i.

ω	11 %	14 %	17 %	20 %	23 %
ρ_{bulk}	1835	1938	1989	1980	1950
ρ_{dry}	1653	1700	1700	1650	1585

$\omega_{optimum} \sim \underline{15.5\ \%}$

ii) Materials dry of optimum can be subject to wetting collapse & should be avoided. Materials wet of optimum are preferred. Select material as close as possible to optimum on wet side for easily compactible ductile material.

b) i) Plot graph of ρ vs $\sqrt{t}$

Estimate from graph $\rho_{ult} \sim 125\text{mm}$

$$\Rightarrow \sqrt{t_x} \sim 3.3$$

$$t_x = 10.9$$

$$\frac{C_v t_x}{d^2} = \frac{3}{4} \qquad d = 5\text{m}$$

$$C_v \sim \frac{4d^2}{3t_x} = 3.06\ \text{m}^2/\text{yr}$$

Check against final value

$t = 10$ yrs $\quad T_v = \dfrac{3.06 \times 10}{25} = 1.22$

$\Rightarrow R_v = 0.978 \qquad \rho_{ult} \sim 115$ mm

Try $\rho_{ult} = 120$

$\sqrt{t_x} \sim 31 \qquad t_x \sim 9.6$

$C_v \sim 3.5 \ m^2/yr$

$t = 10yrs \qquad T_v = 1.4 \qquad R_v = 0.987$

$\rho_{ult} = \underline{\underline{114mm}}$ OK.

ii) $$\rho = \rho_{ult}\left[1 - \tfrac{2}{3}\exp\left(\tfrac{1}{4} - \frac{3C_v t}{d^2}\right)\right]$$

$$\frac{\partial \rho}{\partial t} = \rho_{ult}\left[-\tfrac{2}{\cancel{3}} \times -\frac{\cancel{3}C_v}{d^2}\exp\left(\tfrac{1}{4} - \frac{3C_v t}{d^2}\right)\right]$$

$$= \frac{2\rho_{ult} C_v}{d^2}\exp\left(\tfrac{1}{4} - \frac{3C_v t}{d^2}\right) = 12 \ mm/yr$$

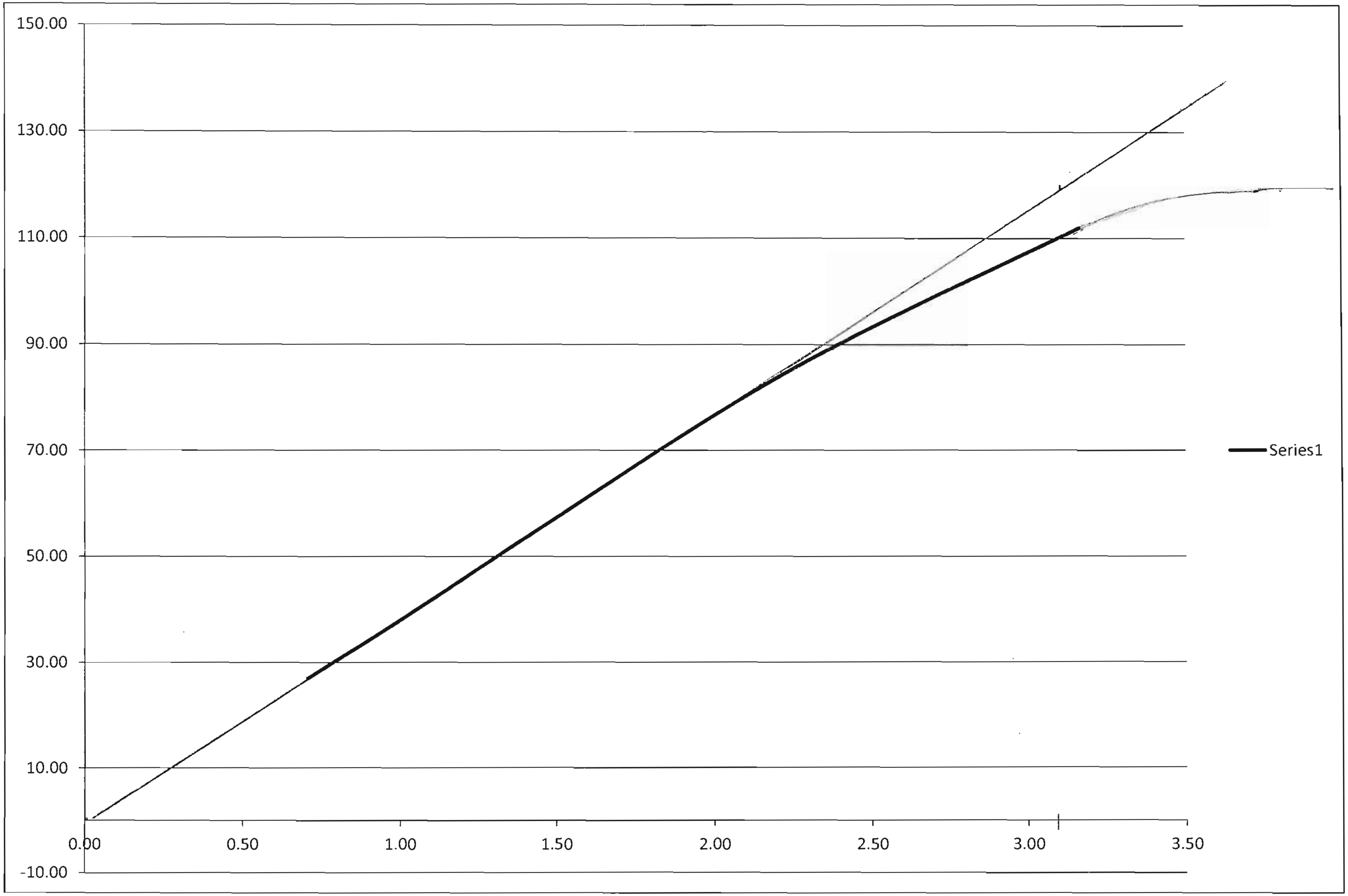
$$\frac{2 \times 0.115 \times 3.5}{25}\exp\left(\tfrac{1}{4} - \frac{3 \times 3.5 \times t}{25}\right) = 0.012$$

