# Lateral earth pressure

$$K_0 = (1-\sin\phi) \rightarrow NC$$
$$K_0 = OCR^{\sin\phi}\cdot(1-\sin\phi) \rightarrow OC$$
$\Big\}$ – Jacky.

$$K_0 = 0.19 + 0.233\log(I_P) \rightarrow NC$$
$$K_0(OC) = K_0(NC)\sqrt{OCR} \rightarrow OC$$
$\Big\}\rightarrow$ Alpan.

$(1+0.5\tan\beta)^2 \rightarrow$ Correction factor. when the soil is inclined with retaining wall.

## # cohesionless soil

$$K_a = \frac{1-\sin\phi}{1+\sin\phi} = \tan^2\left(45^\circ-\frac{\phi}{2}\right) \rightarrow \text{Active pressure}$$
$$K_p = \frac{1+\sin\phi}{1-\sin\phi} = \tan^2\left(45^\circ+\frac{\phi}{2}\right) \rightarrow \text{passive}$$

## # partially cohesive soil:

$$P_{ac} = K_a\cdot\gamma h - 2c\sqrt{K_a}.$$

$$h_c = \frac{2c}{\gamma\sqrt{K_a}} = \frac{2c}{\gamma}\tan(45^\circ+\phi/2)$$
critical height

theoritical unsupported height $H_u = 2h_c = \dfrac{4c}{\gamma\sqrt{K_a}}$.

$$P_{ac} = \frac{1}{2}K_a\cdot\gamma H^2 - 2cH\sqrt{K_a} + \frac{2c^2}{\gamma}$$
$$P_{pc} = K_p\gamma H + 2\sqrt{K_p}.$$

# Lateral earth pressure

$K_o = (1 - \sin\varphi) \rightarrow NC$
$K_o = OCR^{\sin\varphi} (1 - \sin\varphi) \rightarrow OC$
) → Jacky.

$K_o = 0.19 + 0.233 \log (I_P) \rightarrow NC$
$K_o(OCC) = K_o(NCC)\sqrt{OCR} \rightarrow OC$
) → Alpan.

$(1 + 0.5 \tan\beta)^2 \rightarrow$ Correction factor. when the soil is inclined with retaining wall.

## # cohesionless soil

$$K_a = \frac{1-\sin\varphi}{1+\sin\varphi} = \tan^2\left(45^\circ - \frac{\varphi}{2}\right) \rightarrow \text{Active pressure}$$

$$K_p = \frac{1+\sin\varphi}{1-\sin\varphi} = \tan^2\left(45^\circ + \frac{\varphi}{2}\right) \rightarrow \text{passive}$$

## # partially cohesive soil:

$$P_{ac} = K_a.\gamma h - 2c\sqrt{K_a}.$$

$$h_c = \frac{2c}{\gamma\sqrt{K_a}} = \frac{2c}{\gamma}\tan(45^\circ + \varphi/2)$$

critical height

theoritical unsupported height $H_u = 2h_c$.

$$= \frac{4c}{\gamma\sqrt{K_a}}.$$

$$P_{ac} = \frac{1}{2}K_a.\gamma H^2 - 2cH\sqrt{K_a} + \frac{2c^2}{\gamma}$$

$$P_{pe} = K_p\gamma H + 2\sqrt{K_p}.$$

Cohesionless back filling.

$$K_a = \frac{\cos\beta - \sqrt{\cos^2\beta - \cos^2\phi}}{\cos\beta + \sqrt{\cos^2\beta - \cos^2\phi}}$$

$$P_a = \frac{1}{2} K_a \gamma H^2 \cos\beta.$$

horizontal $P_{ah} = \frac{1}{2} K_a \gamma H^2 \cos^2\beta.$

$$K_p = \frac{\cos\beta + \sqrt{\cos^2\beta - \cos^2\phi}}{\cos\beta - \sqrt{\cos^2\beta - \cos^2\phi}}.$$

passive $P_p = \frac{1}{2} K_p \gamma H^2 \cos\beta.$

point load. $m > 0.4$

$$P_h = \frac{1.77Q}{H^2} \cdot \frac{m^2 n^2}{(m^2+n^2)^3}$$

$m \leq 0.4$

$$P_h = \frac{1.77Q}{H^2} \cdot \frac{0.4^2 n^2}{(0.4^2+n^2)^3}$$

~~$P_h' = P_h \cdot \cos^2 (1-$~~

Line load.

$m > 0.4$

$$P_h = \frac{4q}{\pi H} \cdot \frac{m^2 n}{(m^2+n^2)^2}$$

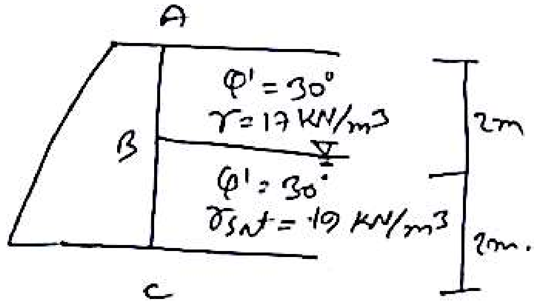
$m \leq 0.4$

$$P_h = \frac{4q}{\pi H} \cdot \frac{0.4^2 n}{(0.4^2+n^2)^2}$$

AK-47

19.1 Determine the lateral earth pressure at rest per unit length of wall shown in Fig. Also determine the location of the resultant earth pressure. $K_o = 1-\sin\phi'$

$\gamma_w = 10\ kN/m^3$




$K_o = 1-\sin\phi'$

$= 1-\sin 30^\circ = 1/2$

At point B.

$\bar{\sigma_z} = 2\times17 = 34\ kN/m^2$

$u = 0$

$P_o = K_o \cdot \bar{\sigma_z}$

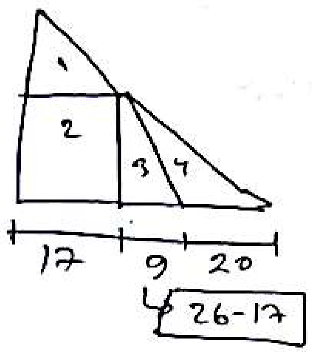
$= 17\ kN/m^2$

At point C

$\bar{\sigma_z} = 2\times17 + (19-10)\times2 = 52\ kN/m^2$

$P_o = 0.5\times52 = 26\ kN/m^2$

$u = 2\times10 = 20\ kN/m^2$




$P_1 = \frac{1}{2}\times17\times2 = 17\ kN.$

$P_2 = 2\times17 = 34\ kN$

$P_3 = \frac{1}{2}\times9\times2 = 9\ kN$

$P_4 = \frac{1}{2}\times20\times2 = 20\ kN.$

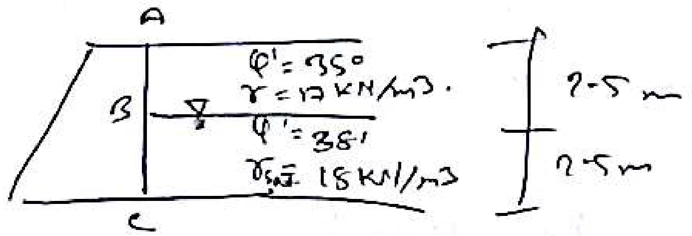
$P = \Sigma P = 80\ kN.$

Line of P. determined by moments about C

$P\bar{z} = 17\times2.667 + 34\times1 + 9\times0.667 + 20\times0.667$

$\Rightarrow \bar{z} = 1.23\ m$ from base

12.2 Determine the active earth pressure on the retaining wall shown in figure. $\gamma_w = 10\ kN/m^3$




$\Rightarrow \quad K_a = \dfrac{1 - \sin\phi'}{1 + \sin\phi'}$

for upper layer. $K_a = \dfrac{1 - \sin 35}{1 + \sin 35} = 0.271$

" lower " $K_a = \dfrac{1 - \sin 38}{1 + \sin 38} = 0.238$

at point B.

$\bar{\sigma}_z = 2.5 \times 17 = 42.5\ kN/m^2$

$u = 0$.

$P_a = 0.271 \times 42.5 = 11.5\ kN/m^2$

below the interface

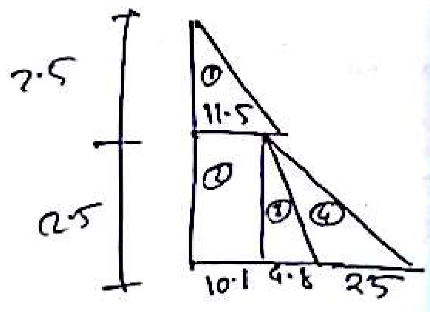
$P_a = 0.238 \times 42.5 = \cancel{10.5}\ 10.1\ kN/m^2$

at point C

$\bar{\sigma}_z = 2.5 \times 17 + 2.5 \times (18 - 10) = 62.5$

$u = 2.5 \times 10 = 25$

$P_a = 0.238 \times 62.5 = 14.9$




$P_1 = \frac{1}{2} \times 2.5 \times 11.5 = 14.4$

$P_2 = 2.5 \times 10.1 = 25.3$

$P_3 = \frac{1}{2} \times 2.5 \times 4.8 = 6$

$P_4 = \frac{1}{2} \times 2.5 \times 25 = 31.3$

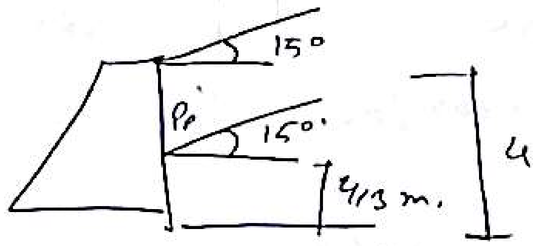
$\Sigma P = 77$

Moment about C.

$$\bar{x} = \frac{14.44 \times 3.33 + 25.3 \times 1.25 + 6 \times 0.833 + 31.3 \times 0.833}{77}$$

$= 1.44$ m

**19.3** Determine the active pressure shown in the fig (use Rankin's theory)



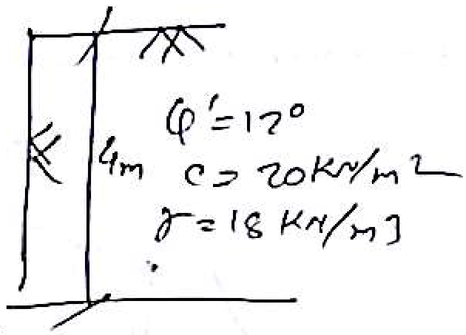

$$K_a = \cos i \times \frac{\cos i - \sqrt{\cos^2 i - \cos^2 \phi'}}{\cos i + \sqrt{\cos^2 i - \cos^2 \phi'}}$$

$$= \cos 15° \times \frac{\cos 15 - \sqrt{\cos^2 15 - \cos^2 30}}{\cos 15 + \sqrt{\cos^2 15 - \cos^2 30}} = 0.373$$

$P_a = \frac{1}{2} . K_a . \gamma H^2$

$= \frac{1}{2} \times 0.373 \times 19 \times 4^2 = 56.7$ KN.

