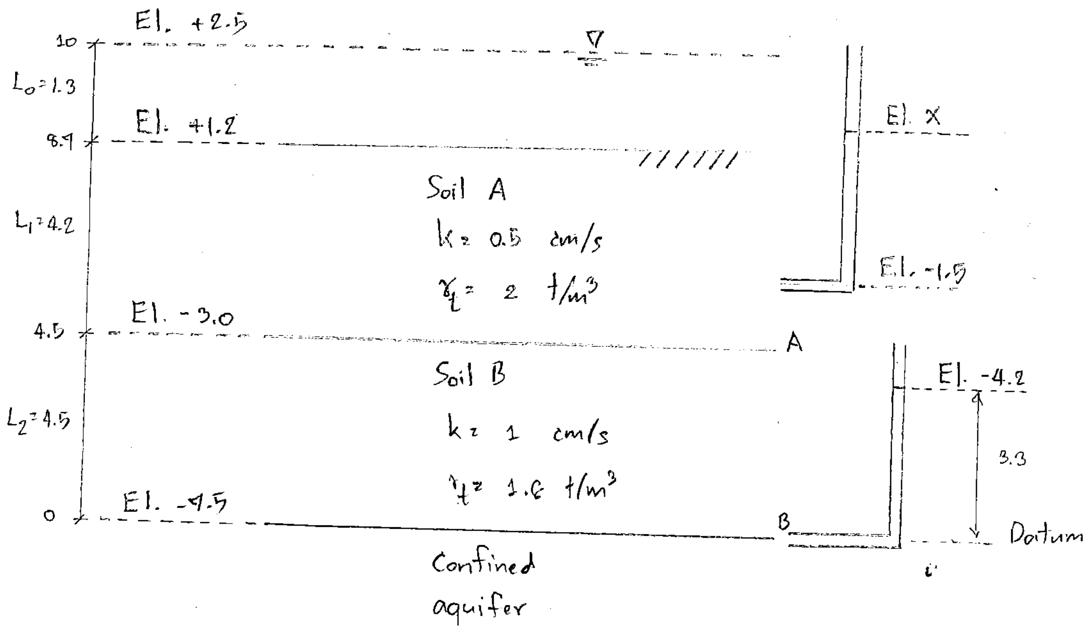
Exam 1

As shown in the figure below, the pump is installed at El. -7.5 to lower the pressure at this point.

1) Draw the vertical effective stress and seepage force / unit volume versus the elevation (from El. +2.5 to -7.5)

2) What is the rate of water that is currently pumping out ?

3) If the pump stops, and there is an artesian occuring at the layer of confined aquifer which can cause the quick condition in the soil. What would a piezometer at El. -1.5 read Elevation "x" ?



Sol^n 1) $\Delta h = 10-(7.5-4.2) = 6.7$ m. (Downward flow)

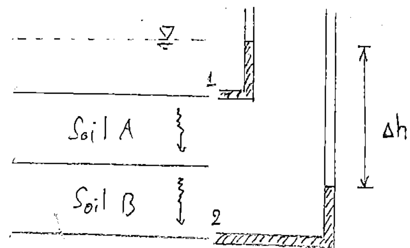
จาก $Q_1 = Q_2$

$$k_1 i_1 A_1 = k_2 i_2 A_2 \quad ; \quad A_1 = A_2$$

$$k_1 i_1 = k_2 i_2$$

$$k_1 \frac{\Delta h_1}{L_1} = k_2 \cdot \frac{\Delta h_2}{L_2}$$

$$\Delta h_1 = \frac{k_2}{k_1} \times \frac{L_1}{L_2} \times \Delta h_2$$



ที่ไหลลง เพราะว่า $h_{t1} > h_{t2}$

แทนค่า $\Delta h_2 = \Delta h - \Delta h_1$

$$\Delta h_1 = \frac{k_2}{k_1} \times \frac{L_1}{L_2} \times (\Delta h - \Delta h_1)$$

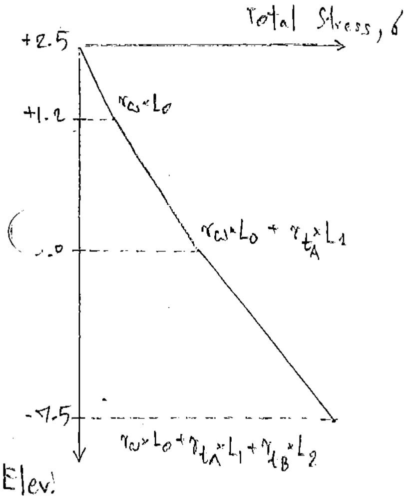
$$\Delta h_1 = \frac{\frac{k_2}{k_1} \times \frac{L_1}{L_2} \times \Delta h}{1 + \frac{k_2}{k_1} \times \frac{L_1}{L_2}} = \frac{\frac{1}{0.5} \times \frac{4.2}{4.5} \times 6.7}{1 + \frac{1}{0.5} \times \frac{4.2}{4.5}} = 4.4 \text{ m.}$$

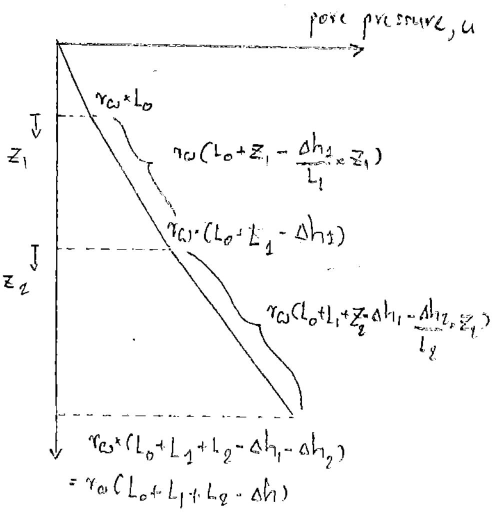
$$\Delta h_2 = 6.7 - 4.4 = 2.3 \text{ m.}$$

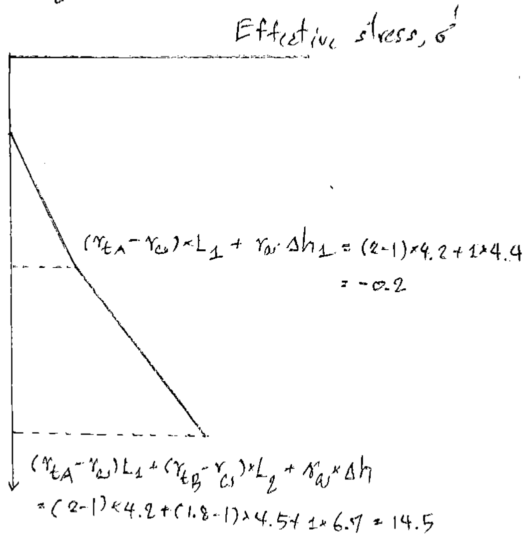
Ele.	h_t	h_e	$h_p = h_t - h_e$
+2.5	$h_e + h_p = 10 + 0 = 10$	10	0
+1.2	$h_e + h_p = 8.7 + 1.3 = 10$	8.7	1.3
-3.0	$h - \Delta h_1 = 10 - 4.4 = 5.6$	4.5	1.1
-7.5	$h - (\Delta h_1 + \Delta h_2) = 10 - (4.4 + 2.3) = 3.3$	0	3.3

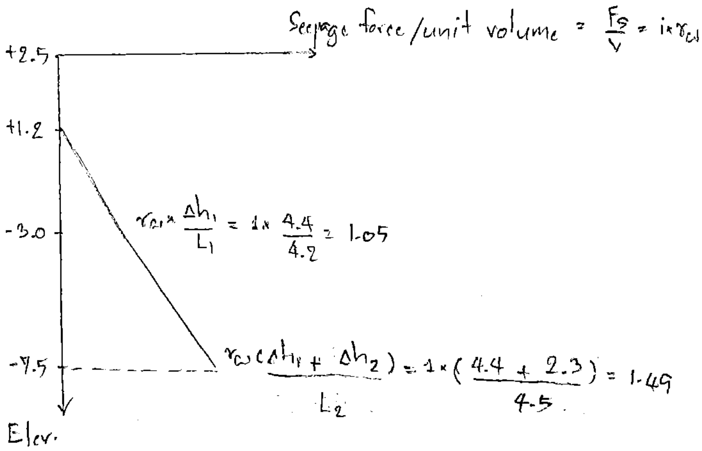
(จาก $i_A = \frac{\Delta h_A}{L_1} = \frac{(L_0 + L_1 - h_p)}{L_1} \Rightarrow h_p = (L_0 + L_1) - \Delta h_A$; $\Delta h_A = \Delta h_1$)
$= (1.3 + 4.2) - 4.4 = 1.1$

(จาก $i_B = \frac{\Delta h_B}{L_2} = \frac{(L_0 + L_1 + L_2 - h_p)}{L_2} \Rightarrow h_p = (L_0 + L_1 + L_2) - \Delta h_B$; $\Delta h_B = \Delta h_1 + \Delta h_2$)
$= (1.3 + 4.2 + 4.5) - 6.7 = 3.3$









2.) $Q_{outflow} = k \cdot A \cdot i$

$= k_B \times A_B \times i_B$; $i_B = \frac{(\Delta h_1 + \Delta h_2)}{L_2}$

$= (1 \times 10^{-2}) \times 1 \times 1.49$

$= 1.49 \times 10^{-2}$ m^3/s ต่อ พ.ท.หน้าตัด 1 m^2

3) quick condition at Ele. -7.5 ($\sigma' = 0$)

$$h_p \text{ at Ele. } -1.5 = L_0 + z_1 - \frac{\Delta h_1}{L_1} \times z_1$$

$$= 1.3 + 4.0 - \frac{4.4}{4.2} \times 4.0$$

$$= 1.1 \text{ m}$$

$\therefore$ piezometer at Elev. -1.5 read Elev. x = $-1.5 + 1.1 = -0.4$

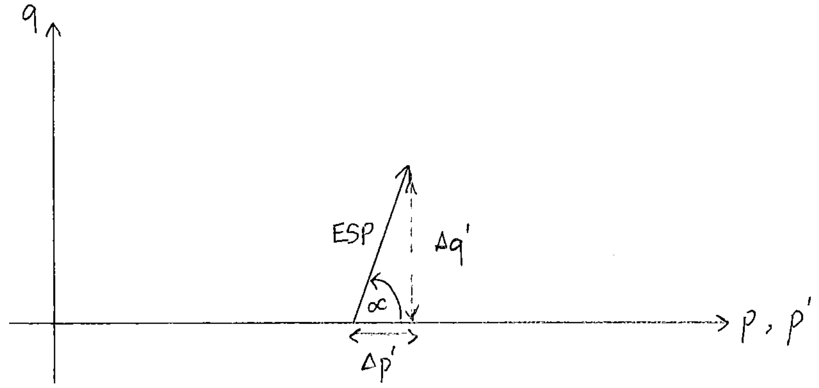
Exam 2

Given : 1. Triaxial Test CIUC(L) : σ_c σ_c' u_s and $\Delta\sigma_v$

2. The effective stress path (ESP) during shearing moves as a straight line making an angle of "α"

Find : 1. derive an expression of A-parameter as a function of those variables.

2. calculate A-parameter if $\alpha = 30°, 60°, 120°, 150°$



Consolidate → Isotropically $\quad \Delta\sigma_v = 0$

$$\sigma_c' = \sigma_c - \cancel{u_b}^{\,0}$$

$$\sigma_c' = \sigma_c$$

Undraine Compression loading $\quad \Delta\sigma_h = 0$ during shearing $(\Delta\sigma_v > 0,\ \Delta u = u_s)$

จากรูป $$\tan\alpha = \frac{\Delta q'}{\Delta p'}$$

$$= \frac{(\Delta\sigma_v' - \Delta\sigma_h')/2}{(\Delta\sigma_v' + \Delta\sigma_h')/2} = \frac{\Delta\sigma_v' - \Delta\sigma_h'}{\Delta\sigma_v' + \Delta\sigma_h'}$$

then $$\Delta u = B[\Delta\sigma_h + A(\Delta\sigma_v - \Delta\sigma_h)]$$

Isotropically consolidate ⟹ Sample is saturated ⟹ $B = 1.0$

$$\Delta u = \Delta\sigma_h + A(\Delta\sigma_v - \Delta\sigma_h)$$

So that
$$\Delta\sigma_v' = \Delta\sigma_v - \Delta u = \Delta\sigma_v - [\Delta\sigma_h + A(\Delta\sigma_v - \Delta\sigma_h)] = \Delta\sigma_v - \Delta\sigma_h - A(\Delta\sigma_v - \Delta\sigma_h)$$
$$\Delta\sigma_h' = \Delta\sigma_h - \Delta u = \Delta\sigma_h - [\Delta\sigma_h + A(\Delta\sigma_v - \Delta\sigma_h)] = \Delta\sigma_h - \Delta\sigma_h - A(\Delta\sigma_v - \Delta\sigma_h)$$
$$= -A(\Delta\sigma_v - \Delta\sigma_h)$$

$$\Delta\sigma_v' - \Delta\sigma_h' = \Delta\sigma_v - \Delta\sigma_h - \cancel{A(\Delta\sigma_v - \Delta\sigma_h)} + \cancel{A(\Delta\sigma_v - \Delta\sigma_h)} = \Delta\sigma_v - \Delta\sigma_h$$

$$\Delta\sigma_v' + \Delta\sigma_h' = \Delta\sigma_v - \Delta\sigma_h - A(\Delta\sigma_v - \Delta\sigma_h) - A(\Delta\sigma_v - \Delta\sigma_h) = (1-2A)(\Delta\sigma_v - \Delta\sigma_h)$$

So $$\tan\alpha = \frac{(\Delta\sigma_v - \Delta\sigma_h)}{(1-2A)(\Delta\sigma_v - \Delta\sigma_h)} = \frac{1}{1-2A}$$

$$A = \frac{1}{2}\left(1 - \frac{1}{\tan\alpha}\right) = \frac{\tan\alpha - 1}{2\tan\alpha}$$

If $\alpha = 30°, 60°, 120°, 150°$ ⟹ $A = -0.37,\ 0.21,\ 0.79,\ 1.37$

Exam 3

The soft clay deposite, having $\gamma_t = 1.6\ t/m^3$ and the ground water table is at the surface, has the thickness of 10 m. A point in the soil mass, located at 8 m below the ground surface and having the in-situ pore pressure of 6 t/m^2 and $K_o = 0.8$ is subjected to the stress condition of extension loading. At failure, the value of undrained shear strength is 2.04 and $A_f = 0.6$.

Find the piezometer head at depth of 8 m.

Sol^n 1.) before shearing (at K_o-line)

$$\sigma_{vc} = \gamma_t \times Z = 1.6 \times 8 = 12.8\ t/m^2 \qquad (\text{in-situ } u = 6\ t/m^2)$$

$$\sigma'_{vc} = \sigma_{vc} - u = 12.8 - 6 = 6.8\ t/m^2$$

$$\sigma'_{hc} = K_o \times \sigma'_{vc} = 0.8 \times 6.8 = 5.44\ t/m^2$$

$$\sigma_{hc} = \sigma'_{hc} + u = 5.44 + 6 = 11.44\ t/m^2$$

Total Stress Path (TSP)

$$p = \frac{\sigma_{vc} + \sigma_{hc}}{2} = \frac{12.8 + 11.44}{2} = 12.12$$

$$q = \frac{\sigma_{vc} - \sigma_{hc}}{2} = \frac{12.8 - 11.44}{2} = 0.68$$

Effective Stress Path (ESP)

$$p' = \frac{\sigma'_{vc} + \sigma'_{hc}}{2} = \frac{6.8 + 5.44}{2} = 6.12$$

$$q' = \frac{\sigma'_{vc} - \sigma'_{hc}}{2} = \frac{6.8 - 5.44}{2} = 0.68$$

2.) $\bar{C}K_oUE\ (L)$ => failure, $\Delta\sigma_v = \Delta\sigma_3 = 0$, $\Delta\sigma_h = \Delta\sigma_1 > 0$

$c_u = 2.04\ t/m^2$

At failure $\quad q_f = c_u = 2.04\ t/m^2$

$$\Delta\sigma_v = \Delta\sigma_3 = \sigma_{vf} - \sigma_{vc}$$

$$0 = \sigma_{vf} - \sigma_{vc}$$

$$\sigma_{vf} = \sigma_{vc} = 11.44$$

$$q_f = c_u = \frac{\sigma_{vf} - \sigma_{hf}}{2}$$

$$-2.04 = \frac{11.44 - \sigma_{hf}}{2}$$

$$\sigma_{hf} = 15.52\ t/m^2$$

$$\Delta\sigma_h = \Delta\sigma_1 = \sigma_{hf} - \sigma_{hc}$$

$$\Delta\sigma_h = 15.52 - 11.44 = 4.08\ t/m^2$$

$$\Delta u = B[\Delta\sigma_3 + A_f(\Delta\sigma_1 - \Delta\sigma_3)] = 1.0[0 + 0.6(4.08 - 0)] = 0.648\ t/m^2$$

pore pressure at failure, $u_f = u + \Delta u = 6 + 0.648 = 6.648\ t/m^2$, $h_p = \frac{u_f}{\gamma_w} = 6.648$ m.

