PROBLEM 1

$D = 4m$

$t = 5 \times 10^{-2} m$

$V = 6MN$

$H = 3MN$ @ $h = 15m$

$S_u = k_{su} z$

$k_{su} = 5 \, kPa/m$

$\gamma_T = 15.5 \, kN/m^3$

$\sigma_y = 200 MPa$

$E = 210 \, GPa$

(a) $e/D = \frac{15}{4} = 3.75$

[5%]

$n = 9 k_{su} = (9)(5) = 45 \, kPa/m$

$\frac{H}{n D^3} = \frac{3000 \, kPa}{(45 kPa/m)(4m)^3} = 1.4$ [10%]

From Data book $\frac{L}{D} \approx 4$ $D \approx 16m$ [10%]

(b) Check for failure of long pile

$M_p = \sigma_y D^2 t = (200 \times 10^3 kPa)(4m)^2 (5 \times 10^{-2} m) = 160 MPa$ [10%]

$\frac{M_p}{n D^4} = \frac{(160 \, MPa)}{(45 kPa/m)(4m)^4} = 13.8$

From Data book : $\frac{M_p}{n D^4} \geq 8$ ✓OK [15%]

(c) $S_u = k_{su} z < \gamma' z = \sigma'_{vo}$ Therefore $\alpha = \frac{1}{2} \left(\frac{\gamma' z}{k_{su} z} \right)^{0.5}$

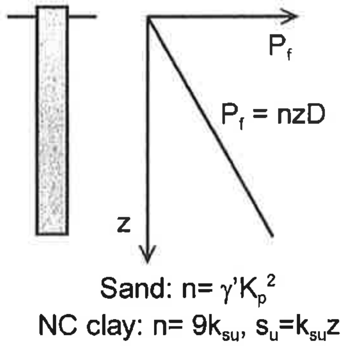
$\alpha = \frac{1}{2} \left(\frac{\gamma' z}{k_{su} z} \right)^{0.5} = \frac{1}{2} \left(\frac{5.5}{5} \right)^{0.5} = 0.52$

6.3 Lateral capacity: linearly increasing lateral resistance with depth

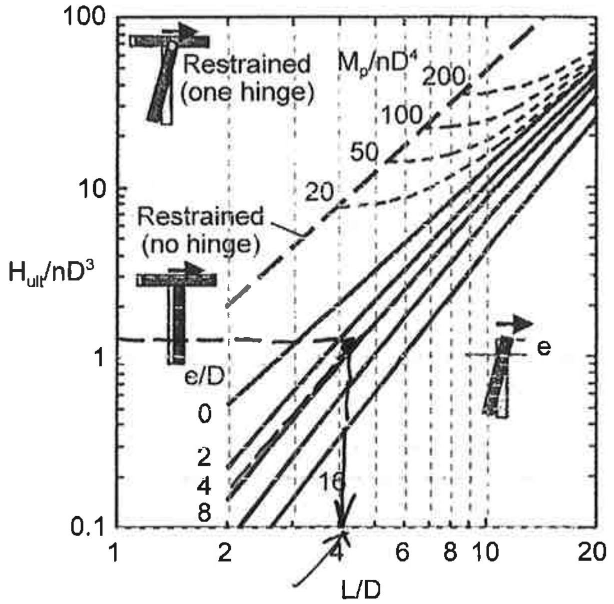
Lateral soil resistance (force per unit length), $P_u = nzD$

In sand, $n = \gamma' K_p^2$
In normally consolidated clay with strength gradient k; $s_u = kz$; $n=9k$