19.4 Determine the stress at the top and bottom of the cut shown in fig. Also determine the maximum depth of potential crack and maximum depth of unsupported excavation




$$P_a = K_a \cdot \gamma z - 2c'\sqrt{K_a}.$$

$$K_a = \frac{1 - \sin 12}{1 + \sin 12} = 0.656$$

$$P_a = 0.656 \times 18\, z - 2 \times 20 \times \sqrt{0.656}$$

$$= 11.817 - 32.4$$

at $z = 0$ $\cdot$ $P_a = -32.4\ KN/m^2$

" $z = 4$ $P_a = 14.8\ KN/m^2$

depth of crack

$$z_c = \frac{2c'}{\gamma\sqrt{K_a}} = \frac{2 \times 20}{18 \times \sqrt{0.656}} = 2.745 m$$

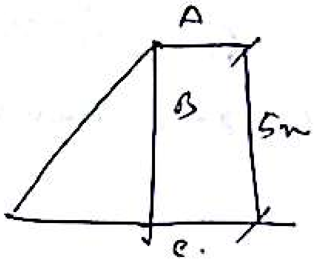
max depth of unsupported excavation

$$H_c = \frac{4c'}{\gamma\sqrt{K_a}}. = 5.490\ m$$

19.5 A 5m high retaining wall is shown in Fig. Determine the ranking active pressure on the wall

(i) Before formation of crack

(ii) After " " "




$\phi = 30^\circ$

$c = 5\ KN/m^2$

$\gamma = 17.5\ KN/m^2$

$$K_a = \frac{1-\sin\phi}{1+\sin\phi} = \frac{1-\sin 30}{1+\sin 30} = 0.333$$

$$P_a = K_a \cdot \gamma z - 2c'\sqrt{K_a}.$$

$$= 0.33 \times 17.5 \times z - 2 \times 5 \times \sqrt{0.333}$$

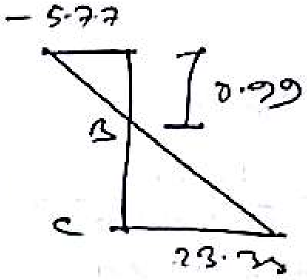
$$= 5.832 - 5.77$$

at $z = 0$. $P_a = -5.77$

at $z = 5$ $P_a = 23.38$.

at B at $P_a = 0$. $5.832 - 5.77 = 0$

$\Rightarrow z = 0.99\ m$.




Before formation of crack.

Negative pressure $P_1 = \frac{1}{2} \times 0.99 \times 5.77$
$= 2.86\ KN$.

positive " $P_2 = \frac{1}{2} \times 4.01 \times 23.38$
$= 46.88\ KN$.

net $P_a = 46.88 - 2.86 = 44.02\ KN$

Line to $P_a$ is determined by taking moment about C

$$\bar{z} = \frac{46.88 \times \frac{4.01}{3} - 2.86 \times (4.01 + 0.67)}{44.02}$$

$$= 1.12\ m.$$

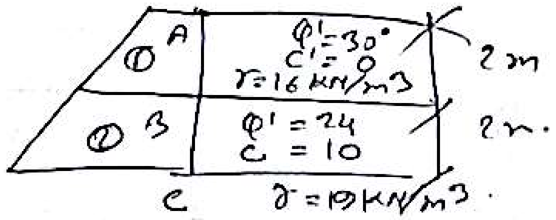
After formation of crack

after formation of crack the -ve pressure is eliminated.

$$P_a = \frac{1}{2} \times 23.38 \times 4.01 = 46.88$$

will act at a height of $\frac{4.01}{3}$ m from above

**19.6** Determine the ranking passive force per unit length of the wall shown in fig. the water table at level B. $\gamma_w = 10\ KN/m^3$




top layer.

$$K_{p_1} = \frac{1+\sin 30}{1-\sin 30} = 3.00$$

bottom layer.

$$K_{p_2} = \frac{1+\sin 24}{1-\sin 24} = 2.37$$

$$P_p = K_p \gamma z + 2c'\sqrt{K_p}$$

At A. $z = 0$. $P_p = 0$

at B $z = 2m$. $\bar{\sigma}_v = 2 \times 16 = 32\ KN/m^2$

top layer $P_p = 3 \times 32 = 96\ KN/m^2$

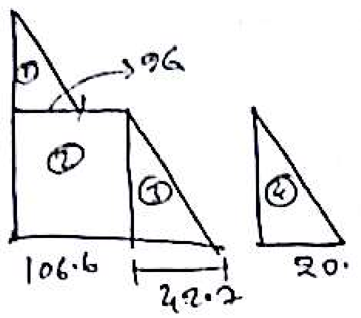
bottom " $P_p = 32 \times 2.37 + 2 \times 10 \times \sqrt{2.37}$

$= 106.6\ KN/m^2$

At C. $\bar{\sigma}_v = 2 \times 16 + 2 \times (19 - 10) = 50\ KN/m^2$

$P_p = 50 \times 2.37 + 2 \times 10\sqrt{2.37} = 149.3$

$u = 2 \times 10 = 20\ KN/m^2$



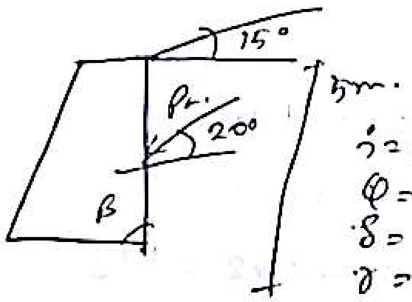


total pressure = $P_1 + P_2 + P_3 + P_4$

$= \frac{1}{2} \times 2 \times 96 + 106.6 \times 2 + \frac{1}{2} \times 42.7 \times 2 + \frac{1}{2} \times 2 \times 20$

$= 371.9$ kN.

**17.7** Determine columb's active force on the retaining wall shown in fig. $\gamma = 17.5$ kN/m³.





$i = 15°$

$\phi = 30°$

$\delta = 20°$

$\gamma = 17.5$ kN/m³

$\beta = 75°$

$$K_a = \frac{\sin^2(\beta + \phi')}{\sin^2\beta \cdot \sin(\beta - \delta)\left[1 + \sqrt{\frac{\sin(\phi' + \delta) \cdot \sin(\phi' - i)}{\sin(\beta - \delta) \cdot \sin(\beta + i)}}\right]}$$

$$= \frac{\sin^2(75 + 30)}{\sin^2 75 \cdot \sin(75 - 20) \cdot \left[1 + \sqrt{\frac{\sin(30 + 20) \cdot \sin(30 - 15)}{\sin(75 - 20) \cdot \sin(75 - 15)}}\right]}$$

$= 0.548$

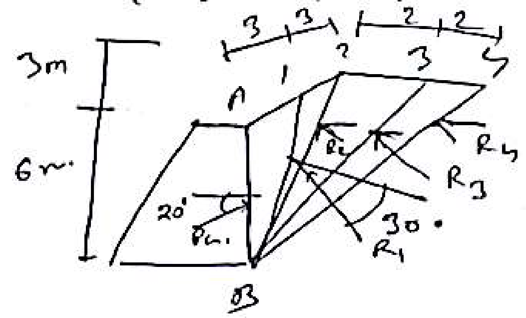
$P_a = \frac{1}{2} K_a \gamma \cdot H^2$

$= \frac{1}{2} \times 0.548 \times 17.5 \times 5^2 = 119.9$ KN.

This will act at a height of 5/3 m and inclined at 20° to normal in the direction shown.

<u>10.8</u> Determine the active thrust on the retaining wall shown in Fig. The Backfill is cohesion less

$\varphi = 30°$ . $\gamma = 19$ KN/m³. $\delta = 20°$



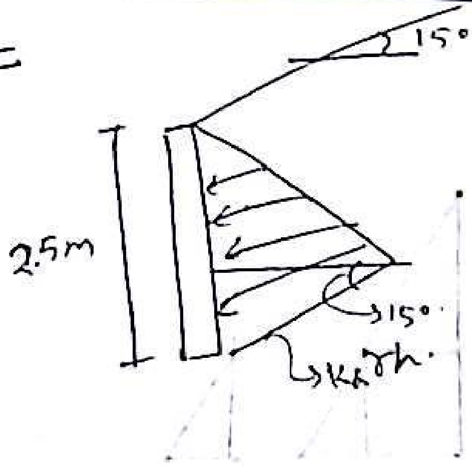

AB1 $W_1 = (6 \times 3/2) \times 19 = 171$ KN

AB2 $W_2 = (6 \times 6/2) \times 19 = 342$ KN

AB3 $W_3 = \frac{1}{2} \times 2 \times 9 \times 19 + 342 = 513$

AB4 $W_4 = \frac{1}{2} \times 2 \times 9 \times 19 + 513 = 684$

Aziz Sheet




$H = 2.5m$

$\phi = 35°$

$\gamma = 18\ KN/m^3$

$OCR = 2$

$\beta = 15°$

Let the earth pressure is at rest

$$K_o = (1-\sin\phi)\, OCR^{\sin\phi} \cdot (1+0.5\tan^2\beta)^2$$

$$= (1-\sin 35)\, 2^{\sin 35}(1+0.5\tan 15)^2$$

$$= 0.816$$

total force.

$$P_o = \frac{1}{2} \cdot K_a \gamma h \times \cos\beta \cdot h$$

$$= \frac{1}{2} \times 0.1816 \times 18 \times 2.5 \times \cos 15 \times 2.5$$

$$= 44.34\ KN/m$$

Horizontal thrust

$$P_H = P_o \cos\beta$$

$$= 44.34 \cos 15$$

$$= 42.83\ KN/m$$

From Alpan's formula.