$$\sigma'_{vf} = \sigma_{vf} - u_f = 11.44 - 6.648 = 4.792\ t/m^2$$

$$\sigma'_{hf} = \sigma_{hf} - u_f = 15.52 - 6.648 = 8.872\ t/m^2$$

Total Stress Path (TSP)

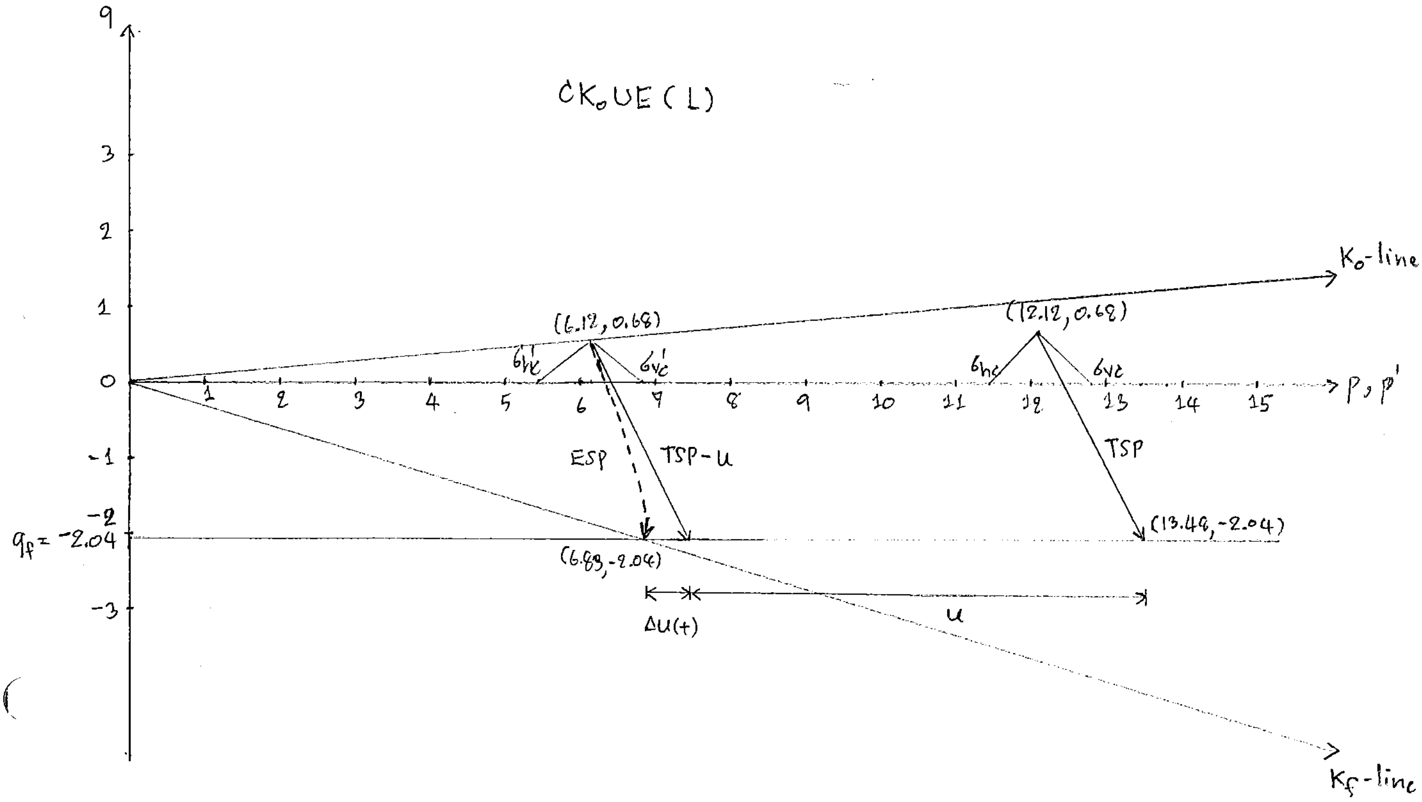
$$p_f = \frac{\sigma_{vf} + \sigma_{hf}}{2} = \frac{11.44 + 15.52}{2} = 13.48$$

$$q_f = \frac{\sigma_{vf} - \sigma_{hf}}{2} = \frac{11.44 - 15.52}{2} = -2.04$$

Effective Stress Path (ESP)

$$p'_f = \frac{\sigma'_{vf} + \sigma'_{hf}}{2} = \frac{4.792 + 8.872}{2} = 6.83$$

$$q'_f = \frac{\sigma'_{vf} - \sigma'_{hf}}{2} = \frac{4.792 - 8.872}{2} = -2.04$$



q
CK₀UE (L)
3
2
1
0
-1
-2
q_f = -2.04
-3
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
p, p'
K_0-line
K_f-line
(6.12, 0.68)
(12.12, 0.68)
σ'_{hc}
σ'_{vc}
σ_{hc}
σ_{vc}
ESP
TSP-u
TSP
(6.89, -2.04)
(13.46, -2.04)
Δu(+)
u

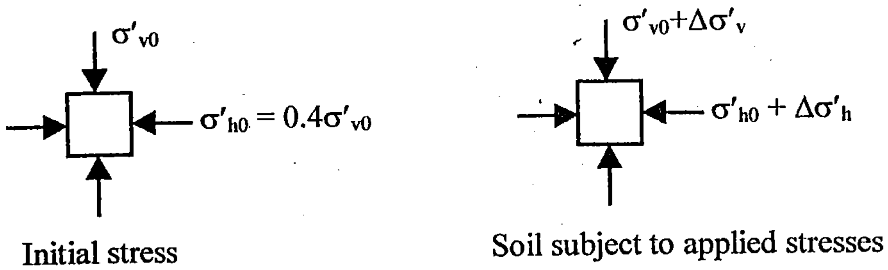
p-q Diagram

Question 1: (10 points)

A soil obeys the Mohr-Coulomb failure criterion, in which the effective stress parameters are: $a' = 0.7\ t/m^2$, $\alpha' = 28°$. The soil begins with an anisotropic state of stress as shown in the figure below. The increment effective stresses are applied such that: $\Delta\sigma'_h = -\Delta\sigma'_v/4$, where $\Delta\sigma'_v > 0$, until the soil fails.

1) Draw the stress path in p-q diagram and mark the point of failure on K_f line

2) Calculate the shear and normal stresses on the failure plane and the orientation of the failure plane.

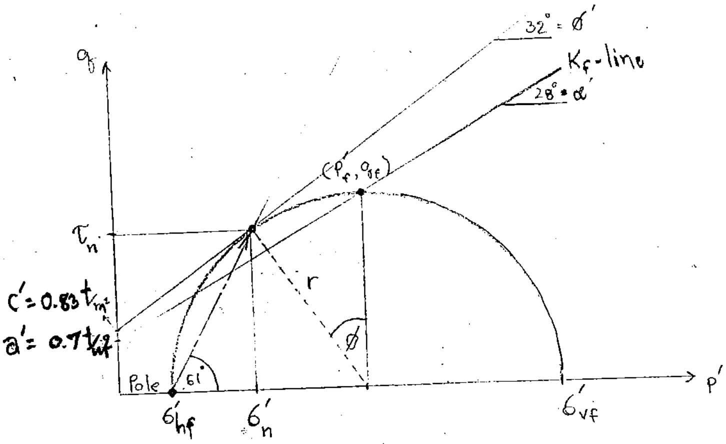


$$p'_o = \frac{\sigma'_{vo} + \sigma'_{ho}}{2} = \frac{\sigma'_{vo} + 0.4\sigma'_{vo}}{2} = 0.7\sigma'_{vo}$$

$$q_o = \frac{\sigma'_{vo} - \sigma'_{ho}}{2} = \frac{\sigma'_{vo} - 0.4\sigma'_{vo}}{2} = 0.3\sigma'_{vo}$$

$$\Delta p' = \frac{\Delta\sigma'_v + \Delta\sigma'_h}{2} = \frac{\Delta\sigma'_v + (-\frac{\Delta\sigma'_v}{4})}{2} = \frac{3\Delta\sigma'_v}{8}$$

$$\Delta q = \frac{\Delta\sigma'_v - \Delta\sigma'_h}{2} = \frac{\Delta\sigma'_v - (-\frac{\Delta\sigma'_v}{4})}{2} = \frac{5}{8}\Delta\sigma'_v$$



จุดบน Envelope ใดๆ จะมีความสัมพันธ์ คือ

$$a' + p'\tan\alpha' = q$$

$$0.7 + (p'_o + \Delta p')\tan 28° = q_o + \Delta q \quad \text{------ } (*)$$

แทน p'_o, q_o, $\Delta p'$, Δq ใน (*) จะได้ความสัมพันธ์

$$(0.7\tan 28° - 0.3)\sigma'_{vo} + (\frac{3\tan 28°}{8} - \frac{5}{8})\Delta\sigma'_v + 0.7 = 0$$

$$\therefore \Delta\sigma'_v = -\left[\frac{0.7 + (0.7\tan 28° - 0.3)\sigma'_{vo}}{(\frac{3\tan 28°}{8} - \frac{5}{8})}\right]$$

$$= -\left(\frac{0.7 + 0.072\sigma'_{vo}}{(-0.426)}\right) = 1.64 + 0.17\sigma'_{vo}$$

จาก $\Delta p' = \frac{3}{8}\Delta\sigma'_v = 0.615 + 0.064\sigma'_{vo}$

จะ: $\Delta q = \frac{5}{8}\Delta\sigma'_v = 1.025 + 0.106\sigma'_{vo}$

ที่ Failure $p'_f = p'_o + \Delta p' = 0.7\sigma'_{vo} + (0.615 + 0.064\sigma'_{vo}) = 0.615 + 0.764\sigma'_{vo}$

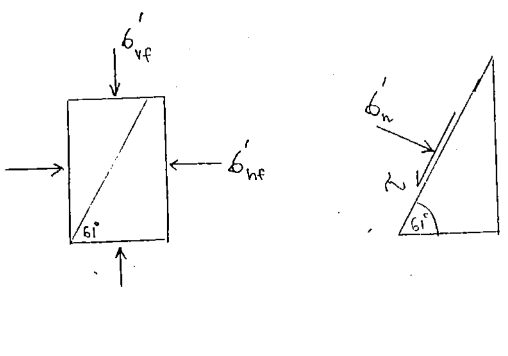
$q_f = q_o + \Delta q = 0.3\sigma'_{vo} + (1.025 + 0.106\sigma'_{vo}) = 1.025 + 0.406\sigma'_{vo}$

$$\phi' = \sin^{-1}(\tan\alpha') = \sin^{-1}(\tan 28°) = 32°$$

$$c' = \frac{a'}{\cos\phi'} = \frac{0.7}{\cos 32°} = 0.83\ t/m^2 \qquad r = q_f$$

$$\sigma'_n = p'_f - r\sin\phi' = 0.072 - 0.549\sigma'_{vo}$$

$$\tau = r\cos\phi' = 0.869 + 0.344\sigma'_{vo}$$

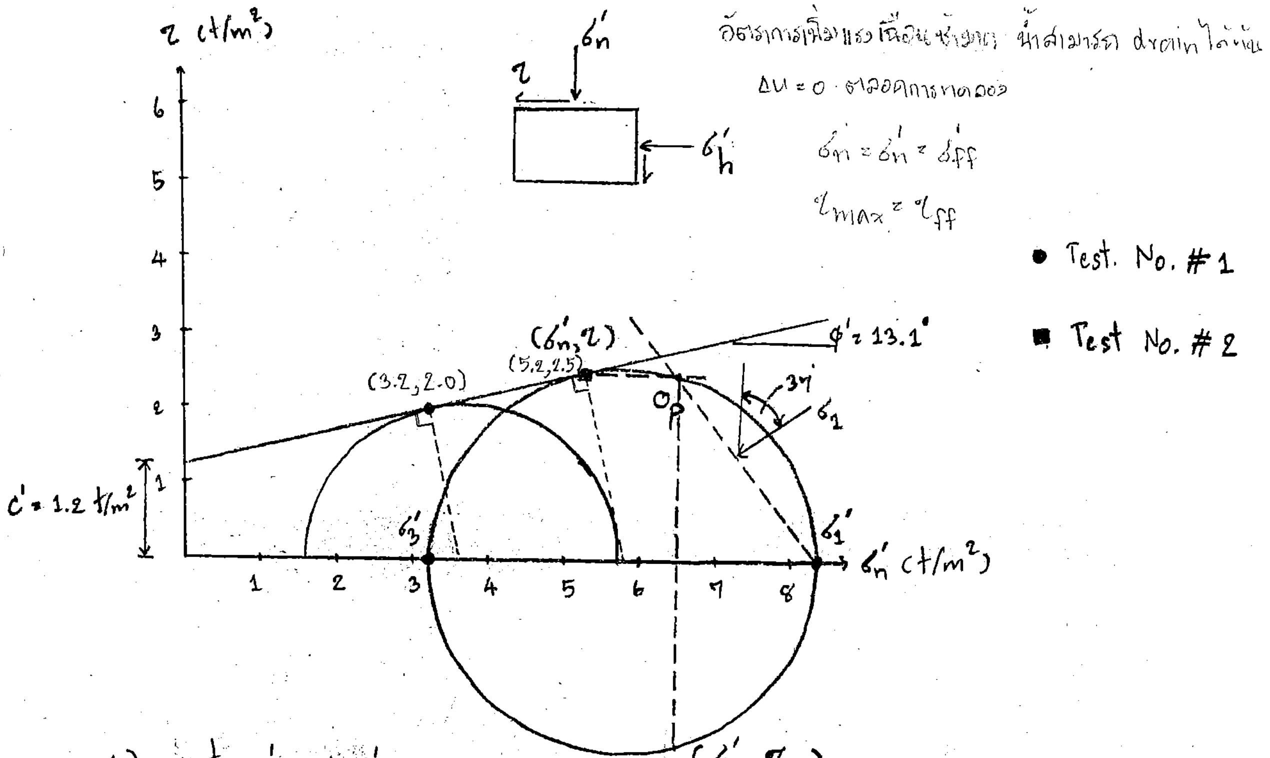


Question 2: (10 points)
The followings are the results at failure of the direct shear test on a dry sand:

Test No.	Normal stress t/m^2	Shear stress t/m^2
#1	3.2	2.0
#2	5.2	2.5

Assuming the soil obey Mohr-Coulomb failure criterion,

1) Calculate the effective strength parameter (c',ϕ') and (a',α')
2) For Test #2, calculate the magnitude of σ_1, and σ_3 ; and the direction of σ_1 to the vertical line.
3) For Test #2, calculate the magnitude of horizontal stress at failure.



