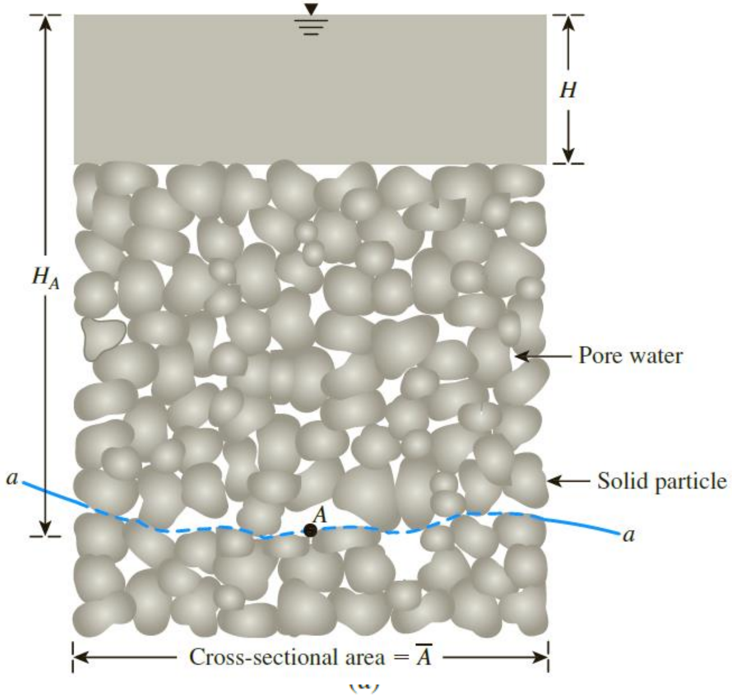
Dr. Khalil Qatu

ENCE 331: Stresses in Soil

Stresses in static conditions (No seepage)



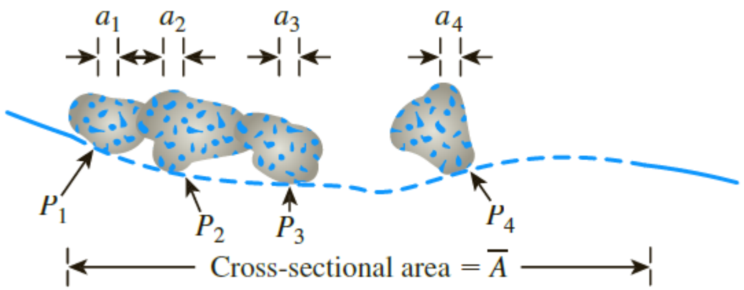
$$\sigma = H\gamma_w + (H_A - H)\gamma_{sat}$$

