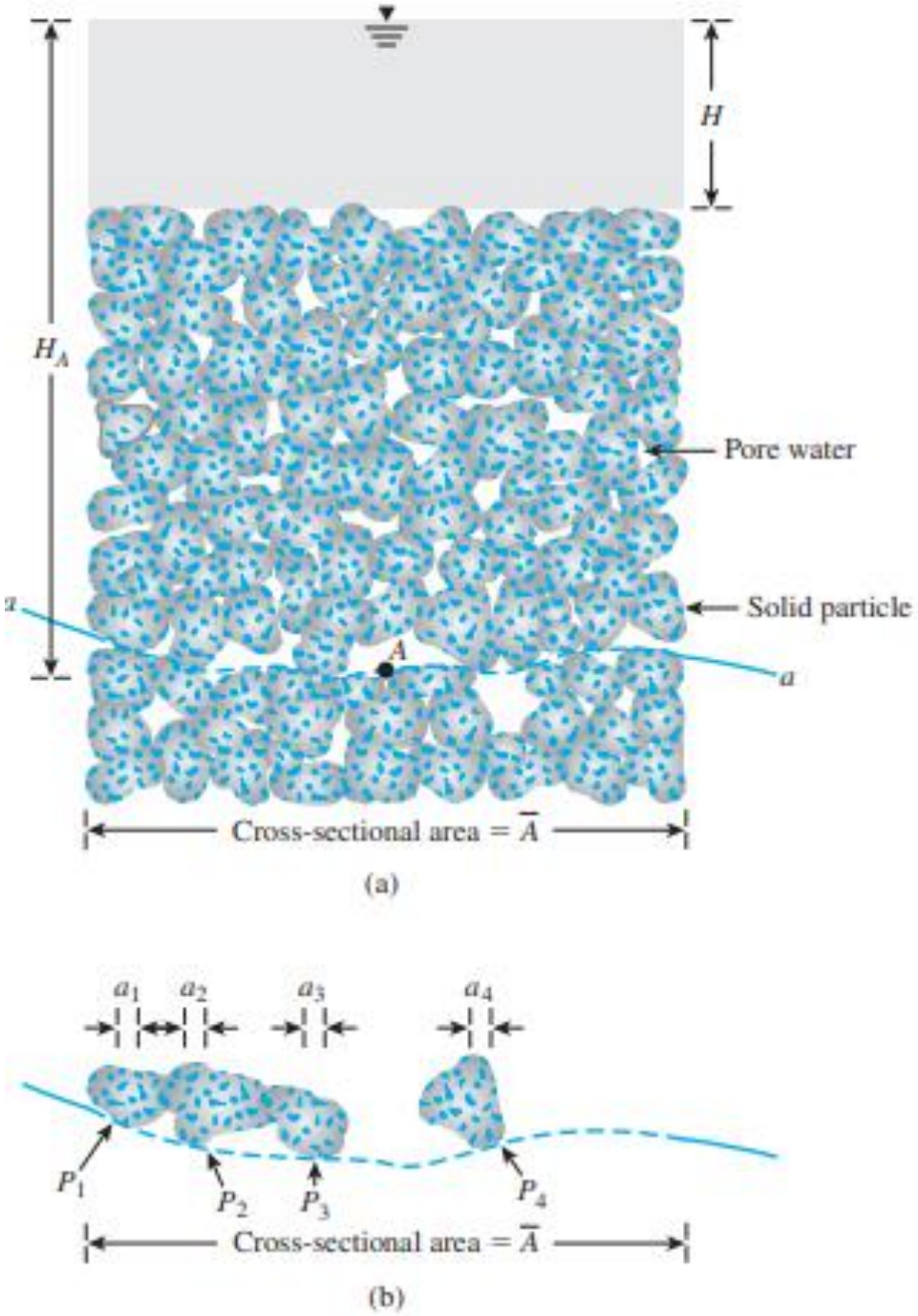
- The total stress, σ, given by Eq. can be divided into two parts:
  1. A portion is carried by water in the continuous void spaces.

     - hydrostatic pressure = pore water pressure

  2. The rest is carried by the soil solids at their points of contact.

     - effective stress (σ')

$$\sigma' = \frac{P_{1(v)} + P_{2(v)} + P_{3(v)} + \cdots + P_{n(v)}}{\bar{A}}$$



8.1 Stresses in Saturated Soil without Seepage

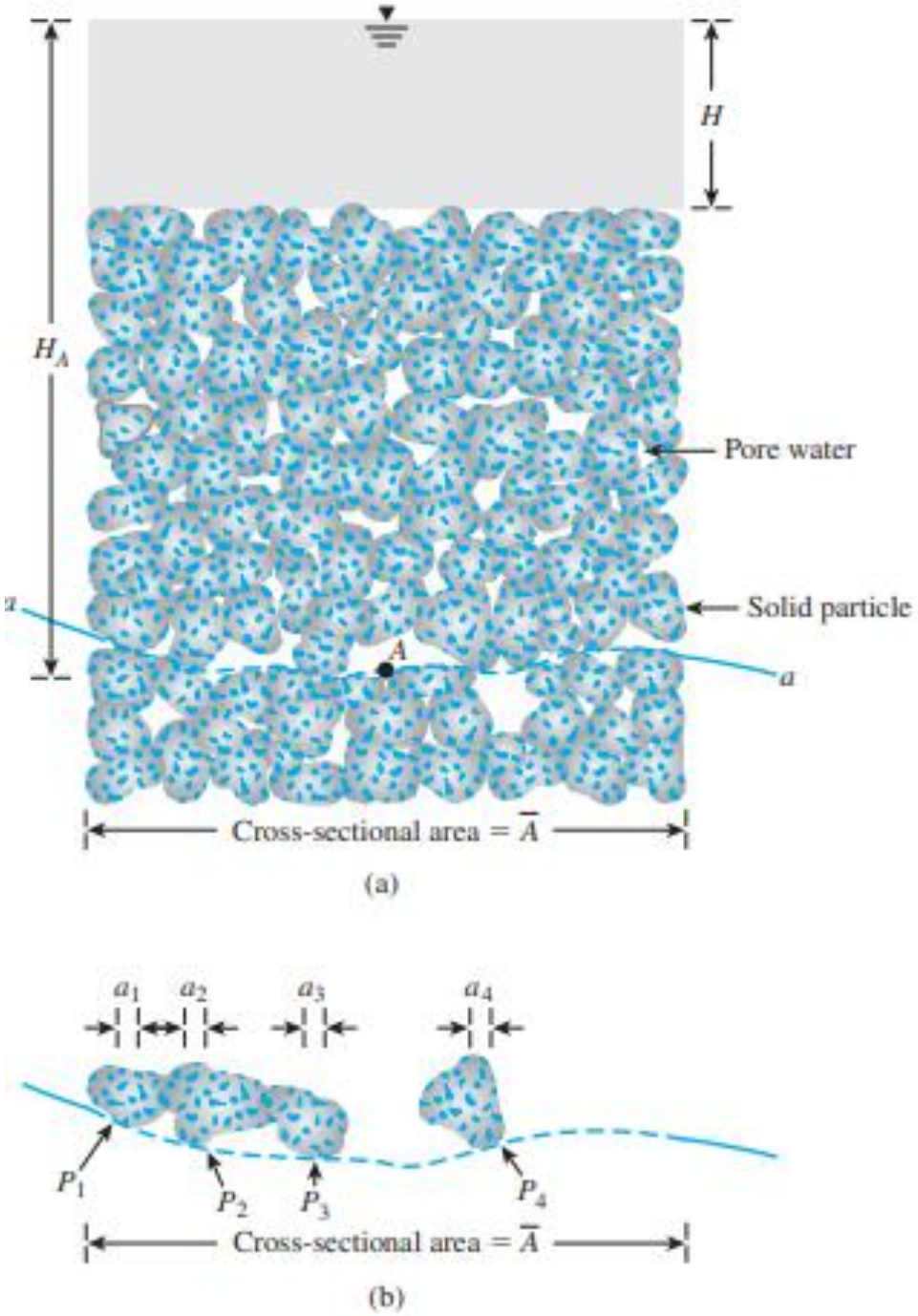
$$\sigma = \sigma' + \frac{u(\bar{A} - a_s)}{\bar{A}} = \sigma' + u(1 - a_s')$$