1.) $\tan\alpha' = \sin\phi'$

$\longrightarrow \alpha' = \tan^{-1}(\sin\phi') = \tan^{-1}(\sin 13.1°) = 12.8°$

$\longrightarrow a' = c' \cdot \cos\phi' = 1.2 \cos 13.1° = 1.2$ t/m²

$c' = 1.2$ t/m²

$\phi' = 13.1°$

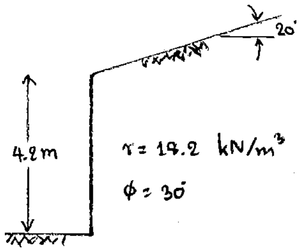
2.) จากรูป $\sigma_1' = 8.3$ t/m² , $\sigma_3' = 3.3$ t/m² for Test #2

ลากเส้นแนวระนาบ หา pole, O_p จะได้ plane of σ_1'

จะได้ direction of σ_1' to the vertical line = 37°

3.) ลากเส้นดิ่ง จากจุด pole ลงมาตัดกับ mohr circle ตาม direction of horizontal plane

จากรูป จะได้ $\sigma_h' = 6.5$ t/m² for Test #2



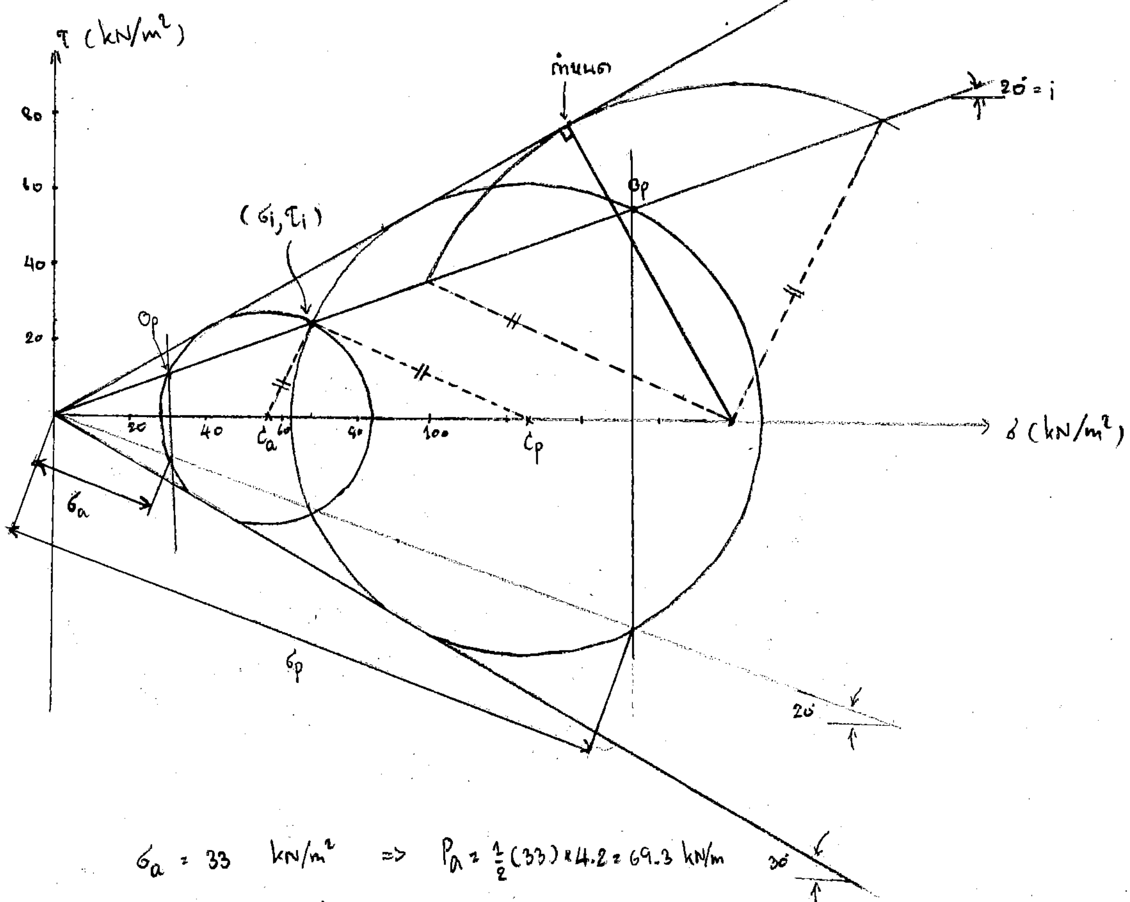
$\gamma = 18.2\ kN/m^3$

$\phi = 30°$

$\sigma_i = \gamma \cdot H\cos i \cdot \cos i = 18.2 \times 4.2 \cos^2(20°) = 67.50$

$\tau_i = \gamma \cdot H\cos i \cdot \sin i = 18.2 \times 4.2 \cos(20°) \cdot \sin(20°) = 24.60$

①



$\sigma_a = 33\ kN/m^2 \Rightarrow P_a = \frac{1}{2}(33) \times 4.2 = 69.3\ kN/m$

$\sigma_p = 164\ kN/m^2 \Rightarrow P_p = \frac{1}{2}(164) \times 4.2 = 344.4\ kN/m$

②

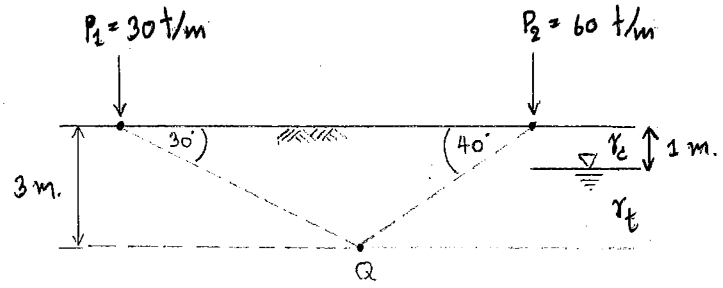
$$K_a = \cos\beta \frac{\cos\beta - \sqrt{\cos^2\beta - \cos^2\phi}}{\cos\beta + \sqrt{\cos^2\beta - \cos^2\phi}} = \cos 20° \frac{\cos 20° - \sqrt{\cos^2 20° - \cos^2 30°}}{\cos 20° + \sqrt{\cos^2 20° - \cos^2 30°}} = 0.94 \times \frac{0.575}{1.305} = 0.414$$

$$\Longrightarrow P_a = \frac{1}{2} \times K_a \gamma H^2 = \frac{1}{2} \times 0.414 \times 18.2 \times 4.2^2 = 66.4\ kN/m$$

$$K_p = \cos\beta \frac{\cos\beta + \sqrt{\cos^2\beta - \cos^2\phi}}{\cos\beta - \sqrt{\cos^2\beta - \cos^2\phi}} = \cos 20° \frac{\cos 20° + \sqrt{\cos^2 20° - \cos^2 30°}}{\cos 20° - \sqrt{\cos^2 20° - \cos^2 30°}} = 0.94 \times \frac{1.305}{0.575} = 2.133$$

$$\Longrightarrow P_p = \frac{1}{2} K_p \gamma H^2 = \frac{1}{2} \times 2.133 \times 18.2 \times 4.2^2 = 342.4\ kN/m$$

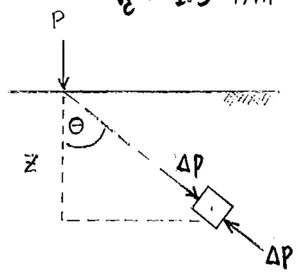
Quiz 1



Given $K_o = 2$; อัตราการเพิ่ม load ช้ามาก

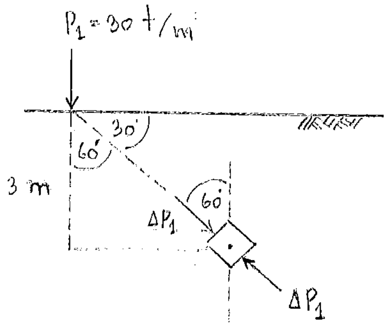
$\gamma_t = 1.7\ t/m^3$

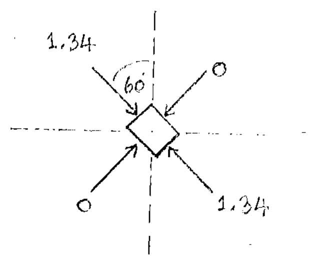
$\gamma_c = 1.5\ t/m^3$



$$\Delta P = P(1-\sin\theta)\cdot\frac{1}{z}$$

Soln 1.) พิจารณา $P_1 = 30\ t/m$





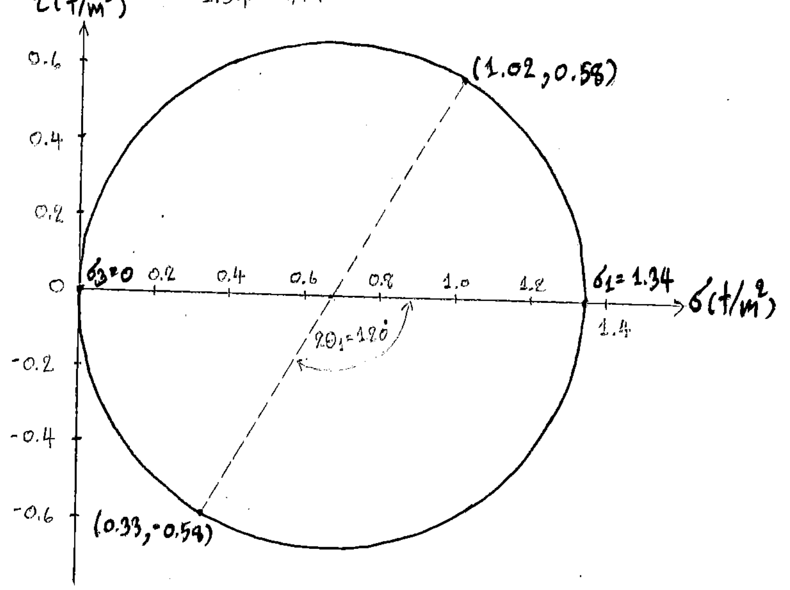
$$\Delta P_1 = P_1(1-\sin\theta_1)\times\frac{1}{z} \quad ; \ \theta_1 = 60°$$

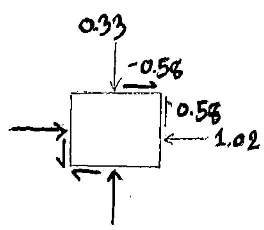
$$= 30\times(1-\sin 60°)\times\frac{1}{3.}$$

$$= 1.34\ t/m^2$$

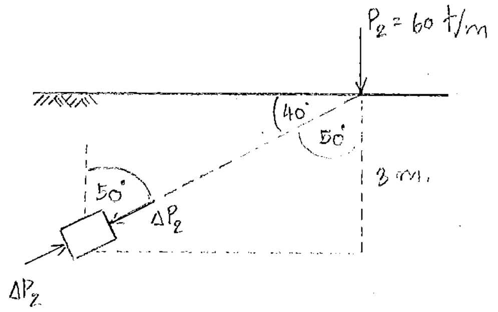
$\sigma_1 = \Delta P_1 = 1.34\ t/m^2$

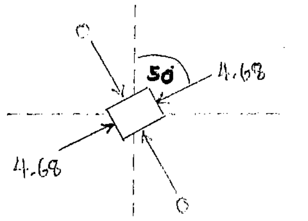
$\sigma_3 = 0$





2.) พิจารณา $P_2 = 60$ t/m





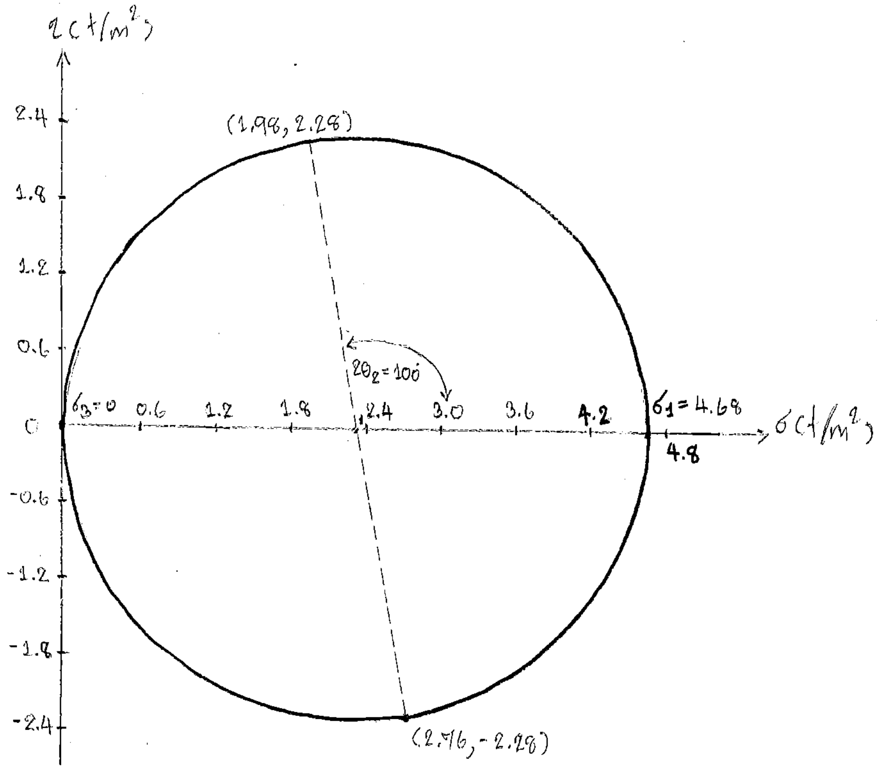
$$\Delta P_2 = P_2(1-\sin\theta_2)\times\frac{1}{z} \quad ; \quad \theta_2 = 50^\circ$$

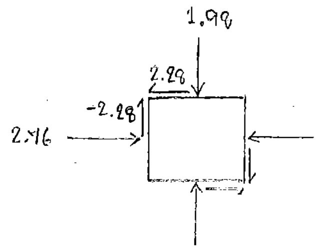
$$= 60\times(1-\sin 50^\circ)\times\frac{1}{3}$$

$$= 4.68 \ t/m^2$$

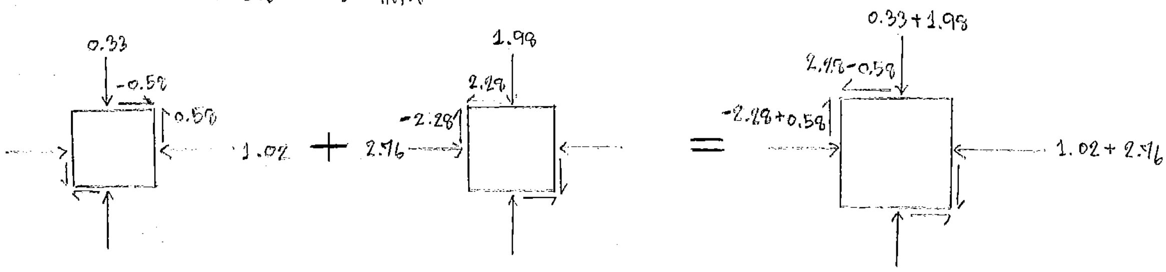
$$\sigma_1 = \Delta P_2 = 4.68 \ t/m^2$$

$$\sigma_3 = 0$$

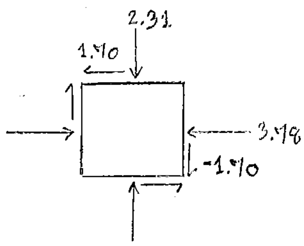




รวม stress ที่เกิดขึ้นในแต่ละแกน



→ Incremental stress



3.) พิจารณา initial state of stress ที่จุด Q

assume pore pressure เป็น hydrostatic

$u_o = \gamma_w z = 1.0 \times 2 = 2.0\ t/m^2$

$\sigma_{vo} = (1.5\times 1)+(1.7\times 2) = 4.9\ t/m^2$

$\sigma'_{vo} = \sigma_{vo} - u_o = 4.9 - 2.0 = 2.9\ t/m^2$

$\sigma'_{ho} = K_o \sigma'_{vo} = 2\times 2.9 = 5.8\ t/m^2$

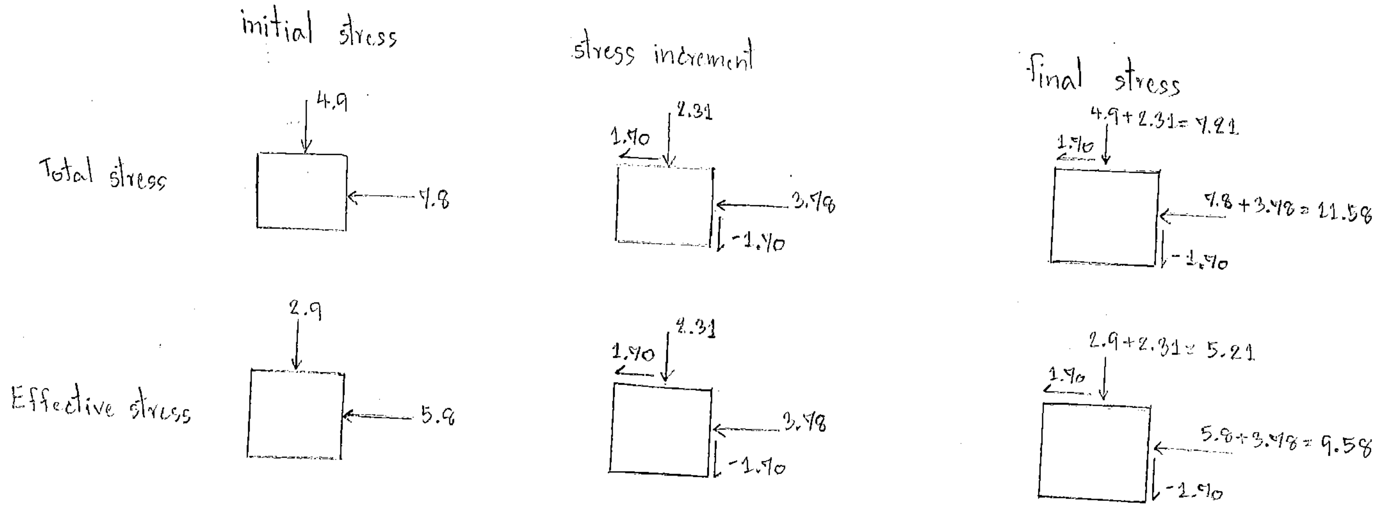
$\sigma_{ho} = \sigma'_{ho} + u_o = 5.8 + 2.0 = 7.8\ t/m^2$

$p = \dfrac{\sigma_{vo}+\sigma_{ho}}{2} = \dfrac{4.9+7.8}{2} = 6.35$

$q = \dfrac{\sigma_{vo}-\sigma_{ho}}{2} = \dfrac{4.9-7.8}{2} = -1.45$

$p' = \dfrac{\sigma'_{vo}+\sigma'_{ho}}{2} = \dfrac{2.9+5.8}{2} = 4.35$

$q' = q = \dfrac{\sigma'_{vo}-\sigma'_{ho}}{2} = \dfrac{2.9-5.8}{2} = -1.45$



▸ ข้อสมมติเพิ่ม load ช้ามาก ทำให้ $\Delta u = 0$

$\Delta\sigma_v = 2.31 \longrightarrow \Delta\sigma'_v = \Delta\sigma_v + \cancel{\Delta u}^{0} = 2.31$

$\Delta\sigma_h = 3.78 \longrightarrow \Delta\sigma'_h = \Delta\sigma_h + \cancel{\Delta u}^{0} = 3.78$

