Question 1

(a) At a depth of 7m, present day in-situ stresses:

$\sigma_v = 17 \times 7 = 119$ kPa

$u = 10 \times 5 = 50$ kPa

$\therefore \sigma_v' = \sigma_v - u = 119 - 50 = \underline{69 \text{ kPa}}$

$K_0 = \dfrac{\sigma_h'}{\sigma_v'} = 0.8 \Rightarrow \sigma_h' = 0.8 \times 69 = \underline{55 \text{ kPa}}$

$OCR = \dfrac{\sigma_{vo}'}{\sigma_v'} = 1.5 \Rightarrow \sigma_{vo}' = 1.5 \times 69 = \underline{104 \text{ kPa}}$

$K_{nc} = \dfrac{\sigma_{ho}'}{\sigma_{vo}'} = 0.65 \Rightarrow \sigma_{ho}' = 0.65 \times 104 = \underline{68 \text{ kPa}}$

(σ_{vo}', σ_{ho}' are previous maximum vertical and horizontal effective stresses, when clay was in normally consolidated state) [4]

(b) In the future, ground water table is permanently lowered to 4m below ground surface

$\sigma_v = 17 \times 7 = 119$ kPa (as at present)

$u = 10 \times 3 = 30$ kPa (reduced from 50 kPa)

$\therefore \sigma_v' = \sigma_v - u = 119 - 30 = 89$ kPa (increased from 69 kPa)

$\therefore$ new $OCR = \dfrac{\sigma_{vo}'}{\sigma_v'} = \dfrac{104}{89} = \underline{1.17}$ [2]

(c) (i) Present day q, p', p:

$\sigma_v' = 69$ kPa, $\sigma_h' = 55$ kPa, $\sigma_v = 119$ kPa, $\sigma_h = 105$ kPa

$\therefore q = \sigma_v - \sigma_h = 119 - 105 = 14$ kPa

$p' = \frac{1}{3}\sigma_v' + \frac{2}{3}\sigma_h' = \frac{1}{3} \times 69 + \frac{2}{3} \times 55 = 60$ kPa

$p = p' + u = 60 + 50 = 110$ kPa

$c_u = q_f / 2 = 25 \text{ kPa} \Rightarrow q_f = 50$ kPa

Total stress path $\Delta\sigma_r = 0$ (constant cell pressure)

$\therefore \Delta q = \Delta\sigma_a - \Delta\sigma_r = \Delta\sigma_a$

$\Delta p = \frac{1}{3}\Delta\sigma_a + \frac{2}{3}\Delta\sigma_r = \frac{1}{3}\Delta\sigma_a$

$\therefore \frac{\Delta q}{\Delta p} = \frac{\Delta\sigma_a}{1/3\,\Delta\sigma_a} = 3$

$q_f = 50 \quad \therefore \Delta q$ (from A' to B') $= 50 - 14 = 36$ kPa

At failure $q_f = M p_f' \Rightarrow p_f' = \frac{50}{0.9} = 56$ kPa

$\therefore$ pore pressure at failure, $u_f = p_f - p_f'$

$p_f = p + \Delta p$

$\Delta p = \Delta q / 3 = 36/3 = 12$ kPa

$\therefore p_f = 110 + 12 = 122$ kPa

$\therefore u_f = 122 - 56 = \underline{66 \text{ kPa}}$ [6]