$t = \cancel{1.94 \ yrs}$ $\quad \underline{t = 2.94 \ years}$

Check phase II $\qquad t = 2.94 \qquad T_v = \frac{2.94 \times 3.5}{25}$

$= 0.41 > \underline{\underline{1/12}}$

OK.


150.00
130.00
110.00
90.00
70.00
50.00
30.00
10.00
-10.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
Series1

2. Centre of silt layer, $\sigma_v' = 36$ kPa

clay $\sigma_v' = 4 \times 18 + 5 \times 6 = 102$ kPa

After construction silt $\sigma_v' = 86$ kPa

clay 152 kPa

Plot h vs $\ln \sigma_v'$

Silt strain = $\dfrac{0.09}{19.94} = 0.0045$

Clay strain = $\dfrac{0.73}{19.38} = 0.0376$

$$\rho = \underbrace{0.0045 \times 4}_{18\text{ mm}} + \underbrace{0.0376 \times 10}_{376\text{mm}}$$

$= \underline{\underline{394 \text{ mm}}}$

b) $E_{avg\text{-}clay} = \dfrac{50\text{ kPa}}{0.0376} = 1330$ kPa

$$C_v = \frac{1330\text{ kPa} \times 10^{-9}}{10 \text{ kN/m}^3} = 133 \times 10^{-9} \text{ m}^2/\text{s}$$