$u = H_A \gamma_w = pore\ water\ pressure = hydrostatic\ pr.$

$a_s' = \frac{a_s}{A}$ = fraction of unit cross-sectional area of the soil mass occupied by solid-to-solid contacts

- a_s' is very small

$\boldsymbol{\sigma = \sigma' + u,}$ **The principle of effective stress**



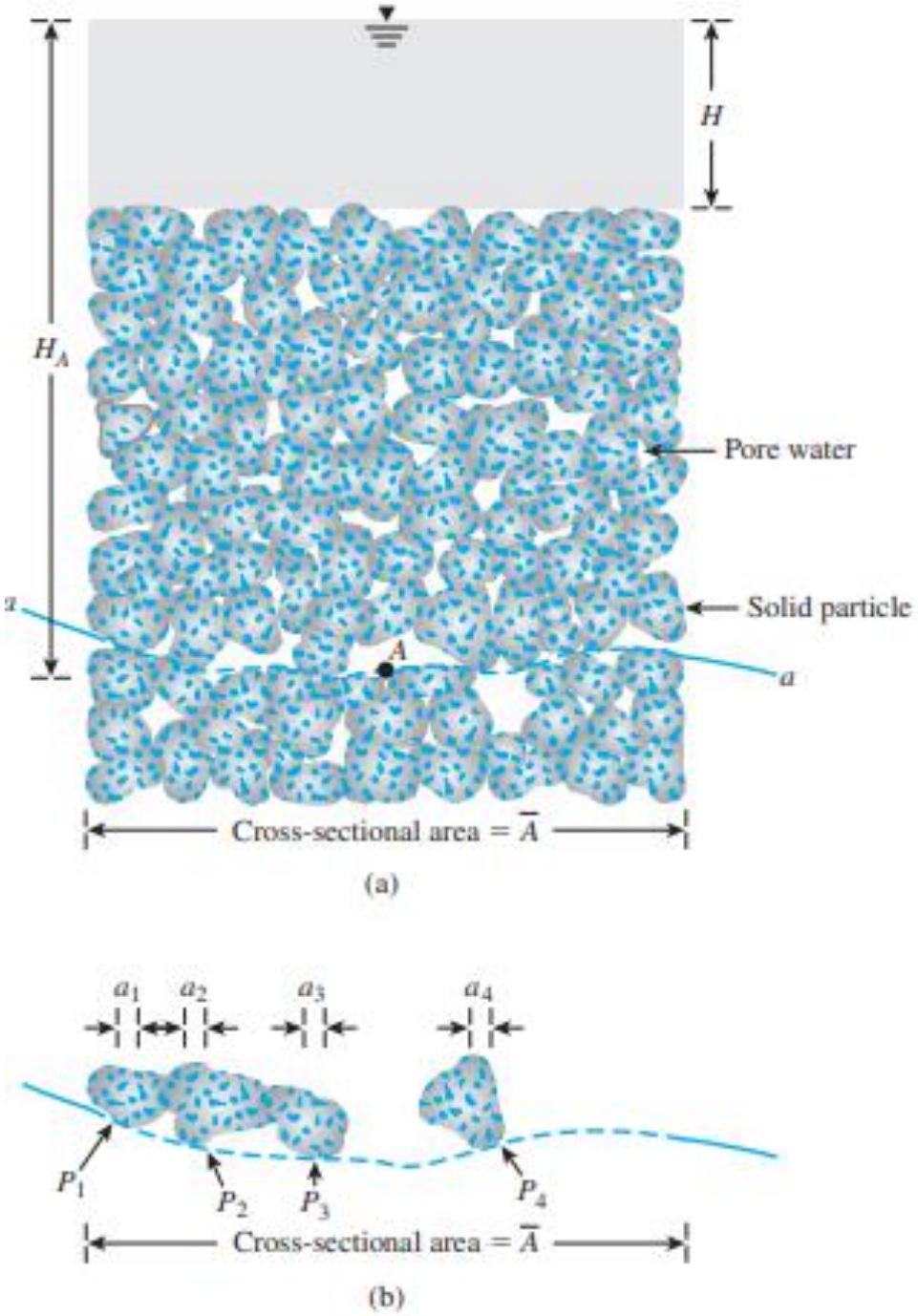
8.1 Stresses in Saturated Soil without Seepage

$\sigma = \sigma' + u$, **The principle of effective stress**

$$\sigma' = [\mathrm{H}\gamma_w + (H_A - H)\gamma_{sat}] - H_A\gamma_w$$
$$= (H_A - H)(\gamma_{sat} - \gamma_w)$$
$$= (\text{Height of the soil column}) \times \gamma'$$

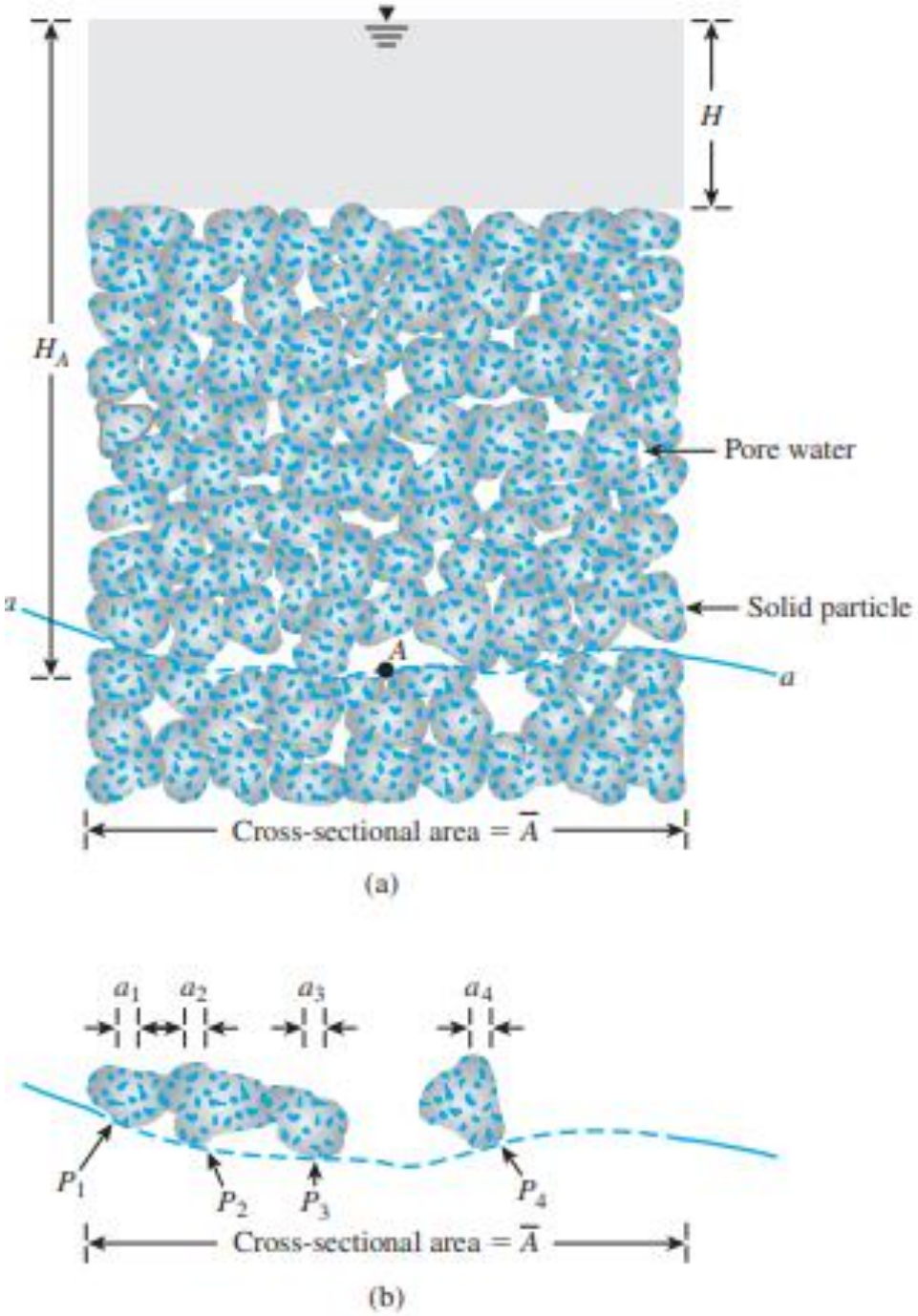
$\gamma' = \gamma_{sat} - \gamma_w$: submerged unit weight of soil

- It can be seen that the effective stress at any point A is independent of the depth of water, H, above the submerged soil.