Pore pressure

Stress in soil

σ': Effective stress

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



$$u = H_A * \gamma_w$$

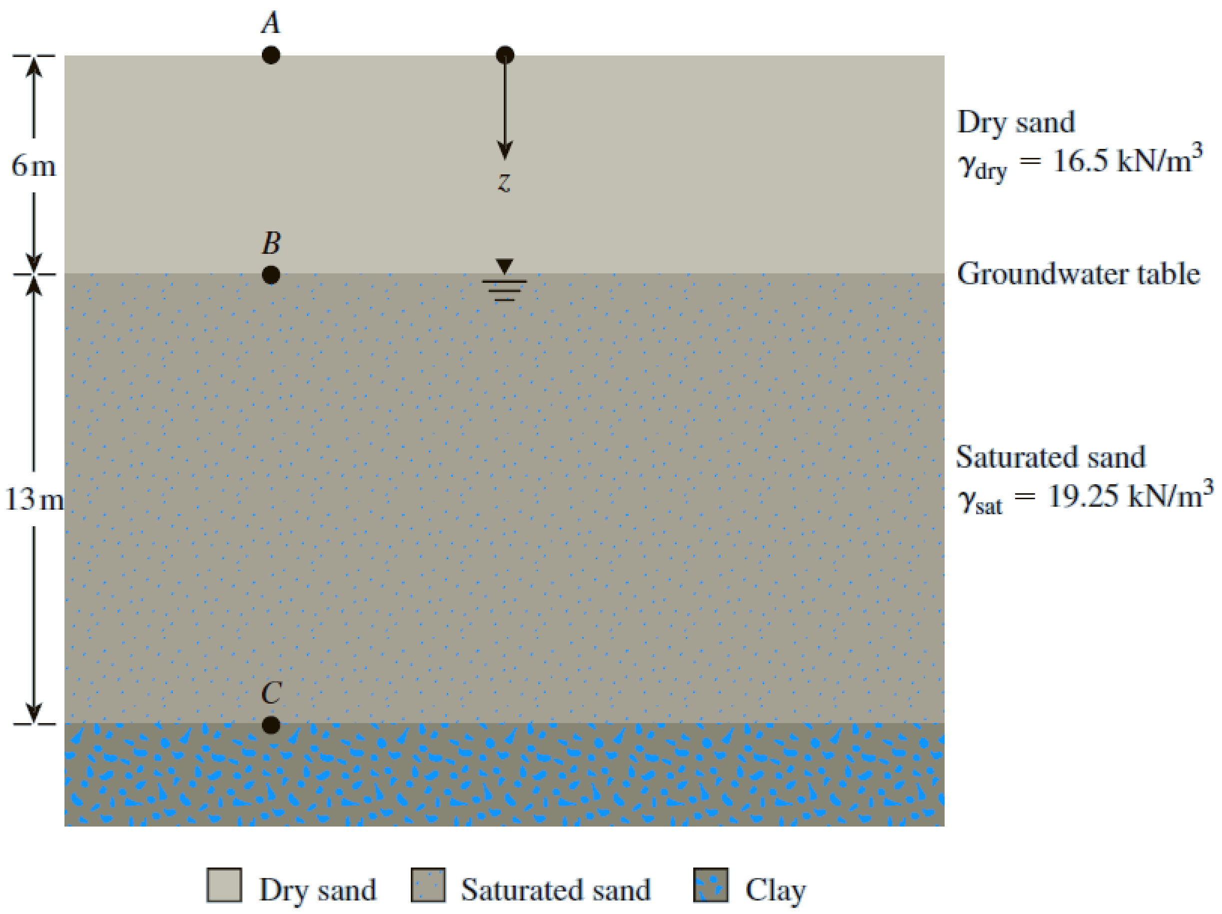
$$\sigma' = (H_A - H) * \gamma'$$

$$\gamma' = \gamma_{sat} - \gamma_w$$

$$\gamma_{sat} = \frac{(G_s+e)}{1+e}\gamma_w$$

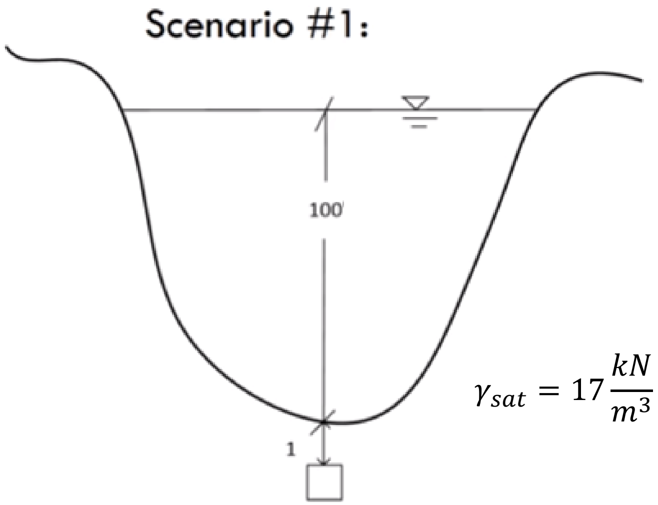
$$\gamma' = \frac{(G_s-1)}{1+e}\gamma_w$$

Example

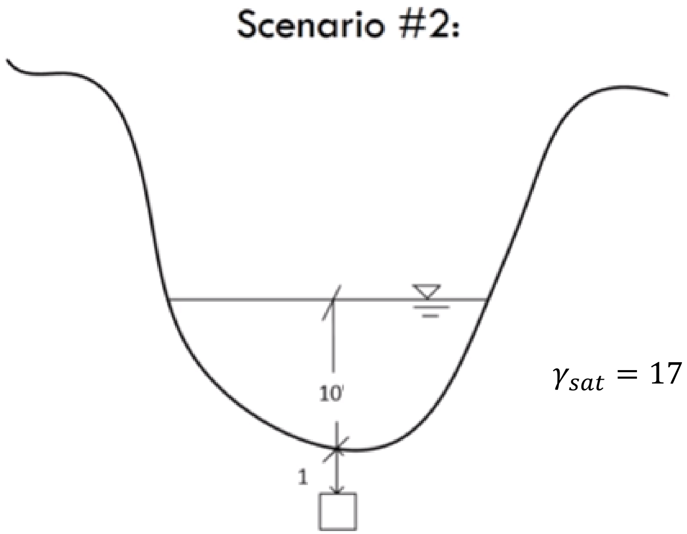


A
z
6 m
B
13 m
C
Dry sand
$\gamma_{dry} = 16.5$ kN/m^3
Groundwater table
Saturated sand
$\gamma_{sat} = 19.25$ kN/m^3
Dry sand
Saturated sand
Clay