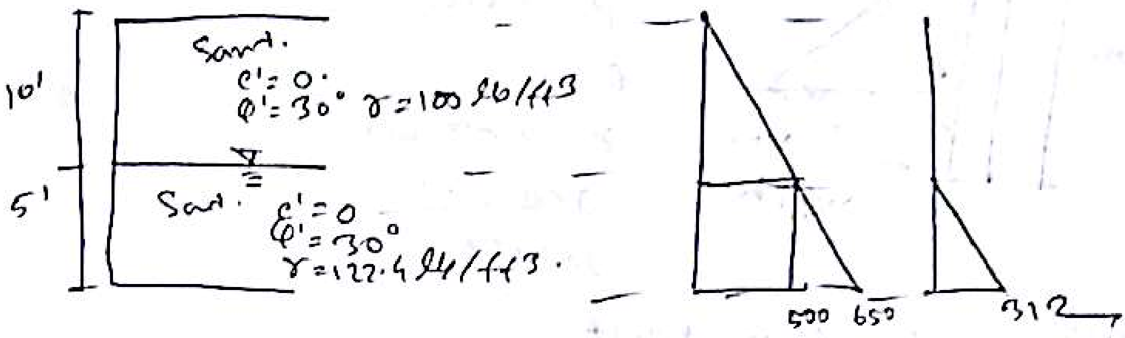
$$K_a = [0.19 + 0.233 \log I_p] \times \sqrt{OCR} \times (1+0.5\tan\beta)^2$$

$$= (1-\sin\phi) \cdot 2^{\sin\phi} \cdot (1+0.5\tan\beta)^2$$

$$\Rightarrow [0.19 + 0.233\log I_p]\sqrt{2} = (1-\sin 35) \times 2^{\sin 35}$$

$$\Rightarrow I_p = 12.9$$

Example- 12.1 BM Das.




earth pressure is at rest

$$K_o = \frac{1-\sin 30}{1+\sin 30} = 0.5$$

at $z = 10$. $\sigma_1' = K_o \cdot \gamma h = \frac{1}{2} \times 100 \times 10 = 500$

$u_1 = 0$.

at $z = 15$ $\sigma_1' = 500 + \frac{1}{2} \times (122 - 62.4) \times 5$

$= 650$ lb/ft2.

$u_2 = \cancel{K_o \cdot \gamma h} \cdot 62.4 \times 5$

$= 312$

total lateral force $= \frac{1}{2} \times 500 \times 10 + 5 \times 500 + \frac{1}{2} \times 150 \times 5 + \frac{1}{2} \times 5 \times 312$

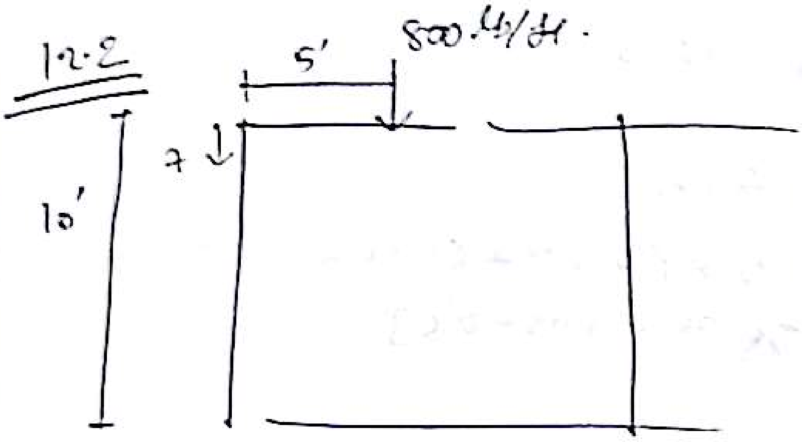
$= 6155$

location of $\bar{x}$ from ground.

$$= \frac{\frac{1}{2} \times 500 \times 10 \times (\frac{10}{3} + 5) + 5 \times 500 \times 2.5 + \frac{1}{2} \times 150 \times 5 \times \frac{5}{3} + \frac{1}{2} \times 5 \times 312 \times \frac{5}{3}}{6155}$$

$= 4.71$ ft (from the bottom).

1.2.2




for line load $m = \frac{x}{h} = \frac{5}{10} = 0.5$

$m = 0.5 > 0.4$

divide the height into 8 equal parts.

$z = 0, 1.25, 2.5, 3.75, 5, 6.25, 7.5, 8.75, 10.$

$n = \frac{z}{h}.$

for $n = \frac{0}{10} = 0$ $\quad ph_0 = 0.$

$n = \frac{1.25}{10} = 0.125 \quad ph_1 = \frac{4q}{\pi H} \cdot \frac{m^2 n}{(m^2+n^2)^2}$

$= 45.11$

$q = 800$
$H = 10.$
$m = 0.5$
$n = 0.125$

$n = \frac{2.5}{10} = 0.25 \quad ph_2 = 65.2$

$n = \frac{3.75}{10} = 0.375 \quad ph_3 = 62.58$

$n = \frac{5}{10} = 0.5 \quad ph_4 = 50.93$

$n = \frac{6.25}{10} = 0.625 \quad ph_5 = 38.78$

~~$n = \frac{8.75}{10} = 0.875$ ph~~

$n = \frac{7.5}{10} = 0.75 \quad ph_6 = 28.93$

$n = \frac{8.75}{10} = 0.875 \quad ph_7 = 21.6$

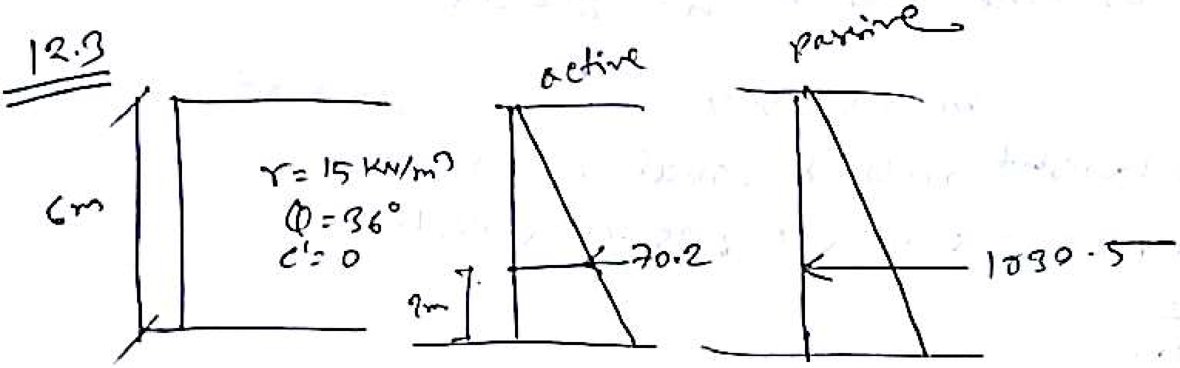
$n = \frac{10}{10} = 1$  $P_{hs} = 16.3$

total increase in lateral force.

$= \frac{1}{2} \times 1.25 \times [0 + 16.3 + 2 \times (45.11 + 65.2 + 62.58 + 50.93 + 38.78 + 28.93 + 21.6]$

$= 401.6$ lb/ft

12.3




(a) active force.

$K_a = \frac{1 - \sin\phi}{1 + \sin\phi} = \frac{1 - \sin 36}{1 + \sin 36} = 0.26$

$P_{ae} = \frac{1}{2} K_a \cdot \gamma h \cdot \times h = \frac{1}{2} \times 0.26 \times 15 \times 6^2$

$= 70.2$ lb/ft

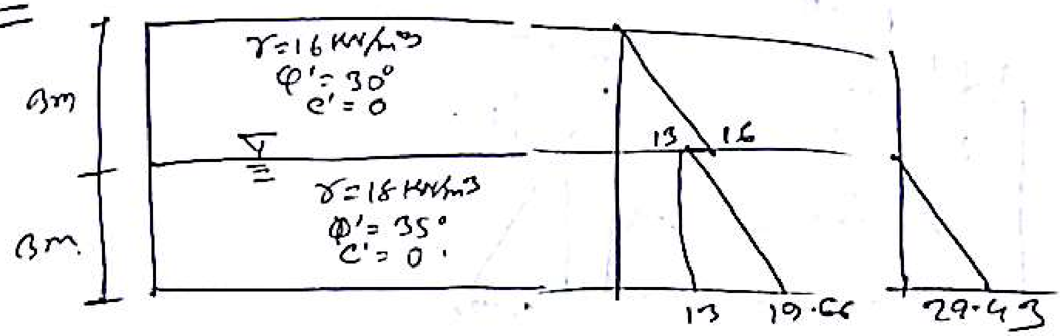
(b) passive force

$K_p = \frac{1 + \sin\phi}{1 - \sin\phi} = 3.85$

$P_{pe} = \frac{1}{2} \times 3.85 \times 15 \times 6 \times 6$

$= 1039.5$ lb/ft

12.4




for upper layer.

$$K_a = \frac{1-\sin\phi}{1+\sin\phi} = 1/3.$$

$$\sigma = K_a \gamma h = \frac{1}{3} \times 16 \times 3 = 16$$

for bottom layer.

