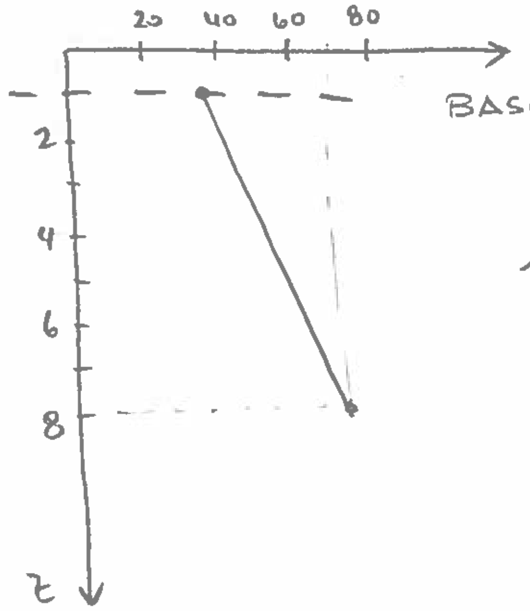
PROBLEM 1

(a) Strength profile



$$k = \frac{70-35}{8-1} = 5\ \text{kPa/m}$$

Assume $B = 2$ m and a square foundation

$$q_{ult} = s_c d_c N_c S_u + \gamma h$$

$$s_c = 1 + 0.2\frac{B}{L} = 1.2$$

$$d_c = 1 + 0.33\tan^{-1}\left(\frac{h}{B}\right) = 1 + 0.33\tan^{-1}\left(\frac{1}{2}\right) = 1.05$$

Factor the strength, assume strength at a depth $\approx \frac{B}{2}$ below the foundation base

$$S_u^* = \frac{S_u}{\gamma_F} = \frac{S_{u0} + kB/2}{\gamma_F}$$

$$S_u^* = \frac{35 + (5)(1)}{1.4} = 28.6\ \text{kPa}$$

$$q_{all} = (1.2)(1.05)(5.14)(28.6) + (18-10)(1) = 193\ \text{kPa}$$

Alternatively Davis and Booker (1973) can be used (but it is not in the data book)

B is slightly too big - We can reduce the size

$$B = \sqrt{\frac{V_A}{q_{all}}} = \sqrt{\frac{400\,kN}{193\,kPa}} = 1.45 \quad \Rightarrow \text{Use } B = 1.5\,m$$

Check whether coefficients and strength change significantly

$$d_c = 1 + 0.33 \tan^{-1}\left(\frac{1}{1.5}\right) = 1.06$$

$$S_u^* = \frac{35 + (5)(1.5/2)}{1.4} = 27.7\,kPa$$

$$q_{all} = 187.4\,kPa \quad \checkmark OK$$

$$q_A = \frac{400\,kN}{(1.5m)^2} = 177.8\,kPa$$

$$q_B = \frac{250}{(1.5)^2} = 111.1\,kPa$$

$$q_C = \frac{180}{(1.5)^2} = 80\,kPa$$

Check design combination 1

$$S_u = 35 + (5)(1.5/2) = 38.75\,kPa$$

$$q_{ult} = 261.4\,kPa$$

$$\frac{(V_A)(1.35)}{(1.5)^2} = 240\,kPa < q_{ult} \quad \checkmark OK$$

(b) The bearing pressures for the footings are quite different, which is going to produce different settlements for each footing. Depending on the amount of differential settlement distortion could become excessive and cause both non-structural and structural damage.

(e)

$$\tau_{mob_A} = \frac{q_A}{N_c} = \frac{177.8\,kPa}{6} = 29.6\,kPa$$

Su should be calculated at $z = 0.3D$ below the foundation base

$$S_u^m = 35 + (5)(0.3)(1.5) = 37.25\,kPa$$

$$\frac{W}{D} = \left(\frac{2\,\tau_{mob}}{S_u}\right)^{1/b} \frac{\gamma_{M=2}}{M_c} = \left[\frac{(2)(29.6)}{(37.25)}\right]^{1/0.6} \frac{0.095}{1.3} = 0.0158$$