(ii) Drained test : $\Delta\sigma_r = 0, \ \Delta u = 0, \ \Delta\sigma_r' = 0$

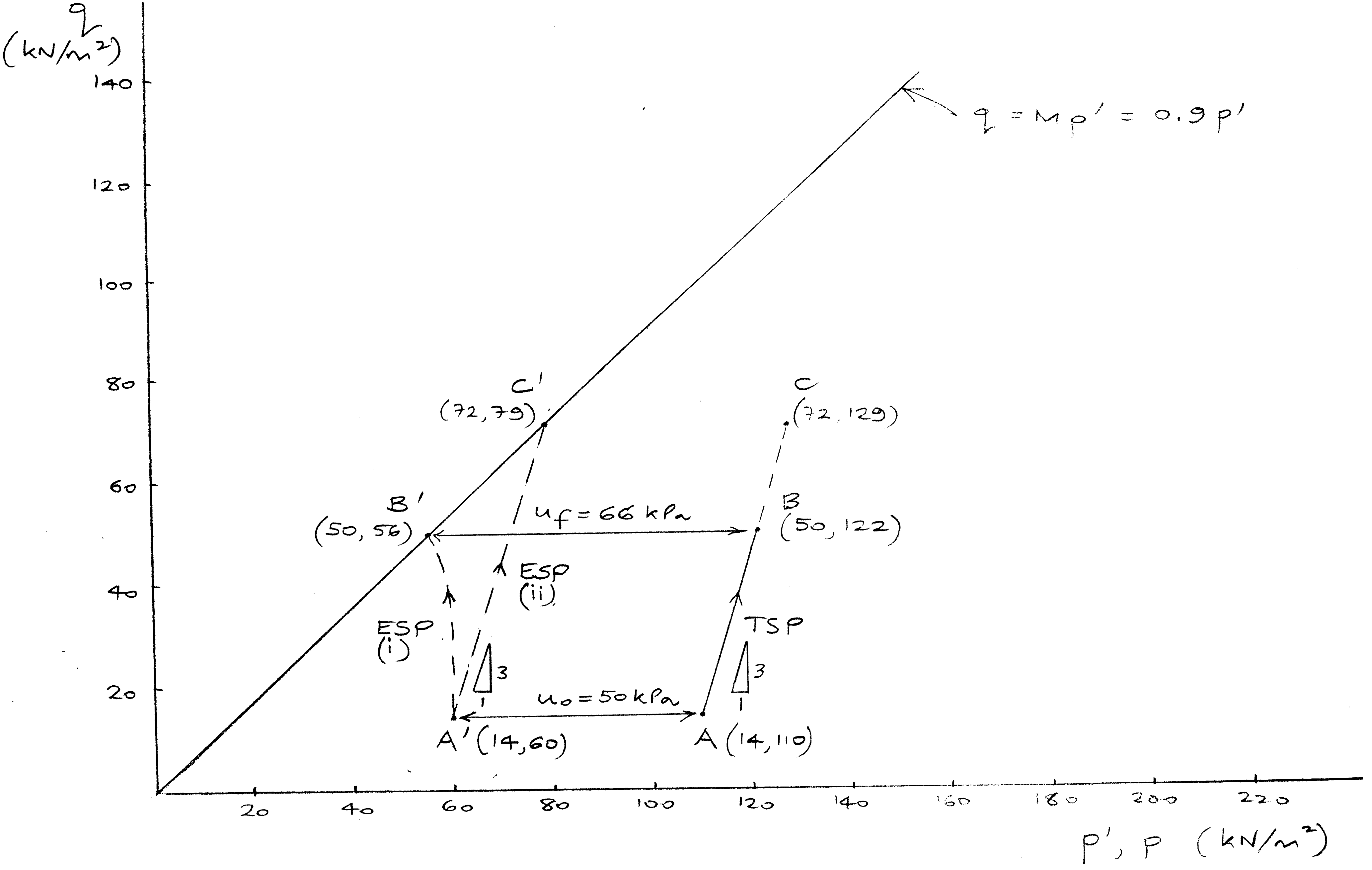
$\therefore \Delta p' = \frac{1}{3}\Delta\sigma_a' + \frac{2}{3}\Delta\sigma_r' = \frac{1}{3}\Delta\sigma_a'$

$\Delta q = \Delta\sigma_a - \Delta\sigma_r = \Delta\sigma_a$

$\therefore$ Effective stress path (ESP) $\frac{\Delta q}{\Delta p'} = \frac{\Delta\sigma_a'}{1/3\,\Delta\sigma_a'} = 3$

Graphical construction of ESP (ESP(ii))
at 3:1 slope intersects $q = Mp'$ line at C'
at which $q_f = \underline{72 \text{ kPa}}$ [6]