$$K_a = \frac{1-\sin 35}{1+\sin 35} = 0.271$$

at $z = 3$ $\quad \sigma = K_a \gamma h = 0.271 \times 16 \times 3 = 13$

at $z = 6$ $\quad \sigma = 13 + K_a \gamma' h = 13 + 0.271 \times (18 - 9.81) \times 3$

$$= 19.66$$

$$u = 9.81 \times 3 = 29.43$$

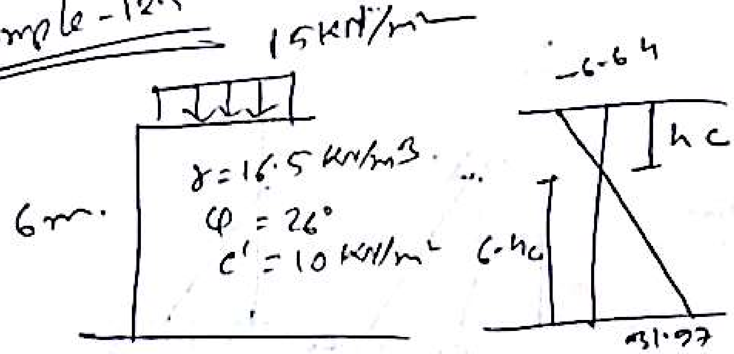
force per unit width $= \frac{1}{2} \times 16 \times 3 + 13 \times 3 + \frac{1}{2} \times (19.66 - 13) \times 3 + \frac{1}{2} \times 29.43 \times 3$

$$= 117.14\ kN.$$

$$\bar{z} = \frac{\frac{1}{2} \times 16 \times 3 \times (3+1) + (13 \times 3 \times 1.5) + \frac{1}{2} \times (19.66 - 13) \times 3 \times 1 + \frac{1}{2} \times 29.43 \times 3 \times 1}{117.14}$$

$= 1.78\ m.$

Example - 12.5




$$K_a = \frac{1-\sin 26}{1+\sin 26} = 0.39$$

at $z = 0$. $\sigma_a' = qK_a - 2c\sqrt{K_a}$

$= 15 \times 0.39 - 2 \times 10 \times \sqrt{0.39}$

$= -6.64$ KN/m²

at $z = 6$m $\sigma_a' = qK_a + K_a \gamma h - 2c\sqrt{K_a}$

$= 15 \times 0.39 + 0.39 \times 16.5 \times 6 - 2 \times 10\sqrt{0.39}$

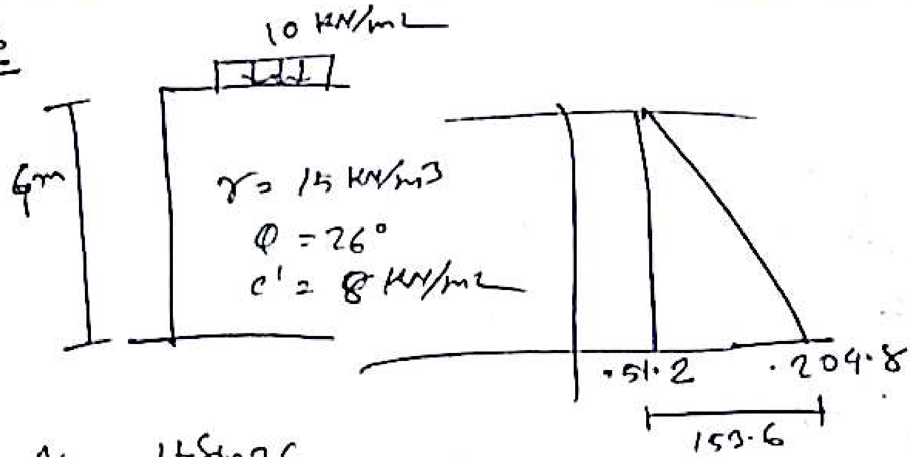
$= 31.97$ KN/m²

$$\frac{31.97}{6-h_c} = \frac{6.64}{h_c} \Rightarrow h_c = 1.03\text{m}.$$

Active force $= \frac{1}{2} \times 31.97 \times (6-1.03)$

$= 79.45$ KN/m. (after crack)

12.6




$$K_p = \frac{1+\sin 26}{1-\sin 26} = 2.56$$

at $z=0$ $\quad \sigma_p' = qK_p + 2c\sqrt{K_p}$.

$$= 10\times 2.56 + 2\times 8\times\sqrt{2.56}$$

$$= 51.2 \text{ Kpa}.$$

$z = 4$ m $\quad \sigma_p = 51.2 + K_p\gamma h$.

$$= 51.2 + 2.56\times 15\times 4$$

$$= 204.8 \text{ Kpa}.$$

passive resistance per unit width.

$$P_p = 51.2\times 4 + \tfrac{1}{2}\times 153.6\times 4 = 512 \text{ kN/m}$$

$$\bar{z} = \frac{51.2\times 4\times 2 + \frac{1}{2}\times 153.6\times 4\times\frac{4}{3}}{512}$$

$$= 1.6 \text{m}.$$

# Question:

2015-16 → 4,5

2014-15 → 3,5,6,7

2013-14 → 2, 6, 7, 8

2012-13 → 8, 7, 6

2011-12 → 3

2010-11 → 1(b), 3, 4

2009-10 → 2, 4

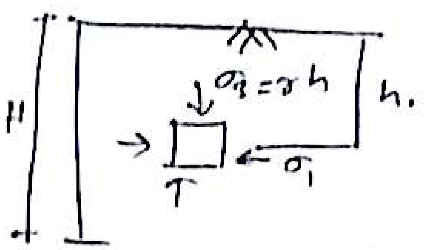
8-9 → 1 (a) → Shit (3), 4

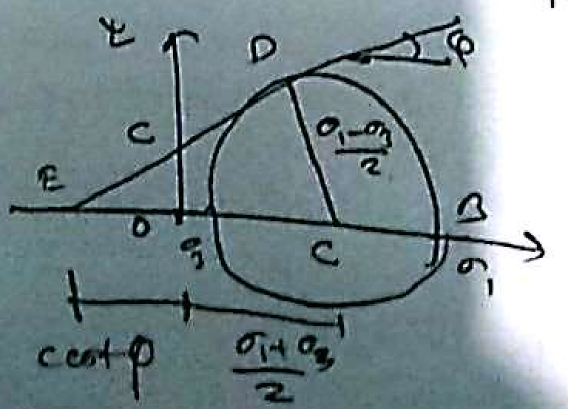
2013-14 (2) Passive earth pressure in a c-φ soil: Let us assume a vertical and smooth retaining wall with a c-φ back fill having a horizontal surface for passive case. $\sigma_h > \sigma_v$.

At a given depth h on an element the vertical stress is $\sigma_v = \sigma_3 = \gamma h$.

lateral stress is $\sigma_h = \sigma_1$

It is assumed that the wall has yeilded sufficiently to satisfy passive earth condition such that $\sigma_1 = K_p \sigma_3$



From the mohr circle.

$$\sin\varphi = \frac{\frac{\sigma_1 - \sigma_3}{2}}{\frac{\sigma_1+\sigma_3}{2} + c\cdot\cot\varphi} = \frac{en}{cE}$$

$$\Rightarrow \sin\varphi = \frac{\sigma_1 - \sigma_3}{\sigma_1+\sigma_3+2c\cot\varphi}.$$

$$\Rightarrow \sigma_1(1-\sin\varphi) = \sigma_3(1+\sin\varphi) + 2c\cot\varphi$$

$$\Rightarrow \sigma_1 = \sigma_3\cdot\left(\frac{1+\sin\varphi}{1-\sin\varphi}\right) + \frac{2c\cot\varphi}{1-\sin\varphi}$$

$$\frac{\cot\varphi}{1-\sin\varphi} = \sqrt{\frac{1-\sin^2\varphi}{(1-\sin\varphi)^2}} = \sqrt{\frac{(1+\sin\varphi)(1-\sin\varphi)}{(1-\sin\varphi)^2}} = \sqrt{\frac{1+\sin\varphi}{1-\sin\varphi}} = \sqrt{K_p}$$

$$\therefore \sigma_1 = \sigma_3\cdot K_p + 2c\sqrt{K_p} = K_p\gamma h + 2c\sqrt{K_p}$$

$$\Rightarrow P_{pc} = K_p\gamma h + 2c\sqrt{K_p}.$$

Depth of unsupported height $= h_c$.

at $h_c$ $P_{pc} = 0$.

$$0 = K_p\gamma h_c + 2c\sqrt{K_p}.$$

$$\Rightarrow -h_c = \frac{2c}{\gamma\sqrt{K_p}} = \frac{2c}{\gamma\sqrt{\tan^2(45^\circ+\frac{\varphi}{2})}}$$

$$\Rightarrow -h_c = \frac{2c}{\gamma\tan(45^\circ+\varphi/2)}$$

Unsupported height $2h_c = \dfrac{4c}{\gamma(\tan 45^\circ+\varphi/2)}$

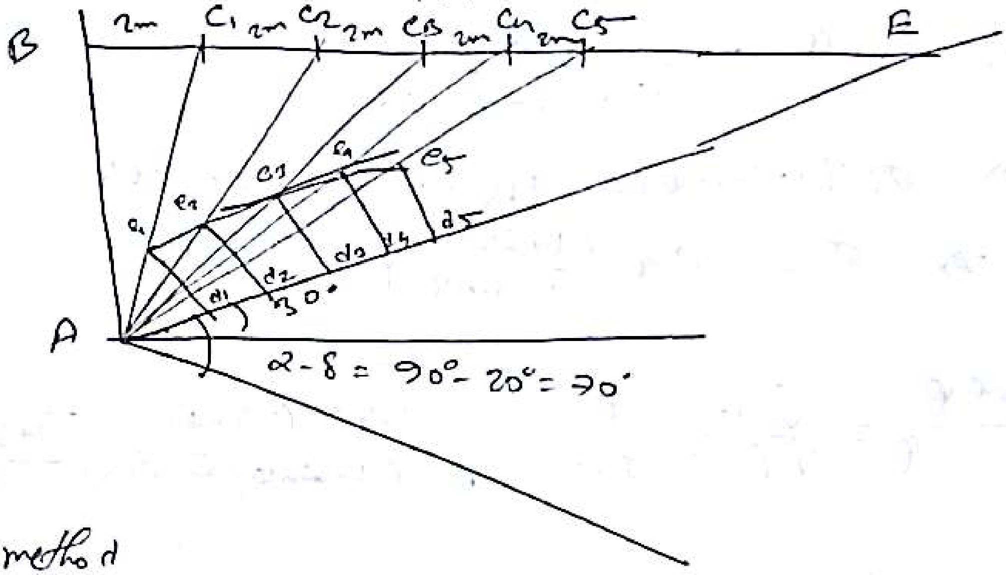
2013-14 (6) culman's graphical method.