$\Delta\tau = 1.70 \longrightarrow \Delta\tau' = \Delta\tau + \cancel{\Delta u}^{0} = 1.70$

▸ final stress

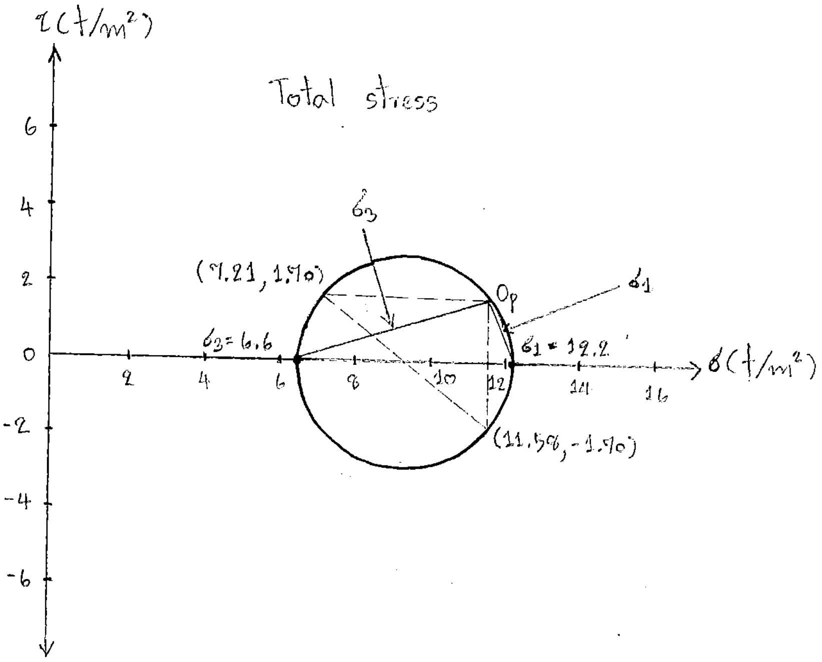
$\sigma_{vf} = \sigma_{vo} + \Delta\sigma_v = 4.9 + 2.31 = \mathbf{7.21\ t/m^2}$

$\sigma_{hf} = \sigma_{ho} + \Delta\sigma_h = 7.8 + 3.78 = \mathbf{11.58\ t/m^2}$

$\sigma'_{vf} = \sigma'_{vo} + \Delta\sigma'_v = 2.9 + 2.31 = \mathbf{5.21\ t/m^2}$

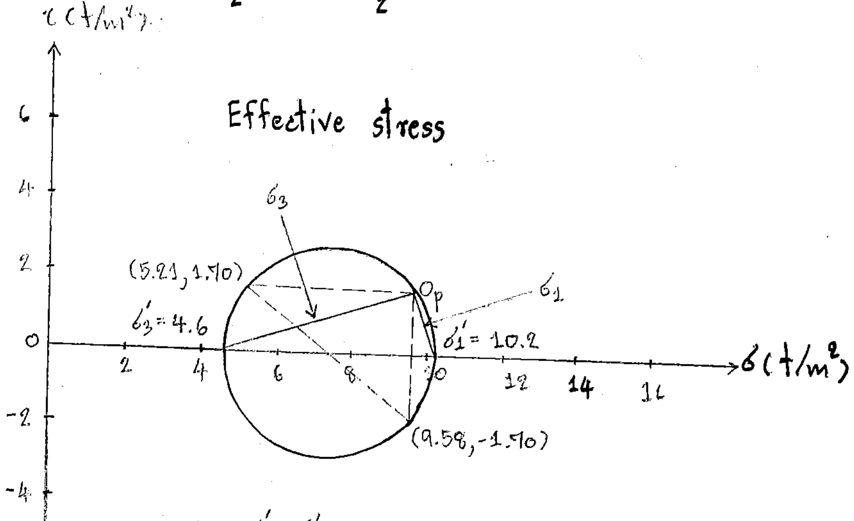
$\sigma'_{hf} = \sigma'_{ho} + \Delta\sigma'_h = 5.8 + 3.78 = \mathbf{9.58\ t/m^2}$

$\tau_f = \Delta\tau = \mathbf{1.70\ t/m^2}$



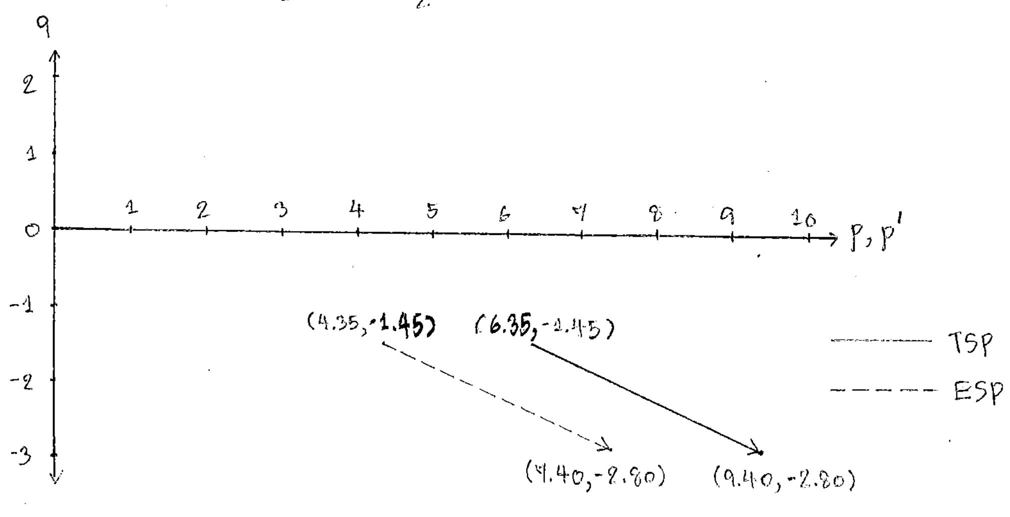
$$p_f = \frac{\sigma_1+\sigma_3}{2} = \frac{12.2+6.6}{2} = 9.40$$

$$q_f = -\frac{\sigma_1-\sigma_3}{2} = -\frac{12.2-6.6}{2} = -2.80$$



$$p_f' = \frac{\sigma_1'+\sigma_3'}{2} = \frac{10.2+4.6}{2} = 7.40$$

$$q_f' = -\frac{\sigma_1'-\sigma_3'}{2} = -\frac{10.2-4.6}{2} = -2.80$$



Quiz 2

The anisotropically consolidated triaxial extension test on normally consolidated clay yields the value of $\dfrac{c_u}{\sigma'_{vc}} = 0.22$ and $A_f = 0.9$. The value of $\sigma_c = 30\ t/m^2$.

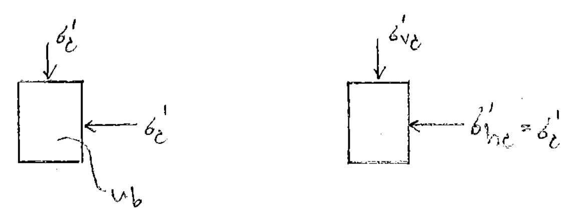
During consolidation the value of $K = 0.5$. Estimated the followings:

(a) The excess pore pressure at failure when the total stress path during shear is unloading extension. The back pressure is $20\ t/m^2$

(b) The value of ϕ' for normally consolidated clay

(c) The ratio of $\left(\dfrac{\sigma'_1}{\sigma'_3}\right)$ at q_f condition

Sol^{n} 1.) At the end of consolidation : before shearing



$\sigma'_c = \sigma_c - u_b = 30 - 20 = 10\ t/m^2$; $\sigma'_{hc} = \sigma'_c = \underline{10}\ t/m^2$

$K_o = \dfrac{\sigma'_{hc}}{\sigma'_{vc}} \Longrightarrow \sigma'_{vc} = \dfrac{\sigma'_{hc}}{K_o} = \dfrac{10}{0.5} = \underline{20}\ t/m^2$

$\sigma_{hc} = \sigma'_{hc} + u = \sigma'_{hc} + (u_b + \Delta u) = 10 + (20 + 0) = \underline{30}\ t/m^2$

$\Delta u = 0$ เนื่องจาก end of consolidation before shearing

$\sigma_{vc} = \sigma'_{vc} + u = \sigma'_{vc} + (u_b + \Delta u) = 20 + (20 + 0) = \underline{40}\ t/m^2$

- initial shear stress, q

$p = \dfrac{\sigma_{vc} + \sigma_{hc}}{2} = \dfrac{40 + 30}{2} = 35$ | $p' = \dfrac{\sigma'_{vc} + \sigma'_{hc}}{2} = \dfrac{20 + 10}{2} = 15$

$q = \dfrac{\sigma_{vc} - \sigma_{hc}}{2} = \dfrac{40 - 30}{2} = 5$ | $q' = q = \dfrac{\sigma'_{vc} - \sigma'_{hc}}{2} = \dfrac{20 - 10}{2} = 5$

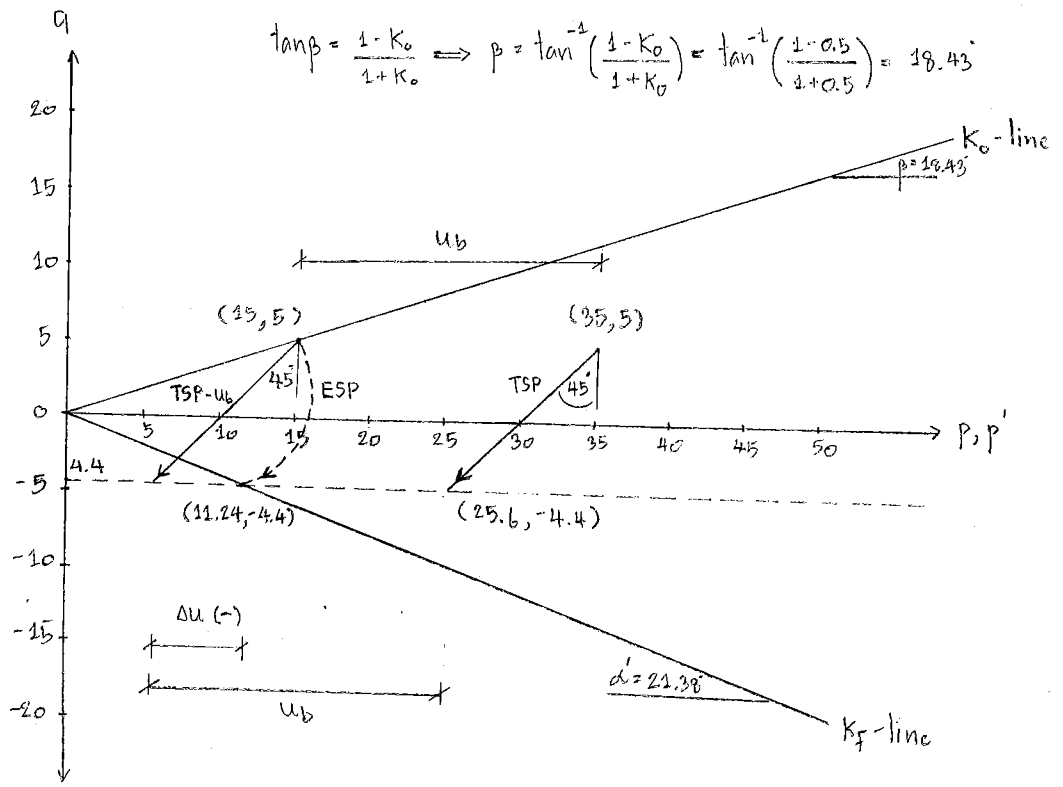
2.) ทำการ shearing จนถึง failure โดยทำ triaxial extension unloading test

$\dfrac{c_u}{\sigma'_{vc}} = 0.22 \Longrightarrow c_u = 0.22 \times \sigma'_{vc} = 0.22 \times 20 = 4.4\ t/m^2$

ที่ failure $\quad q_f = c_u = 4.4\ t/m^2$

เขียน p-q diagram

$\tan\beta = \frac{1-K_o}{1+K_o} \Rightarrow \beta = \tan^{-1}\left(\frac{1-K_o}{1+K_o}\right) = \tan^{-1}\left(\frac{1-0.5}{1+0.5}\right) = 18.43^\circ$



TSP จุด $(p_f, q_f) = (25.6, -4.4)$

- since triaxial extension unloading test

$\Delta\sigma_h = \Delta\sigma_1 = 0 \quad , \quad \Delta\sigma_v = \Delta\sigma_3 < 0$

$\Delta u = B[\Delta\sigma_3 + A(\Delta\sigma_1 - \Delta\sigma_3)]$; B = 1 for saturated clay in triaxial test

ที่ failure $\Delta u = \Delta\sigma_3 + A_f(-\Delta\sigma_3)$; $\Delta\sigma_3 = \sigma_{vf} - \sigma_{vc}$, $\Delta\sigma_1 = \sigma_{hf} - \sigma_{hc} = 0 \Rightarrow \sigma_{hf} = \sigma_{hc} = 30\ t/m^2$

$\Delta u = -18.9 + 0.7\times(18.8)$
$= -5.64\ t/m^2$

$p_f = \frac{\sigma_{vf} + \sigma_{hf}}{2} = 25.6 \Rightarrow \frac{\sigma_{vf} + \sigma_{hc}}{2} = 25.6$

$\frac{\sigma_{vf} + 30}{2} = 25.6 \Rightarrow \sigma_{vf} = 21.2\ t/m^2$

$\Delta\sigma_3 = 21.2 - 40 = -18.8\ t/m^2$

ESP จุด $(p'_f, q'_f) = (p_f - u_b - \Delta u, -4.4) = (25.6 - 20 - (-5.64), -4.4) = (11.24, -4.4)$

- เขียน K_f-line ผ่านจุด ESP จุด (p'_f, q'_f) จะได้

$\alpha' = \tan^{-1}\left(\frac{q'_f}{p'_f}\right) = \tan^{-1}\left(\frac{4.4}{11.24}\right) = \mathbf{21.38^\circ}$

$\sin\phi' = \tan\alpha' \Rightarrow \phi' = \sin^{-1}(\tan\alpha') = \sin^{-1}(\tan 21.38) = 23.05^\circ$

- $p'_f = \frac{\sigma'_{1f} + \sigma'_{3f}}{2} = 11.24$ ——— (1)

$q'_f = \frac{\sigma'_{1f} - \sigma'_{3f}}{2} = 4.4$ ——— (2)

(1) + (2) $\Rightarrow \sigma'_{1f} = 11.24 + 4.4 = 15.64\ t/m^2$

(1) − (2) $\Rightarrow \sigma'_{3f} = 11.24 - 4.4 = 6.84\ t/m^2$

$\left(\frac{\sigma'_{1f}}{\sigma'_{3f}}\right) = \frac{15.64}{6.84} = 2.29$

$\mathbf{\Delta u = \sigma_{3f} - \sigma'_{3f} - u_b = \sigma_{vf} - \sigma'_{vf} - u_b = 21.2 - 6.84 - 20 = -5.64\ t/m^2}$ ——— **OK**

Quiz 3 In the K_o consolidated undrained triaxial extension test (loading), using effective consolidation stress before shearing $\sigma_c = 30\ t/m^2$ and the back pressure of 20 t/m^2 yield the results as follows :

(i) $\dfrac{c_u}{\sigma'_{vc}} = 0.8$, $K_o = 0.6$

(ii) $A_f = 0.7$

(iii) $\phi' = 28^\circ$, $c' = 0$

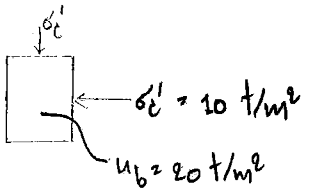
Find the values of

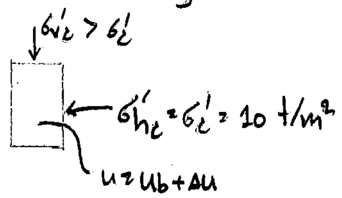
(a) initial shear stress

(b) the value of pore pressure at failure

(c) the ratio of $\dfrac{\sigma'_{1f}}{\sigma'_{3f}}$

Sol^n 1.) At the end of consolidation ; before shearing





$\sigma_c = \sigma'_c + u_b \Longrightarrow \sigma'_c = \sigma_c - u_b = 30 - 20 = 10\ t/m^2$, $\sigma'_{hc} = \sigma'_c = \underline{10}\ t/m^2$

$K_o = \dfrac{\sigma'_{hc}}{\sigma'_{vc}} \Longrightarrow \sigma'_{vc} = \dfrac{\sigma'_{hc}}{K_o} = \dfrac{10}{0.6} = \underline{16.67}\ t/m^2$

$\sigma_{hc} = \sigma'_{hc} + u = \sigma'_{hc} + (u_b + \Delta u) = 10 + (20+0) = \underline{30}\ t/m^2$

$\Delta u = 0$ เนื่องจาก end of consolidation before shearing

$\sigma_{vc} = \sigma'_{vc} + u = \sigma'_{vc} + (u_b + \Delta u) = 16.67 + (20+0) = \underline{36.67}\ t/m^2$