Example



$\gamma_{sat} = 17\frac{kN}{m^3}$



$\gamma_{sat} = 17\frac{kN}{m^3}$

$\sigma =$

$u =$

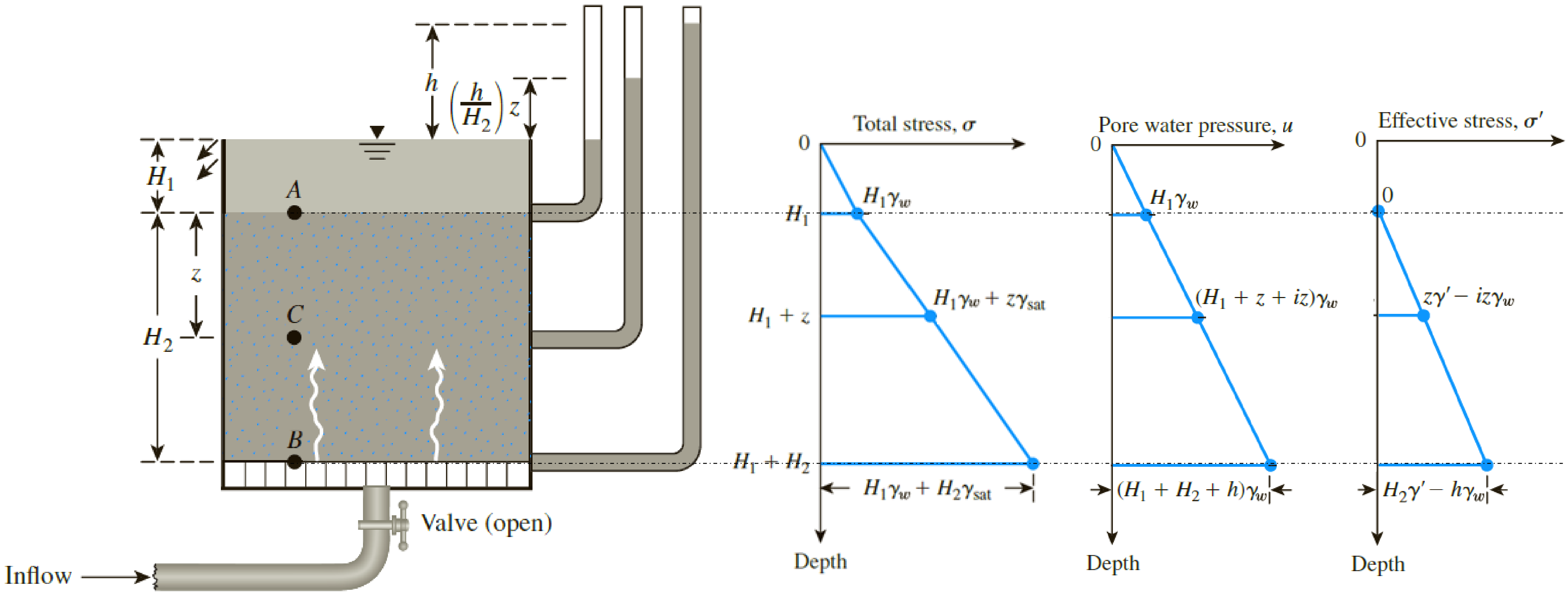
$\sigma' =$

$\sigma =$

$u =$

$\sigma' =$

Stresses with upward seepage



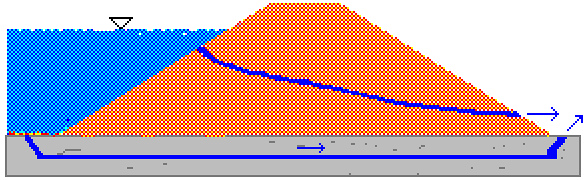
$$i_c = \frac{\gamma'}{\gamma_w}$$

$$i_c = \frac{(G_s - 1)}{1 + e}$$

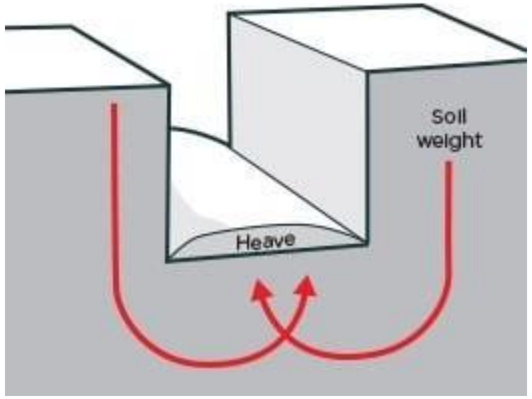
Zero effective stress conditions

- Boiling: Hydraulic gradient is very high; water appears to be boiling up from the sand

- Piping: or internal erosion, high hydraulic gradient causes erosion channels to form.



- Heaving: at the base of slope, soil heaves up.



- Liquefaction: …. ??

Example

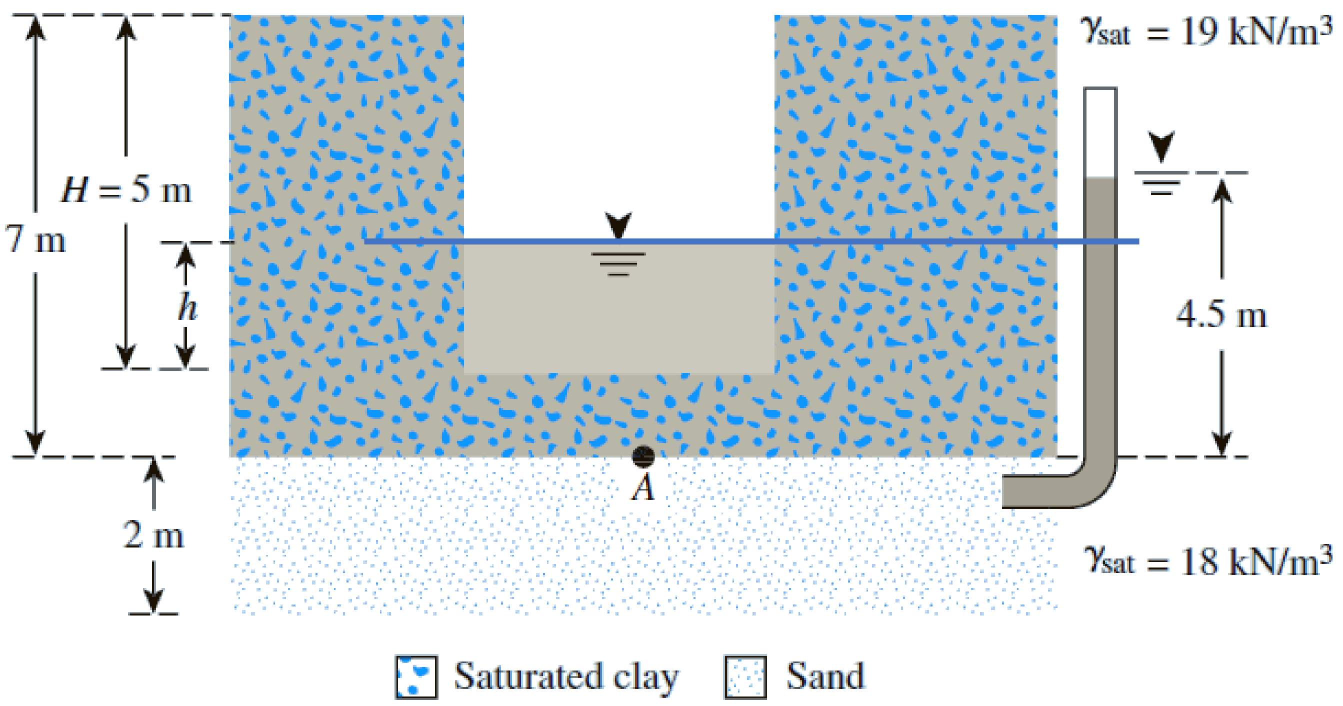
A cut is made in a stiff, saturated clay that is underlain by a layer of sand. What should be the height of the water, h, in the cut so that the stability of the saturated clay is not lost?