$= 4.2$ m²/yr

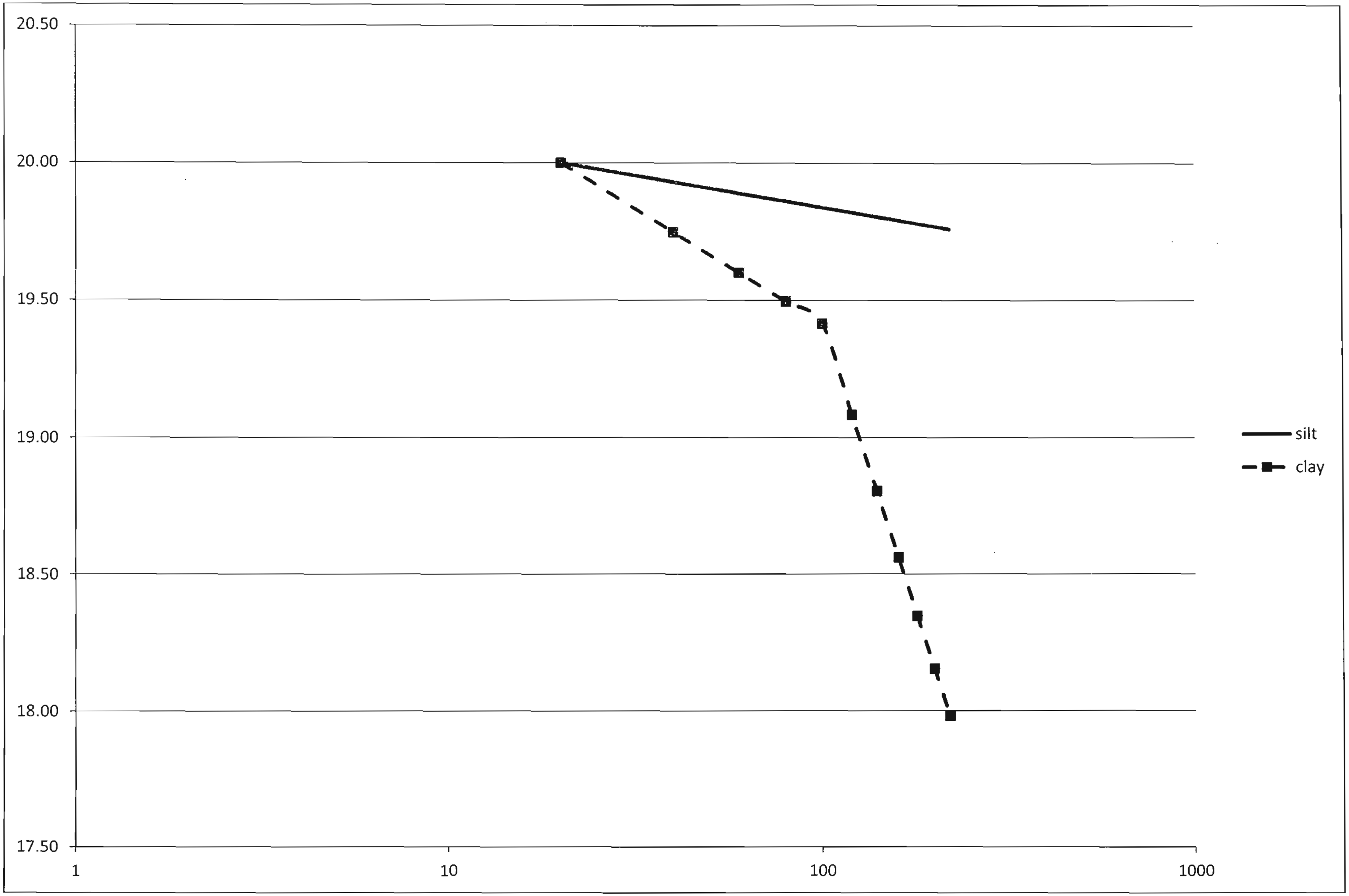
90% settlement = 355mm

clay settlement = $\underline{\underline{337\text{mm}}}$

$R_v = 0.895$ $T_v \sim 0.8 = \dfrac{C_v t}{d^2}$ $d = 5$m

silt much more permeable than clay

$t = \underline{\underline{4.76}}$ years


20.50
20.00
19.50
19.00
18.50
18.00
17.50
1
10
100
1000
silt
clay

Silt 36 - 136 kPa
Clay 102 - 202 kPa

c)

$$\varepsilon_{silt} = \frac{0.13}{19.94} = 0.0065$$

$$\varepsilon_{clay} = \frac{1.24}{19.38} = 0.064$$

$$\rho_{ult} = \underbrace{0.0065 \times 4}_{0.026} + \underbrace{0.064 \times 10}_{0.640}$$

