1

(a)

NC to 400 kPa

$v = N - \lambda \ln \sigma' = \Gamma + \lambda - \kappa - \lambda \ln \sigma'$

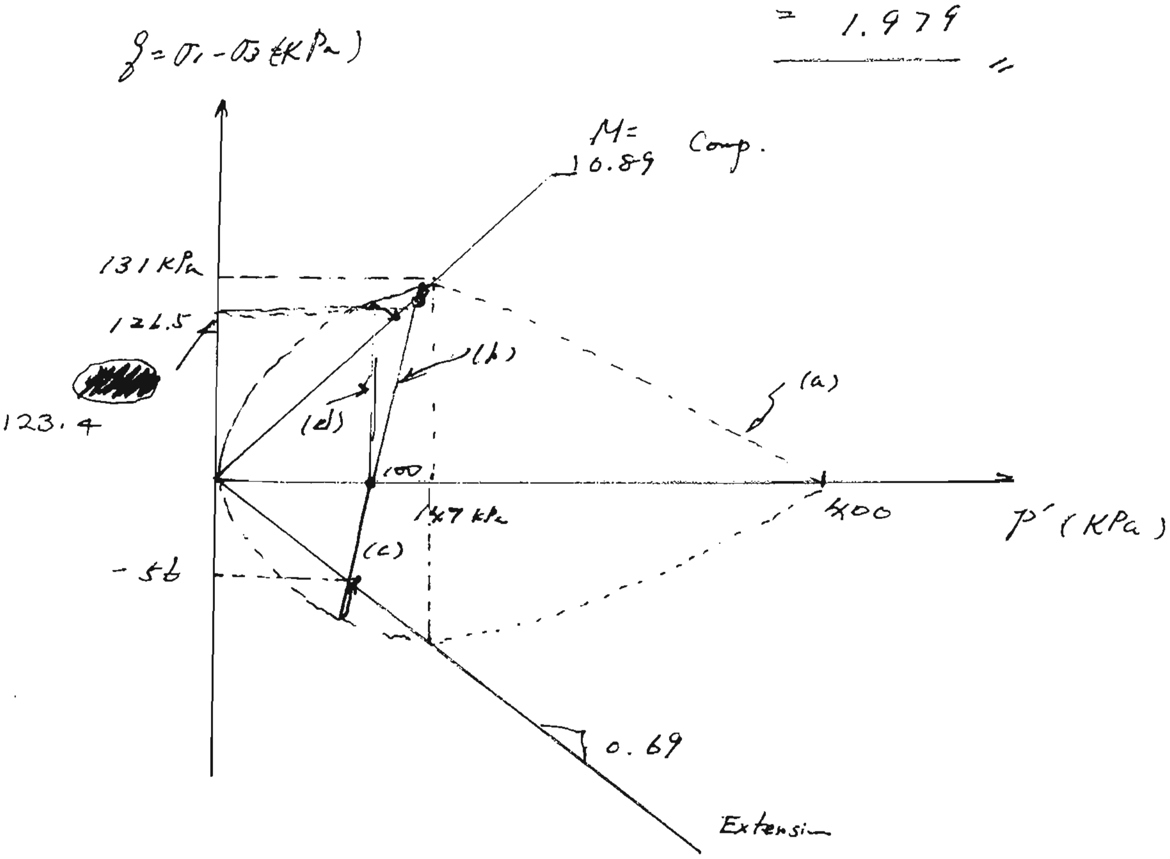
$= 2.759 + 0.161 - 0.062 - 0.161 \ln 400$

$= 1.893$

Swelled back to 100 kPa

$v = 1.893 + \kappa \ln\left(\frac{400}{100}\right) = 1.893 + 0.062 \ln\left(\frac{400}{100}\right)$

$= \underline{1.979}$ //



(b) $\frac{\Delta q}{\Delta p} = \frac{\Delta \sigma_1}{\Delta \sigma_1/3} = 3$

$M = \frac{q}{p'} = \frac{\Delta q}{100 + \Delta q/3} = 0.89$

$0.89\,(100 + \Delta q/3) = \Delta q$

$q = \Delta q = \frac{100 \times 0.89}{(1 - 0.89/3)} = \underline{126.5 \text{ kPa}}$