(d) Undrained test gives $q_f = 50$ kPa ($c_u = 25$ kPa)
drained test gives $q_f = 72$ kPa
$\therefore$ almost 50% greater strength gained by slow filling of tank under drained conditions. Therefore may be advisable to fill tank slowly in stages
[2]


q (kN/m²)
140
120
100
80
60
40
20
20
40
60
80
100
120
140
160
180
200
220
p′, p (kN/m²)
q = Mp′ = 0.9p′
C′ (72, 79)
C (72, 129)
B′ (50, 56)
B (50, 122)
uf = 66 kPa
ESP (ii)
ESP (i)
TSP
3
1
3
1
u₀ = 50 kPa
A′ (14, 60)
A (14, 110)

Question 2

(a) $\sigma_v = 15 \times 20 = 300$ kPa

$u = 13 \times 10 = 130$ kPa

$\therefore \sigma_v' = 300 - 130 = 170$ kPa

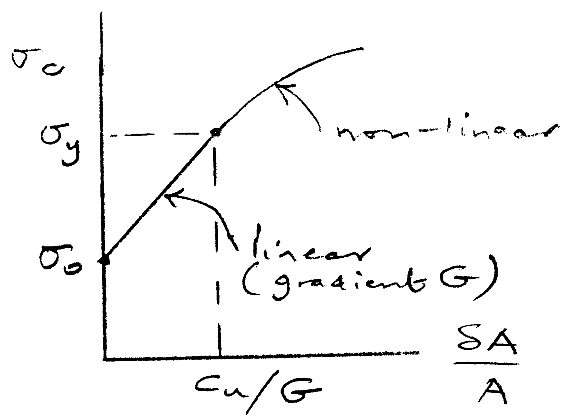
$K_o = \dfrac{\sigma_h'}{\sigma_v'} \Rightarrow \sigma_h' = 1.5 \times 170 = 255$ kPa

$\sigma_o = \sigma_{ho} = \sigma_h' + u = 255 + 130 = \underline{385 \text{ kPa}}$ [15%]

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

when $\sigma_y = \sigma_o + c_u$

i.e. at $\sigma_y = 385 + 150 = \underline{535 \text{ kPa}}$



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

$\dfrac{\delta A}{A} \simeq 2\varepsilon_c$ 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. $\sigma_c = \sigma_o + c_u \left[1 + \ln \dfrac{G}{c_u} \right]$

$= 385 + 150 \left[1 + \ln \dfrac{50 \times 10^3}{150} \right]$

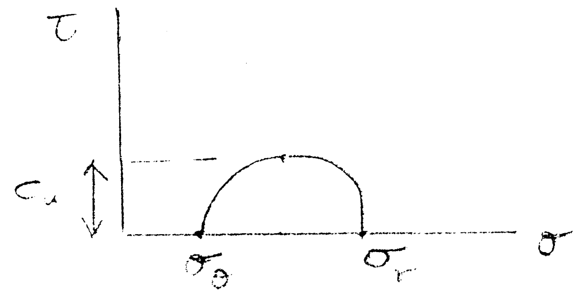
$= 385 + 1021 = \underline{1406 \text{ kPa}}$ [15%]

(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) $\sigma_c = 1.5 \times \sigma_y = 1.5 \times 535 = 803$ kPa

$\sigma_c - \sigma_0 = c_u\left[1 + \ln\dfrac{G}{c_u} + \ln\dfrac{\delta A}{A}\right]$ DATA BOOK

$\therefore \dfrac{803 - 385}{150} = 1 + 5.81 + \ln\dfrac{\delta A}{A}$

$\therefore \ln\dfrac{\delta A}{A} = -4.02 \Rightarrow \dfrac{\delta A}{A} = 0.018$

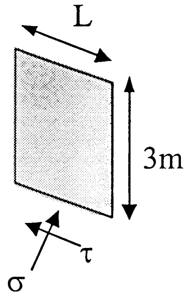
$\therefore \dfrac{r_p}{r_c} = \left(\dfrac{50\times10^3}{150} \times 0.018\right)^{0.5} = 2.45$

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

$\therefore r_p = 2.45 \times 40 = \underline{98\text{ mm}}$ [20%]

QUESTION 3.