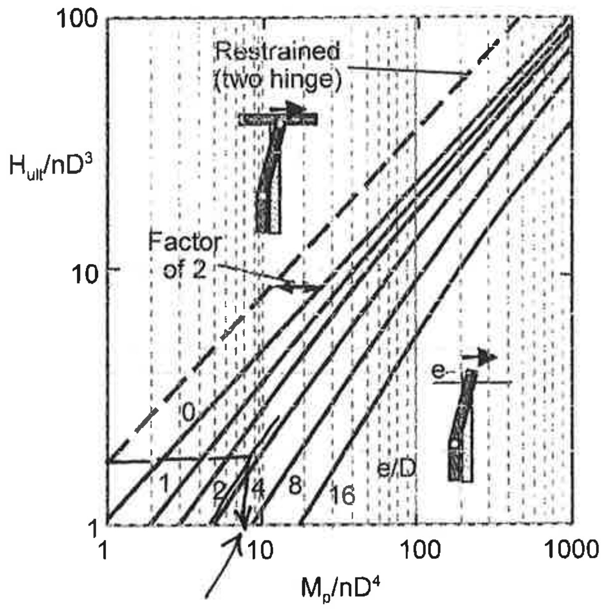
H_{ult}	ultimate horizontal load on pile
M_p	plastic moment capacity of pile
D	pile diameter
L	pile length
e	load level above pile head (=M/H for H-M pile head loading)
γ'	effective unit weight
K_p	passive earth pressure coefficient, $K_p = (1+\sin\phi)/(1-\sin\phi)$



Sand or normally-consolidated clay



Short pile failure mechanism

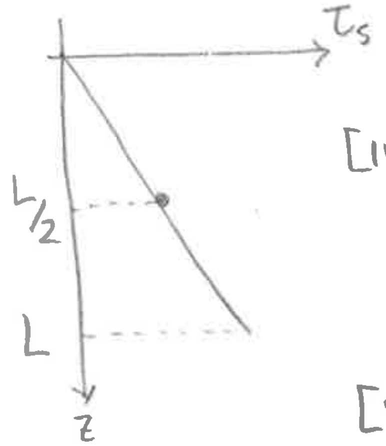


Long pile failure mechanism

Lateral pile capacity
(linearly increasing lateral resistance with depth)

$Q_s = \alpha S_u A = \alpha k_{su} \left(\frac{L}{2}\right) \pi D L =$

$= (0.52)(5)\left(\frac{16}{2}\right)(4)(16)\pi = 4.18 MN$ [10%]



Plugged $Q_b = N_c S_u A_b = (9)(5)(16)\pi \frac{(4)^2}{4} =$

$= 9.05 MN$ [5%]

wt. of plug $W = \frac{\pi D^2}{4} L \gamma' = \pi \frac{(4m)^2}{4} (16m)(5.5 kN/m^3) =$ [5%]

$= 1.11 MN$

V_{ult} (plugged) $= Q_b + Q_s - W = 4.18 + 9.05 - 1.11 = 12.12 MN$

V_{ult} (unplugged) $= 2Q_s = 8.36 MN$ [5%]

The pile will be unplugged, but $V_{ult} > 6MN$ ✓ok

(d)

$$\frac{V}{w_{head} D G_L} = \frac{2}{1-\nu}\frac{\eta}{\xi} + \frac{2\pi}{\zeta} \rho \frac{L}{D}$$

$\zeta = 4$

$\eta = \xi = 1$ $\quad G_L = 150 S_u = (150)(5)z = 750z$ [10%]

$\rho = 0.5$

$\nu = 0.3$

$$w_{head} = \frac{V}{DG_L}\left[\frac{1}{\frac{2}{1-\nu} + 2\pi\rho\frac{L}{D}}\right]$$ [15%]

$$= \frac{6MN}{(4)(750)(16)}\left[\frac{1}{\frac{2}{1-0.3} + \frac{2\pi}{4}(0.5)\left(\frac{16}{4}\right)}\right] = 2 \times 10^{-2} m$$

For $\zeta = \ln\left\{5\rho(1-\nu)\frac{L}{D}\right\} = \ln\left[(5)(0.5)(1-0.3)\frac{16}{4}\right] = 1.94 \Rightarrow w_{head} = 1.3 \times 10^{-2} m$

PROBLEM 2

(a) (i) $q = 300$ kPa

$$\tau_{mob} = \frac{q}{5.9} = 51 \text{ kPa}$$

Operational depth $z = 0.3D = (0.3)(40m) = 12m$

$$S_u = 100 + (5)(12+1) = 165 \text{ kPa}$$

$$\frac{\tau_{mob}}{S_u} = \frac{51}{165} = 0.31$$

$\gamma_u = 0.008$

$$\frac{\tau_{mob}}{S_u} = 0.5\left(\frac{\gamma}{\gamma_{M=2}}\right)^{0.6}$$

$$\gamma = \gamma_{M=2}\left(\frac{2\tau_{mob}}{S_u}\right)^{1/0.6} = 0.008\left[(0.32)(2)\right]^{1/0.6} =$$

$$= 3.8 \times 10^{-3}$$

$$W_u = \frac{\gamma_{mob} D}{1.35} = \frac{(3.8\times10^{-3})(40m)}{1.35} = 0.113 \text{ m}$$