8.1 Stresses in Saturated Soil without Seepage

- Effective stress is approximately the force per unit area carried by the soil skeleton.
- Effective stress in a soil mass controls its volume change and strength.
- Increasing the effective stress induces soil to move into denser state packing



8.1 Stresses in Saturated Soil without Seepage

- Submerged soil in a tank where there is no seepage.
- Variations of the total stress, pore water pressure, and effective stress,

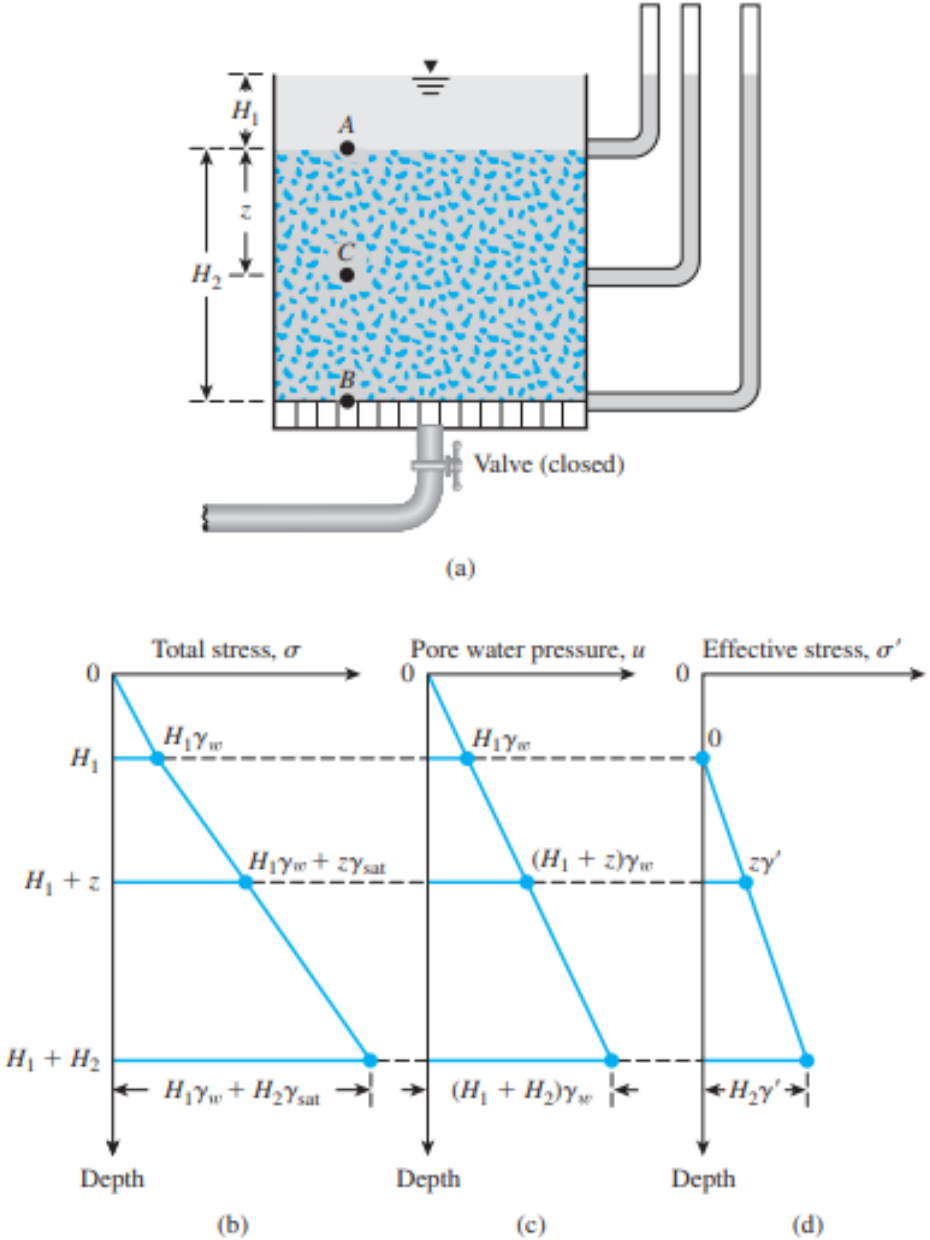
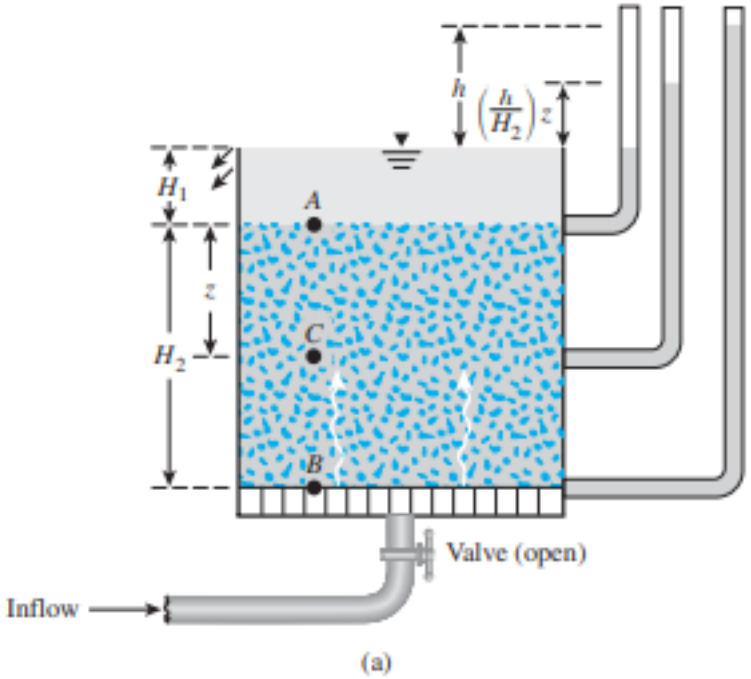
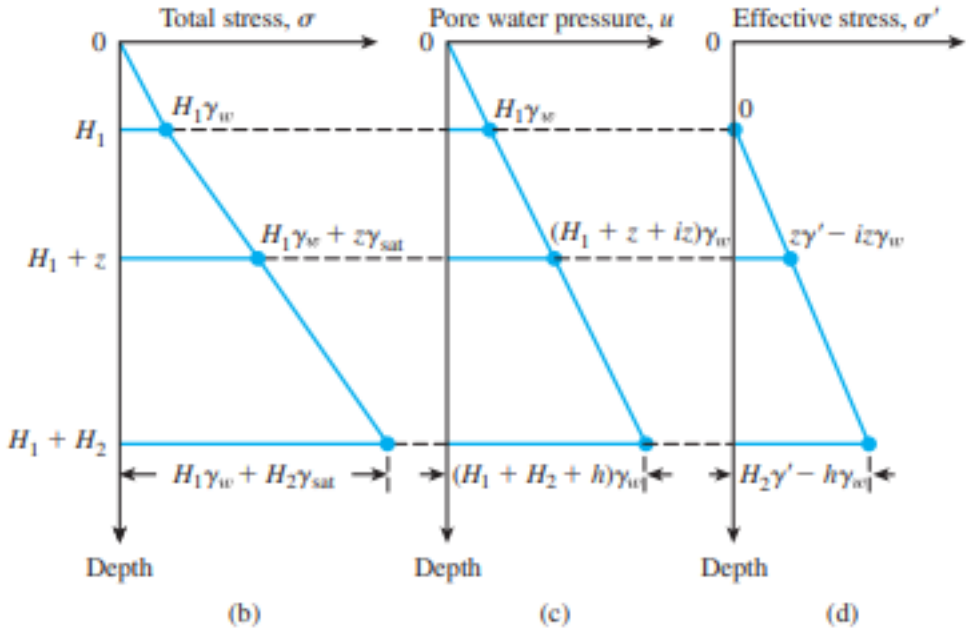


Figure 9.2 (a) Layer of soil in a tank where there is no seepage; Variation of (b) total stress, (c) pore water pressure, and (d) effective stress with depth for a submerged soil layer without seepage

8.2 Stresses in Saturated Soil with Upward Seepage

- Upward Seepage
- The total stress at any point in the soil mass is due solely to the weight of soil and water above it.