$$= \underline{\underline{666\ mm}}$$

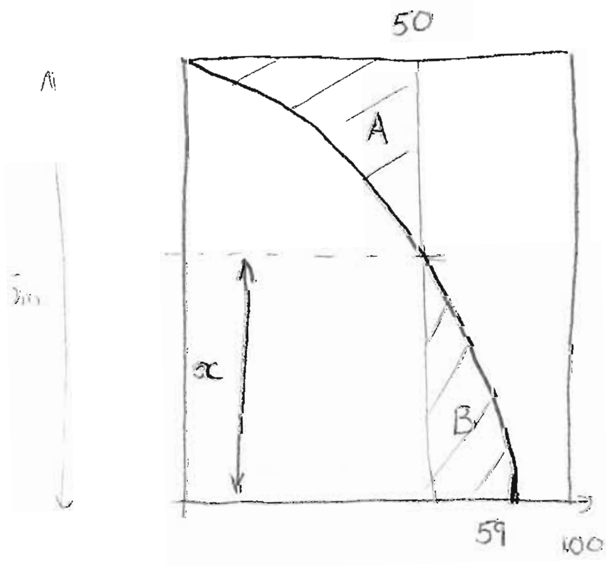
When $\rho = 394$

$\rho_{clay} = 368\ mm$

$$R_{v\ clay} = \frac{368}{640} = 0.575$$

$T_v = 0.26$

$$t = \frac{0.26 \times 25}{4.2} = \underline{\underline{1.55\ yrs}}$$



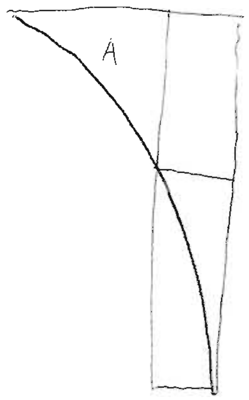
$b = \exp(1/4 - 3 \times 0.26)$
$= 0.59$

Area "A" swells on κ
Area "B" consolidates on λ

$$x = \sqrt{\frac{9}{59}} \times 5 = 1.95\ m$$

$$\text{Settlement from B} = 272 \times \left(\frac{1.95}{5}\right)^2$$

$= 41.37\ mm$



Area $A = \frac{1}{3} \times 59 \times 5 - \frac{1}{3} \times 9 \times 1.95$

$- 9 \times 3.05$

$= 65$ kPa.m

Area $B = \frac{2}{3} \times 9 \times 1.95$

$= 11.7$ kPa.m

If B gives settlement of 41.4 mm

A gives swell of $\sim 41.4 \times \frac{65}{11.7} \times \left(\frac{K}{\lambda}\right)$ $\frac{1}{5}$

~ 46mm

Silt swells by 8mm

Overall swelling of $\sim$ 12.6mm

d) To increase rate of settlement, drainage could be improved using drains, inserted into the clay. These would increase C_v & hence speed up consolidation.

1 (a) line $AB = \frac{H}{\tan\theta} - \frac{H}{\sqrt{3}}$

$OAB = \frac{1}{2}\left(\frac{1}{\tan\theta} - \frac{1}{\sqrt{3}}\right)H^2$

(b) wedge $= \frac{1}{2}\cdot 18\left(\frac{1}{\tan\theta} - \frac{1}{\sqrt{3}}\right)H^2\, v \sin\theta$

surcharge $= 30\cdot\left(\frac{1}{\tan\theta} - \frac{1}{\sqrt{3}}\right)\cdot H\cdot v\sin\theta$

(c) line $OB = \frac{H}{\sin\theta}$

dissipative work $50\cdot\frac{H}{\sin\theta}\cdot v$

(d) $9\left(\frac{1}{\tan\theta} - \frac{1}{\sqrt{3}}\right)H^2 v\sin\theta + 30\left(\frac{1}{\tan\theta} - \frac{1}{\sqrt{3}}\right)H\cdot v\sin\theta$

$= 50\cdot\frac{H}{\sin\theta}\cdot v$

$(9H + 30)\left(\cos\theta - \frac{1}{\sqrt{3}}\sin\theta\right) = \frac{50}{\sin\theta}$

$9H + 30 = \frac{50}{\left(\cos\theta\cdot\sin\theta - \frac{1}{\sqrt{3}}\sin^2\theta\right)}$

$X = \cos\theta\cdot\sin\theta - \frac{1}{\sqrt{3}}\sin^2\theta$

$\frac{dX}{d\theta} = \cos^2\theta - \sin^2\theta - \frac{2}{\sqrt{3}}\sin\theta\cos\theta$

when $\theta = 30°$

$= \left(\frac{\sqrt{3}}{2}\right)^2 - \left(\frac{1}{2}\right)^2 - \frac{2}{\sqrt{3}}\cdot\frac{1}{2}\cdot\frac{\sqrt{3}}{2} = \frac{3}{4} - \frac{1}{4} - \frac{1}{2} = 0$