$$\sigma = h * \gamma_w + 2 * \gamma_{clay} = 9.81h + 2 * 19 = 9.81h + 38$$

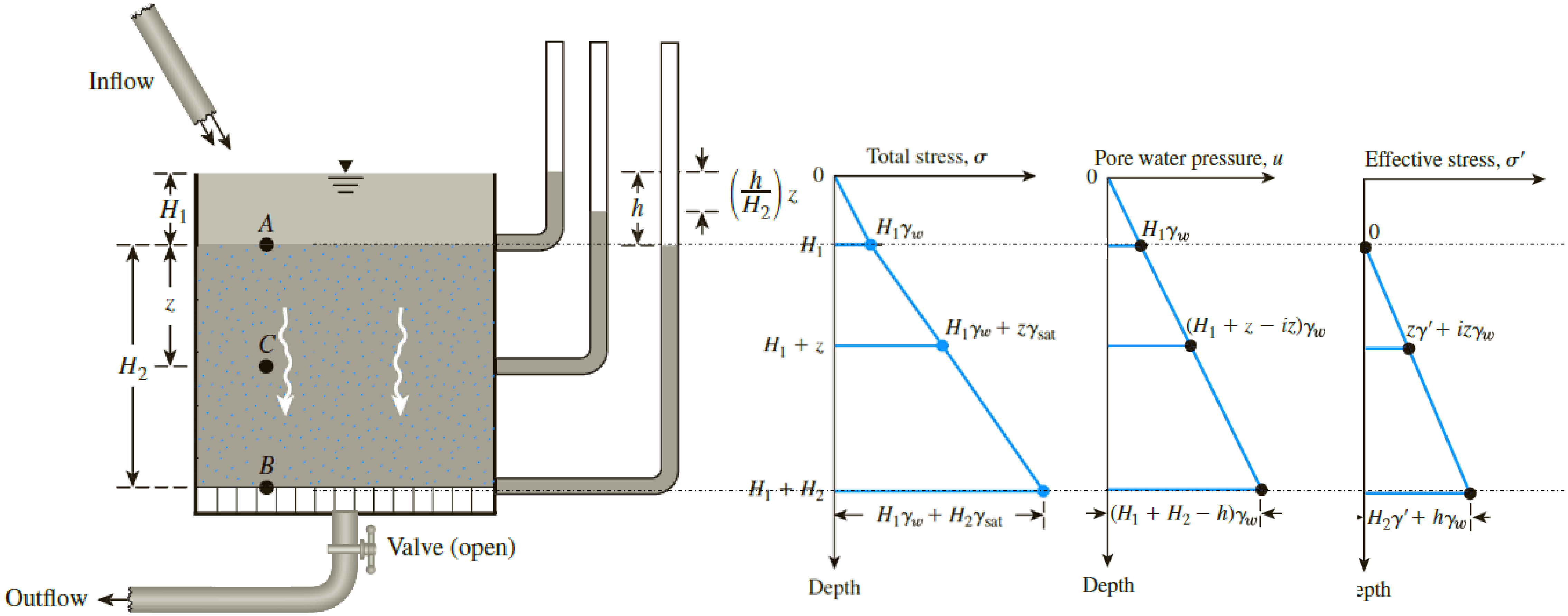
$$u = 4.5 * \gamma_w = 4.5 * 9.81 = 44.14\ kPa$$

$$\sigma' = \sigma - u = 9.81h + 38 - 44.14$$

$$\sigma' = 9.81h - 6.14 = 0$$
$$h > 0.625\ m$$



Stresses with downward seepage



Example

A section through a dam is shown across. Determine:

- The effective stress at point 2 if the saturated unit weight for the soil is 18 kN/m^3.