8.2 Stresses in Saturated Soil with Upward Seepage

- Upward Seepage
- Effective stress calculation at points A and B
- At A

  Total stress: $\sigma_A = H_1\gamma_w$

  Pore water pressure: $u_A = H_1\gamma_w$

  Effective stress: $\sigma'_A = \sigma_A - u_A = 0$
- At B

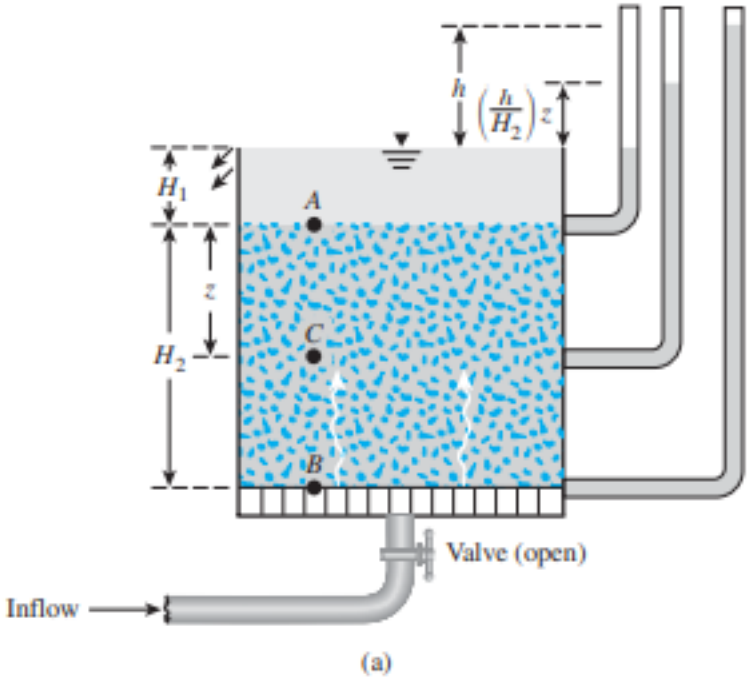
  Total stress: $\sigma_B = H_1\gamma_w + H_2\gamma_{sat}$

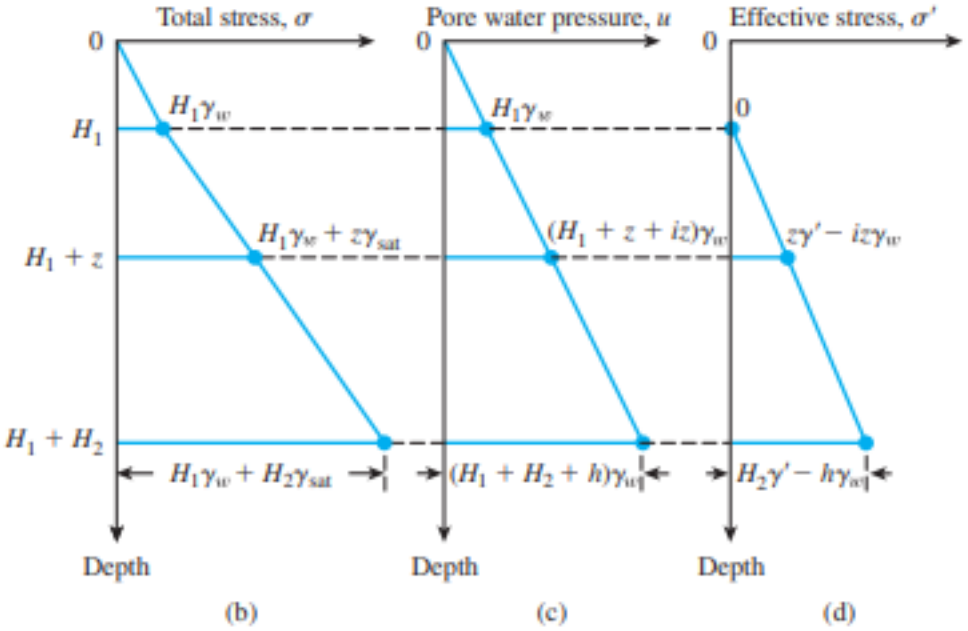
  Pore water pressure: $u_B = (H_1 + H_2 + h)\gamma_w$

  Effective stress: $\sigma'_B = \sigma_B - u_B$

  $= H_2(\gamma_{sat} - \gamma_w) - h\gamma_w$

  $= H_2\gamma' - h\gamma_w$





8.2 Stresses in Saturated Soil with Upward Seepage

- At C

  Total stress: $\sigma_C = H_1\gamma_w + z\gamma_{sat}$

  Pore water pressure: $u_C = (H_1 + z + \frac{h}{H_2}z)\gamma_w$

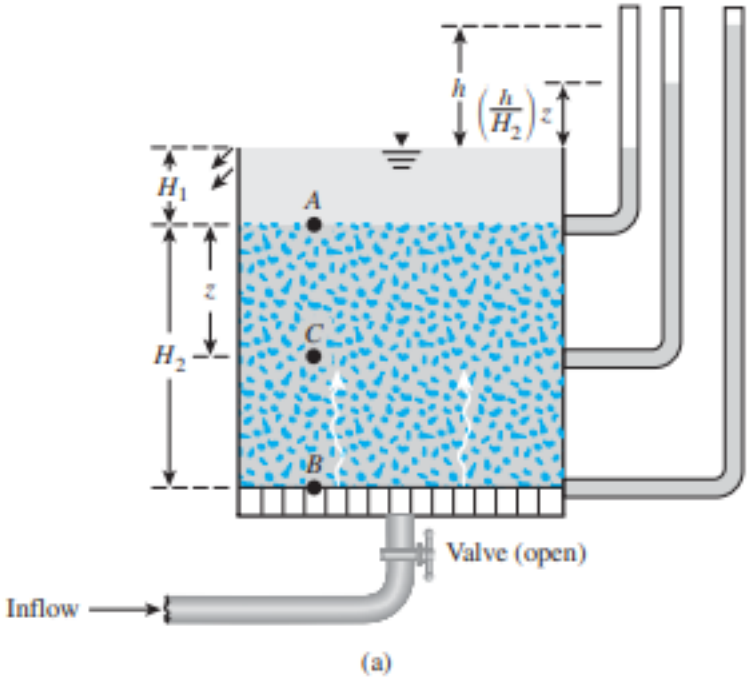
  Effective stress: $\sigma'_C = \sigma_C - u_c$