$$W = (0.0158)(1500) = 24\,mm$$

If we use the same W/D settlement for the B footing

$$\frac{\tau_{mob}}{S_u} = 0.5\left(\frac{\gamma}{\gamma_{M=2}}\right)^b = 0.5\left(\frac{M_c\, W/D}{\gamma_{M=2}}\right)^b = 0.5\left[\frac{(1.3)(0.0158)}{0.02}\right]^{0.6}$$

$$\frac{\tau_{mob}}{S_u} = 0.795 = \frac{V}{A N_c S_u} \Rightarrow A = \frac{V}{(0.795) N_c S_u} = \frac{250\,kN}{(0.795)(6)(37.25}$$

$$A = 1.407\,m^2$$

$$B = 1.186\,m \qquad B_B = 1.2\,m$$

Check

$$S_u = 35 + (5)(1.2)(0.3) = 36.8\,kPa \Rightarrow B = 1.19\,m \checkmark ok$$

angular distortion between A and B

$$\beta = \frac{\Delta}{L} = \frac{24 - (0.0158)(1200)}{5000} \approx \frac{1}{1000}$$

For footing C

4/B

$$A = \frac{180\,kN}{(0.795)(6)(36.8\,kPa)} = 1.025\,m^2 \Rightarrow B = 1\,m$$

$$S_u = 35 + (5)(0.3)(1) = 35.3\,kPa \qquad B \approx 1.02\,m$$

$$W = (0.0158)(1\,m) = 16\,mm$$

$$\beta_{BC} = \frac{19\,mm - 16\,mm}{7000\,mm} = \frac{1}{2300} \checkmark \text{ok}$$

$$\beta_{AC} = \frac{24 - 16}{\sqrt{(5000)^2 + (7000)^2}} = \frac{1}{1000} \checkmark \text{ok}$$

Check $q_c = \frac{180}{1^2} = 180\,kPa$

$$q_{all} = (1.2)(1.08)(5.14)\frac{(37.5)}{1.4} + 8 = 186\,kPa > q_c$$ but barely

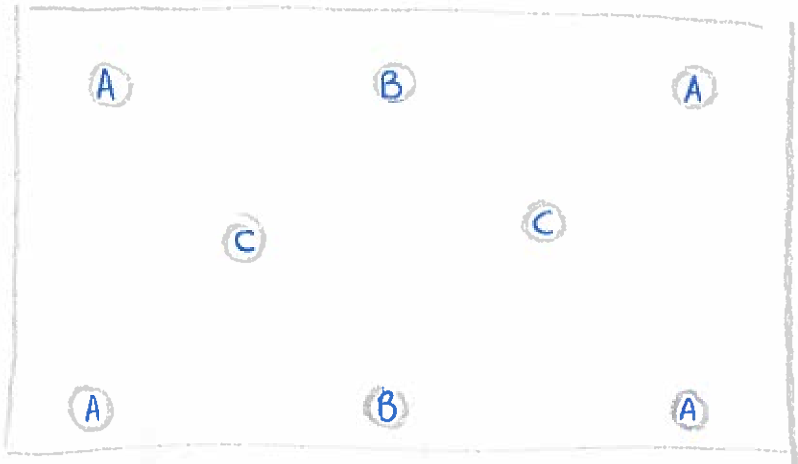
Very popular question, with most students attempting it. Very few students considered a code approach, using partial factors. Most students were able to apply the bearing capacity equation od shape, embedment modification coefficients. The question on mobilisable strength design was answered well by a small numbered of students, but most did not go back and check capacity was still sufficient when they proposed footing sizes.