$\varphi = 30^\circ$

$\delta = 20^\circ$

$\gamma = 18\ kN/m^3$

10 m wall.




Rankine method

$$K_a = \frac{1-\sin\varphi}{1+\sin\varphi} = \frac{1}{3}$$

$$P_{ac} = \frac{1}{2} K_a \gamma H^2 = \frac{1}{2} \times \frac{1}{3} \times 18 \times 10^2 = 300\ kN/m.$$

culmann method:

$ABC_1 = \frac{1}{2} \times AB \times BC_1 \times \gamma = \frac{1}{2} \times 10 \times 2 \times 18 = 180$

$ABC_2 = \frac{1}{2} \times AB \times BC_2 \times \gamma = \frac{1}{2} \times 10 \times 4 \times 18 = 360$

$ABC_3 = \frac{1}{2} \times AB \times BC_3 \times \gamma = \frac{1}{2} \times 10 \times 6 \times 18 = 540.$

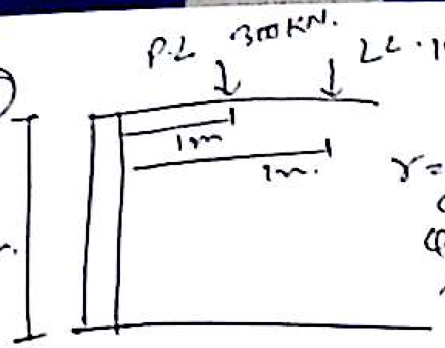
$ABC_4 = \frac{1}{2} \times AB \times BC_4 \times \gamma = \frac{1}{2} \times 10 \times 8 \times 18 = 720$

$ABC_5 = \frac{1}{2} \times AB \times BC_5 \times \gamma = \frac{1}{2} \times 10 \times 10 \times 18 = 900\ kN$

900 kN = 9 cm.

1 cm = 100 kN.

(2)




$\gamma = 19.2\ KN/m^3$
$c = 0$
$\phi = 38°$
$\mu = 0.35$

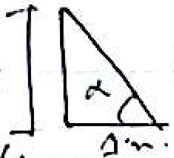
$x = n \quad m = \frac{x}{h} = \frac{1}{5} = 0.2 < 0.4$

$$P_h = \frac{0.28\,Q}{H^2}\,\frac{n^2}{(0.16+n^2)^3}$$

$0.28$
$= 1.77 \times 0.4^2$
$= 0.28$

At a lateral distance of 1.5m from wall

$P_h' = P_h \cos^2(1.1\alpha)$.



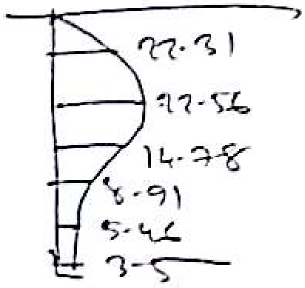

$\alpha = \tan^{-1}\left(\frac{1.5}{1}\right)$
$= 56.31°$

$$= \frac{0.28\,Q}{H^2}\,\frac{n^2}{(0.16+n^2)^3}\cdot\cos^2(1.1\alpha)$$

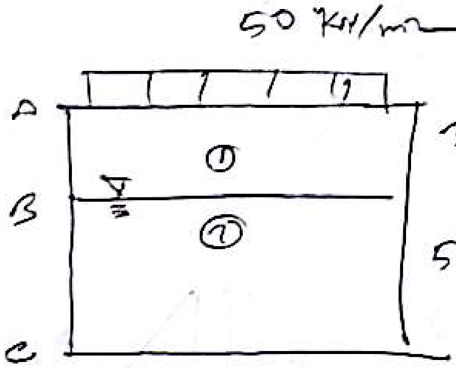
for line load. $m \le 0.4 \quad m = \frac{x}{h} = \frac{2}{5} = 0.4$

$$P_h = \frac{Q}{H}\cdot\frac{0.203\,n}{(0.16+n^2)^2}$$

| Depth → | $n = \frac{y}{h}$ | Line load. $\frac{Q}{H}\cdot\frac{0.203n}{(0.16+n^2)^2}$ | Point load. $\frac{0.28Q}{H^2}\,\frac{n^2}{(0.16+n^2)^3}\cos^2(1.1\alpha)$ | total |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |
| 0.833 | 0.167 | 3.12 | 19.19 | 22.31 |
| 1.667 | 0.33 | 4.15 | 18.41 | 22.56 |
| 2.5 | 0.5 | 2.70 | 12.08 | 14.78 |
| 3.33 | 0.667 | 1.5 | 7.41 | 8.91 |
| 4.167 | 0.833 | 0.83 | 4.63 | 5.46 |
| 5 | 1 | 0.48 | 3.02 | 3.5 |




(8)




$\gamma_1 = 16\ KN/m^3$
$\phi_1 = 30°$ $q_0 = 50\ KN/m^2$

$\gamma_2 = 18\ KN/m^3$
$\phi_2 = 33°$

$c_1 = 10$
$c_2 = 5$

For Soil 1

$$K_{a1} = \frac{1-\sin\phi_1}{1+\sin\phi_1} = 1/3$$

At A, $P_{ac} = q_0 K_a + K_a \gamma_1 h - 2c_1\sqrt{K_a}$

$$= 50\times\frac{1}{3} + \frac{1}{3}\times 16\times 0 - 2\times 10\times\sqrt{1/3}$$

$$= 5.12\ KN/m$$

for soil 2. $K_{a2} = \dfrac{1-\sin\phi_2}{1+\sin\phi_2} = 0.29$

At B for Soil 1.

$P_{ac} = q_0 K_a + K_a \gamma_1 h_1 - 2c_1\sqrt{K_a}$

$= 50\times\frac{1}{3} + \frac{1}{3}\times 16\times 3 - 2\times 10\sqrt{1/3}$

$= 21.1\ KN/m$

at B, we have to consider both surcharge load and overlying for soil 2.

$$\sigma_v = q_0 + \gamma_1 h_1 = 50 + 16\times 3$$
$$= 98 \text{ kN/m}^2$$

$$P_{ac} = K_{a2}.\sigma_v - 2c_2\sqrt{K_{a2}}$$
$$= 0.29\times 98 - 2\times 5\times \sqrt{0.29}$$
$$= 23.03 \text{ kN/m}$$

at C.

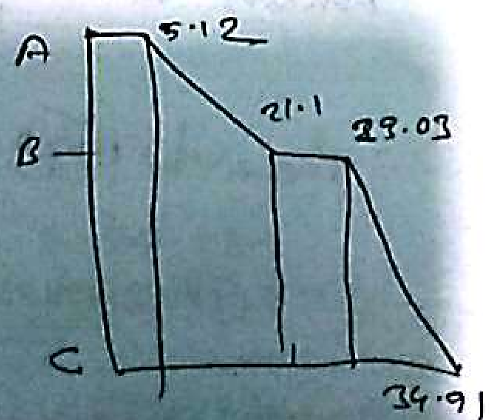
$$P_{ac} = q_0 K_{a2} + K_{a2}\gamma_2 h_2 - 2c_2\sqrt{K_{a2}} + \gamma_1 h_1 K_{a2}.$$

$$= 50\times 0.29 + 0.29\times(18-9.81)\times 5$$
$$- 2\times 5\times\sqrt{0.29} + (10\times 3)\times 0.29$$
$$= 34.91 \text{ kN/m}^2$$

Neglecting water pressure.

total thrust

$$= (5.12\times 8) + \tfrac{1}{2}\times(21.1-5.12) + (23.03-5.12)\times 5$$
$$+ (34.91-23.03)\times\tfrac{1}{2}\times 5$$
$$= 184.18 \text{ kN/m}.$$



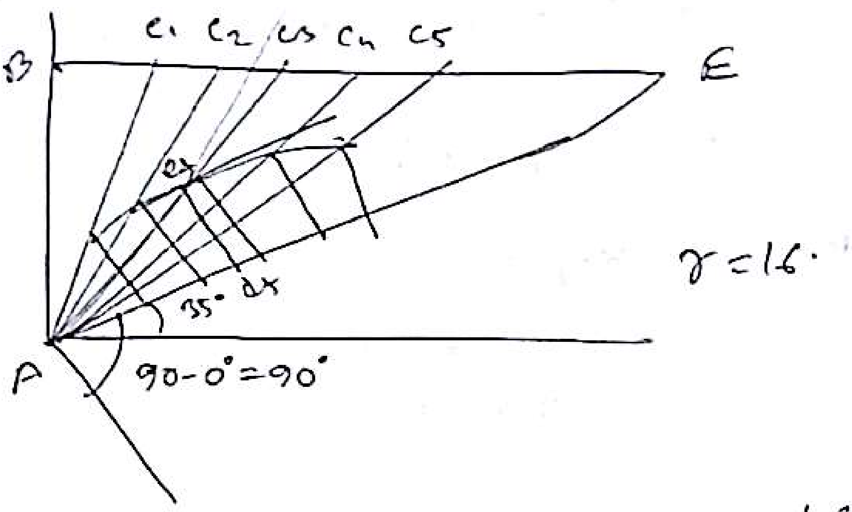

taking moment about C.

$$184.18h = 40.96\times(\tfrac{8}{2}) +$$
$$23.97\times[5+ \tfrac{1}{3}\times 3]$$
$$+ 89.55\times 5/2$$

$= 3.15$ m. (from base)

2012-13

(6)




(6) Weight of wedges $= \frac{1}{2} \times AB \times (Bc_1 | Bc_2 | Bc \ldots)\gamma$

$W_{ABC_1} = \frac{1}{2} \times 10 \times 2 \times 16 = 160\ KN$

$W_{ABC_2} = \frac{1}{2} \times 10 \times 4 \times 16 = 320\ KN$

$W_{ABC_3} = \frac{1}{2} \times 10 \times 6 \times 16 = 480\ KN$

$W_{ABC_4} = \frac{1}{2} \times 10 \times 8 \times 16 = 640\ KN$

$W_{ABC_5} = \frac{1}{2} \times 10 \times 10 \times 16 = 800\ KN$

800 KN = 12 cm. $\quad$ 1 KN = 0.015 cm.

$e_f d_f = 3.5\ cm = \frac{800}{12} \times 3.5 = 233.33\ KN/m.$

Ranking formula.