$$\sigma = 9.4 * \gamma_{sat} + 6.3\gamma_w = 231\ kPa$$

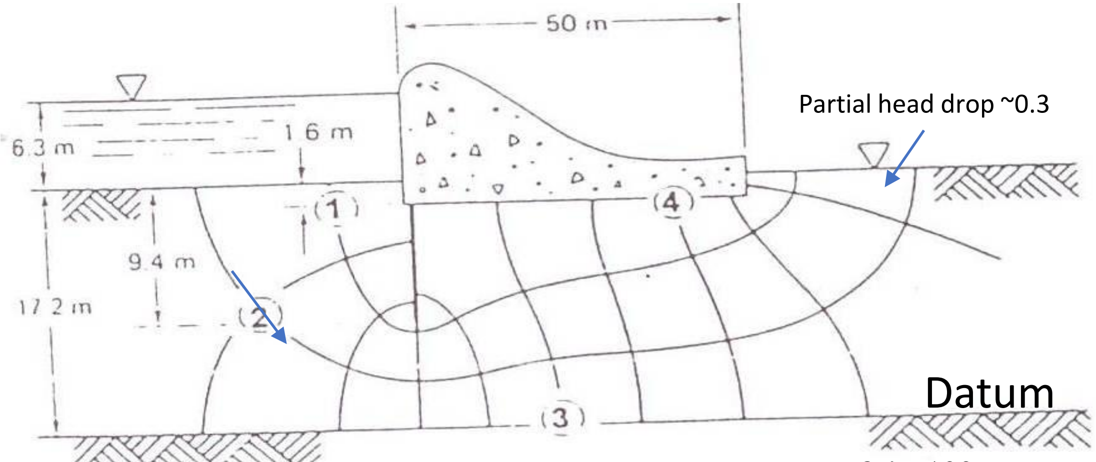
$u \rightarrow$

$$total\ head\ \rightarrow N_d = 9.3\ \rightarrow \Delta h = \frac{H}{N_d} = \frac{6.3}{9.3} = 0.67\,\frac{m}{drop}$$

$$total\ head\ at\ point\ 2 \rightarrow 17.2 + 6.3 - 1 * 0.67 = 22.83m$$

$$elevation\ head + u = 17.2 - 9.4 + u = 22.83m$$

$$\rightarrow Pressure\ head\ = 15.03m \rightarrow u_{@2} = 15.03 * 9.81 = 147.4\ kPa$$



$$scale\ \rightarrow 9.4\ m\ \rightarrow 1.94\ cm\ \rightarrow \frac{9.4 * 100}{1.94} = 484.5$$

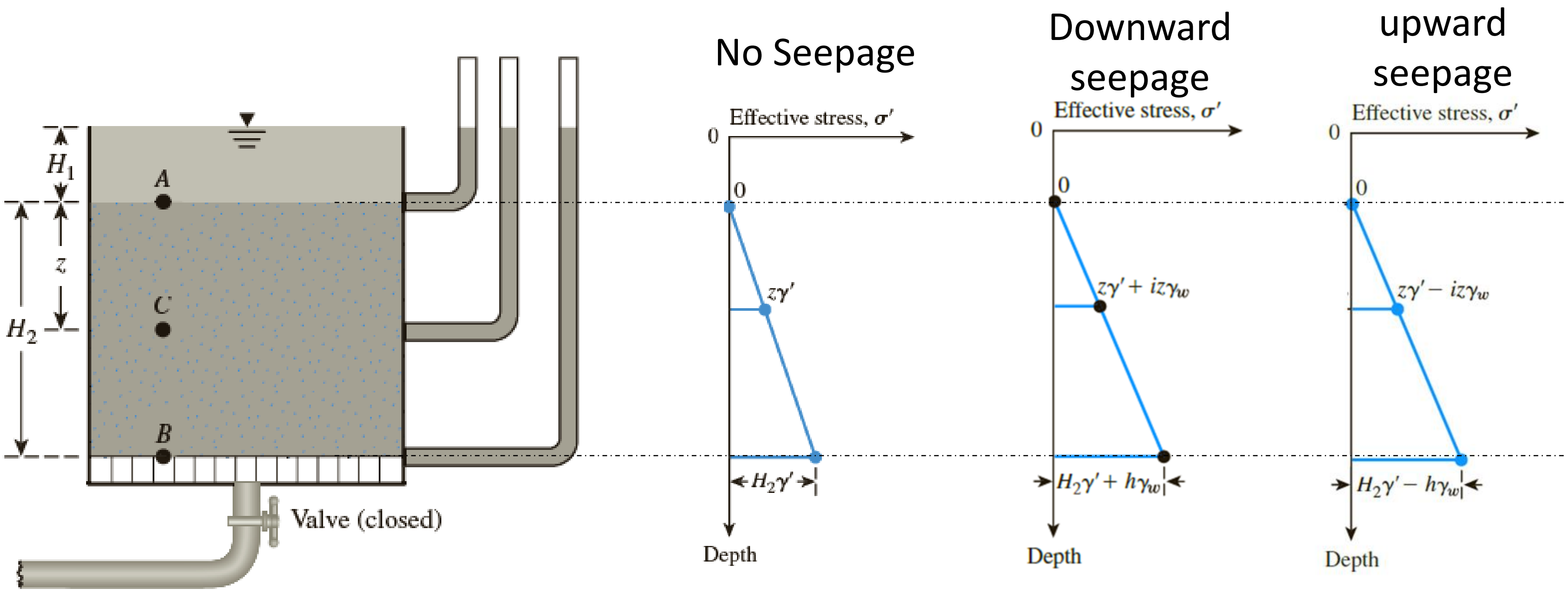
$$1\ cm: 484.5\ cm$$

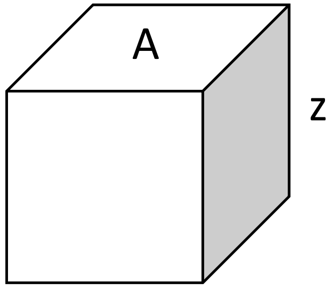
$$\sigma' = \sigma - u = 231 - 147.4 = 83.6\ kPa$$

$$FS_{boiling} = \frac{i_c}{i} = \frac{\frac{\gamma'}{\gamma_w}}{\frac{\Delta h}{l}} = \frac{\frac{18 - 9.81}{9.81}}{\frac{0.67}{9.4}} = \frac{0.834}{0.07} = 11.71$$

$$\sigma' = z\gamma' + iz\gamma_w = 9.4 * (18 - 9.81) + 0.07 * 9.4 * 9.81 = 83.5\ kPa$$