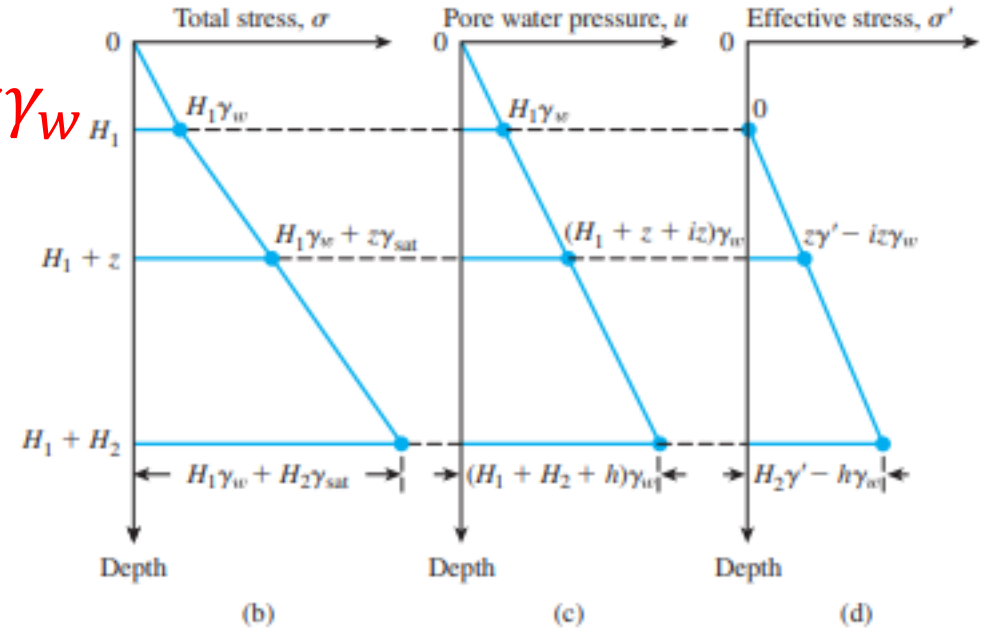
$$= z(\gamma_{sat} - \gamma_w) - \frac{h}{H_2}z\gamma_w$$

$$= z\gamma' - \frac{h}{H_2}z\gamma_w$$

Note that h/H_2 is the hydraulic gradient i caused by the flow, and so

$$\sigma'_C = z\gamma' - iz\gamma_w$$





8.2 Stresses in Saturated Soil with Upward Seepage

- Effective stress at a point located at a depth z measured from the surface of a soil layer is reduced by an amount $iz\gamma_w$ because of upward seepage of water.

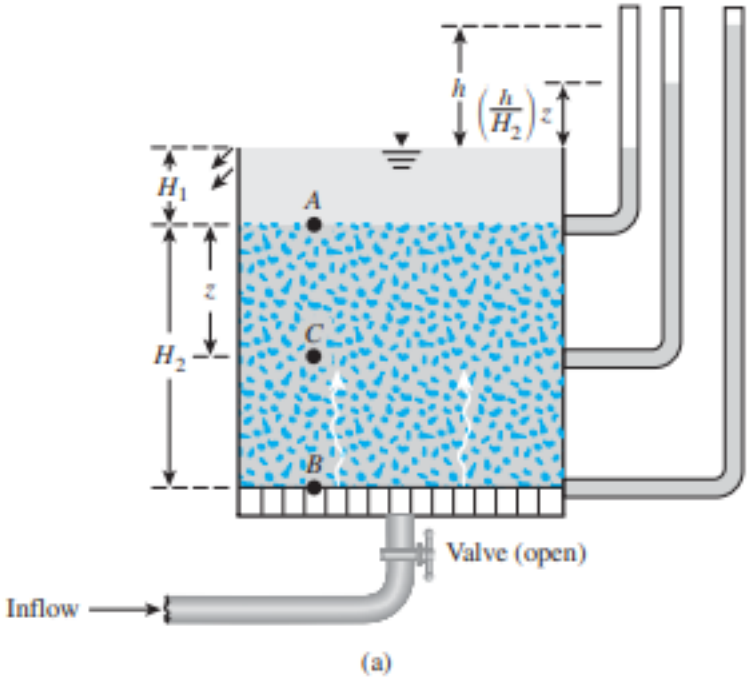
$$\sigma_C' = z\gamma' - i_{cr}z\gamma_w = 0$$

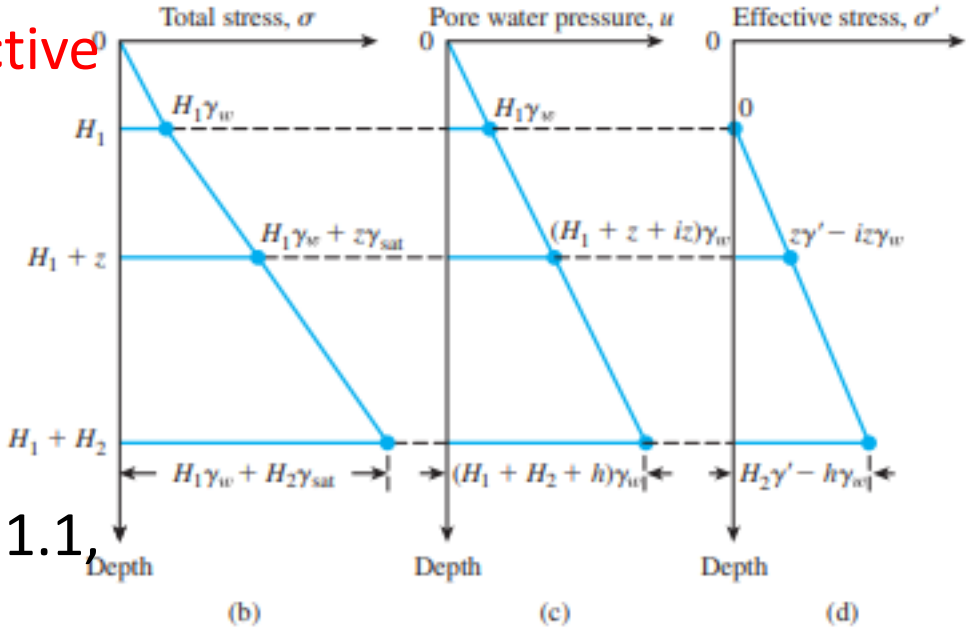
i_{cr} = critical hydraulic gradient (for ZERO effective stress)

- Boiling, or a quick condition

$$i_{cr} = \frac{\gamma'}{\gamma_w}$$

- For most soils, the value of i_{cr} varies from 0.9 to 1.1, with an average of 1





8.3 Stresses in Saturated Soil with Downward Seepage

- Downward seepage

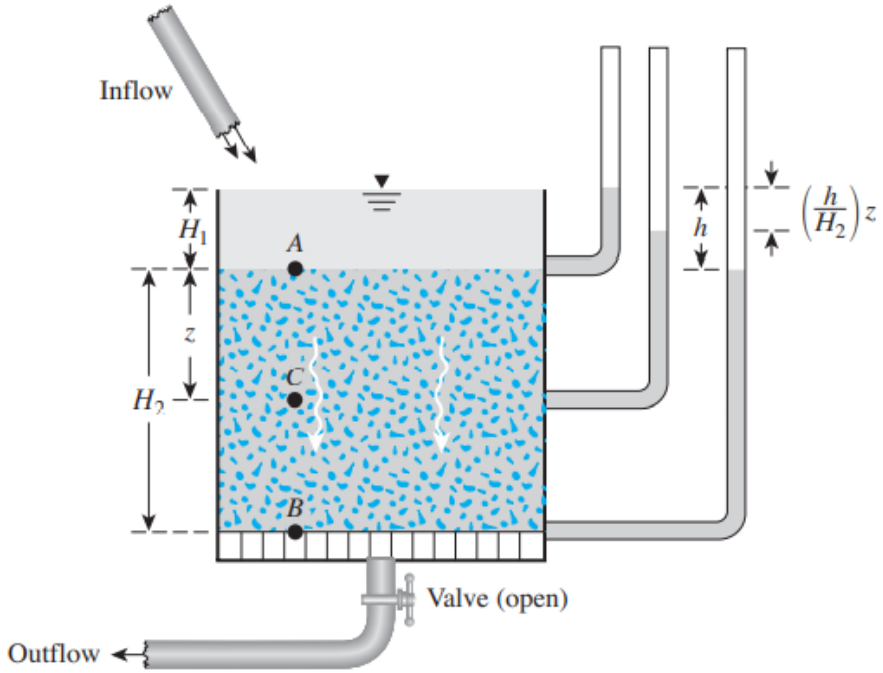
$$\sigma_C = H_1\gamma_w + z\gamma_{sat}$$