$p' = 126.5/0.89 = 142.2$ kPa

$= 1.961$

Question 2

(a) $\sigma_v = 20 \times 20 = 400$ kPa

$u = 18 \times 10 = 180$ kPa

$\therefore \sigma_v' = 400 - 180 = 220$ kPa

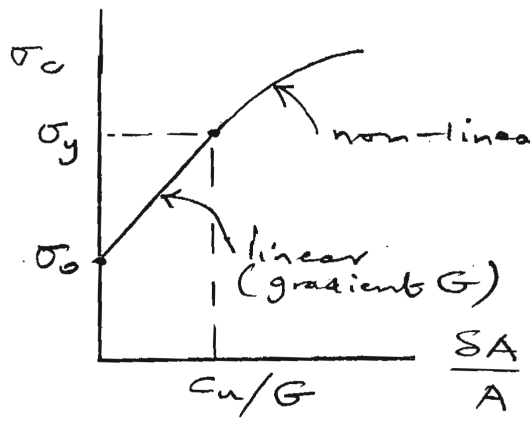
$K_o = \dfrac{\sigma_h'}{\sigma_v'} \Rightarrow \sigma_h' = 1.5 \times 220 = 330$ kPa

$\sigma_o = \sigma_{ho} = \sigma_h' + u = 330 + 180 = \underline{510 \text{ kPa}}$ [15%]

(b) yield first occurs at cavity pressure $\sigma_c = \sigma_y$

when $\sigma_y = \sigma_o + c_u$

i.e. at $\sigma_y = 510 + 150 = \underline{660 \text{ kPa}}$



$\dfrac{\delta A}{A} = \dfrac{c_u}{G} = \dfrac{150}{50 \times 10^3} = 3 \times 10^{-3}$

$\dfrac{\delta A}{A} \simeq 2 \varepsilon_c$ for small strains.

ε_c = cavity strain $= \dfrac{\rho_c}{r_{co}}$

ρ_c = radial displacement

r_{co} = cavity radius

$\therefore \rho_c = \varepsilon_c \cdot r_{co} = \frac{1}{2} \times 3 \times 10^{-3} \times 40 = \underline{0.06 \text{ mm}}$

[30%]

(c) $\delta\sigma_c = \sigma_c - \sigma_o = c_u \left[1 + \ln \dfrac{G}{c_u} + \ln \dfrac{\delta A}{A} \right]$ DATA BOOK

limit pressure when $\dfrac{\delta A}{A} \to 1$, $\ln \dfrac{\delta A}{A} \to 0$

i.e. $\sigma_c = \sigma_o + c_u \left[1 + \ln \dfrac{G}{c_u} \right]$

$= 510 + 150 \left[1 + \ln \dfrac{50 \times 10^3}{150} \right]$

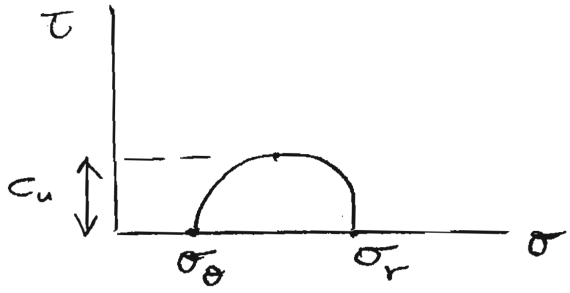
$= 510 + 1021 = \underline{1531 \text{ kPa}}$ [15%]

(note $\sigma_o = \sigma_{ho}$)

(d) $\sigma_r = \sigma_{ho} + G\,\delta A / \pi r^2$

$\sigma_\theta = \sigma_{ho} - G\,\delta A / \pi r^2$

In plastic zone $\sigma_r - \sigma_\theta = 2c_u$



At edge of plastic zone $r = r_p$

$\therefore \sigma_r - \sigma_\theta = 2G\,\delta A / \pi r_p^2 = 2c_u$

$\therefore r_p^2 = G\,\delta A / \pi c_u$

r_c = radius of cavity

$A = \pi r_c^2$

$\therefore \dfrac{r_p}{r_c} = \left(\dfrac{G}{c_u} \cdot \dfrac{\delta A}{A}\right)^{0.5}$ [20%]