Seepage force





$$\sigma_s = iz\gamma_w$$

Seepage force per unit volume

$$f_s = \frac{\sigma_s * A}{V} = \frac{iz\gamma_w * A}{A\ z}$$

Direction ??

$$f_s = \mathrm{i}\gamma_w$$

Seepage force

- Critical section in Sheet piles

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

where FS = factor of safety

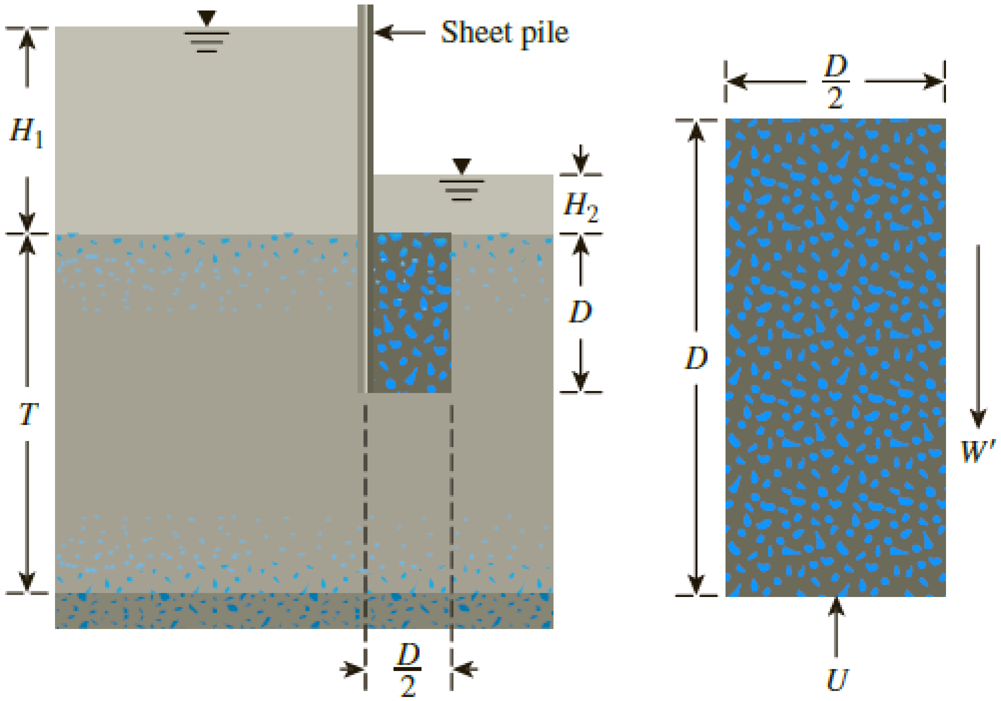
W' = submerged weight of soil in the heave zone per unit length of sheet pile = $D(D/2)(\gamma_{sat} - \gamma_w) = (\frac{1}{2})D^2\gamma'$

U = uplifting force caused by seepage on the same volume of soil

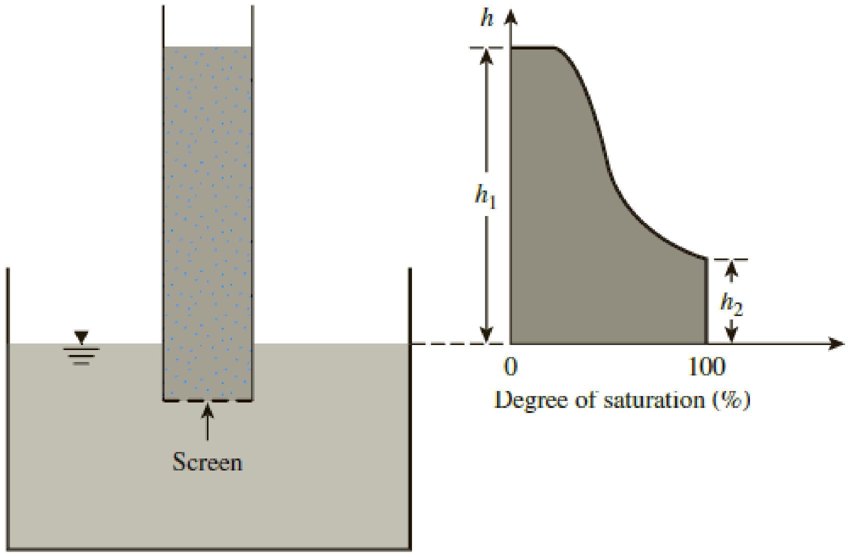
From Eq. (9.13),

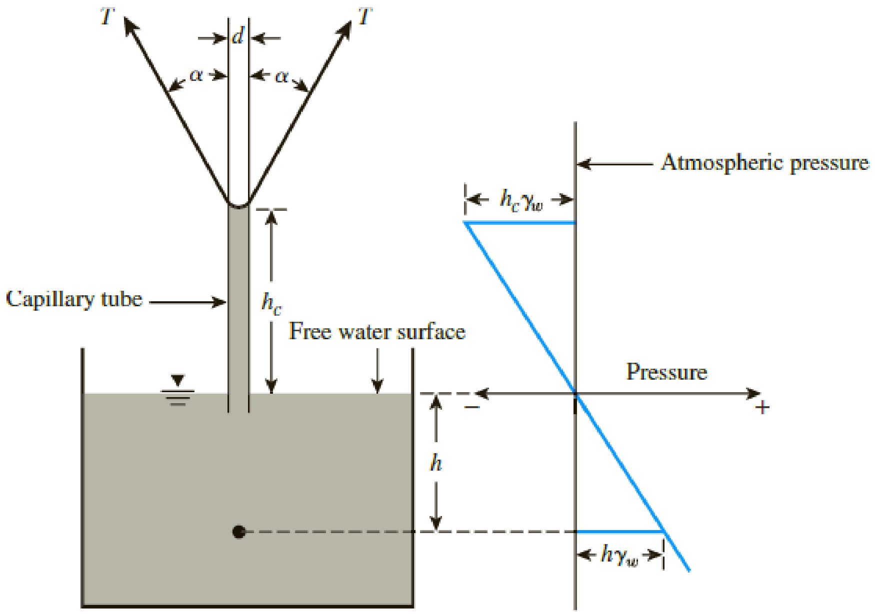
$$U = (\text{Soil volume}) \times (i_{av}\gamma_w) = \tfrac{1}{2}D^2 i_{av}\gamma_w$$