So $\theta = 30°$ is the optimal θ.

$$9H + 30 = \frac{50}{\cos 30^\circ \sin 30^\circ - \frac{1}{\sqrt{3}} \sin^2 30^\circ}$$

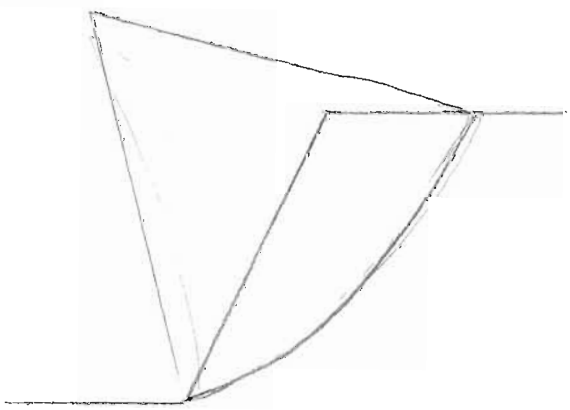
$$= \frac{50}{\frac{\sqrt{3}}{2} \cdot \frac{1}{2} - \frac{1}{\sqrt{3}} \cdot \left(\frac{1}{2}\right)^2}$$

$$= \frac{50}{\frac{\sqrt{3}}{4} - \frac{1}{4\sqrt{3}}}$$

$$= \frac{50}{0.289} = 173.2$$

$$\underline{H = 15.9 \, (m)}$$

(e) This is not the best solution. A circular failure mechanism shown below will give a better solution



2 (a)

The maximum principal stress will be

$\sigma_{max} = 9\ MN/m\ /5m + 0.024 \times 1.5 \approx \underline{1.8\ MPa}$

The minimum principal stress will be

$$\frac{\sigma_{max}}{\sigma_{min}} = \frac{1+\sin\phi}{1-\sin\phi} = \frac{1+\sin 30^\circ}{1-\sin 30} = 3$$

$$\sigma_{min} = \frac{\sigma_{max}}{3} = \frac{1.8\ MPa}{3} = \underline{0.6\ MPa} = 600\ kPa$$

(b) $\sigma_{min} = \sigma_s + 16 \times 1.5 = \sigma_s + 24\ (kPa)$

$\sigma_{max} = 3\sigma_{min} = 3(\sigma_s + 24)\ kPa$

(c)

$S_A = 2(\sigma_s + 24)\ kPa$

$$\frac{S_B}{2(\sigma_s+24)} = \exp\left(2 \cdot \frac{\pi}{2} \tan 30^\circ\right)$$

$$S_B = 2(\sigma_s + 24)\exp(\pi \cdot \tan 30^\circ)$$

$r_B = S_B \sin\phi$

$$\begin{aligned} \sigma_{surcharge} &= S_B + r_B \\ &= (1+\sin\phi)\cdot S_B \\ &= (1+\sin 30^\circ)\cdot 2(\sigma_s+24)\cdot \exp(\pi \cdot \tan 30^\circ) \\ &= 18.40(\sigma_s + 24)\quad (kPa) \end{aligned}$$

$\underline{N_q = 18.40}$

$N_\gamma = 2(18.40 - 1)\tan 30^\circ = 20.10$

$$\sigma_{selfweight} = 20.1 \times \frac{16 \times 5}{2} = 804\ kPa$$

$1800 = 18.40(\sigma_s + 24) + 804$

$\underline{\sigma_s = 30.1\ kPa}$

(d) $\gamma_{dry} = 16\ kN/m^3 = \left(\frac{G_s}{1+e}\right)\gamma_w = \frac{G_s}{1.63} \cdot 9.8$

$G_s = 2.66$

$\gamma_{sat} = \left(\frac{G_s + e}{1+e}\right)9.8 = \left(\frac{2.66 + 0.63}{1.63}\right)9.8 = 19.78\ kN/m^3$

$1800 = 18.40(\sigma_s + 24) + 20.10 \times \frac{9.78 \times 5}{2}$

$1800 = 18.40(\sigma_s + 24) + 491$

$\underline{\sigma_s = 47.1\ kPa}$ //

(e) $1800 = 18.40(\sigma_s + 9.78 \times 1.5) + 491 + \underline{9.8 \times 1.5}$

uplift water pressure

$\underline{\sigma_s = 55.7\ kPa}$ //