4D5 - PROBLEM 2

a) Bored pile base stiffness ~ 0

$$\frac{Q_s}{\omega} = \frac{2\pi L G_{avg}}{\zeta} = \frac{2\pi \times 12.5}{4} = 19.6 \text{ MN/m}$$

b)



Pile A has :
- A at 8D
- A at 16D
- A at 17.89 D
- B at 8D
- B at $8\sqrt{2}$ D
- C at $4\sqrt{2}$ D
- C at $2\sqrt{40}$ D

B has
- 2 × A at 8D
- 2 × C at $4\sqrt{2}$ D
- 2 × A at $8\sqrt{2}$ D
- B at 8D

C has
- 2 × A at $4\sqrt{2}$ D
- 2 × A at $2\sqrt{40}$ D
- C at 8D
- 2 × B at $4\sqrt{2}$ D

Interaction factors (ratio of settlement to pile)

radius / D	ω / ω_p
8	0.307
$4\sqrt{2}$	0.393
16	0.134
$8\sqrt{2}$	0.220
$2\sqrt{40}$	0.192
17.89	0.106

$$\tau = \frac{\tau_s R}{r}$$

$$G \frac{\partial \omega}{\partial r} = \frac{\tau_s R}{r}$$

$$\int_0^{\omega} \partial \omega = \int_{r_m}^{r} \frac{\tau_s R}{G} \frac{dr}{r}$$

$$\omega = \left(\frac{\tau_s R}{G}\right) \ln\left(\frac{r}{r_m}\right)$$

$$\omega_p = \frac{\tau_s R}{G} \ln\left(\frac{r_p}{r_m}\right)$$

$$\frac{\omega}{\omega_p} = \frac{\ln\left(r/r_m\right)}{\ln\left(r_p/r_m\right)} = \frac{\ln(r) - \ln(r_m)}{\cancel{\ln(r_p) - \ln(r_m)} \; -4}$$

$$= \frac{\overset{4 + \ln(R)}{\cancel{\ln r_m}} - \ln r}{4} = \frac{4 + \ln\left(\frac{R}{r}\right)}{4}$$

$$\omega_A = \omega_{AO}(1 + 0.307 + 0.134 + 0.106) + \omega_{BO}(0.307 + 0.220)$$
$$+ \omega_{CO}(0.393 + 0.192)$$

$$= 1.547\,\omega_{AO} + 0.527\,\omega_{BO} + 0.585\,\omega_{CO}$$

$$\omega_B = \omega_{AO} \times (0.307 \times 2 + 0.220 \times 2) + \omega_{BO} \times (1.307)$$
$$+ \omega_{CO}(2 \times 0.393)$$

$$= \omega_{AO} \times 1.054 + 1.307\,\omega_{BO} + 0.786\,\omega_{CO}$$

$$\omega_C = \omega_{AO}(2 \times 0.393 + 2 \times 0.192) + \omega_{BO}(2 \times 0.393)$$
$$+ \omega_{CO}(1 + 0.307)$$

$$= \omega_{AO} \times 1.17 + \omega_{BO} \times 0.786 + \omega_{CO} \times 1.307$$

$$\omega_A = \omega_B = \omega_C = \omega.$$

$$1.547\frac{\omega_{AO}}{\omega} + 0.527\frac{\omega_{BO}}{\omega} + 0.585\frac{\omega_{CO}}{\omega} = 1$$

$$1.054\frac{\omega_{AO}}{\omega} + 1.307\frac{\omega_{BO}}{\omega} + 0.786\frac{\omega_{CO}}{\omega} = 1$$

$$1.17\frac{\omega_{AO}}{\omega} + 0.786\frac{\omega_{BO}}{\omega} + 1.307\frac{\omega_{CO}}{\omega} = 1$$

$$\frac{\omega_{AO}}{\omega} = 0.4935 \qquad \frac{\omega_{BO}}{\omega} = 0.2705 \qquad \frac{\omega_{CO}}{\omega} = 0.1606$$

4 piles A, 2 B & 2C so

$$4 \times 0.4935 + 2 \times 0.2705 + 2 \times 0.1606 = 2.8362$$

c) load on A is $\frac{0.4935}{2.8362} \times 100 = 17.4 \text{ kN}$ 8/13

B $\frac{0.2705}{2.8362} \times 100 = 9.54 \text{ kN}$

C $\frac{0.1606}{2.8362} \times 100 = 5.66 \text{ kN}$

$$\omega = \frac{17.4 \times 10^{-3}}{19.6} \times \frac{1}{0.4935} = \underline{\underline{1.8 \text{ mm}}}$$

A difficult question in general well handled by students and tackled by most candidates. Some candidates did not distinguish between different types of piles when determining the effects of neighbours, but most did well. The final system stiffness was often miscalculated. In general well handled by those who did a complete job.