[30%]

(ii)

$G = 25$ MPa

$$W_r = \frac{(1-\nu)}{G}\frac{q_{avg}}{2}\sqrt{BL}\, I_{rigid} = \left(\frac{0.5}{25}\right)\left(\frac{0.3MPa}{2}\sqrt{40^2}\right)(0.9)$$

[10%]

$= 0.108$ m

(iii) $$W_{corner} = \frac{(1-\nu)}{G}\frac{qB}{2} I_{rect} = \left(\frac{0.5}{25}\right)\left(\frac{0.3\,MPa\sqrt{40^2}}{2}\right)(0.561) = 0.067\text{m}$$

[10%]

$$W_{centre} = 4\frac{(1-\nu)}{G}\frac{qB}{2} I_{rect} = \left(\frac{0.5}{25}\right)\left(\frac{0.3}{2}\sqrt{20^2}\right)(0.561)(4) = 0.135$$

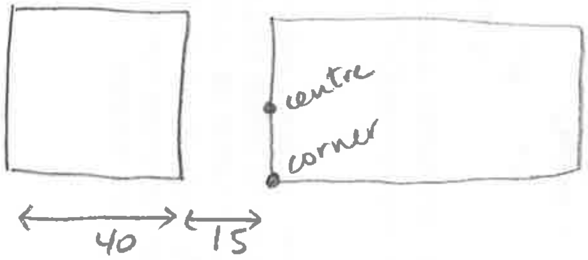
[10%]

$$\delta = \frac{0.135 - 0.067}{20\sqrt{2}} = 0.0024$$ [5%] 5/10

(iv) A flexible foundation assumes pressure distribution under the foundation is uniform, while a rigid foundation would have increased pressure at the edges.

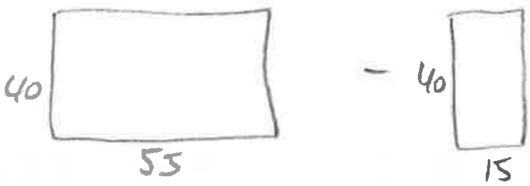
(b)

[15%]



$z = 20\,m$

corner



$m = \frac{55}{20} = 2.75$ $m = \frac{40}{20} = 2$

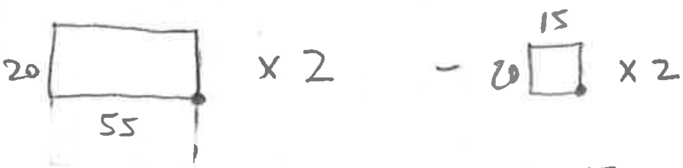
$n = \frac{40}{20} = 2$ $n = \frac{15}{20} = 0.75$

$I_r = 0.235$ $I_r = 0.17$

[10%]

$\Delta\sigma = (300\,kPa)(0.235 - 0.17) = 19.5\,kPa$

centre



$m = \frac{55}{20} = 2.75$ $m = \frac{15}{10} = 0.75$

$n = \frac{20}{20} = 1$ $n = \frac{20}{20} = 1$

$I_r = 0.205$ $I_r = 0.15$

$\Delta\sigma = 300(0.205 - 0.15)(2) =$

$= 33\,kPa$

[10%]

PROBLEM 3

(a) API design parameters

$$q_{bf} = N_q \sigma'_{vo} \le q_{b,lim}$$

$$\tau_s = k \sigma'_{vo} \tan\delta \le \tau_{s,lim}$$

$$\sigma'_{vo} = \gamma' z = (10 \text{ kN/m}^3) z$$

loose sand $z \le 30$ m $N_q = 12$ $q_{b\,lim} = 2.9$ MPa

$$q_{bf} = (12)(10z) = 120z \qquad z \le \frac{2.9 \times 10^3}{(12)(10)} = 24.1 \text{ m}$$