▸ initial shear stress, q

$p = \dfrac{\sigma_{vc} + \sigma_{hc}}{2} = \dfrac{36.67 + 30}{2} = 33.34$	$p' = \dfrac{\sigma'_{vc} + \sigma'_{hc}}{2} = \dfrac{16.67 + 10}{2} = 13.34$
$q = \dfrac{\sigma_{vc} - \sigma_{hc}}{2} = \dfrac{36.67 - 30}{2} = 3.34$	$q' = q = \dfrac{\sigma'_{vc} - \sigma'_{hc}}{2} = \dfrac{16.67 - 10}{2} = 3.34$

2.) ทำการ shearing จนถึง failure โดยทำ triaxial extension loading test

$\dfrac{c_u}{\sigma'_{vc}} = 0.8 \Longrightarrow c_u = 0.8 \times \sigma'_{vc} = 0.8 \times 16.67 = 13.34\ t/m^2$

ที่ failure $q_f = c_u = \underline{13.34}\ t/m^2$

$\tan\alpha' = \sin\phi' \Longrightarrow \alpha' = \tan^{-1}(\sin\phi') = \tan^{-1}(\sin 28^\circ) = 25.15^\circ$

$\tan\alpha' = \tan 25.15^\circ = 0.47$

$\dfrac{q_f}{p'_f} = \tan\alpha' \Longrightarrow p'_f = \dfrac{q_f}{\tan\alpha'} = \dfrac{13.34}{0.47} = \underline{28.38}\ t/m^2$

$$p'_f = \frac{\sigma'_{1f} + \sigma'_{3f}}{2} = 28.38 \quad \text{——— (1)}$$

$$q_f = \frac{\sigma'_{1f} - \sigma'_{3f}}{2} = 13.34 \quad \text{——— (2)}$$

$(1)+(2) \Longrightarrow \quad \sigma'_{1f} = 28.38 + 13.34 = 41.72 \ t/m^2$

$(1)-(2) \Longrightarrow \quad \sigma'_{3f} = 28.38 - 13.34 = 15.04 \ t/m^2$

$\dfrac{\sigma'_{1f}}{\sigma'_{3f}} = \dfrac{41.72}{15.04} = 2.77$

▶ since triaxial extension (loading) test

$\sigma'_{1f} = \sigma'_{hf} = 41.72 \ t/m^2$ | $p'_f = 28.38$

$\sigma'_{3f} = \sigma'_{vf} = 15.04 \ t/m^2$ | $q_f = -13.34$

▶ at failure , $\Delta u = B[\Delta\sigma_3 + A(\Delta\sigma_1 - \sigma_3)]$

$\Delta\sigma_3 = \sigma_{vf} - \sigma_{vc} \Longrightarrow \sigma_{vf} = \sigma_{vc} = 36.67 \ t/m^2$

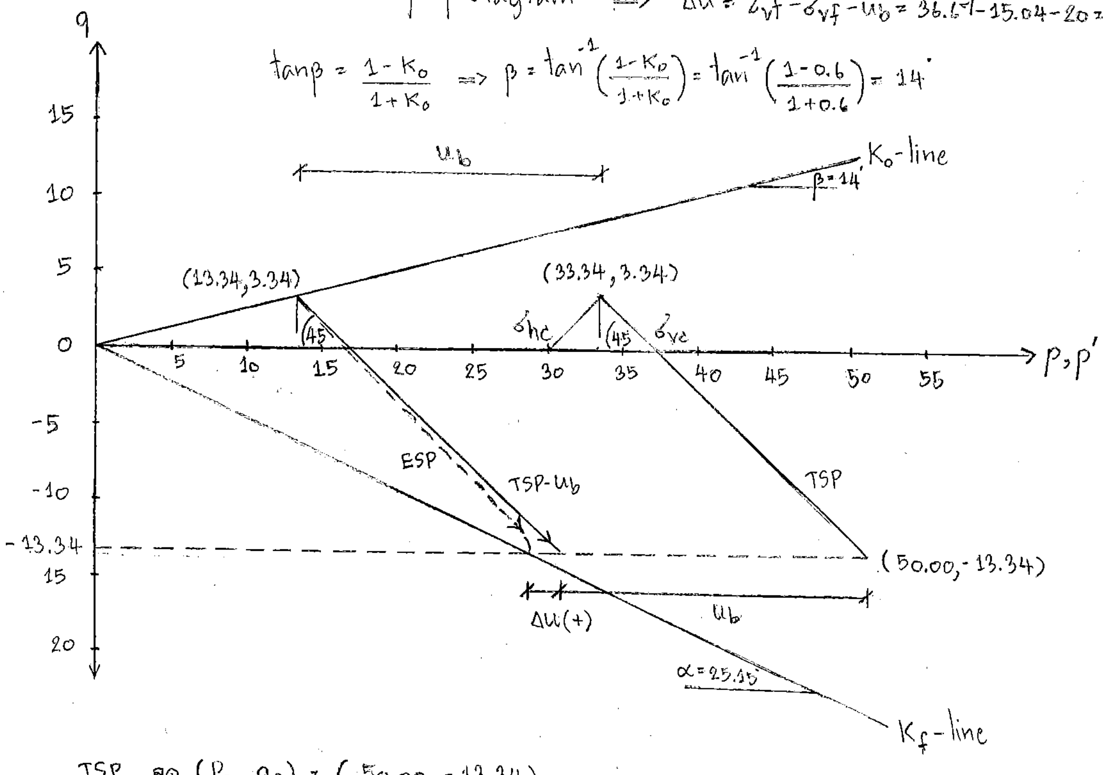
$\Delta\sigma_1 = \sigma_{hf} - \sigma_{hc} = 63.33 - 30 = 33.33 \ t/m^2$ | $p_f = \dfrac{\sigma_{vf} + \sigma_{hf}}{2} = 50.00$, $\sigma_{vf} = 36.67 \ t/m^2$, $\sigma_{hf} = 63.33 \ t/m^2$

triaxial **extension loading** $\Delta\sigma_v = \Delta\sigma_3 = 0$, $\Delta\sigma_h = \Delta\sigma_1 > 0$

$\Delta u = A_f \times \Delta\sigma_1 = 0.7 \times 33.33 = 23.33 \ t/m^2$

พิจารณาหา Δu จาก p-q diagram $\Longrightarrow \Delta u = \sigma_{vf} - \sigma'_{vf} - u_b = 36.67 - 15.04 - 20 = 1.63 \ t/m^2$

$\tan\beta = \dfrac{1-K_o}{1+K_o} \Longrightarrow \beta = \tan^{-1}\left(\dfrac{1-K_o}{1+K_o}\right) = \tan^{-1}\left(\dfrac{1-0.6}{1+0.6}\right) = 14^\circ$



TSP จุด $(p_f, q_f) = (50.00, -13.34)$

u ที่ failure $= u_b + \Delta u = 20 + 1.63 = 21.63 \ t/m^2$

Exam 1 Consolidation test on normally consolidated clay ($\sigma_s' = 0.3\ t/m^2$, $\sigma_v = 0.5\ t/m^2$, $K_o = 1.5$ for initial condition) until $\sigma_{vf} = 5\ t/m^2$, $K_{o\,NC} = 0.6$ for final condition

Solⁿ

1.) Initial condition before consolidated

$$\sigma_s = \sigma_s' + u_s = 0$$

$$u_s = -\sigma_s' = -0.3\ t/m^2$$

$$\sigma_{vo} = 0.5\ t/m^2$$

$$\sigma_{vo}' = \sigma_{vo} - u_s = 0.5-(-0.3) = 0.8\ t/m^2$$

$$K_o = \frac{\sigma_{ho}'}{\sigma_{vo}'}$$

$$\sigma_{ho}' = K_o \cdot \sigma_{vo}' = 1.5 \times 0.8 = 1.2\ t/m^2$$

$$\sigma_{ho} = \sigma_{ho}' + u_s = 1.2+(-0.3) = 0.9\ t/m^2$$

$$p = \frac{\sigma_{vo}+\sigma_{ho}}{2} = \frac{0.5+0.9}{2} = 0.7$$

$$q = \frac{\sigma_{vo}-\sigma_{ho}}{2} = \frac{0.5-0.9}{2} = -0.2$$

$$p' = \frac{\sigma_{vo}'+\sigma_{ho}'}{2} = \frac{0.8+1.2}{2} = 1.0$$

$$q' = q = \frac{\sigma_{vo}'-\sigma_{ho}'}{2} = \frac{0.8-1.2}{2} = -0.2$$

ตัวอย่างดินจะมีการดูดน้ำ ด้วย $-u_s$ จึงต้องเพิ่ม load ด้วย $\frac{\Delta p}{p} = 1.0$ ก่อนจะ consolidated ไปที่ $K_{o\,NC}$

$$\frac{\Delta p}{p} = 1.0 \implies \Delta p = \sigma_{v1} = 1.0 \times p$$

$$\sigma_{v1} = 1.0 \times \sigma_{vo} = 1.0 \times 0.5 = \mathbf{0.5\ t/m^2}$$

▶ ตัวอย่างดินมี σ_s' ควรที่ **เพิ่ม load เพื่อให้ตัวอย่าง saturated และ pore pressure เกิดขึ้นเล็กน้อย** ($\Delta u \approx 0$)

ดังนั้น ก่อนเริ่มทำ consolidated จึงกำหนดให้ initail total stress และ effective stress มีค่าเท่ากันได้

$$\sigma_{v1} = \sigma_{v1}' = \mathbf{0.5}\ t/m^2$$

$$\sigma_{h1} = \sigma_{h1}' = K_o \cdot \sigma_{v1} = 1.5 \times 0.5 = 0.75\ t/m^2$$

$$p = \frac{\sigma_{v1}+\sigma_{h1}}{2} = \frac{0.5+0.75}{2} = 0.625$$

$$q = \frac{\sigma_{v1}-\sigma_{h1}}{2} = \frac{0.5-0.75}{2} = -0.125$$

$$p' = \frac{\sigma_{v1}'+\sigma_{h1}'}{2} = \frac{0.5+0.75}{2} = 0.625$$

$$q' = \frac{\sigma_{v1}'-\sigma_{h1}'}{2} = \frac{0.5-0.75}{2} = -0.125$$

▶ เพิ่ม load ด้วย $\Delta\sigma_v$ ทันที

load ที่เพิ่มขึ้น $\Delta\sigma_v = \sigma_{vf} - \sigma_{v1} = 5 - 0.5 = 4.5\ t/m^2$

การเคลื่อนตัวเกิดเฉพาะแนวดิ่ง (เป็น 1-D) $\Delta u = \Delta\sigma_v = 4.5\ t/m^2$

$$\sigma_{v2} = \sigma_{v1} + \Delta\sigma_v = 0.5+4.5 = 5.00\ t/m^2$$

$$\sigma_{h2} = \sigma_{h1} + \Delta\sigma_v = 0.75+4.5 = 5.25\ t/m^2$$

$$p = \frac{\sigma_{v2}+\sigma_{h2}}{2} = \frac{5.00+5.25}{2} = 5.125$$

$$q = \frac{\sigma_{v2}-\sigma_{h2}}{2} = \frac{5.00-5.25}{2} = -0.125$$

▶ ที่ final consolidation Δu ลดลงจาก $4.5\ t/m^2 \rightarrow 0$

ลาก TSP ไปตัดที่เส้น $K_o = 1.5$

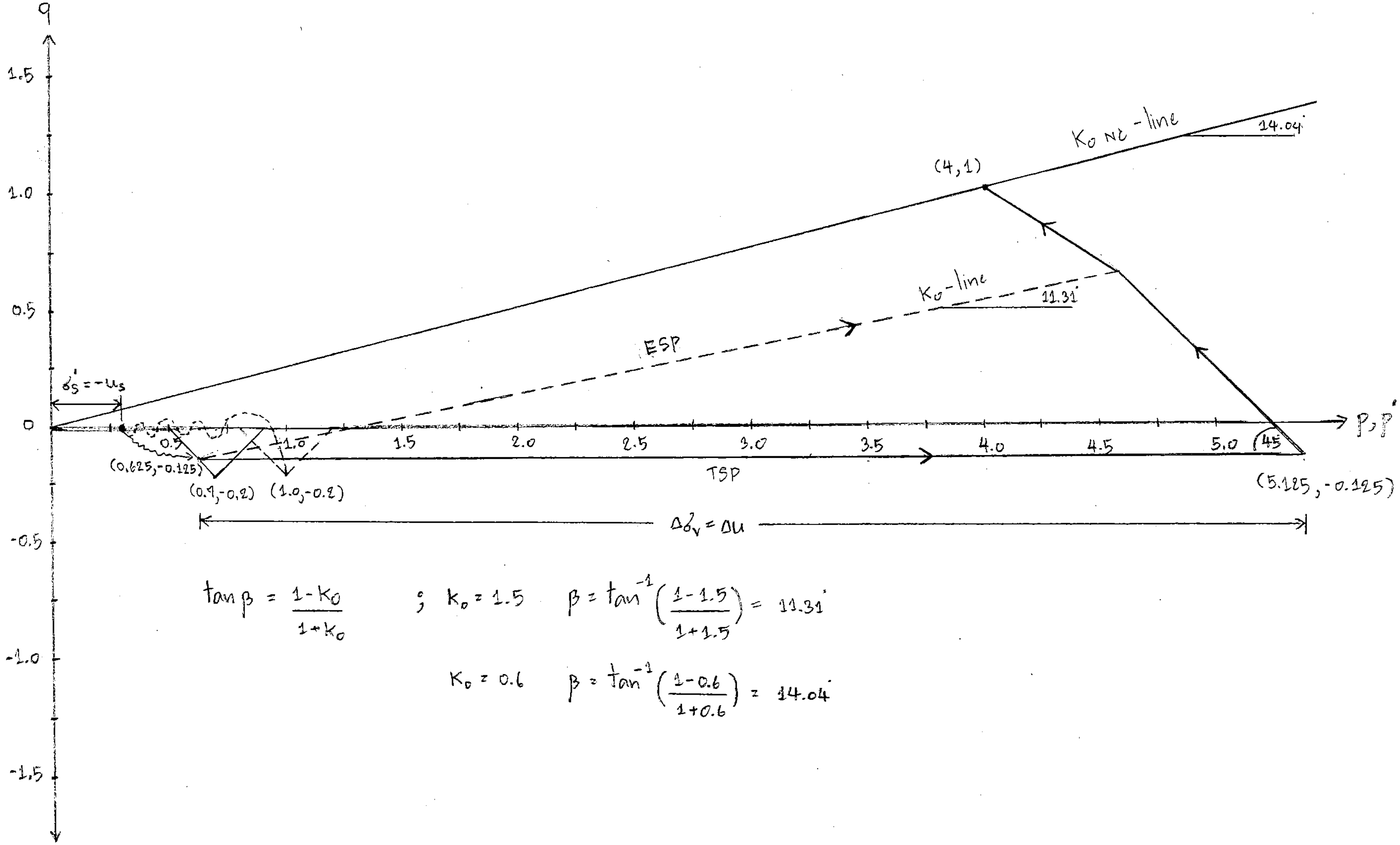
▶ ที่ failure TSP และ ESP เป็นเส้นเดียวกัน หลังจากสิ้นสุด consolidation

$$\sigma_{vf} = \sigma_{vf}' = 5\ t/m^2$$

$$\sigma_{hf}' = K_o \cdot \sigma_{vf}' = 0.6 \times 5 = 3\ t/m^2 = \sigma_{hf}$$

$$p = p' = \frac{\sigma_{vf}+\sigma_{hf}}{2} = \frac{\sigma_{vf}'+\sigma_{hf}'}{2} = \frac{5+3}{2} = 4$$

$$q = q' = \frac{\sigma_{vf}-\sigma_{hf}}{2} = \frac{\sigma_{vf}'-\sigma_{hf}'}{2} = \frac{5-3}{2} = 1$$



$\tan\beta = \dfrac{1-K_0}{1+K_0}$; $K_0 = 1.5$ $\quad \beta = \tan^{-1}\left(\dfrac{1-1.5}{1+1.5}\right) = 11.31°$

$K_0 = 0.6$ $\quad \beta = \tan^{-1}\left(\dfrac{1-0.6}{1+0.6}\right) = 14.04°$

Exam 2 K_o consolidated triaxial extension (unloading) test.