$$u_C = (H_1 - iz)\gamma_w$$

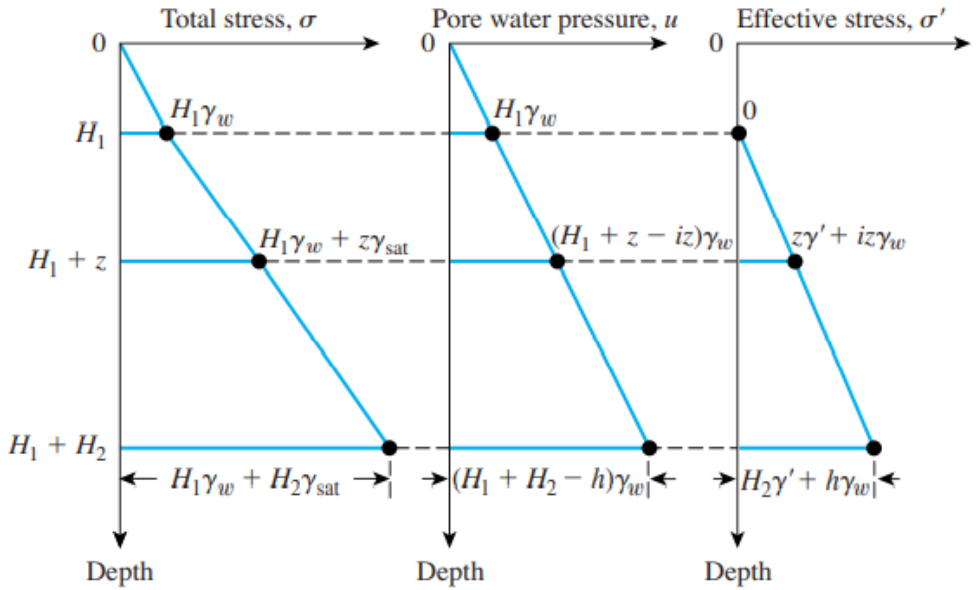
$$\sigma_C' = \sigma_C - u_c$$

$$= H_1\gamma_w + z\gamma_{sat} - (H_1 + z - iz)\gamma_w$$

$$= z\gamma' + iz\gamma_w$$



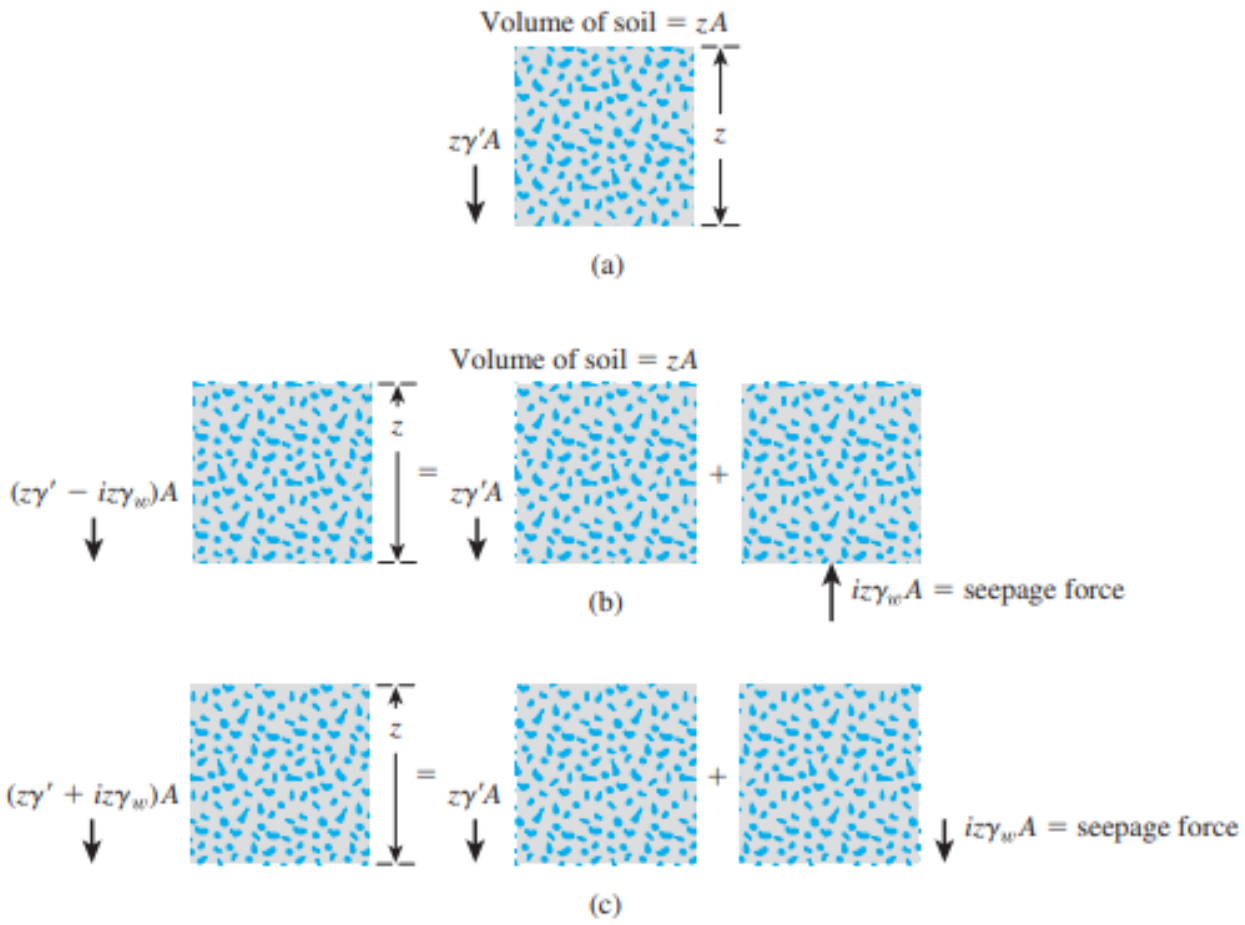
(a)



8.4 Seepage Force

- $P_1' = z\gamma' A$ *: No seepage*
- $P_2' = (z\gamma' - iz\gamma_w)A$ *:Upward seepage*
- $P_1' - P_2' = iz\gamma_w A$
- $\frac{P_1' - P_2'}{(volume\ of\ soil)} = \frac{iz\gamma_w A}{zA} = i\gamma_w$: *Seepage force*

(force/vol)



8.5 Heaving in Soil Due to Flow Around Sheet Piles

- The seepage force per unit volume of soil is equal to $i\gamma_w$ and in isotropic soils the force acts in the same direction as the direction of flow.

- After conducting several model tests, Terzaghi(1922) concluded that heaving generally occurs within a distance of D/2 from the sheet piles(when D equals the depth of embedment of sheet piles into the permeable layer).