$k = 1.0$ $\delta = 20°$ $\tau_{s\,lim} = 75$ kPa

$$\tau_s = (1.0)(\tan 20°)(10)z = 3.64z \qquad z \le \frac{75}{(\tan 20°)(10)} = 20.6 \text{ m}$$

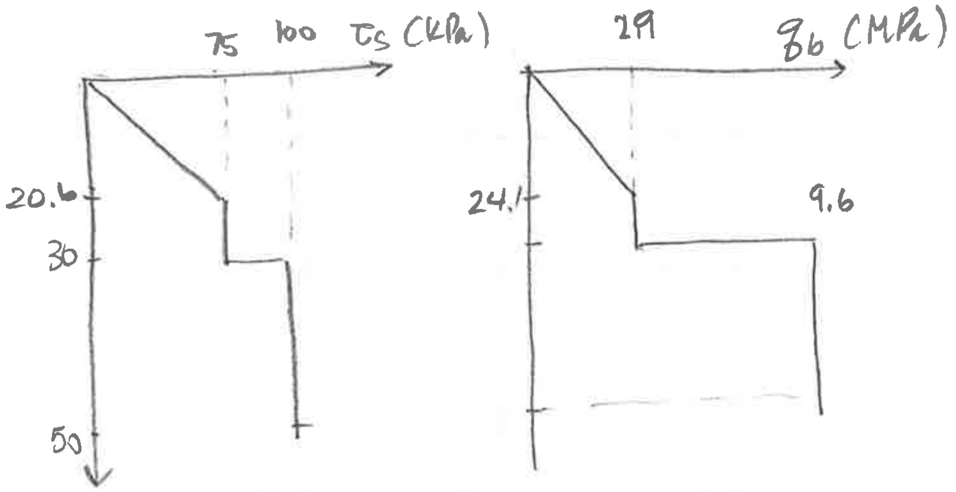
Dense sand

$N_q = 40$ $q_{b\,lim} = 9.6$ MPa

$$q_{bf} = (40)(10)z = 400z \qquad z \le \frac{9.6 \times 10^3}{(40)(10)} = 24 \text{ m}$$

$k = 1.0$ $\delta = 30°$ $\tau_{s\,lim} = 100$ kPa

$$z_{lim} = \frac{100}{(\tan 30°)(10)} = 17.3 \text{ m}$$



[25%]

(b) $30\,m \le L \le 50\,m$

Contribution from 0 to 30m

$$Q_{s<30} = \left[\left(\frac{75}{2}\right)(20.6) + (75)(30-20.6)\right]\pi(0.8) =$$

[5%]

$$= 3713\,kN$$

$$Q_{s>30} = (100)(z-30)\pi(0.8) = 251z - 7540\,kN$$ [10%]

$$Q_b = q_b\frac{\pi D^2}{4} = (9.6\,MPa)\,\pi\frac{(0.8\,m)^2}{4} = 4825\,kN$$ [5%]

$$Q_{compr} = Q_b + Q_s = 3713 + 251z - 7540 + 4825 = 998 + 251z$$

$$Q_{tens} = Q_s = 251z - 3827\,kN$$ [15%]

(c) $Q_c = 400\text{ kN} + 100L$

$Q_t = 100L - 1530\text{ kN}$ for 2.5 factor

[10%]

For n piles $P_{compr} = n_c Q_c \geq 50\text{MN}$

$P_{tens} = n_t Q_t \geq 25\text{MN}$

[5%]

Objective
Minimize nL, for $n_c = n_t$

[20%]

$$n_c = \frac{50\text{MN}}{400 + 100L}$$

$$n_t = \frac{25\text{MN}}{100L - 1530}$$

$\Big\}$ $L = 34.6\text{ m}$

Resulting in $n = 12.96 \Rightarrow n = 13$ piles [5%]

$L \approx 35\text{m}$

PROBLEM 4

(a) From the data book

$$\phi_{max} = \phi_{crit} + 3° \left[I_D \ln\left(\frac{\sigma_c}{p'}\right) - 1 \right]$$

Assume $\sigma_c = 20{,}000\,kPa$

$\phi_{crit} = 35°$ [10%]

$q = \frac{1500\,kN}{2.25\,m^2} = 667\,kPa$

$p' = \frac{1}{3}(\sigma'_{vo} + 2\sigma'_{ho}) = \frac{1}{3}(\sigma'_{vo} + 2k_o\sigma'_{vo}) = \frac{1.8}{3}\sigma'_{vo}$ [10%]