Given $\sigma'_c = 3\ t/m^2$, $K_o = 0.6$, $u_b = 0\ t/m^2$ for initial condition

$\phi' = 28^\circ$, $c' = 0$, $q_f = 1.35\ t/m^2$ for failure condition

Sol^n 1.) $\sigma'_{hc} = \sigma'_c = 3\ t/m^2$

$$\sigma_{hc} = \sigma'_{hc} + u_b = 3 + 0 = 3\ t/m^2$$

$$K_o = \frac{\sigma'_{hc}}{\sigma'_{vc}}$$

$$\sigma'_{vc} = \frac{\sigma'_{hc}}{K_o} = \frac{3}{0.6} = 5\ t/m^2$$

$$\sigma_{vc} = \sigma'_{vc} + u_b = 5 + 0 = 5\ t/m^2$$

$$p = \frac{\sigma_{vc} + \sigma_{hc}}{2} = \frac{5+3}{2} = 4$$

$$q = \frac{\sigma_{vc} - \sigma_{hc}}{2} = \frac{5-3}{2} = 1$$

$$p' = \frac{\sigma'_{vc} + \sigma'_{hc}}{2} = \frac{5+3}{2} = 4$$

$$q' = \frac{\sigma'_{vc} - \sigma'_{hc}}{2} = \frac{5-3}{2} = 1$$

2.) ที่ failure condition

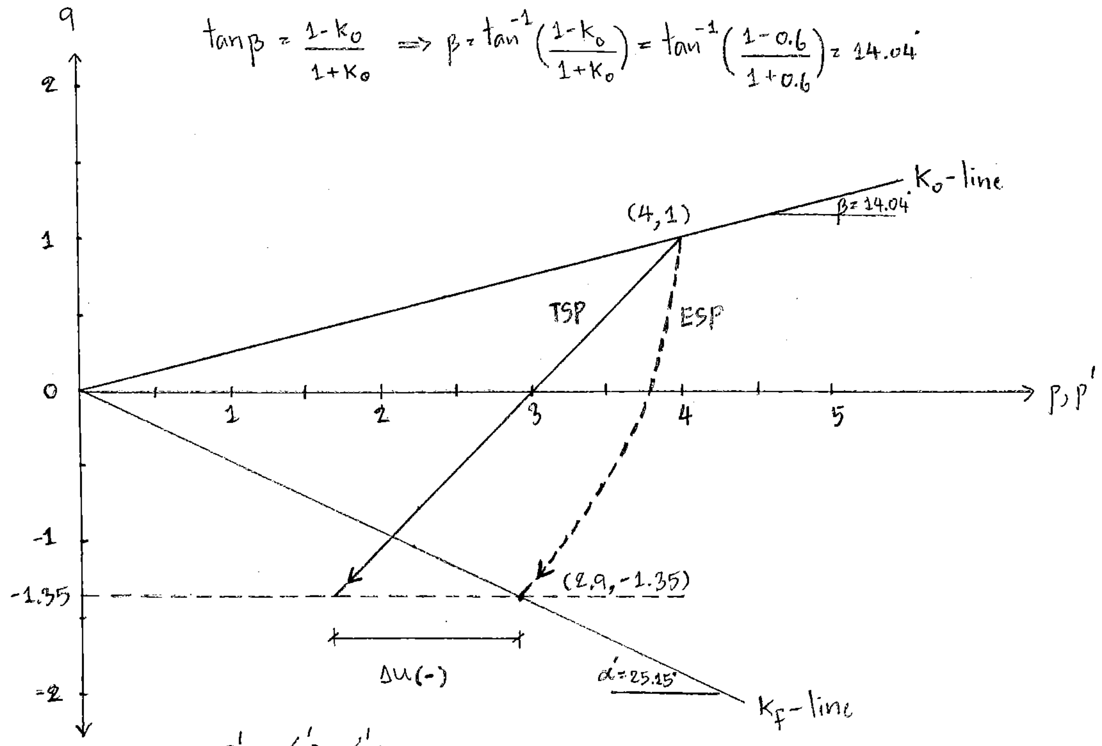
$$\tan\alpha' = \sin\phi' = \sin 28^\circ = 0.469$$

$$\alpha' = \tan^{-1}(\sin 28^\circ) = 25.15^\circ$$

$$a' = c' \cos\phi' = 0 \times \cos 28^\circ = 0$$

$$q_f = S_u = 1.35\ t/m^2$$

$$\tan\beta = \frac{1-K_o}{1+K_o} \Rightarrow \beta = \tan^{-1}\left(\frac{1-K_o}{1+K_o}\right) = \tan^{-1}\left(\frac{1-0.6}{1+0.6}\right) = 14.04^\circ$$



$$p'_f = \frac{\sigma'_{vf} + \sigma'_{hf}}{2} = 2.9$$

$$q'_f = \frac{\sigma'_{vf} - \sigma'_{hf}}{2} = -1.35$$

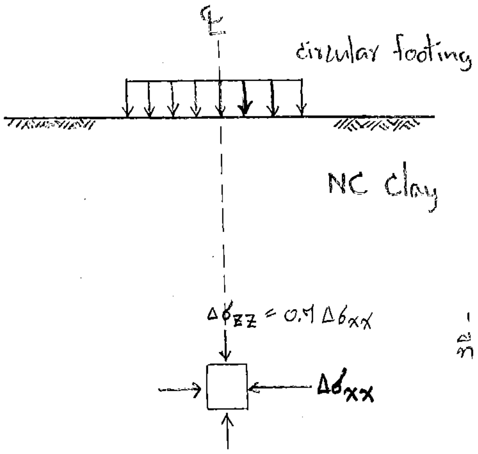
(1) + (2) $\Longrightarrow$ $\sigma'_{vf} = 2.9 - 1.35 = 1.55\ t/m^2 = \sigma'_{3f}$

(1) − (2) $\Longrightarrow$ $\sigma'_{hf} = 2.9 + 1.35 = 4.25\ t/m^2 = \sigma'_{1f}$

$\dfrac{\sigma'_{1f}}{\sigma'_{3f}}$ ที่ $q_f = \dfrac{4.25}{1.55} = 2.74$

Exam 3 At a point underlying the circular footing for normally consolidated clay, the clay is loaded with $\Delta\sigma_{ZZ} = 0.7\,\Delta\sigma_{xx}$. The clay has $K_o = 0.6$, $\sigma'_{vo} = 5\ t/m^2$ and $\sigma'_{vf} = 8\ t/m^2$, $u_o = 3\ t/m^2$ and $u_f = 6\ t/m^2$.

Sol^n



ที่ ℄ ไม่ loading $\Rightarrow \Delta\tau = 0$

- initial condition

$$\sigma'_{vo} = \underline{5}\ t/m^2 \quad , \quad \sigma_{vo} = \sigma'_{vo} + u_o = 5 + 3 = \underline{8}\ t/m^2$$

$$\sigma'_{ho} = K_o \times \sigma'_{vo} = 0.6 \times 5 = \underline{3}\ t/m^2 \quad , \quad \sigma_{ho} = \sigma'_{ho} + u_o = 3 + 3 = \underline{6}\ t/m^2$$

$$p = \frac{\sigma_{vo} + \sigma_{ho}}{2} = \frac{8+6}{2} = 7 \qquad\Bigg|\qquad p' = \frac{\sigma'_{vo} + \sigma'_{ho}}{2} = \frac{5+3}{2} = 4$$

$$q = \frac{\sigma_{vo} - \sigma_{ho}}{2} = \frac{8-6}{2} = 1 \qquad\Bigg|\qquad q' = \frac{\sigma'_{vo} - \sigma'_{ho}}{2} = \frac{5-3}{2} = 1$$

- after loading

$$\sigma'_{vf} = \underline{8}\ t/m^2$$

$$\Delta\sigma_{ZZ} = \sigma_{vf} - \sigma_{vo} = \left[\sigma'_{vf} + (u_o + \Delta u)\right] - \sigma_{vo} = \left[\sigma'_{vf} + u_f\right] - \sigma_{vo}$$

$$\Delta\sigma_{ZZ} = \left[8+6\right] - 8 = 6\ t/m^2$$

$$\sigma_{vf} = \sigma_{vo} + \Delta\sigma_{ZZ} = 8 + 6 = \underline{14}\ t/m^2$$

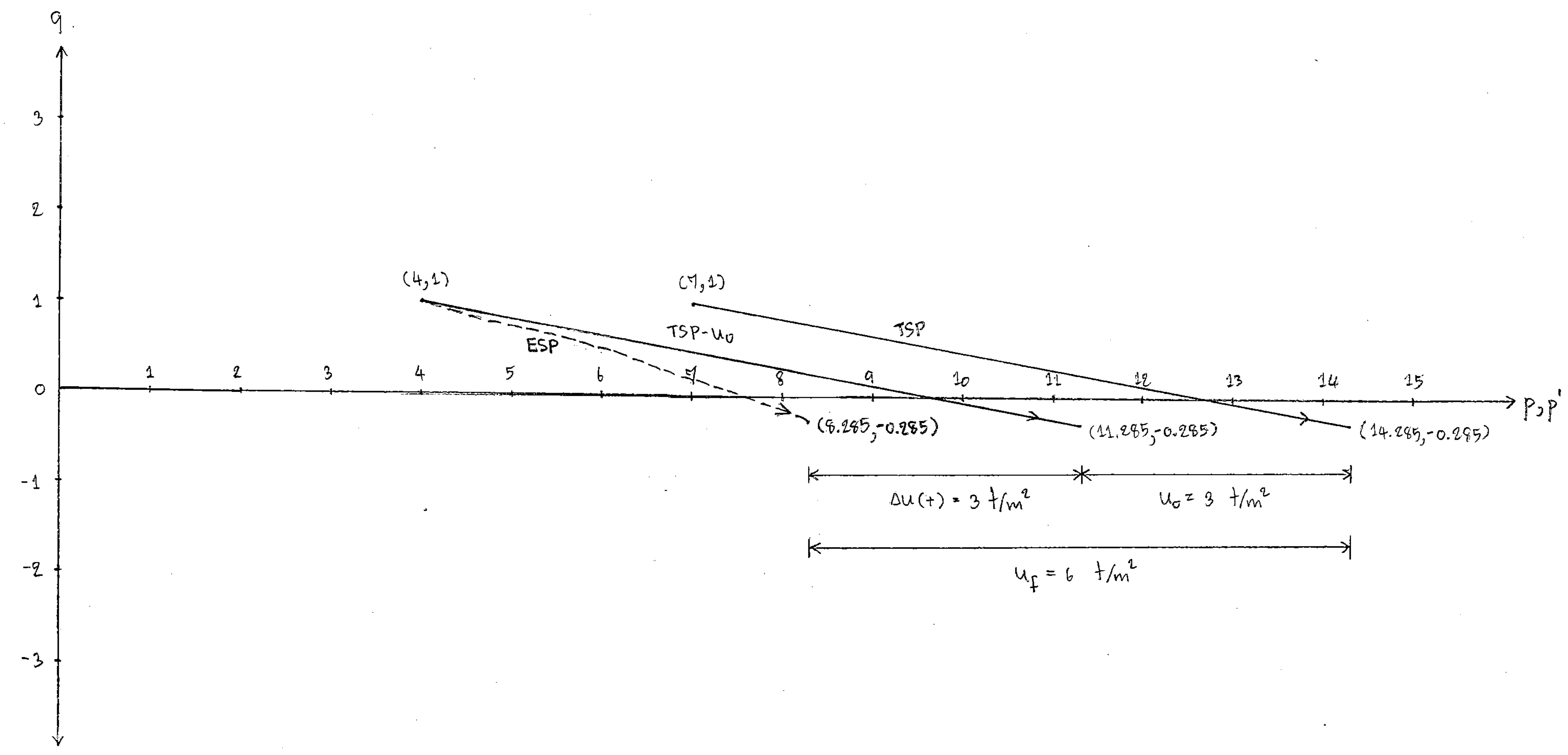
$$\Delta\sigma_{xx} = \frac{\Delta\sigma_{ZZ}}{0.7} = \frac{6}{0.7} = 8.57\ t/m^2$$

$$\sigma_{hf} = \sigma_{ho} + \Delta\sigma_{xx} = 6 + 8.57 = \underline{14.57}\ t/m^2$$

$$\sigma'_{hf} = (\sigma_{ho} + \Delta\sigma_{xx}) - (u_o + \Delta u) = (\sigma_{ho} + \Delta\sigma_{xx}) - u_f = (6 + 8.57) - 6 = \underline{8.57}\ t/m^2$$

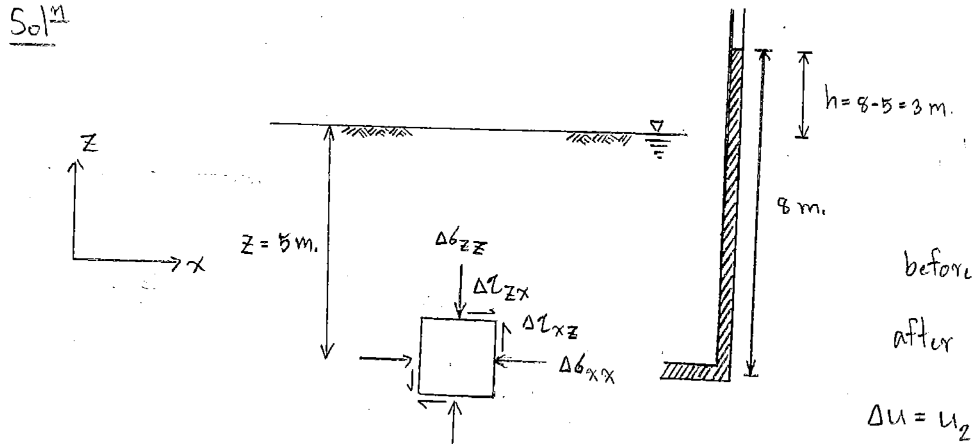
$$p_f = \frac{\sigma_{vf} + \sigma_{hf}}{2} = \frac{14 + 14.57}{2} = 14.285 \qquad\Bigg|\qquad p'_f = \frac{\sigma'_{vf} + \sigma'_{hf}}{2} = \frac{8 + 8.57}{2} = 8.285$$

$$q_f = \frac{\sigma_{vf} - \sigma_{hf}}{2} = \frac{14 - 14.57}{2} = -0.285 \qquad\Bigg|\qquad q'_f = \frac{\sigma'_{vf} - \sigma'_{hf}}{2} = \frac{8 - 8.57}{2} = -0.285$$


q
p, p'
(4,1)
(7,1)
ESP
TSP-u_0
TSP
(8.285,-0.285)
(11.285,-0.285)
(14.285,-0.285)
$\Delta u(+) = 3\ t/m^2$
$u_o = 3\ t/m^2$
$u_f = 6\ t/m^2$

Exam 4 The normally consolidated clay at the depth of 5 m. was stresses with $\Delta\sigma_{zz} = 4\ t/m^2$, $\Delta\sigma_{xx} = 1.0\ t/m^2$ and $\Delta\tau_{xz} = 0.7\ t/m^2$. The piezometric head after the loading is 8 m. Find the Skempton's pore pressure parameter, considered the ground water is at the ground surface.

Sol^{n}



before loading $u_1 = \gamma_\omega \times Z$

after loading $u_2 = \gamma_\omega \times (Z+h)$

$\Delta u = u_2 - u_1 = \gamma_\omega(Z+h) - \gamma_\omega \times Z = \gamma_\omega \times h$

$\Delta\sigma_{xx} = 1.0\ t/m^2$, $\Delta\sigma_{zz} = 4.0\ t/m^2$ (+ve. → compression)

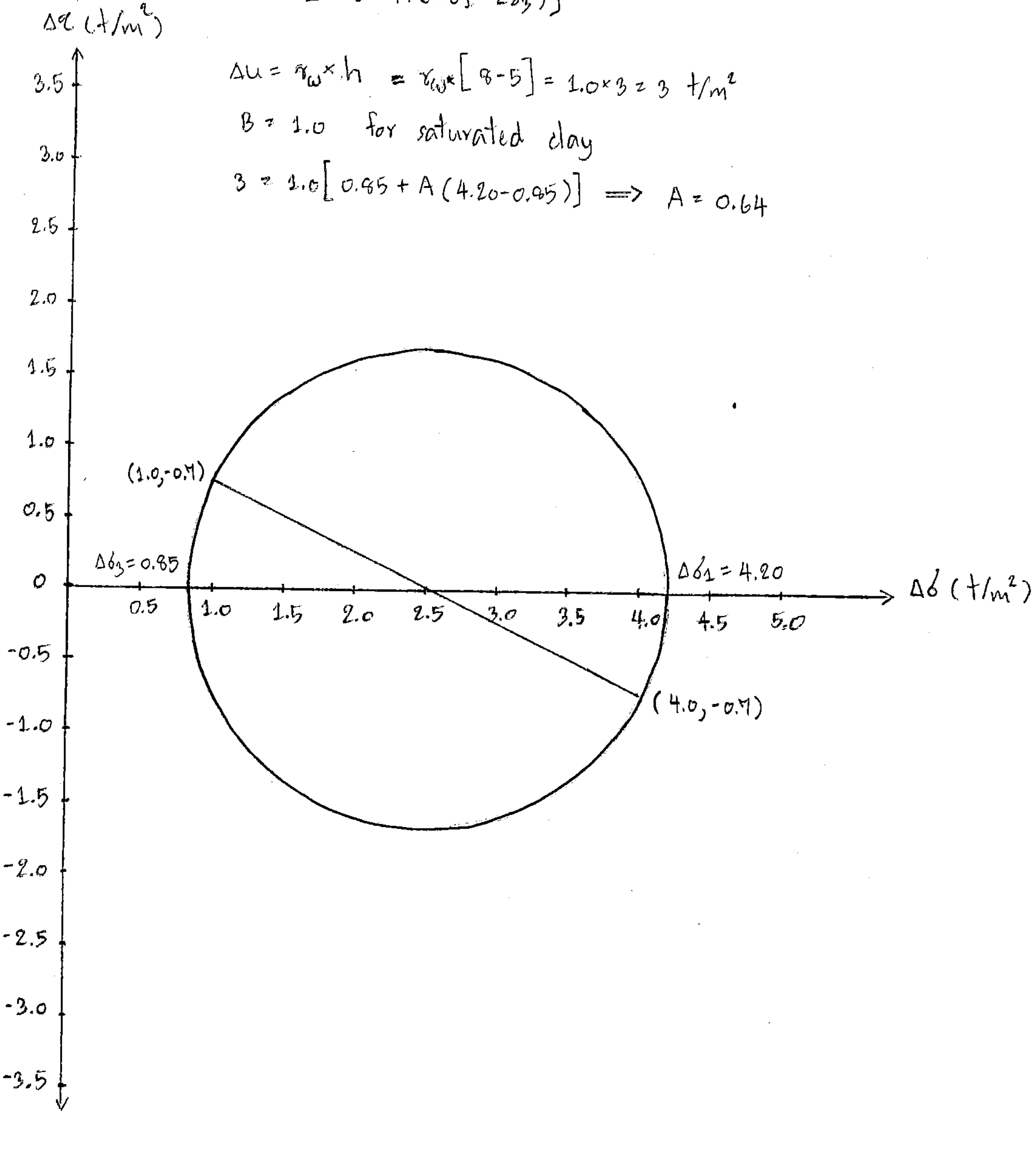
$\Delta\tau_{xz} = 0.7\ t/m^2$ (+ve. → counterclockwise)

$\Delta u = B[\Delta\sigma_3 + A(\Delta\sigma_1 - \Delta\sigma_3)]$

$\Delta u = \gamma_\omega \times h = \gamma_\omega \times [8-5] = 1.0 \times 3 = 3\ t/m^2$

$B = 1.0$ for saturated clay

$3 = 1.0[0.85 + A(4.20 - 0.85)] \implies A = 0.64$

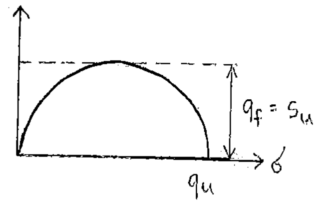


<u>Question 1</u> Three perfectly undisturbed samples from three different depths were taken from a normally consolidated homogeneous clay layer. The unconfined compression test is carried out on those samples. The results are as shown in the table.