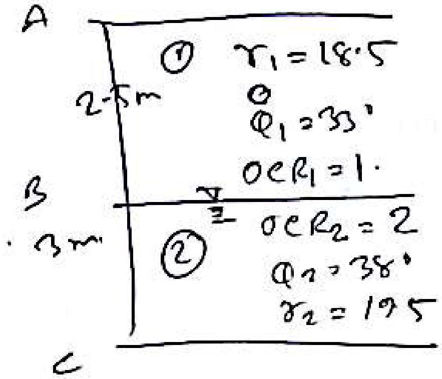
$K_a = \frac{1 - \sin\varphi}{1 + \sin\varphi} = 0.27$

$P_{ae} = \frac{1}{2}\gamma H^2 K_a = \frac{1}{2} \times 16 \times 10^2 \times 0.27$

$= 216\ KN/m.$

(7) Basic consideration.

Rankin considered the equilibrium of a soil element for columb's theory → columb considered the equilibrium of a soil wedge during failure in a soil mass.




For soil 1.

$K_0(1) = (1-\sin\varphi_1) \cdot OCR_1^{\sin\varphi_1}$

$= (1-\sin 33) \, 1^{\sin 33}$

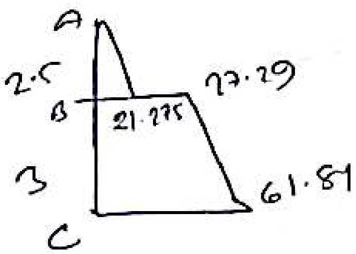
$= 0.46$

At B, for soil 1.

$P_0 = K_0 \cdot \gamma_1 H_1$

$= 0.46 \times 18.5 \times 2.5$

$= 21.275 \text{ KN/m}^2$




~~at B~~ for soil 2

$K_{02} = (1-\sin\varphi_2)\, OCR_2^{\sin\varphi_2}$

$= (1-\sin 38)\, 2^{\sin 38}$

$= 0.59$

$\sigma_v = \gamma_1 H_1 = 18 \times 2.5 = 46.25$

$\sigma_h = K_{02} \cdot \sigma_v = (0.59 \times 46.25)$

$= 27.29 \text{ KN/m}^2$

At C.

$P_0 = 27.29 + K_{02} \cdot \gamma_2 H_2$

$= 27.29 + 0.59 \times 19.5 \times 3 = 61.81 \text{ KN/m}^3$.

Total lateral thrust $= [\frac{1}{2} \times 2.5 \times 21.275 + 3 \times 27.29 + \frac{1}{2} \times (61.81 - 27.29) \times 3]$

$= 160.24 \text{ KN/m}$

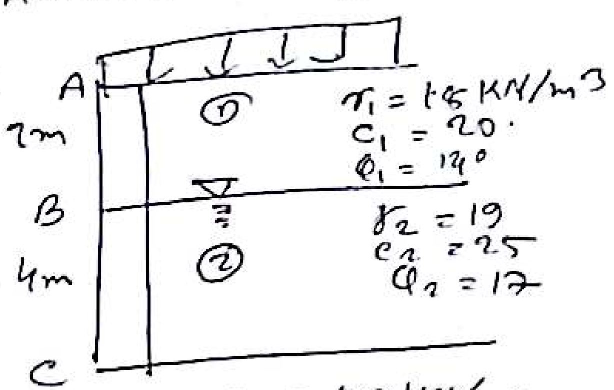
$\boxed{\text{Water pressure ? }}$

↳ maybe procedure এ ঠিক আছে.

passive pressure.

(8)

$P_{pc} = K_p \gamma h + 2c\sqrt{K_p}$




$q_0 = 50\ KN/m^2$

At A.

~~$P_{pc}$~~ =

for soil 1.

$K_{p(1)} = \dfrac{1+\sin 14}{1-\sin 14}$

$= 1.64$

at A $\quad P_{pc} = q_0 K_{p(1)} + 2c_1\sqrt{K_{p(1)}}$

$= 50 \times 1.64 + 2 \times 20 \times \sqrt{1.64}$

$= 133.22\ KN/m^2$

at B for soil 1.

$P_{pc(B)} = 133.22 + K_{p_1}\gamma_1 H_1$

$= 133.22 + 1.64 \times 18 \times 2$

$= 192.26\ KN/m^2$

at B for soil 2

$K_{p(2)} = \dfrac{1+\sin 17}{1-\sin 17}$

$= 1.83$

$\sigma_{v(B)} = q_0 + \gamma_1 h_1$

$= 50 + 18 \times 2 = 86\ KN/m^2$

$P_{pc(B)} = K_{p(2)} \cdot \sigma_{v(B)} + 2c_2\sqrt{K_{p(2)}}$

$= 1.83 \times 86 + 2 \times 25 \times \sqrt{1.86}$

$= 225.6$

at C for soil 2

$P_{pc(c)} = 225.6 + K_{p(2)}\gamma_2' H_2$

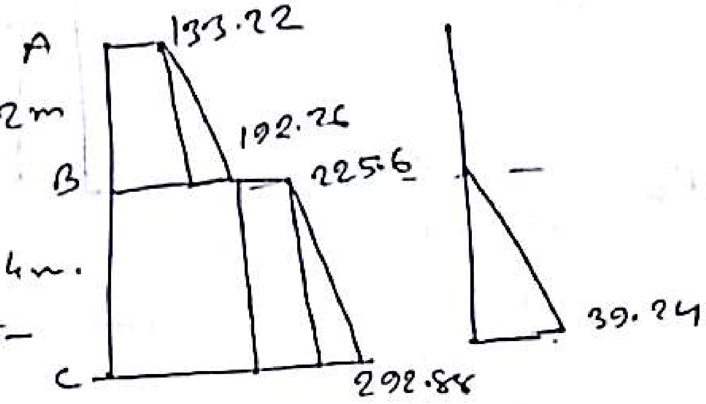
$= 225.6 + 1.83 \times (19 - 9.81) \times 4$

$= 292.88\ KN/m^2$

water pressure at c.

$$P_w = \gamma_w h_2 = 9.81 \times 4$$
$$= 39.24\ kN/m^2$$

Total thrust




$$= 133.22 \times 2 + \frac{1}{2} \times 2 \times (192.26 - 133.22) + 225.6 \times 4 + \frac{1}{2} \times 4 \times (292.88 - 225.6) + \frac{1}{2} \times 4 \times 39.24$$

$$= 1440.92\ kN/m$$

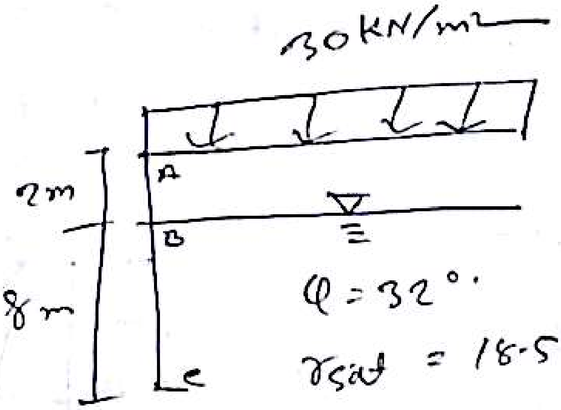
taking moment about C.

$$1440.92 \times h = 266.44 \times (4+1) + 59.04 \times (4 + \tfrac{2}{3}) + 902.4 \times \tfrac{4}{2} + 134.56 \times \tfrac{4}{3} + 78.48 \times \tfrac{4}{3}$$

$\Rightarrow h = 2.57\,m$ from base.

2011-12

3 (b)




$\varphi = 32°$

$\gamma_{sat} = 18.5\ KN/m^3$

$$K_a = \frac{1-\sin\varphi}{1+\sin\varphi}$$

$$= \frac{1-\sin 32}{1+\sin 32} = 0.307$$

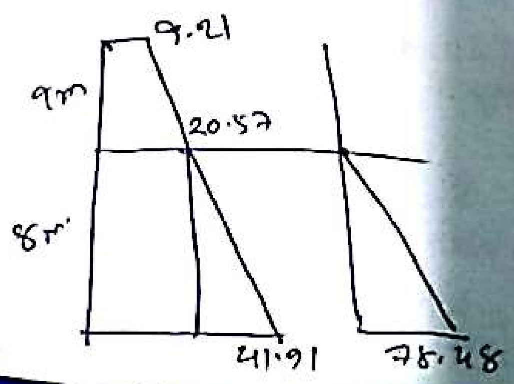
at A. $\sigma_v = 30\ KN/m^2$.

$$P_{ac(A)} = K_a \cdot \sigma_v = 0.307 \times 30$$
$$= 9.21\ KN/m^2$$

at B.
$$P_{ac(B)} = 9.21 + K_a \cdot \gamma_{sat} \cdot h_1$$
$$= 9.21 + 0.307 \times 18.5 \times 2$$
$$= 20.57$$

at C pressure by Soil
$$P_{ac(C)} = 20.57 + K_a(\gamma_{sat} - \gamma_w) \times h_2$$
$$= 20.57 + 0.307 \times (18.5 - 9.81) \times 8$$
$$= 41.91\ KN/m^2$$

at C pressure by water $P_{w(C)} = \gamma_w h_2$
$$= 9.81 \times 8 = 78.48\ KN/m^2$$



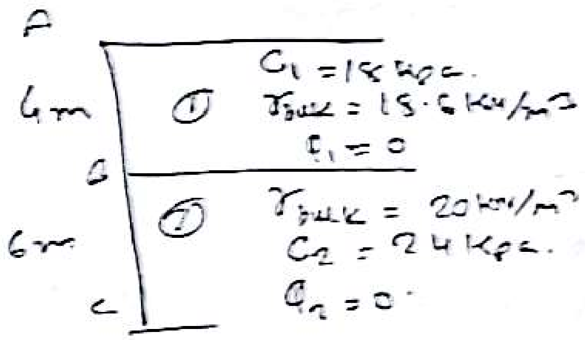
Lateral thrust

$= (9.21 \times 2) + \frac{1}{2} \times 2 \times (20.57 - 9.21) + 20.57 \times 8$
$\quad + \frac{1}{2} \times 8 \times (41.91 - 20.57) + \frac{1}{2} \times 8 \times 78.48$

$= 18.42 + 11.36 + 164.56 + 85.36 + 313.92$

$= 593.62$ kN/m.