(a) The slope angle is 20°. The weight of the block is $3\gamma_d L\cos 20° = 45.1L$ kN/m.

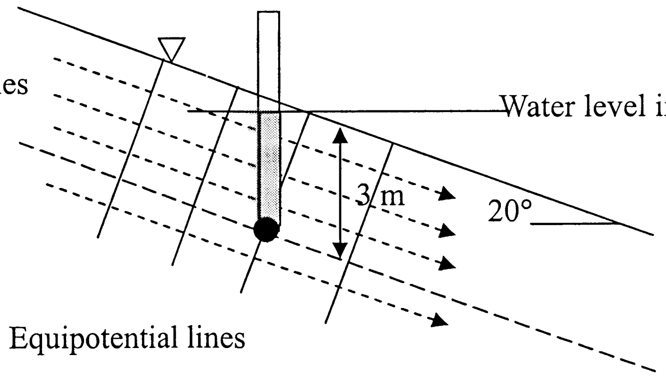


$\sigma = 45.1L\cos 20°/L = \underline{42.4 \text{ kPa}}$

$\tau = 45.1L\sin 20°/L = \underline{15.4 \text{ kPa}}$

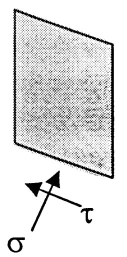
$\underline{\tan^{-1}(\tau/\sigma) = 20° < \text{friction angle } 35°\text{, hence the slope will not fail.}}$

(b)



Pore pressure at A = $3 \times \gamma_w \times \cos 20° \times \cos 20° = 3 \times 9.8 \times 0.939 \times 0.939 = \underline{26.0 \text{ kPa}}$.

(c) The weight of the block is $3\gamma_s L\cos 20° = 50.7L$ kN/m.



$\sigma = 50.7L\cos 20°/L = 47.7$ kPa

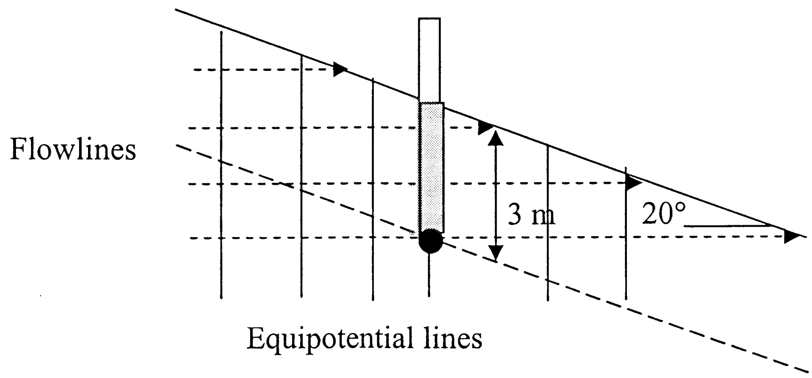
$\tau = 50.7L\sin 20°/L = \underline{17.4 \text{ kPa}}$

$\sigma' = \sigma - u = 47.7 - 26.0 = \underline{21.7 \text{ kPa}}$

$\tan^{-1}(\tau/\sigma') = \tan^{-1}(17.4/21.7) = 38.7° <$ friction angle 40°.

The slope may not fail.

(d)



Pore pressure at A = 3 x γ_w = 29.4 kPa.

(e) The weight of the block is $3\gamma_s L\cos 20°$ = 50.7L kN/m.