Location	Depth (m)	$(\sigma_c')_{in\text{-}situ}$ (t/m^2)	S_u (t/m^2)
A	3	1.8	3.8
B	8	4.8	5.5
C	12	7.2	7.0

If a series of consolidated undrained triaxial tests are performed under three isotropic stresses (shown in the table) on samples taken from A, estimate the friction angle (ϕ') and cohesion (c'). Assume that the Skempton's pore pressure parameter at failure (A_f) is 0.7.

<u>Sol^n</u>



from unconfined compression test

$$q_f = \frac{\sigma_{1f} - \sigma_{3f}}{2} = S_u$$

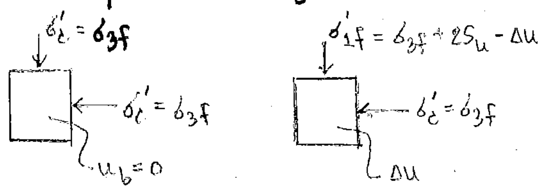
$$\sigma_{1f} = \sigma_{3f} + 2S_u \quad , \quad \sigma_{3f} = \sigma_c$$

Assume that soil samples were taken from the same depth in CU triaxial test as soil samples in UC test (has the same σ_s') so that Mohr's circle of CU triaxial test has radius ($q_f = S_u$) as those samples in UC test.

CU triaxial test assume back pressure, $u_b = 0$ t/m^2

$$\sigma_c = \sigma_c' + \cancel{u_b}^{\,0} = \sigma_c'$$

CU triaxial compression loading test (σ_c' เพิ่มขึ้น)



$$\Delta\sigma_3 = 0 \quad , \quad \Delta\sigma_1 = \sigma_{1f} - \sigma_{3f}$$

$$\Delta u = B[\Delta\sigma_3 + A(\Delta\sigma_1 - \Delta\sigma_3)]$$

for saturated clay $\Rightarrow B = 1.0$, ที่ failure $\Rightarrow A_f = 0.7$

$$\Delta u = A_f \cdot \Delta\sigma_1$$

$$\sigma_{3f}' = \sigma_{3f} - \Delta u$$

$$\sigma_{1f}' = \sigma_{1f} - \Delta u$$

σ'_c (t/m^2)	σ_c (t/m^2)	S_u (t/m^2)	σ_{3f} (t/m^2)	σ_{1f} (t/m^2)	$\Delta\sigma_1$ (t/m^2)	Δu (t/m^2)	σ'_{3f} (t/m^2)	σ'_{1f} (t/m^2)
1.8	1.8	3.8	**1.8**	9.4	7.6	5.32	-3.52	4.08
4.8	4.8	5.5	**4.8**	**15.8**	11.0	7.70	-2.90	8.10
7.2	7.2	7.0	**7.2**	**21.2**	14.0	9.80	-2.60	11.40

$$\sigma_c = \sigma'_c + \overset{0}{\cancel{u_b}} = \sigma'_c$$

$$\sigma_{3f} = \sigma_c$$

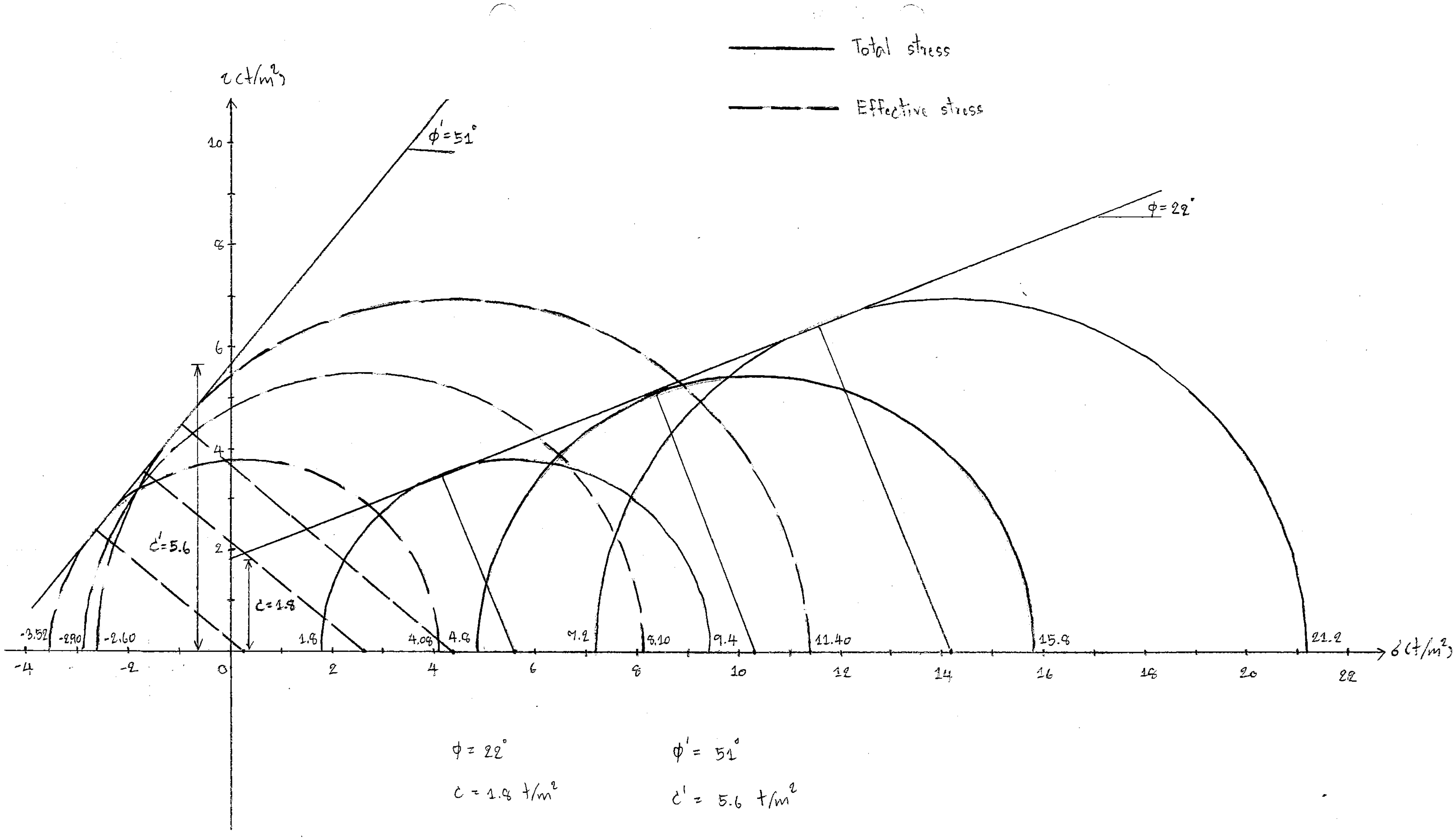
$$\sigma_{1f} = \sigma_{3f} + 2S_u$$

$$\Delta\sigma_1 = \sigma_{1f} - \sigma_{3f}$$

$$\Delta u = A_f \times \Delta\sigma_1 = 0.7 \times \Delta\sigma_1$$

$$\sigma'_{3f} = \sigma_{3f} - \Delta u$$

$$\sigma'_{1f} = \sigma_{1f} - \Delta u$$



$\phi = 22^\circ$

$c = 1.8\ t/m^2$

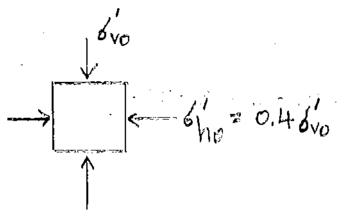
$\phi' = 51^\circ$

$c' = 5.6\ t/m^2$

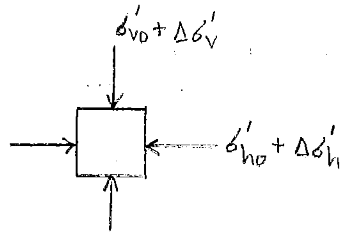
Question 2 A soil obeys the Mohr-Coulomb failure criterion, in which the effective stress parameters are : $c' = 0.7$ t/m², $\phi' = 29°$. The soil begins with an anisotropic state of stress as shown in the figure below. The increment effective stresses are applied such that $\Delta\sigma'_h = \dfrac{-\Delta\sigma'_v}{4}$, where $\Delta\sigma'_v > 0$ until the soil fails.

1.) Draw the stress path in p-q diagram and mark the point of failure on K_f line

2.) Calculate the shear and normal stresses on the failure plane and the orientation of the failure plane.



Initial stress



Soil subject to applied stresses

<u>Sol</u>

Soln 1.) Initial condition

$$p' = \frac{\sigma'_{vo} + \sigma'_{ho}}{2} = \frac{\sigma'_{vo} + 0.4\sigma'_{vo}}{2} = 0.7\sigma'_{vo}$$

$$q = \frac{\sigma'_{vo} - \sigma'_{ho}}{2} = \frac{\sigma'_{vo} - 0.4\sigma'_{vo}}{2} = 0.3\sigma'_{vo}$$

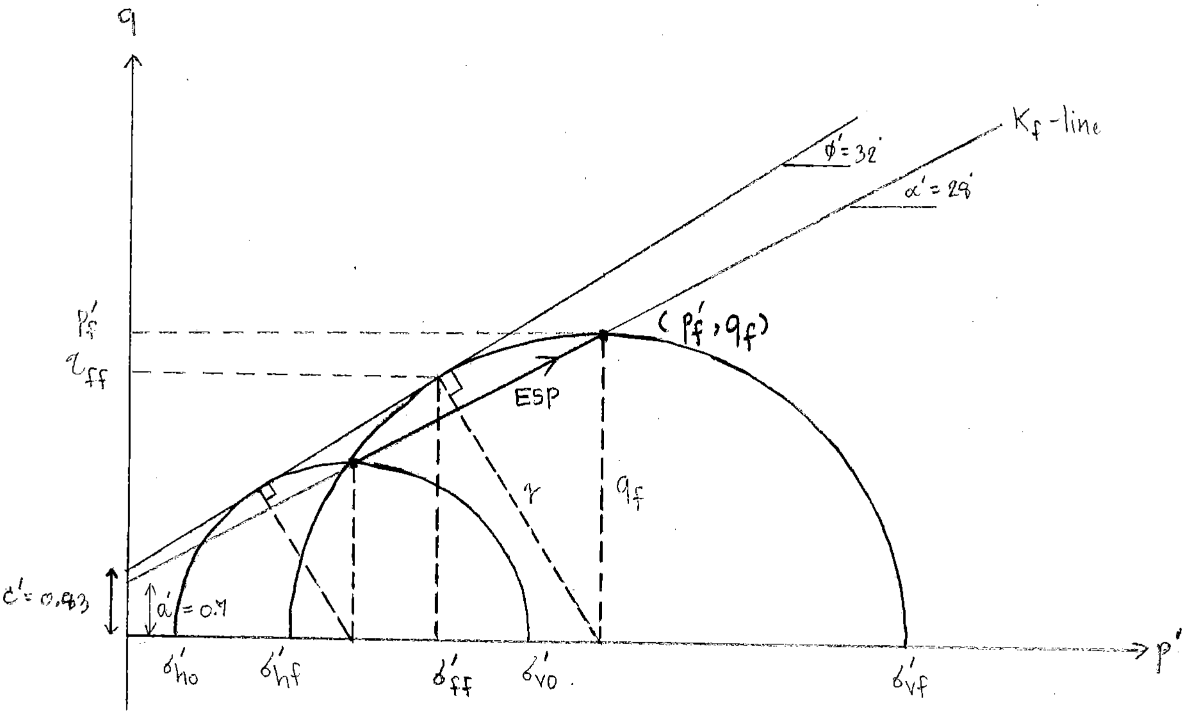
2.) After loading

$$\sigma'_{vf} = \sigma'_{vo} + \Delta\sigma'_v$$

$$\sigma'_{hf} = \sigma'_{ho} + \Delta\sigma'_h = 0.4\sigma'_{vo} + \left(-\frac{\Delta\sigma'_v}{4}\right) = 0.4\sigma'_{vo} - 0.25\Delta\sigma'_v$$

$$p'_f = \frac{\sigma'_{vf} + \sigma'_{hf}}{2} = \frac{(\sigma'_{vo} + \Delta\sigma'_v) + (0.4\sigma'_{vo} - 0.25\Delta\sigma'_v)}{2} = 0.7\sigma'_{vo} + 0.375\Delta\sigma'_v$$

$$q_f = \frac{\sigma'_{vf} - \sigma'_{hf}}{2} = \frac{(\sigma'_{vo} + \Delta\sigma'_v) - (0.4\sigma'_{vo} - 0.25\Delta\sigma'_v)}{2} = 0.3\sigma'_{vo} + 0.625\Delta\sigma'_v$$



$$\sin\phi' = \tan\alpha' \implies \phi' = \sin^{-1}(\tan\alpha') = \sin^{-1}(\tan 28^\circ) = 32^\circ$$

$$c' = \frac{a'}{\cos\phi'} = \frac{0.7}{\cos 32^\circ} = 0.83 \quad t/m^2$$

จาก $\quad q_f = p_f' \cdot \tan\alpha' + a$

$$0.3\sigma'_{vo} + 0.625\Delta\sigma'_v = (0.7\sigma'_{vo} + 0.375\Delta\sigma'_v)\times\tan 28^\circ + 0.7$$

$$(0.625 - 0.375\times\tan 28^\circ)\Delta\sigma'_v = (0.7\times\tan 28^\circ - 0.3)\sigma'_{vo} + 0.7$$

$$\Delta\sigma'_v = \frac{(0.7\times\tan 28^\circ - 0.3)\times\sigma'_{vo} + 0.7}{(0.625 - 0.375\times\tan 28^\circ)}$$

$$\Delta\sigma'_v = 0.169\sigma'_{vo} + 1.64$$

แทนค่า $\quad p'_f = 0.7\sigma'_{vo} + 0.375\times\Delta\sigma'_v = 0.7\sigma'_{vo} + 0.375\times(0.169\sigma'_{vo} + 1.64) = 0.763\sigma'_{vo} + 0.615$

$$q_f = 0.3\sigma'_{vo} + 0.625\times\Delta\sigma'_v = 0.3\sigma'_{vo} + 0.625\times(0.169\sigma'_{vo} + 1.64) = 0.406\sigma'_{vo} + 1.025$$

จาก p'-q diagram

$$\sigma'_{ff} = p'_f - r\times\sin\phi' = p'_f - q_f\times\sin\phi' = (0.763\sigma'_{vo} + 0.615) - (0.406\sigma'_{vo} + 1.025)\times\sin 32^\circ$$

$$= 0.547\sigma'_{vo} + 0.072$$

$$\tau_{ff} = r\times\cos\phi' = q_f\times\cos\phi' = (0.406\sigma'_{vo} + 1.025)\times\cos 32^\circ$$

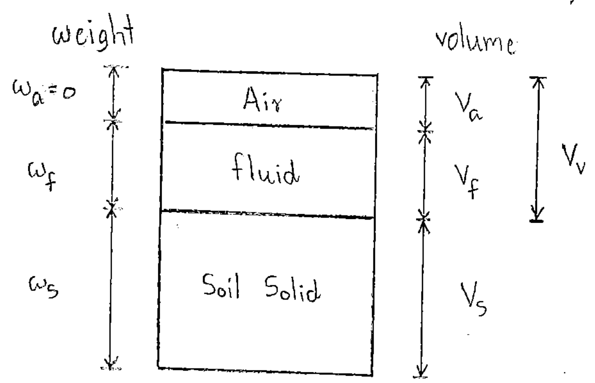
$$= 0.344\sigma'_{vo} + 0.869$$

Question 3 For a soil having a fluid replaces water in voids, specific gravity of fluid is G_f and its weight is ω_f .