(e) $\sigma_c = 1.4 \times \sigma_y = 1.4 \times 660 = 924$ kPa

$\sigma_c - \sigma_o = c_u \left[1 + \ln\dfrac{G}{c_u} + \ln\dfrac{\delta A}{A}\right]$ DATA Book

$\therefore \dfrac{924 - 510}{150} = 1 + 5.81 + \ln\dfrac{\delta A}{A}$

$\therefore \ln\dfrac{\delta A}{A} = -4.05 \Rightarrow \dfrac{\delta A}{A} = 0.017$

$\therefore \dfrac{r_p}{r_c} = \left(\dfrac{50 \times 10^3}{150} \times 0.017\right)^{0.5} = 2.38$

$r_c \doteqdot r_{co} = 40$ mm (for small strains)

$\therefore r_p = 2.38 \times 40 = \underline{95 \text{ mm}}$ [20%]

Question #3

(a) Before embankment construction, stresses at A:

$\sigma_v = 20 \times 10 = 200 \text{ kN/m}^2$

$u_o = 10 \times 9 = 90 \text{ kN/m}^2$

$\therefore \sigma_v' = \sigma_v - u_o = 200 - 90 = 110 \text{ kN/m}^2$

$K_o = 1.0$

$\therefore \sigma_h' = \sigma_v' = 110 \text{ kN/m}^2$

$\therefore \sigma_h = 110 + 90 = 200 \text{ kN/m}^2$

$t = \frac{1}{2}(\sigma_v - \sigma_h) = 0$

$s' = \frac{1}{2}(\sigma_v' + \sigma_h') = 110 \text{ kN/m}^2$

$s = \frac{1}{2}(\sigma_v + \sigma_h) = 200 \text{ kN/m}^2$

$\therefore$ Effective stress (t, s') at A' $(0, 110)$

Total stress (t, s) at A $(0, 200)$

During embankment raising, $\Delta\sigma_h = 0.25\Delta\sigma_v$

$\therefore \Delta t = \frac{1}{2}(\Delta\sigma_v - \Delta\sigma_h) = \frac{1}{2}\Delta\sigma_v(1 - 1/4) = \frac{3}{8}\Delta\sigma_v$

$\Delta s = \frac{1}{2}(\Delta\sigma_v + \Delta\sigma_h) = \frac{1}{2}\Delta\sigma_v(1 + 1/4) = \frac{5}{8}\Delta\sigma_v$

$\therefore \frac{\Delta t}{\Delta s} = \frac{3/8\,\sigma_v}{5/8\,\sigma_v} = \frac{3}{5}$ this is slope of <u>total stress path</u>, TSP

Until yield, <u>effective stress path</u> remains <u>vertical</u> (because behaviour <u>elastic</u> inside yield surface)

Yield first occurs at embankment height H_1 when $\Delta\sigma_v = 50 \text{ kN/m}^2$ at ~~point~~ A soil element

$\therefore \Delta\sigma_h = 0.25 \times 50 = 12.5 \text{ kN/m}^2$

$\therefore \Delta t = \frac{1}{2}(50 - 12.5) = 18.75 \text{ kN/m}^2$

$\Delta s = \frac{5}{3} \times 18.75 = 31.25 \text{ kN/m}^2$

$\therefore$ point C is total stress state (78.75, 231.25) for embankment height H_1

Effective stress path remains vertical, then point C' is effective stress state (18.75, 110).

When embankment height is $0.5H_1$, total stress at point B for which

$t = \frac{1}{2} \times 18.75 = 9.4 \text{ kN/m}^2$

$s = 200 + \frac{1}{2} \times 31.25 = 215.6 \text{ kN/m}^2$

effective stress at point B' for which

$t = 9.4 \text{ kN/m}^2$ (as for TSP)

$s' = 110 \text{ kN/m}^2$ (remains unchanged).