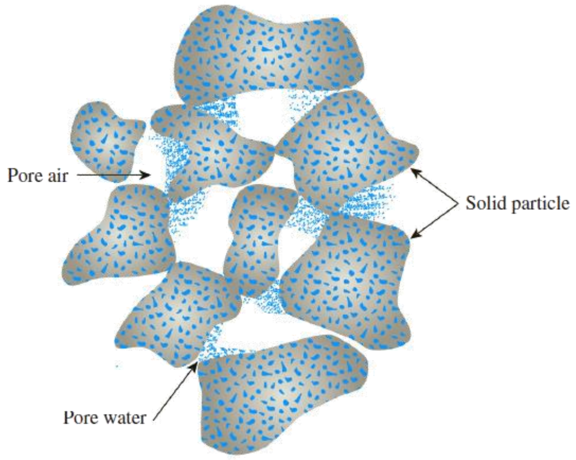
$$FS = \frac{\gamma'}{i_{av}\gamma_w}$$



Partially saturated soils







$$h_1\ (\text{mm}) = \frac{C}{eD_{10}}$$

$$u = -\left(\frac{S}{100}\right)\gamma_w h$$

Table 9.2 Approximate Range of Capillary Rise in Soils

	Range of capillary rise	
Soil type	**m**	**ft**
Coarse sand	0.1–0.2	0.3–0.6
Fine sand	0.3–1.2	1–4
Silt	0.75–7.5	2.5–25
Clay	7.5–23	25–75

Partially saturated soil

Draw the distribution of the total stress, pore water pressure, and effective stress, H_1=2m , H_2=1 m, and H_3=2 m.

$At\ point\ A$:

$\sigma = 0, \quad u = 0, \quad \sigma' = 0$

$At\ point\ B + (just\ above): dry$

$\sigma = H_1\gamma_{d(sand)} = 2 * 17.33 = 34.66\ kPa$

$u = 0,$

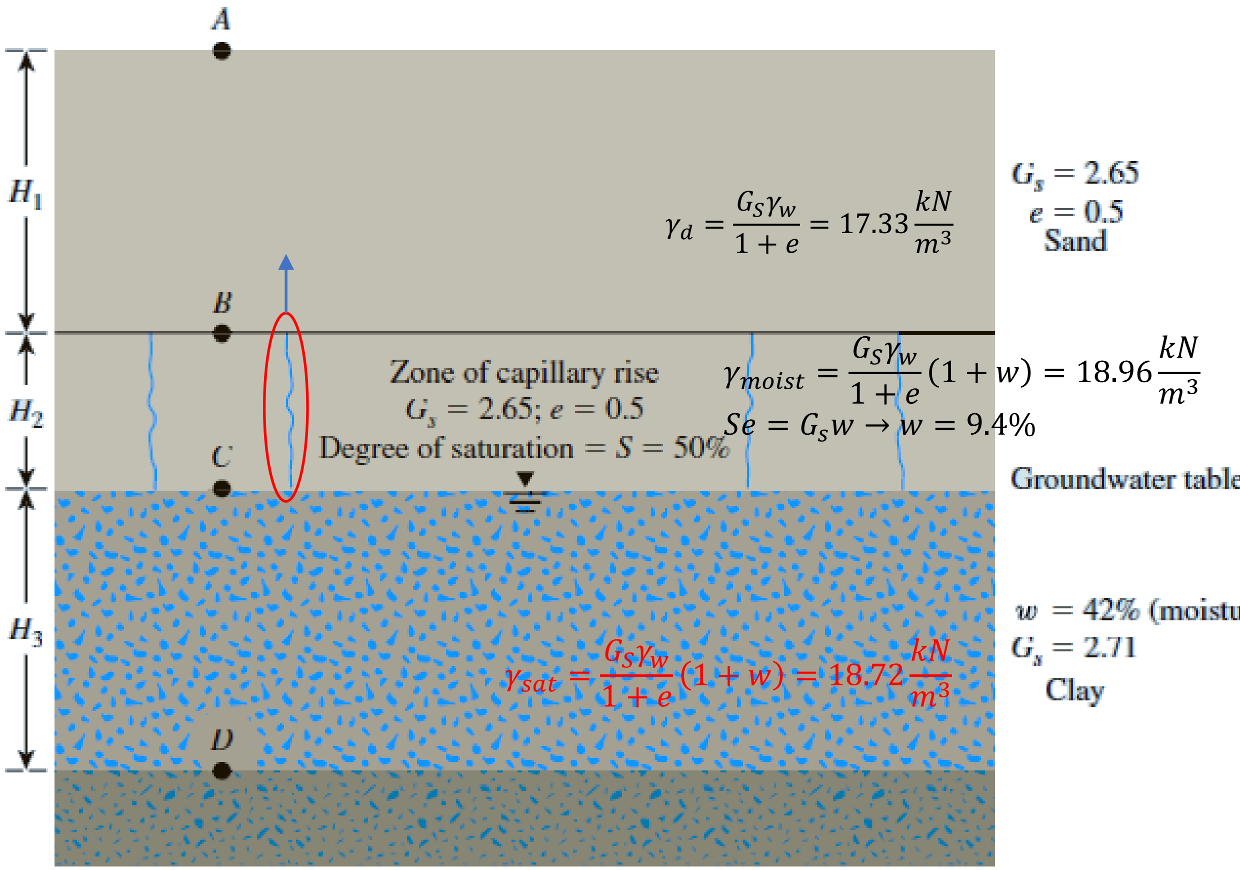
$\sigma' = 34.66\ kPa$

$At\ point\ B - (just\ below): partially\ saturated$

$\sigma = 34.66\ kPa$

$u = -S * \gamma_w * H_2 = -4.9\ kPa$

$\sigma' = \sigma - u = 39.57\ kPa$



Partially saturated soil

Draw the distribution of the total stress, pore water pressure, and effective stress, H_1=2m , H_2=1 m, and H_3=2 m.

$At\ point\ C$:

$\sigma = H_1\gamma_{d(sand)} + H_2\gamma_{moist} = 2*17.33 + 1*18.96 = 53.62\ kPa$

$u = 0,$

$\sigma' = 53.62\ kPa$

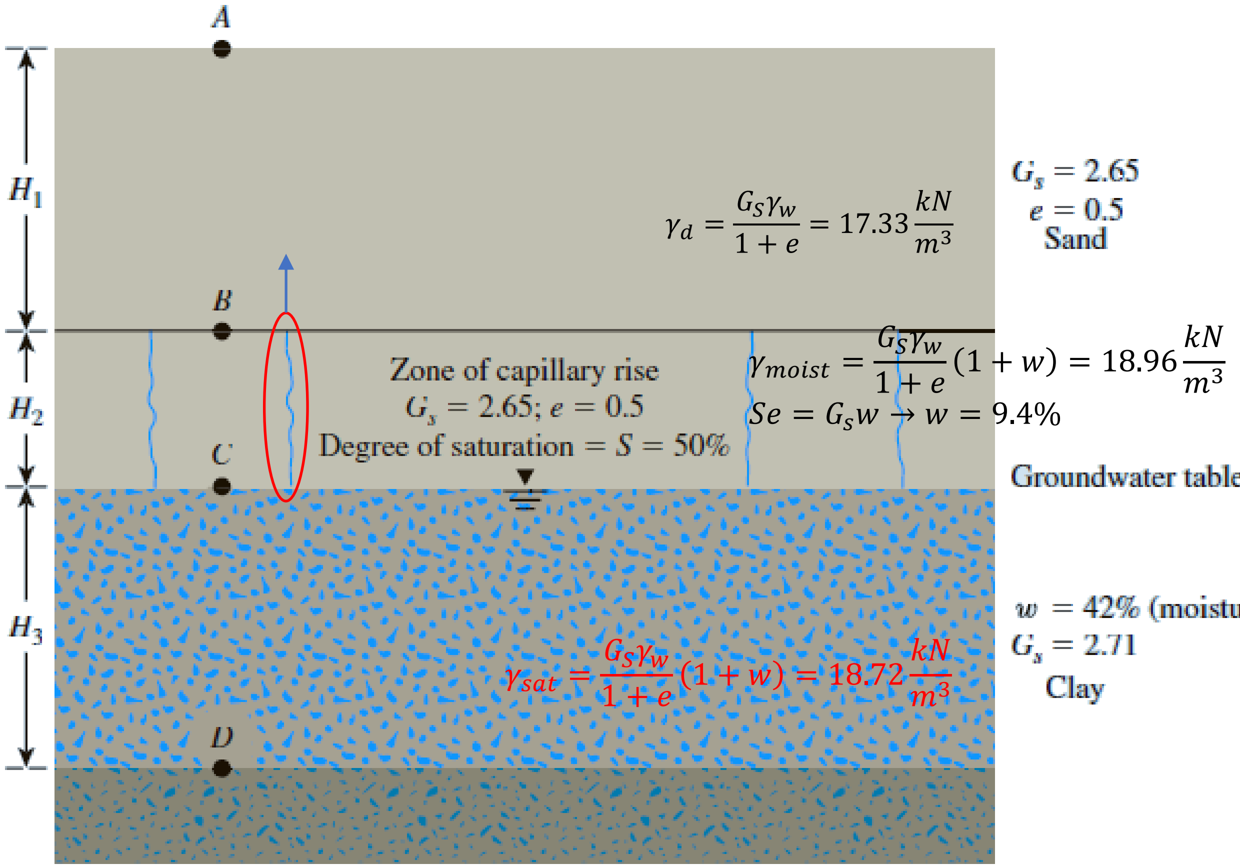
$At\ point\ D$:

$\sigma = H_1\gamma_{d(sand)} + H_2\gamma_{moist} + H_3\gamma_{sat(clay)}$

$= 2*17.33 + 1*18.96 + 2*18.72 = 91.06\ kPa$

$u = H_3 * \gamma_w = 2*9.81 = 19.62\ ,$

$\sigma' = 71.44\ kPa$



Partially saturated soil

Draw the distribution of the total stress, pore water pressure, and effective stress, H_1=2m , H_2=1 m, and H_3=2 m.