2010-1)




layer 1 and layer 2

$$K_a = \frac{1 - \sin\phi}{1 + \sin\phi} = 1$$

depth of tension zone to $\phi = 0$.

$$h_c = \frac{2c}{\gamma}\left(\tan 45° + \phi/2\right) = \frac{2 \times 18}{18.6} = 1.94 \text{ m.}$$

at A. $\quad P_{ae}(A) = K_a \gamma_1 h_1 - 2c\sqrt{K_a}$.

$= 0 - 2 \times 18 \times \sqrt{1}$

$= -36$.

at B for layer ①

$P_{ac}(B) = K_a \gamma_1 h_1 - 2c\sqrt{K_a}$

$= 1 \times 18.6 \times 4 - 2 \times 18\sqrt{1} = 38.4$

at B for layer 2

$\sigma_v = \gamma_1 h_1 = 18 \times 6 = 74.4 \text{ kN/m}^2$

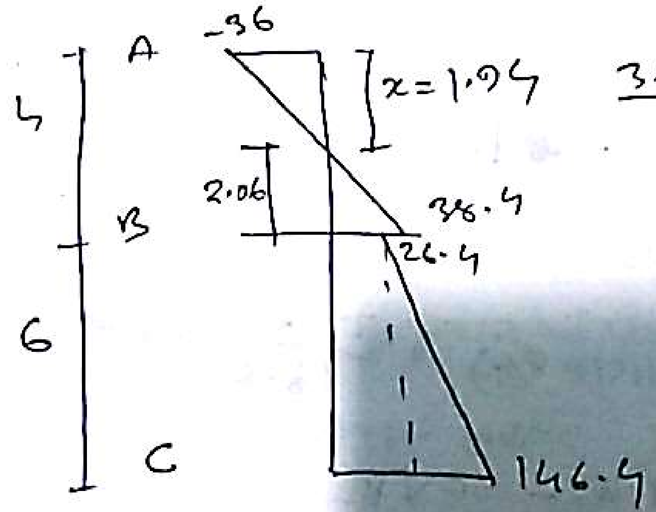
$P_{ac}(B) = K_a . \sigma_v - 2c\sqrt{K_a}$

$= 1 \times 74.4 - 2 \times 24 \times \sqrt{1} = 26.4$

at C for layer 2

$P_{ac}(C) = 26.4 + K_a \gamma_2 h_2$

$= 26.4 + 20 \times 6 \times 1 = 146.4$




$\frac{36}{x} = \frac{38.4}{4-x}$

$\Rightarrow x = 1.94$

Total thrust

$$= \left(\frac{1}{2} \times 2.06 \times 38.4\right) + (26.4 \times 6) + \left(\frac{1}{2} \times 6 \times (146.4 - 26.4)\right)$$

$$= 39.55 + 158.4 + 360$$

$$= 557.95$$

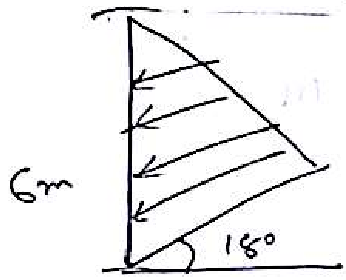
Taking moment about C

$$557.95 \times h = 39.55 \times \left(6 + \frac{2.06}{3}\right) + 158.4 \times \frac{6}{2} + 360 \times \frac{6}{3}$$

$$\Rightarrow h = 2.62$$

↳ from base.

3 (b)




$c = 0$.
$\phi = 33°$
$\gamma = 18\ kN/m^3$
$OCR = 3$.

① Earth pressure at rest

$$K_o = (1 - \sin\phi)\, OCR^{\sin\phi} = (1 - \sin 33) \times 3^{\sin 33}$$

$$= 0.83$$

lateral pressure

$$= K_o\,(1 + \cancel{\tan}\ 0.5 \tan\beta)^2 \gamma h.$$

$$= 0.83\,(1 + 0.5 \tan 18°)^2 \times 18 \times 6 \cos 18$$

$$= 115.2\ kN/m^2$$

lateral thrust $= \frac{1}{2} \times 6 \times 121.13 \times (\cos 18)^2$

$= 328.69$

(ii) Soil moving outward and downward direction

$$K_a = \frac{\cos\beta - \sqrt{\cos^2\beta - \cos^2\phi}}{\cos\beta + \sqrt{\cos^2\beta - \cos^2\phi}}$$

$$= \frac{\cos 18 - \sqrt{\cos^2 18 - \cos^2 33}}{\cos 18 + \sqrt{\cos^2 18 - \cos^2 33}} = 0.36$$

lateral pressure $= K_a \gamma h \cos\beta$

$= 0.36 \times 18 \times 6 \times \cos 18 = 37$

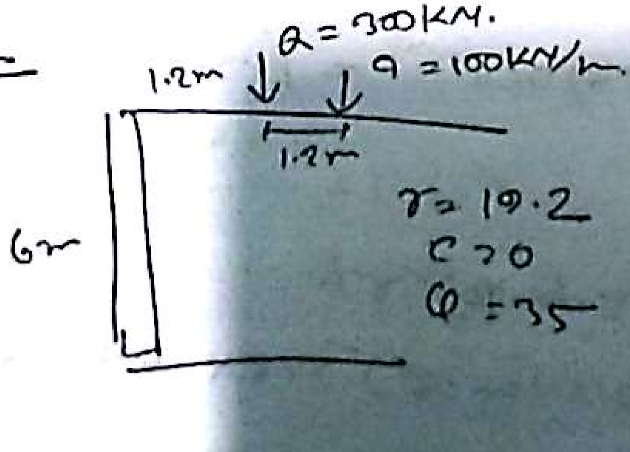
Lateral thrust $= \frac{1}{2} K_a \gamma h^2 \cos\beta$

$= \frac{1}{2} \times 37 \times 6 = 111$

horizontal thrust $= 111 \cos 18$

$= 105.6$

4(a)



For point load

$$m = \frac{x}{H} = \frac{1.2}{6} = 0.2 \le 0.4$$

$$P_n = \frac{1.77Q}{H^2} \times \frac{0.4^2 n^2}{(0.4^2 + n^2)^3}$$

$$= \frac{0.28Q\, n^2}{H^2 (0.16 + n^2)^3}$$

For line load.

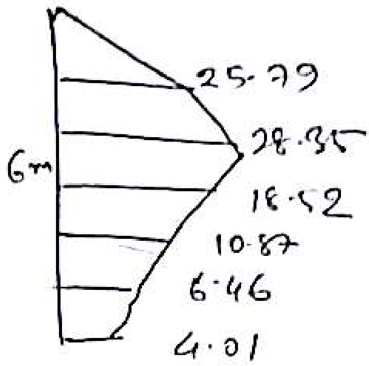
$$m = x/H = \frac{2.4}{6} = 0.4 \le 0.4$$

$$P_n = \frac{4q}{\pi H} \cdot \frac{0.4^2 n}{(0.4^2 + n^2)^2}$$

$$= \frac{q}{H} \cdot \frac{0.203n}{(0.16 + n^2)^2}$$

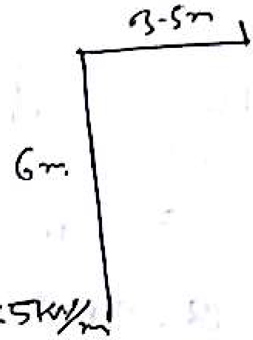
$Q = 300\,kN \quad q = 100\,kN/m.$

| depth $z$ | $n = \frac{z}{H}$ | $P_n = \frac{0.28Q}{H^2} \frac{n^2}{(0.16+n^2)^3}$ | $P_n = \frac{q}{H} \frac{0.203n}{(0.16+n^2)^2}$ | total |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |
| 1 | 1/6 | 9.79 | 16.00 | 25.79 |
| 2 | 1/3 | 13.01 | 15.34 | 28.35 |
| 3 | 1/2 | 8.46 | 10.06 | 18.52 |
| 4 | 2/3 | 4.70 | 6.12 | 10.82 |
| 5 | 5/6 | 2.60 | 3.86 | 6.46 |
| 6 | 1 | 1.50 | 2.51 | 4.01 |




## 2009-10

**2 (b)**



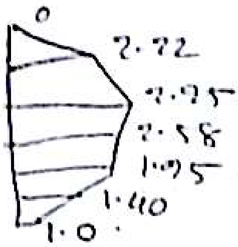

$m = \frac{x}{H} = \frac{3.5}{6}$

$= 0.5833$

$> 0.4$

$P_h = \frac{1.27 q}{H} \cdot \frac{m^2 n}{(m^2+n^2)^2}$

| depth | $n = y/H$ | $P_h = \frac{1.27 \times 25}{6} \times \frac{(0.5833)^2 \times n}{((0.5833)^2+n^2)^2}$ |
|---|---|---|
| 0 | 0 | 0 |
| 1 | 1/6 | 2.22 |
| 2 | 1/3 | 2.95 |
| 3 | 1/2 | 2.58 |
| 4 | 2/3 | 1.95 |
| 5 | 5/6 | 1.40 |
| 6 | 1 | 1.00 |

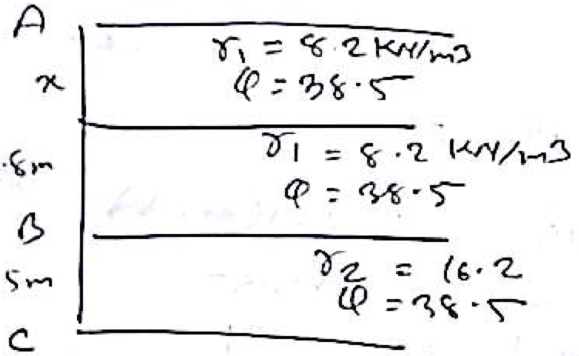



total thrust

$= \frac{1}{2} \times 1 \times [0 + 1 + 2 \times (2.22 + 2.95 + 2.58 + 1.95 + 1.40)]$

$= 11.6$ kN/m.