$\therefore$ (i) pore pressure for embankment height $0.5H_1$

$= s - s'$ (for points B, B')

$= 215.6 - 110 = \underline{105.6 \text{ kN/m}^2}$

(ii) pore pressure for embankment height H_1

$= s - s'$ (for points C, C')

$= 231.25 - 110 = \underline{121.25 \text{ kN/m}^2}$

[40%]

(b) Embankment to height H_2

$\Delta\sigma_v = 80 \text{ kN/m}^2$

$\Delta t = \frac{3}{8} \Delta\sigma_v$ (from before)

$= 30 \text{ kN/m}^2$

Critical state Line reached at point D'

$s' = \frac{t}{\sin 25°} = \frac{30}{\sin 25°} = \frac{30}{0.423} = 70.9 \text{ kN/m}^2$

) point D (TSP)

$$\frac{\Delta t}{\Delta s} = \frac{3}{5} \quad \text{(from before)}$$

$\therefore$ for $\Delta t = 30$ kN/m²

$$\Delta s = \frac{5}{3} \times 30 = 50 \text{ kN/m}^2$$

$\therefore$ point D is at (30, 250)

hence pore pressure $= s - s'$ (for points D, D')

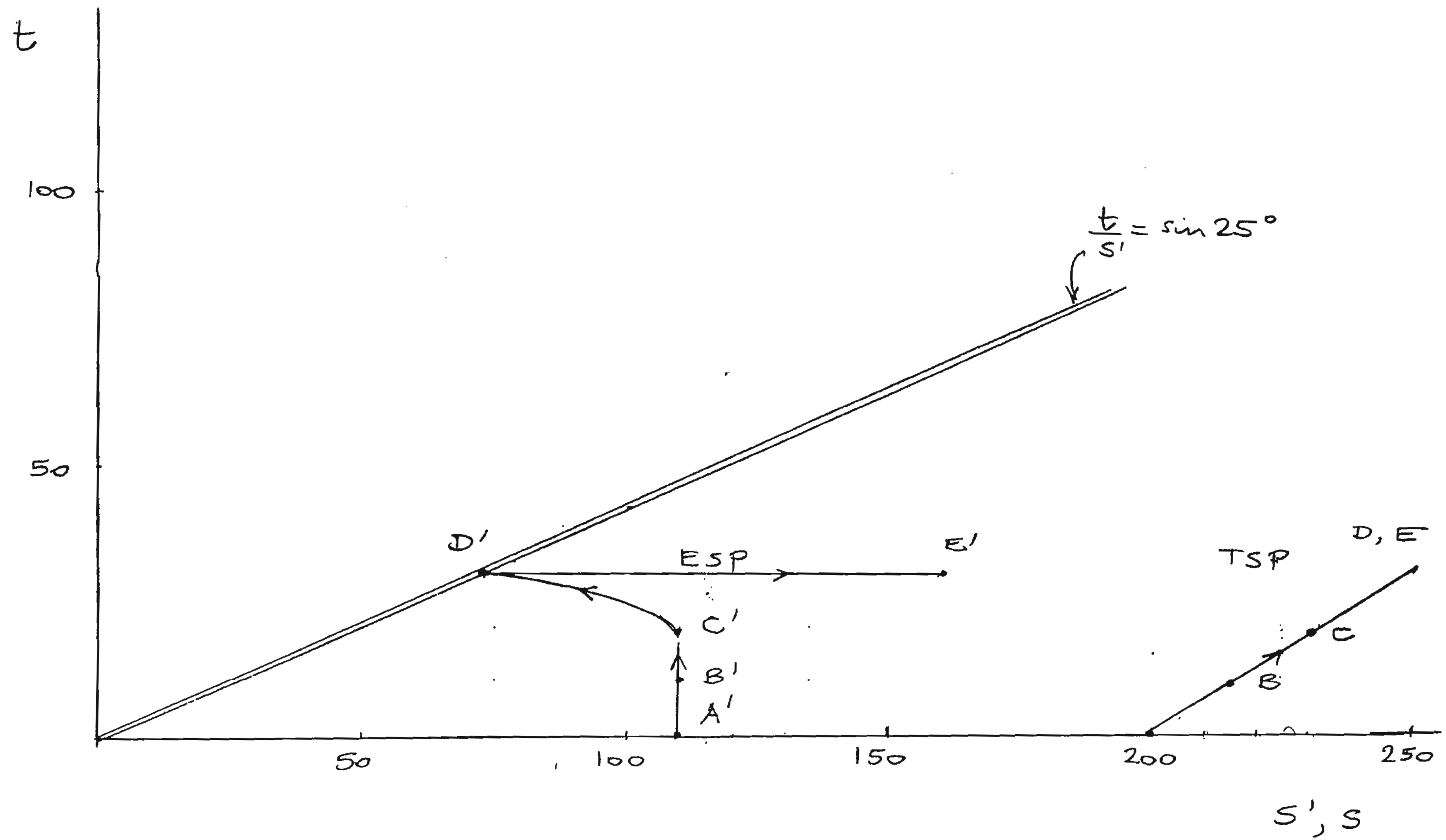
$= 250 - 70.9 = \underline{179.1 \text{ kN/m}^2}$ [40%]