$$FS = \frac{W'}{U}$$

W' = submerged weight of soil

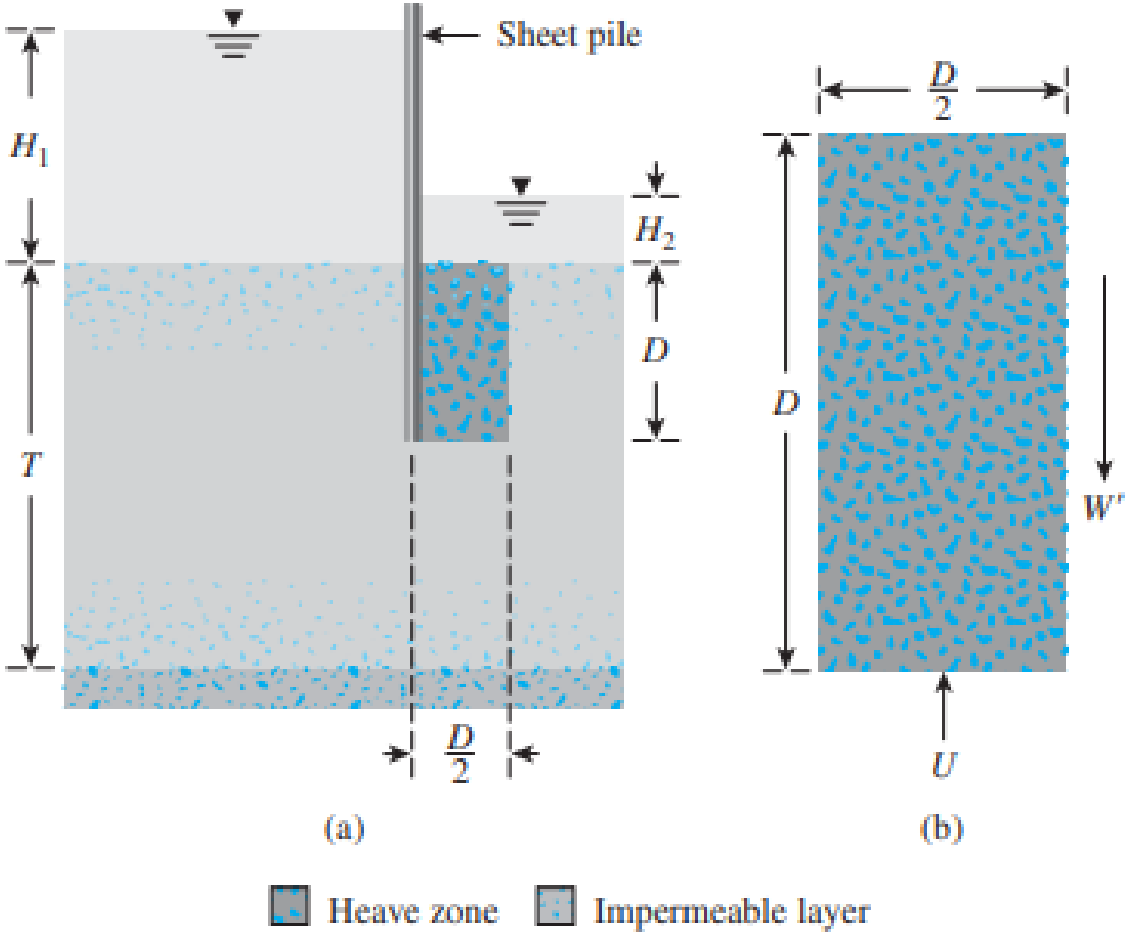
$$= D\left(\frac{D}{2}\right)(\gamma_{sat} - \gamma_w) = (1/2)D^2\gamma'$$

U = uplifting force caused by seepage

U = $(soil\ volume) \times (i_{av}\gamma_w) = 1/2D^2 i_{av}\gamma_w$

i_{av} = average hydraulic gradient at the bottom of the block of soil

$$FS = \frac{\gamma'}{i_{av}\gamma_w}$$



8.6 Effective Stress in Partially Saturated Soil

- Bishop and colleagues (1960)
- $\sigma' = \sigma - u_a + x(u_a - u_w)$
- For dry soil x = 0, for saturated soil x = 1

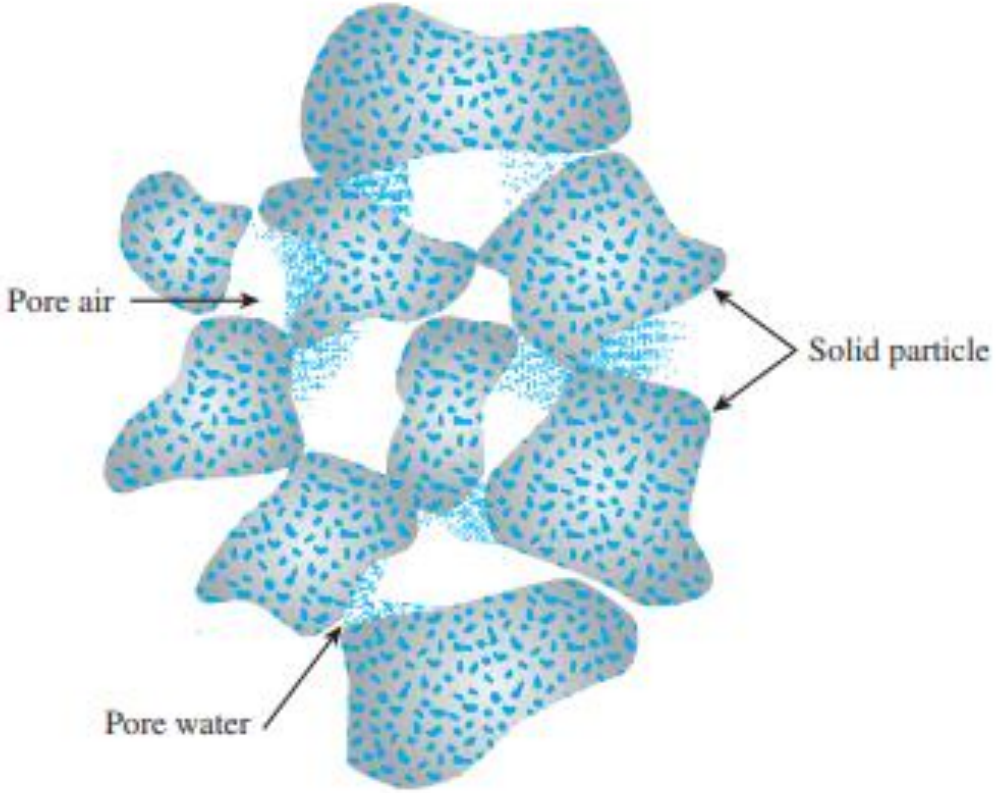
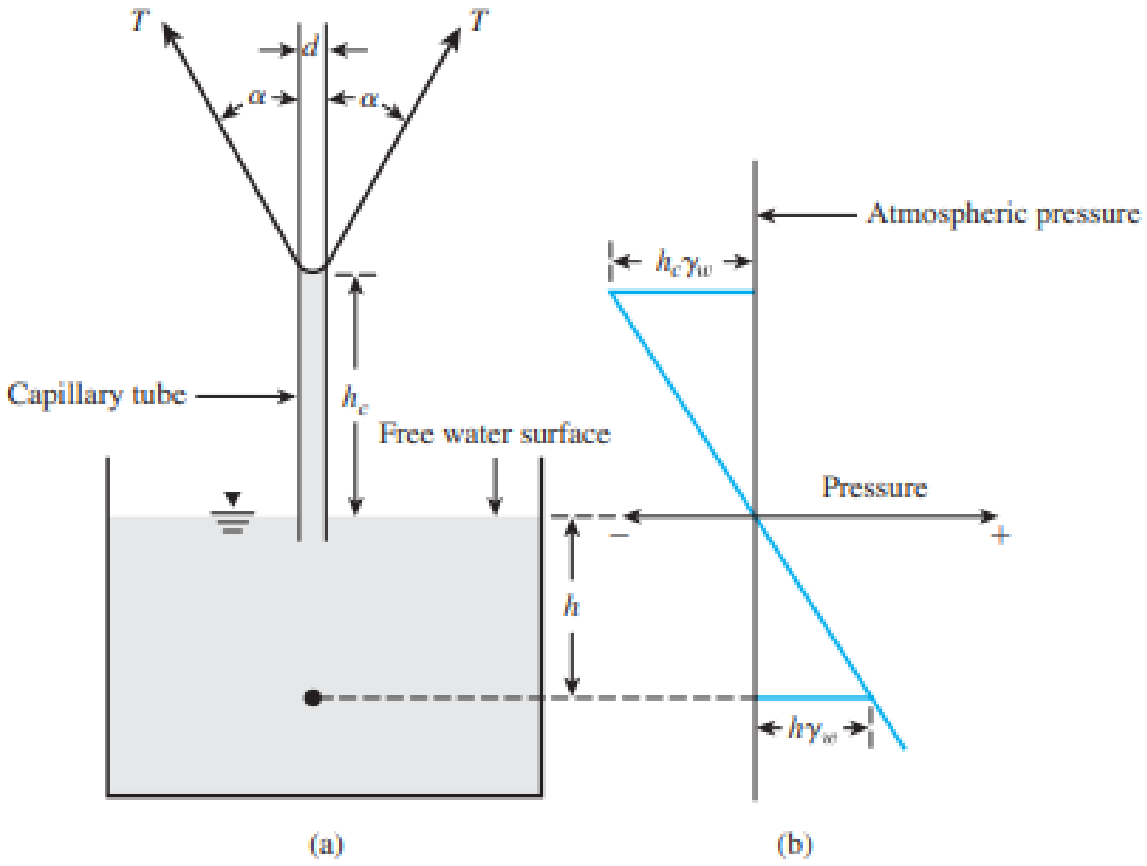