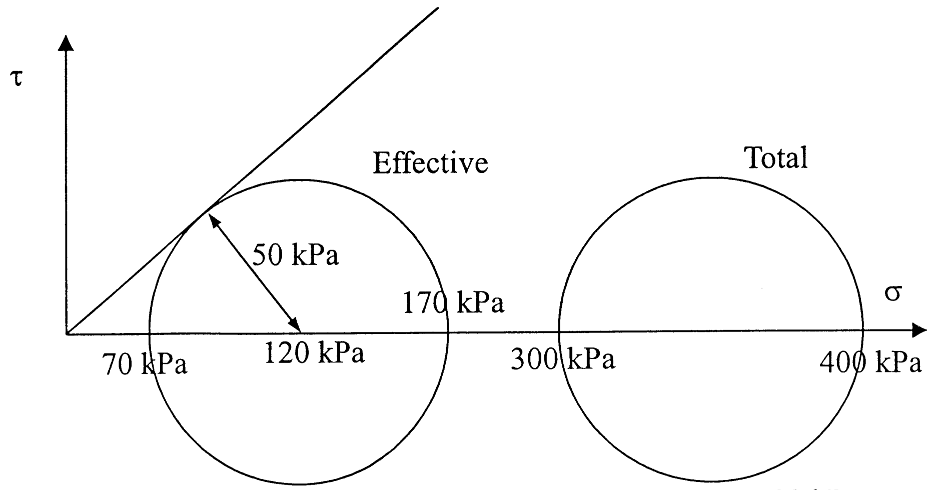
σ = 50.7L cos20°/L = 47.7 kPa
τ = 50.7L sin20°/L = 17.4 kPa
$\sigma' = \sigma - u$ = 47.7 – 29.4 = 18.3 kPa
$\tan^{-1}(\tau/\sigma') = \tan^{-1}(17.4/18.3) = 43.6° >$ friction angle 40°.

The slope will fail.

(g) Same as (a). The slope will not fail.

QUESTION 4

(a)



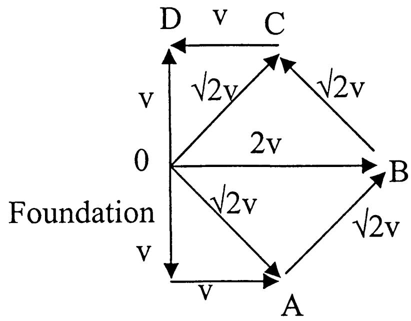
Initial σa = 300 kPa, σ'a = 300-200 = 100 kPa, σr = 300 kPa, σ'r = 300-200 = 100 kPa

At failure, σa = 400 kPa, σ'a = 400 – 230 = 170 kPa, σr = 300, σ'r = 300 – 230 = 70 kPa

Undrained shear strength s_u = (400-300)/2 = 50 kPa

Effective friction angle ϕ' = $\sin^{-1}$(50/120) = 24.6°

(b) (i)



(ii)

Sliding section	Length	velocity	Strength	Dissipated
a-c	20	v	0 (smooth)	0
a-b	20/√2	√2v	s_u	$20vs_u$
b-c	20/√2	√2v	s_u	$20vs_u$
b-d	20	2v	s_u	$40vs_u$
c-d	20/√2	√2v	s_u	$20vs_u$
d-e	20/√2	√2v	s_u	$20vs_u$
c-e	20	v	s_u	$20vs_u$
Boundary e-f	5	v	s_u	$5vs_u$

(iii) Total dissipative work = $145vs_u$ = 145 x 50v = 7250v

External work = Fv - 19 x 20 x 5 v (weight of blockD only; block A and C compensate each other) = Fv – 1900v

F = 7250 + 1900 = 9,150 kN/m.

(c)

(i) q's = 5 x 19 – 5 x 10 = 45 kPa

(ii)

$N_q = \tan^2(45 + \phi/2)e^{(\pi\tan\phi)} = \tan^2(45 + 24.6/2)e^{(\pi\tan 24.6)} = 10.2$

$N_\gamma = 2(N_q - 1)\tan\phi = 2(10.2-1)\tan(24.6) = 8.4$

(Or use the chart provided)

Fs= 20 x (0.5 x 9 x 20 x 8.4 + 45 x 10.2) = 24,300 kN/m

Need to add water pressure uplift effect

Fu = 20 x 5 x 10 = 1,000 kN/m

F = Fs + Fu = 25,300 kN/m