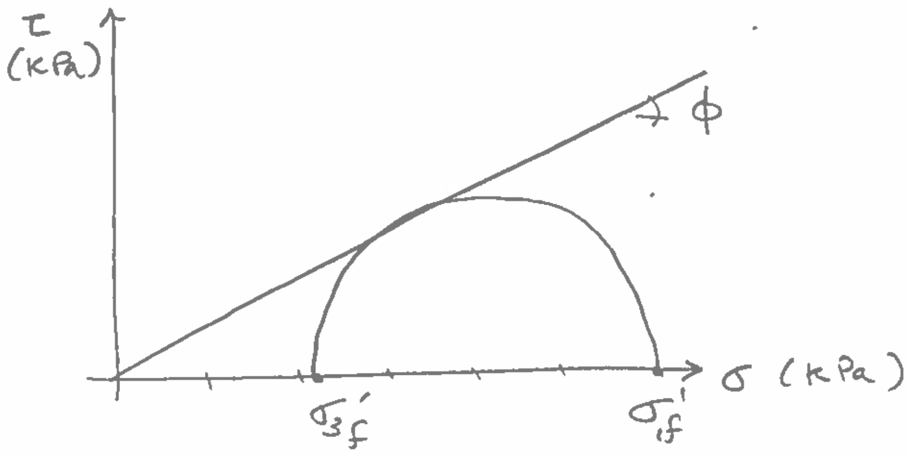
PROBLEM 3

(a)