3(a) Before increasing the height




$P_h = \frac{1}{2} K_a \gamma h^2$

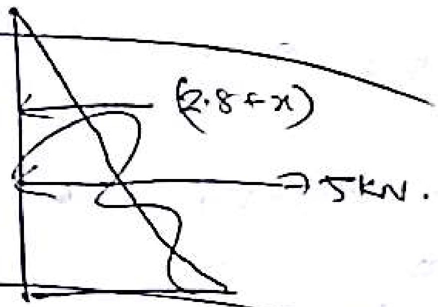
$\Rightarrow 75 = \frac{1}{2} K_a \times 16.2 \times 6.3^2$

$\Rightarrow K_a = 0.233$

~~$\tan^2(45° - \phi/2) = 0.233$~~

~~after adding cinder.~~

~~$\frac{1}{2} K_a \gamma$.~~




$\tan(45° - \phi/2) = 0.233$

$\Rightarrow \phi = 38.5°$

Let x height added.

at B. $P_{ae(B)} = K_a \gamma_1 h_1$

$= 0.233 \times 8.2 \times (2.8 + x)$

at B layer 2 $\sigma_v = \gamma_1 h_1 = 8.2 \times (2.8 + x)$

$\cancel{P_{ac(B)} = \gamma_1 h_1 =}$

$P_{ac(B)} = K_a . \sigma_v$

$= 0.233 \times 8.2 \times (2.8 + x)$

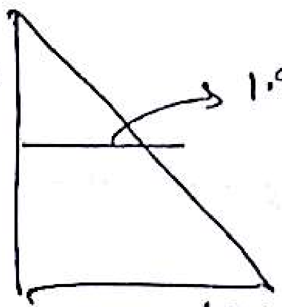
at c.

$P_{ac(C)} = 0.233 \times 8.2 \times (2.8+x) + K_a \gamma_2 h_2$

$= 0.233 \times 8.2 \times (2.8+x) + 0.233 \times 16.2 \times 3.5$

$= 1.91 (2.8+x) + 13.21$

total thrust




$= \frac{1}{2} \times (2.8+x) \times 1.91(x+2.8)$

$+ 1.91(x+2.8) \times 3.5$

$+ \frac{1}{2} \times 3.5 \times 13.21$

$\Rightarrow 75 = 0.955 (x+2.8)^2$

$+ 6.685 (x+2.8)$

$+ 23.12$

$\Rightarrow 0.955 P^2 + 6.885 P - 51.88 = 0$

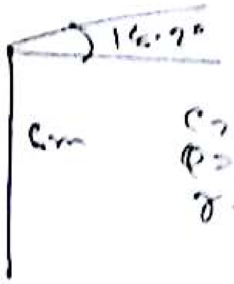
$\Rightarrow P = 4.66$ or $-11.6$

$x + 2.8 = 4.66$ $\qquad x + 2.8 = -11.6$

$\Rightarrow x = 1.86$ $\qquad \Rightarrow x = -14.46.$

$\boxed{x = 1.86}$

4(b) For active pressure




$c = 0$
$\varphi = 30°$
$\gamma = 17 \text{ kN/m}^3$

$$K_a = \frac{\cos\beta - \sqrt{\cos^2\beta - \cos^2\varphi}}{\cos\beta + \sqrt{\cos^2\beta - \cos^2\varphi}}$$

$$= \frac{\cos 18.2 - \sqrt{\cos^2 18.2 - \cos^2 30}}{\cos 18.2 + \sqrt{\cos^2 18.2 - \cos^2 30}} = 0.417$$

Active horizontal thrust $= \frac{1}{2} K_a . \gamma H^2 \cos\beta \times \cos\beta$

$= \frac{1}{2} \times 0.417 \times 17 \times 6^2 \times \cos(18.2) \times \cos(18.2)$

$= 121.2 \times \cos(18.2) = 115.13$

For passive pressure

$$K_p = \frac{1 + \sin\varphi}{1 - \sin\varphi} = \frac{1 + \sin 30°}{1 - \sin 30°} = 3$$

passive thrust $= \frac{1}{2} \times K_p . \gamma H^2$

$= \frac{1}{2} \times 3 \times 17 \times D^2$

$\therefore$ $25.5 D^2 = 115.31$

$\Rightarrow$ $D = 2.13$ m.

2008-09

1 (a)

For loose state.

$e_1 = 0.5$

$\gamma_{d1} = 17.8$ kN/m3

$\varphi = 30^\circ$

$$K_{P_1} = \frac{1+\sin 30^\circ}{1-\sin 30^\circ} = 3$$

$$\text{passive thrust} = \frac{1}{2} K_{P_1} \cdot \gamma_{d_1} H^2$$
$$= \frac{1}{2} \times 3 \times 17.8 \times 8^2$$
$$= 1708.8 \text{ kN/m}.$$

For dense state. $\gamma_d = 18.8$ kN/m3.

$\varphi = 35^\circ$

$$K_P = \frac{1+\sin 35}{1-\sin 35} = 3.69$$

$$\text{passive thrust} = \frac{1}{2} K_P \gamma_d H$$
$$= \frac{1}{2} \times 3.69 \times 18.8 \times 8^2$$
$$= 2219.9$$

$$\text{Ratio} = \frac{1708.8}{2219.9} = 0.77 : 1$$

According to Aziz

$$\frac{V_2}{V_1} = \frac{1+e_2}{1+e_1} \Rightarrow \frac{H_2 \times A}{H_1 \times A} = \frac{1+0.4}{1+0.5}$$

$$\Rightarrow H_2 = 7.47 \text{ m}.$$

$$P_2 = \frac{1}{2} \times 3.\cancel{69} \times 18.8 \times 7.47^2 = 1940.76$$

1 (a)

$\gamma = 22\ kN/m^3$

Unsupported height $= 4\ m$.

$$H_u = \frac{4c}{\gamma} \tan(45 + \frac{\phi}{2})$$

$$\Rightarrow 4 = \frac{4c}{22} \Rightarrow c = 22\ kN/m^3$$

1 (b)

$I_P = LL - PL = 40 - 25 = 15\%$.

$OCR = 2.5$

$$K_{0(NCC)} = \cancel{K_{0(NCC)}}\ 0.19 + 0.233 \log(I_P)$$

$$= 0.19 + 0.233 \log(15) = 0.46$$

$$K_{0(OCC)} = K_{0(NCC)} \times \sqrt{OCR} = 0.46\sqrt{2.5}$$

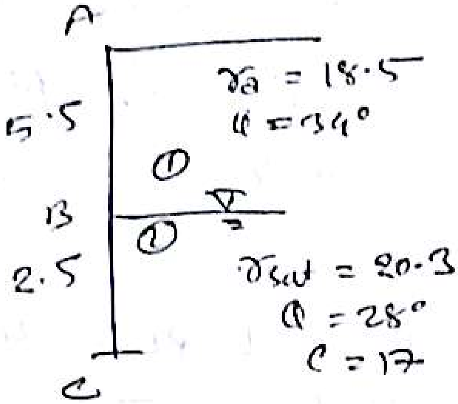
$$= 0.73$$

$$\text{Thrust} = \frac{1}{2} K_0 \gamma H^2 = \frac{1}{2} \times 0.734 \times \gamma \times 6^2$$

$$= 13.212\,\gamma.$$

2(a) বাদে.

4 (a)




For layer ①

$$K_{a(1)} = \frac{1-\sin 34}{1+\sin 34}$$
$$= 0.28$$

For layer 2

$$K_{a2} = \frac{1-\sin 28}{1+\sin 28}$$
$$= 0.36$$

at B for layer 1.

$$P_{ac}(B) = K_{a(1)} \gamma_1 h_1$$
$$= 0.28 \times 18.5 \times 5.5 = 128.5$$

at B for layer 2

$$\sigma_v = \gamma_1 h_1 = 18.5 \times 5.5 = 101.75$$

$$P_{ac}(B) = K_{a(2)} \cdot \sigma_v - 2c\sqrt{K_{a(2)}}$$
$$= 0.36 \times 101.75 - 2 \times 17 \times \sqrt{0.36}$$
$$= 16.23 \text{ kN/m}^2$$

At C.

$$P_{ac}(C) = 16.23 + K_{a(2)}(\gamma_{sat} - \gamma_w) h_2$$
$$= 16.23 + 0.36 \times (20.3 - 9.81) \times 2.5$$
$$= 25.671$$

water pressure $\cdot P_w = \gamma_w h_2$
$$= 9.81 \times 2.5$$
$$= 24.5$$

Total thrust

$= \left(\frac{1}{2} \times 5.5 \times 28.5\right) + \left(2 \times 5 \times 16.23\right) + \frac{1}{2} \times 2.5 \left(25.67 - 16.23\right) + \frac{1}{2}\left(2.5 \times 24.5\right)$

$= 161.4$