(c) Original pore pressure $u_0 = 90$ kN/m²

$\therefore$ change in pore pressure as effective stress path moves from D' to E' $= 179.1 - 90$

$= \underline{89.1 \text{ kN/m}^2}$

Total stress path does not change. [20%]

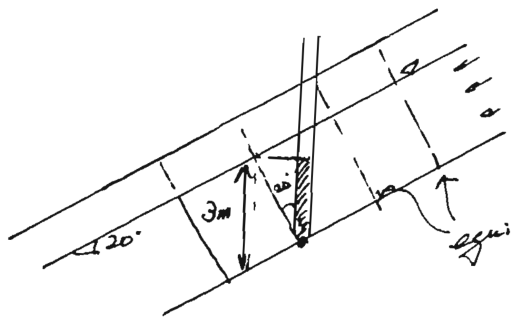

t
100
50
50
100
150
200
250
S', S
$\frac{t}{s'} = \sin 25°$
D'
ESP
E'
C'
B'
A'
TSP
D, E
C
B

4 (a) $\gamma = \left(\frac{G_s + e}{1+e}\right)\gamma_w$

$= \left(\frac{2.65 + 0.7}{1 + 0.7}\right)9.8$

$= \underline{19.31 \ \ KN/m^3}$

(b)



$U = 3 \times 9.8 \times \cos 20° \times \cos 20°$

$= \underline{26.0 \ \ KPa}$

(c) $\sigma_1 = (1m \times 18 + 3m \times 19.3)\cos^2 20°$

$= 75.9 \times \cos^2 20$

$= \underline{67.0 \ \ KPa}$

$\tau = 75.9 \times \cos 20 \times \sin 20$

$= \underline{24.4 \ \ KPa}$

$\sigma' = 67.0 - 26.0 = \underline{41.0 KPa}$

$\phi'_{mob} = \tan^{-1}\left(\frac{24.4}{41.0}\right)$

$= \underline{30.8°}$

(d) $I_D = \frac{0.9 - 0.7}{0.9 - 0.5} = 0.5$

$I_C = \ln\left(\frac{20.000}{41.0}\right) = 6.19$

$I_R = 0.5 \times 6.19 - 1 = 2.10.$

$\phi_{peak} = \phi_{crit} + 5I_R = 36° + 5 \times 2.10 = 46.5°$

$\phi_{crit} = 36°$

$$F.S' \text{ for peak} = \frac{\tan 46.5^\circ}{\tan 30.8} = \underline{1.76}$$

$$FS \text{ for critical} = \frac{\tan 36^\circ}{\tan 30.8^\circ} = \underline{1.22}$$

(e) At the top interface,

$$\sigma = 1 \times 18 \times \cos^2 20^\circ = 15.9 \text{ KPa}$$

$$\tau = 1 \times 18 \times \cos 20^\circ \sin 20^\circ = 5.8 \text{ KPa}$$

$$\tan 26^\circ = \frac{5.8}{(15.9 - u)} = 0.488$$

$$u = \frac{15.9 \times 0.488 - 5.8}{0.488} = 4.01 \text{ KPa}$$

At the sandstone interface

$$\tan 36^\circ = \frac{24.4}{(67 - u)} = 0.727$$

$$u = \frac{67 \times 0.727 - 24.4}{0.727} = 33.4 \text{ KPa}$$

At the top $0 \rightarrow 4.01$ KPa

At the bottom $26.0 \rightarrow 33.4$ KPa

probably fail at the top interface first.