$\sigma_3 = 30\,kPa$

$(\sigma_1 - \sigma_3)_f = 75\,kPa$

$\Delta u_{ex_f} = -15\,kPa$



$\sigma'_{3f} = 30 - (-15) = 45\,kPa$

$\sigma'_{1f} = 45 + 75 = 120\,kPa$

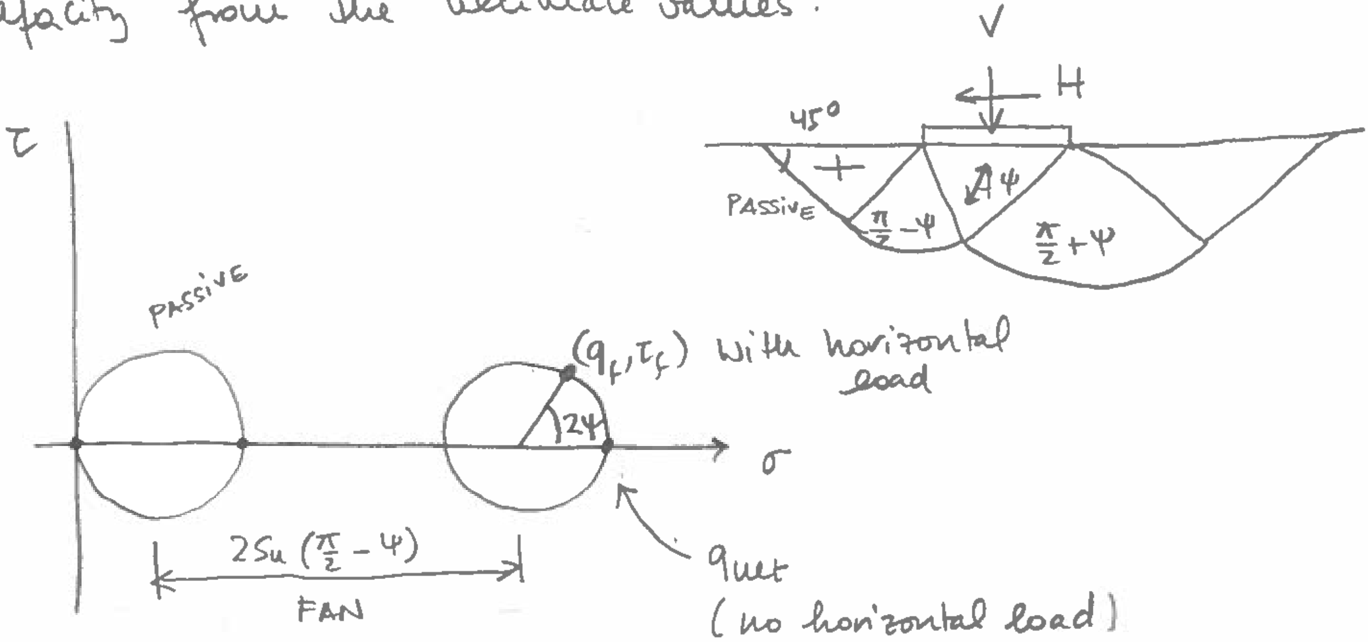
$S_u = \frac{75}{2} = 37.5\,kPa$

$\phi = \sin^{-1}\left(\frac{75}{45+120}\right) = 27°$

(b) I selected the value of $(\sigma_1 - \sigma_3)$ at large strains to assess the strength both drained and undrained to be conservative. However, it is also possible to use $S_u = \frac{100\,kPa}{2} = 50\,kPa$ with the understanding that the foundation should only be loaded to a fraction of the ultimate

load and is unlikely to reach peak strength before
settlements exceed serviceability state limit

(c) The interaction between the loads reduces the combined capacity from the ultimate values.



Databook:

$$\frac{H}{H_{ult}} = 1 - \left(2\frac{V}{V_{ult}} - 1\right)^2$$

(d) $V_{ult} = (2+\pi) S_u B$

$H_{ult} = BS_u$

$$\frac{H}{BS_u} = 1 - \left(\frac{2V}{(2+\pi)BS_u} - 1\right)^2$$

Factor the strength

$$\frac{80}{\frac{37.5}{1.4}B} = \cancel{1} - \left[\frac{(2)(200)}{(5.14)(\frac{37.5}{1.4})B}\right]^2 - \cancel{1} + \frac{(4)(200)}{(5.14)(\frac{37.5}{1.4})B}$$

$$B^2\left(\frac{2.99}{B}\right) = -\left(\frac{8.44}{B^2} + \frac{5.81}{B}\right)B^2$$

$$B = \frac{8.44}{(5.81-2.99)} = 3\,m.$$

Factor the loads

$$\frac{(80)(1.3)}{(37.5)\,B} = 1 - \left[\frac{(200)(2)(1.3)}{(5.14)(37.5)B}\right]^2 - 1 + \frac{(4)(200)(1.3)}{(5.14)(37.5)B}$$

$$\frac{2.77}{B} = \frac{7.28}{B^2} - \frac{5.40}{B}$$

$$B = \frac{7.28}{(5.40-2.77)} = 2.77$$

$$\frac{H}{H_{ult}} = \frac{80}{(37.5)(3)} = 0.71$$

$$\boxed{B = 3m}$$

$$V/V_{ult} = \frac{200}{(5.14)(37.5)(3)} = 0.34 < 0.5$$

Foundation fails in sliding

(e)

$$q_f = N_q \sigma'_{vo} + N_\gamma \frac{\gamma' B}{2}$$

$$N_q = \tan^2\left(\frac{\pi}{4} + \phi/2\right) e^{\pi \tan\phi} = 13.2$$

$$N_\gamma = 2(N_q - 1)\tan\phi = 12.4$$

Factor the loads $\gamma_F V = (1.3)(200) = 260\,kN/m$

$$q_f = (13.2)(19.5-10)(1) + \frac{(12.4)}{2}(9.5)(3) = 302.1\,kN/m > 260\,KN/m$$

Factor soil properties $\tan\phi/1.25$ and $\phi = \tan^{-1}\left(\frac{\tan\phi}{1.25}\right)$

$\phi = 22.2°$

$N_q = 7.68$

$N_\gamma = 5.44$

$$q = (7.68)(9.5)(1) + \frac{(5.44)}{2}(9.5)(3) = 150.5\,\frac{kN}{m} < 200\,\frac{kN}{m}$$ X

Will fail in long term -

Very few students attempted this question, but those that did generally did quite well. In a few cases, students did not consider interaction between vertical and horizontal capacity. The drained bearing capacity proved to be more challenging and most students failed to consider the factored code approach.