$k_o \approx 0.4$

at a depth of 2 m σ'_{vo} prior to load application is $\sigma'_{vo} = (20)(0.5) + (10)(1.5) = 25\,kPa$ [5%]

σ'_v after application of load $\sigma'_v = 667 + 25 = 700\,kPa$

$p' = (0.6)(700\,kPa) = 420\,kPa$

$\phi_{max} = 35° + 3° \left[0.65 \ln\left(\frac{20{,}000}{420}\right) - 1 \right] = 39.5°$ [15%]

(b) (i) $q_f = s_q N_q \sigma'_{vo} + s_\gamma N_\gamma \frac{\gamma' B}{2}$

Reduce strength $\frac{\tan\phi_{peak}}{1.25} = 0.659 \Rightarrow \phi = 33.4°$ [10%]

$s_q = 1 + \frac{B}{L}\sin\phi = 1.55$

$s_\gamma = 1 - 0.3\frac{B}{L} = 0.7$ [10%]

$N_q = \tan^2(45 + \phi/2)\,e^{\pi\tan\phi} = 27.3$

$N_\gamma = 2(N_q - 1)\tan\phi = 34.7$

$\sigma'_{vo} = (0.5)(20) + (0.5)(10) = 15\,kPa$

$q_f = (1.55)(27.3)(15) + (0.7)(34.7)(10)\frac{(1.5)}{2} =$

$= 636 + 182 = 818\,kPa$

$V_{ult} = (1.5)^2(818) = 1.84\,MPa > 1.5\,MPa$ ✓ ok [10%]

(ii) When the foundation is smaller the contact pressure increases. A larger confining stress decreases dilation and therefore ϕ_{peak}. [10%]

(d) $$\frac{M}{BV_{ult}} = \frac{1}{2}\frac{V}{V_{ult}}\left[1 - \frac{V}{V_{ult}}\right]$$

$V = 1.5\,MN$ $\quad V/V_{ult} = 0.815$

$V_{ult} = 1.84\,MN$

$$M_{max} = \frac{BV_{ult}}{2}\frac{V}{V_{ult}}\left[1 - \frac{V}{V_{ult}}\right] = 0.21\,MNm$$

or $$e = \frac{M}{V} = \frac{0.21\,MNm}{1.5\,MN} = 0.14\,m$$

[20%]

Q1 Pile on clay with VHM loading

31 attempts, Average mark 17.2/20 (86%), Maximum 20, Minimum 10.

This was a popular question attempted by all the students, who did very well. The question was very similar to the coursework assigned for the course and most students could answer all the questions. One of the few problems they encountered was to check for both plugged and unplugged mechanism.

Q2 Raft foundation settlements

31 attempts, Average mark 13.0/20 (65%), Maximum 18, Minimum 6.

All students answered this question as well. Overall, the answers on mobilizable strength design were mostly correct, with perhaps some confusion on the reference depth for strength calculations. A number of students did not use a Poisson ratio of 0.5 for the undrained case. Most students calculated distortion using the whole diagonal of the foundation instead of half, obtaining a smaller value.

There was a typo on part (b), asking the stress increase at 1 m under the adjacent building. The stress increase at the location is clearly 0. Some students seemed puzzled and a few could also explain correctly why that was indeed to be expected. Overall, most students did well anyway and the issues did not seem to have significant impact on the overall performance on this question.

Q3 Pile group in sand

21 attempts, Average mark 12.2/20 (61%), Maximum 20, Minimum 1.

Most students could find the shaft and base resistance variation with depth correctly. Some di did not apply the limits, or applied them only to the top layer. The most problems were raised by the optimization problem, where a good number of students could not devise a strategy to calculate the number of piles and their length that would minimize the material.

Q4 Shallow foundation on sand

10 attempts, Average mark 11.5/20 (58%), Maximum 15, Minimum 8.

About a third of the students answered this question. All students could relate stress under the foundation to the friction angle and especially dilatancy. The most common mistake was in applying the factor of safety to the ultimate capacity or the friction angle directly, rather than the tangent. Most students were also able to address the eccentric load.

G. Biscontin (Principal Assessor)