Determine 1.) Degree of saturation, S

2.) Air - voids content, A_v

Sol^n



1.) $$e = \frac{V_v}{V_s} = \frac{\frac{V_f}{S}}{\frac{\omega_s}{\gamma_s}} = \frac{\frac{\omega_f}{\gamma_f \cdot S}}{\frac{\omega_s}{\gamma_s}} = \frac{\omega_f}{\omega_s} \times \frac{\gamma_s}{\gamma_f} \times \frac{1}{S}$$

$$S = \frac{\omega_f}{\omega_s} \times \frac{\gamma_s}{\gamma_f} \times \frac{1}{e} = \frac{\omega_f}{\omega_s} \times \frac{\gamma_s}{G_f \times \gamma_\omega} \times \frac{1}{e} = \frac{\omega_f}{\omega_s} \times \frac{G_s}{G_f} \times \frac{1}{e}$$

2.) $$V_a = V_v - V_f = V_v - S \cdot V_v = (1-S) V_v = (1-S) \times e \cdot V_s$$

since $$e = \frac{V_v}{V_s}$$

$$e + 1 = \frac{V_v}{V_s} + 1 = \frac{V_v + V_s}{V_s} = \frac{V}{V_s}$$

$$\frac{V_s}{V} = \frac{1}{1+e}$$

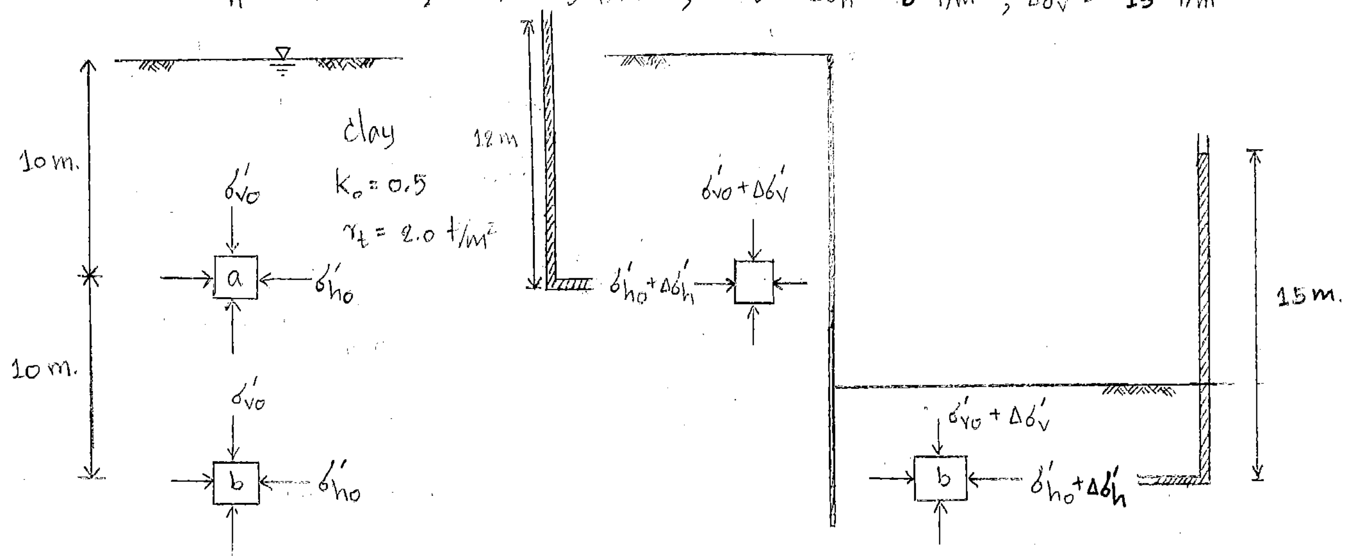
$$\frac{V_a}{V} = (1-S) \times e \times \frac{V_s}{V} = (1-S) \times e \times \frac{1}{1+e}$$

$$A_v = \frac{V_a}{V} = (1-S) \times \frac{e}{1+e}$$

Question 4 . Clay obeys the Mohr-Coulomb failure criterion, which has initial state of stress as shown in the figure below. The horizontal stress reduced by excavation which is druged at depth from ground surface in a few days.

Draw p-q diagram of soil at a, b in short term and long term.

Given ที่ a $\Delta\sigma_h = -4\ t/m^2$, $\Delta\sigma_v = -3\ t/m^2$; ที่ b $\Delta\sigma_h = -8\ t/m^2$, $\Delta\sigma_v = -15\ t/m^2$



Sol^{n} 1.) soil element A

▶ Initial stress $\sigma_{vo} = \gamma_t \cdot z = 2.0 \times 10 = 20\ t/m^2$, $u_o = \gamma_w \cdot z = 1.0 \times 10 = 10\ t/m^2$

$$\sigma'_{vo} = \sigma_{vo} - u_o = 20 - 10 = 10\ t/m^2$$

$$\sigma'_{ho} = K_o \cdot \sigma'_{vo} = 0.5 \times 10 = 5\ t/m^2$$

$$\sigma_{ho} = \sigma'_{ho} + u_o = 5 + 10 = 15\ t/m^2$$

$$p_o = \frac{\sigma_{vo} + \sigma_{ho}}{2} = \frac{20 + 15}{2} = 17.5 \qquad p'_o = \frac{\sigma'_{vo} + \sigma'_{ho}}{2} = \frac{10 + 5}{2} = 7.5$$

$$q_o = \frac{\sigma_{vo} - \sigma_{ho}}{2} = \frac{20 - 15}{2} = 2.5 \qquad q'_o = \frac{\sigma'_{vo} - \sigma'_{ho}}{2} = \frac{10 - 5}{2} = 2.5$$

▶ End of construction $\sigma_{vu} = \sigma_{vo} + \Delta\sigma_v = 20 - 3 = 17\ t/m^2$

$$\sigma'_{vu} = \sigma'_{vo} + \Delta\sigma'_v = \sigma'_{vo} + \Delta\sigma_v - \Delta u = 10 - 3 - 2 = 5\ t/m^2$$

$$\sigma_{hu} = \sigma_{ho} + \Delta\sigma_h = 15 - 4 = 11\ t/m^2$$

$$\sigma'_{hu} = \sigma'_{ho} + \Delta\sigma'_h = \sigma'_{ho} + \Delta\sigma_h - \Delta u = 5 - 4 - 2 = -1\ t/m^2$$

before excavation $u_1 = \gamma_w \cdot z$

after excavation $u_2 = \gamma_w \cdot h$

$$\Delta u = u_2 - u_1 = \gamma_w \times (h - z) = 1.0 \times (12 - 10) = 2\ t/m^2$$

$$p = \frac{\sigma_{vu} + \sigma_{hu}}{2} = \frac{17 + 11}{2} = 14 \qquad p' = \frac{\sigma'_{vu} + \sigma'_{hu}}{2} = \frac{5 + (-1)}{2} = 2$$

$$q = \frac{\sigma_{vu} - \sigma_{hu}}{2} = \frac{17 - 11}{2} = 3 \qquad q' = \frac{\sigma'_{vu} - \sigma'_{hu}}{2} = \frac{5 - (-1)}{2} = 3$$

▶ End of consolidation (Long term)

$$\Delta u = 0$$

$$\sigma_{vf} = \sigma_{vo} + \Delta\sigma_v = 20 - 3 = 17 \ t/m^2$$

$$\sigma'_{vf} = \sigma'_{vo} + \Delta\sigma_v - \cancel{\Delta u}^{0} = 10 - 3 = 7 \ t/m^2$$

$$\sigma_{hf} = \sigma_{ho} + \Delta\sigma_h = 15 - 4 = 11 \ t/m^2$$

$$\sigma'_{hf} = \sigma'_{ho} + \Delta\sigma_h - \cancel{\Delta u}^{0} = 5 - 4 = 1 \ t/m^2$$

$$p_f = \frac{\sigma_{vf} + \sigma_{hf}}{2} = \frac{17 + 11}{2} = 14 \qquad p'_f = \frac{\sigma'_{vf} + \sigma'_{hf}}{2} = \frac{7 + 1}{2} = 4$$

$$q_f = \frac{\sigma_{vf} - \sigma_{hf}}{2} = \frac{17 - 11}{2} = 3 \qquad q'_f = \frac{\sigma'_{vf} - \sigma'_{hf}}{2} = \frac{7 - 1}{2} = 3$$

2.) soil element B

▶ Initial stress $\sigma_{vo} = \gamma_t \cdot Z = 2.0 \times 20 = 40 \ t/m^2$, $u_o = \gamma_w \times Z = 1.0 \times 20 = 20 \ t/m^2$

$$\sigma'_{vo} = \sigma_{vo} - u_o = 40 - 20 = 20 \ t/m^2$$

$$\sigma'_{ho} = K_o \cdot \sigma'_{vo} = 0.5 \times 20 = 10 \ t/m^2$$

$$\sigma_{ho} = \sigma'_{ho} + u_o = 10 + 20 = 30 \ t/m^2$$

$$p_o = \frac{\sigma_{vo} + \sigma_{ho}}{2} = \frac{40 + 30}{2} = 35 \qquad p'_o = \frac{\sigma'_{vo} + \sigma'_{ho}}{2} = \frac{20 + 10}{2} = 15$$

$$q = \frac{\sigma_{vo} - \sigma_{ho}}{2} = \frac{40 - 30}{2} = 5 \qquad q'_o = \frac{\sigma'_{vo} - \sigma'_{ho}}{2} = \frac{20 - 10}{2} = 5$$

▶ End of construction (Short term)

before excavation $u_1 = \gamma_w \times z$

after excavation $u_2 = \gamma_w \times h$

$$\Delta u = u_2 - u_1 = \gamma_w \times (h - z) = 1.0 \times (15 - 20) = -5 \ t/m^2$$

$$\sigma_{vu} = \sigma_{vo} + \Delta\sigma_v = 40 - 15 = 25 \ t/m^2$$

$$\sigma'_{vu} = \sigma'_{vo} + \Delta\sigma'_v = \sigma'_{vo} + \Delta\sigma_v - \Delta u = 20 + (-15) - (-5) = 10 \ t/m^2$$

$$\sigma_{hu} = \sigma_{ho} + \Delta\sigma_h = 30 - 8 = 22 \ t/m^2$$

$$\sigma'_{hu} = \sigma'_{ho} + \Delta\sigma'_h = \sigma'_{ho} + \Delta\sigma_h - \Delta u = 10 + (-8) - (-5) = 7 \ t/m^2$$

$$p = \frac{\sigma_{vu} + \sigma_{hu}}{2} = \frac{25 + 22}{2} = 23.5 \qquad p' = \frac{\sigma'_{vu} + \sigma'_{hu}}{2} = \frac{10 + 7}{2} = 8.5$$

$$q = \frac{\sigma_{vu} - \sigma_{hu}}{2} = \frac{25 - 22}{2} = 1.5 \qquad q' = \frac{\sigma'_{vu} - \sigma'_{hu}}{2} = \frac{10 - 7}{2} = 1.5$$

- End of consolidation (Long term)

$$\Delta u = 0$$

$$\sigma_{vf} = \sigma_{vo} + \Delta\sigma_v = 40+(-15) = 25 \ t/m^2$$

$$\sigma'_{vf} = \sigma'_{vo} + \Delta\sigma'_v = \sigma'_{vo} + \Delta\sigma_v - \cancelto{0}{\Delta u} = 20+(-15) = 5 \ t/m^2$$

$$\sigma_{hf} = \sigma_{ho} + \Delta\sigma_h = 30+(-8) = 22 \ t/m^2$$

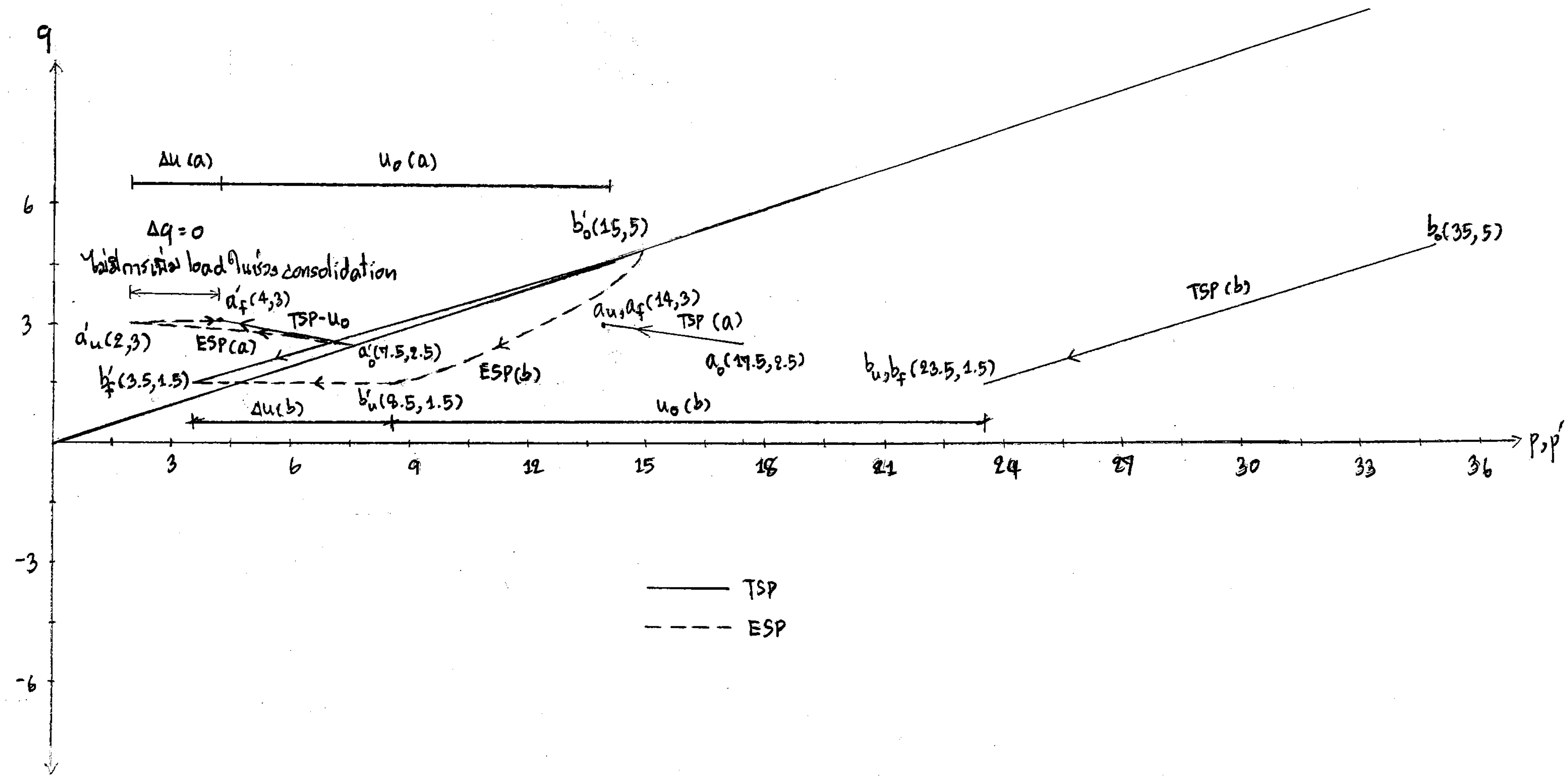
$$\sigma'_{hf} = \sigma'_{ho} + \Delta\sigma'_h = \sigma'_{ho} + \Delta\sigma_h - \cancelto{0}{\Delta u} = 10+(-8) = 2 \ t/m^2$$

$$p_f = \frac{\sigma_{vf}+\sigma_{hf}}{2} = \frac{25+22}{2} = 23.5$$

$$q_f = \frac{\sigma_{vf}-\sigma_{hf}}{2} = \frac{25-22}{2} = 1.5$$

$$p'_f = \frac{\sigma'_{vf}+\sigma'_{hf}}{2} = \frac{5+2}{2} = 3.5$$

$$q'_f = \frac{\sigma'_{vf}-\sigma'_{hf}}{2} = \frac{5-2}{2} = 1.5$$



q
p, p'
Δu (a)
u_o (a)
Δq = 0
ไม่มีการเพิ่ม load ในช่วง consolidation
a'_f(4,3)
TSP-u_o
a'_u(2,3)
ESP(a)
a'_o(7.5,2.5)
b'_f(3.5,1.5)
b'_u(8.5,1.5)
Δu(b)
u_o (b)
b'_o(15,5)
a_u, a_f(14,3)
TSP (a)
a_o(17.5,2.5)
ESP(b)
b_u, b_f(23.5,1.5)
TSP (b)
b_o(35,5)
TSP
ESP