PROBLEM 4 12/13

Pile performanc is affected by stress state.

Bored piles

Relief of lateral stress depends on use or not of support fluid. Lateral stress reduces to zero (no support) or hydrostatic will drilling mud. Low friction on pile shaft

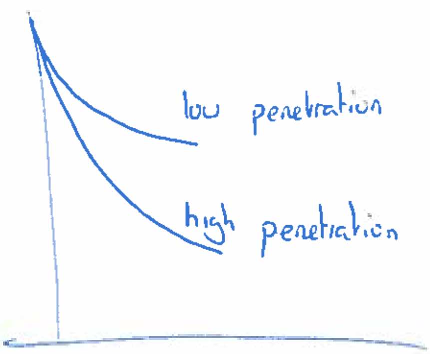
Base stress relieved and ground disturbed. Stiffness approaches zero.

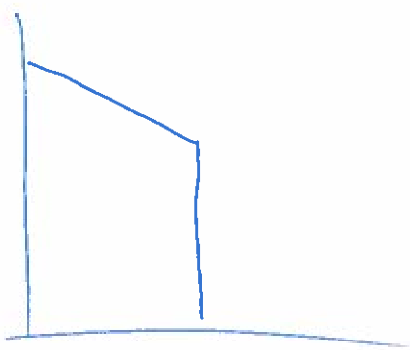
Driven piles

Pile penetration increases σ_h and u. Drainage will affect final value of σ_h' as soil consolidates away from pile, dependent on OCR. Cyclic penetration may reduce stresses due to friction fatigue, removing capacity.

Base pre-loaded and hence stiff.

b) Friction fatigue reduces σ_h due to cyclic compaction leading to strength near top of pile reducing during driving.



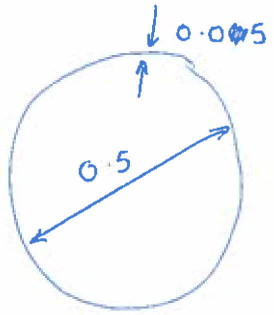


API gives cap on maximum τ_s achieving same overall effect will different approach.

15/13

c) i) Pile compressibility leads to relative pile-soil displacement being high at surface reducing with depth. At high depths, all load may have been shed in friction leading to no load transfer.

ii)



$$E_p = 210 \text{ GPa} \times \frac{\pi \times 0.05 \times 0.005}{\pi \times 0.25^2}$$

$$= 84 \text{ GPa}$$

$\zeta \sim 4$

$\lambda = \frac{84000}{10}$

$\eta = 1$

$\xi = 1$

$\rho = 1$

$\nu \sim 1/2$

$$\mu = \frac{\sqrt{\frac{8}{4 \times 84000}}}{0.5} = 0.0309$$

$$\frac{\tanh \mu L}{\mu L} = 0.89$$

$\frac{L}{D} = 40.$

$$\frac{V}{w_{head}} = D G_L \frac{\frac{2\eta}{(1-\nu)\xi} + \rho \frac{2\pi}{\zeta} \frac{\tanh \mu L}{\mu L} \frac{L}{D}}{1 + \frac{1}{\pi \lambda} \frac{8\eta}{(1-\nu)\xi} \frac{\tanh \mu L}{\mu L} \frac{L}{D}}$$

$$= 0.5 \times 10^7 \times \left[\frac{4 + \frac{\pi}{2} \times 0.89 \times 40}{1 + \frac{1}{\pi \times 8400} \times 16 \times 0.89 \times 40} \right]$$

$$= 3.06 \times 10^8$$

$$= \underline{306} \text{ MN/m}$$

A popular question on stresses around piles due to installation and effects on pile behaviour. Many candidates described stress changes in a) but neglected to explicitly say how these affect performance. Many candidates obviously ran out of time towards the end of the question, part c on compliance of long piles was often picked up, but several candidates then assumed rigid piles in part d.