Figure 9.13 Partially saturated soil

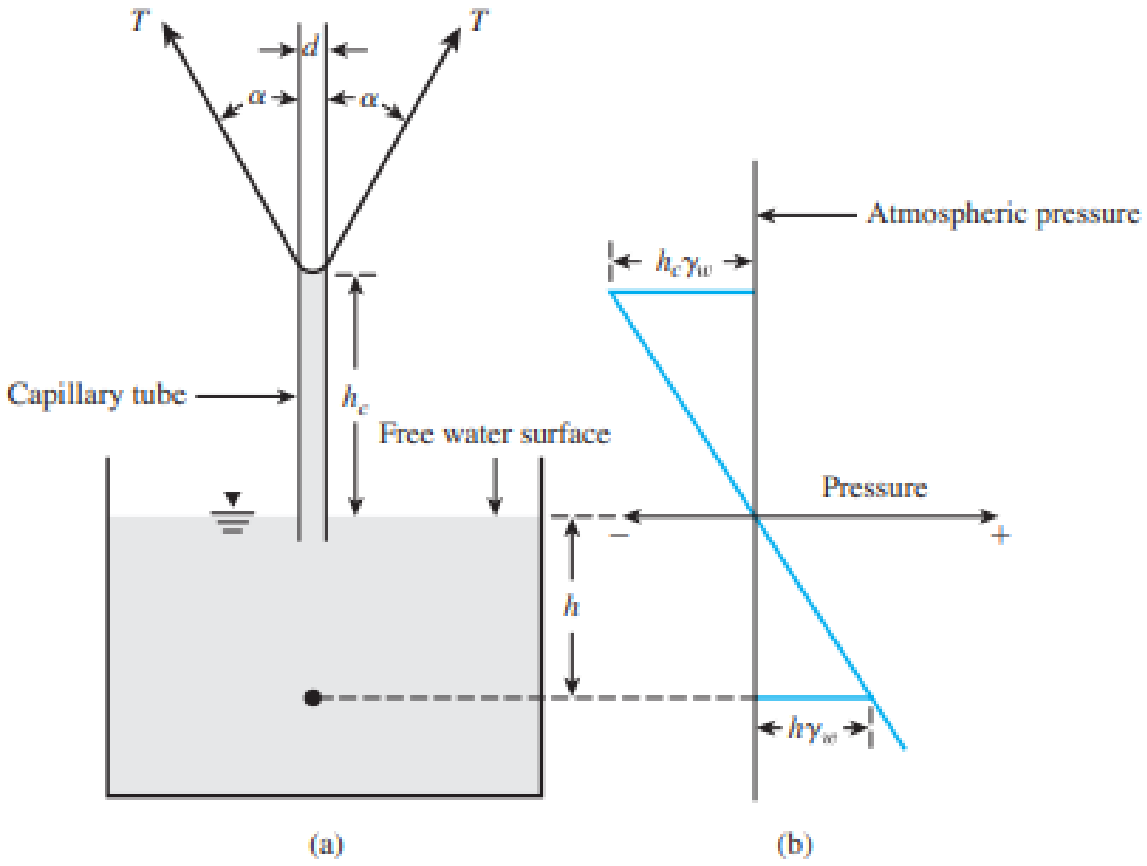
8.7 Capillary Rise in Soils

- The continuous void spaces in soil can behave as bundles of capillary tubes of variable cross section.
- Because of surface tension force, water may rise above the phreatic surface.
- $(\frac{\pi}{4d}d^2)\mathrm{h_c}\gamma_w = \pi dTcosa$
- $h_c = \frac{4Tcosa}{d\gamma_{,w}}$
- $h_c \propto \frac{1}{d}$ ← The smaller d, the larger the capillary rise
- Capillary tubes formed in soils because of the continuity of voids



8.7 Capillary Rise in Soils

- The pressure at any point in the capillary tube above the free water surface will be negative with respect to the atmospheric pressure and the magnitude may be given by $h\gamma_w$(where h = height above the free water surface).

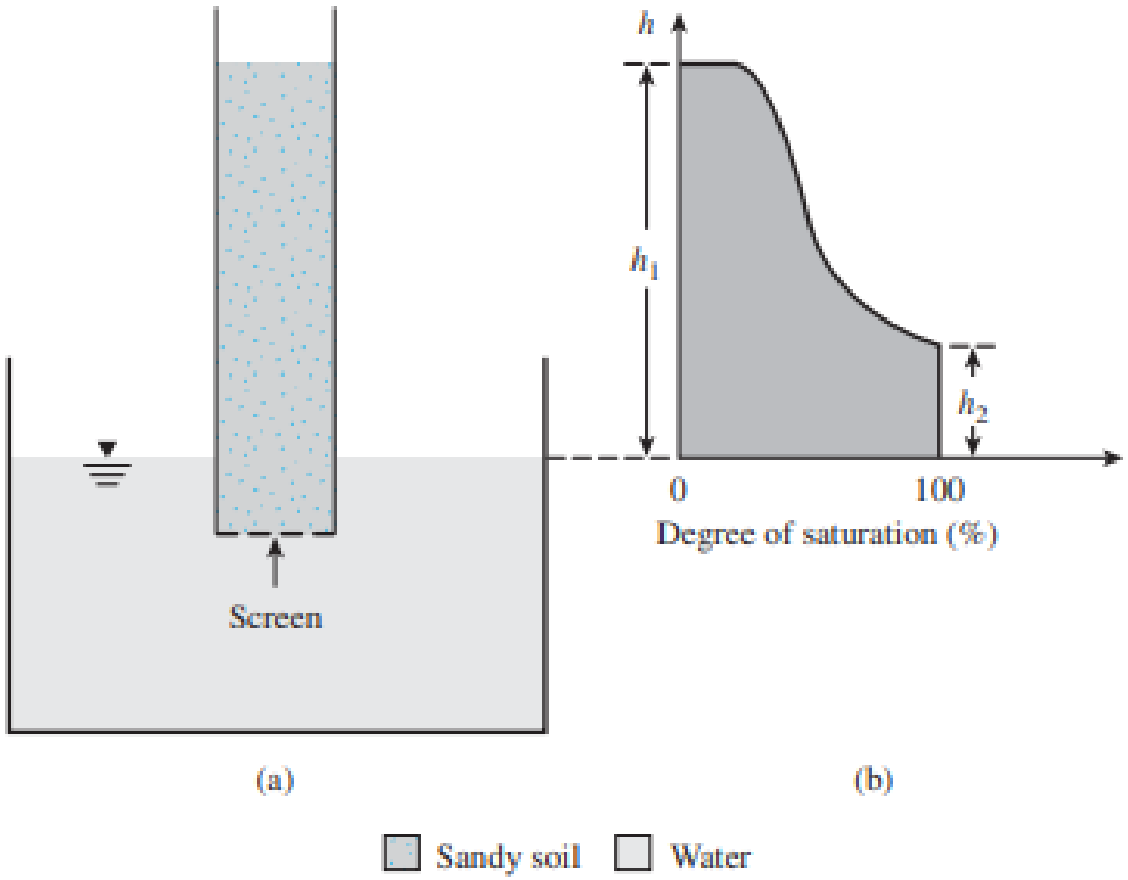


8.7 Capillary Rise in Soils

- Hazen (1930)
- $h_1(mm) = \frac{C}{eD_{10}}$

D_{10} = effective size (mm)

e = void ratio

C = a constant that varies from 10 to 50 mm^2

- $\sigma = \sigma' + u$
- Fully saturated by capillary rise
- $u = -\gamma_w h$
- Partial saturation by capillary action
- $u = -\left(\frac{S}{100}\right)\gamma_w h$