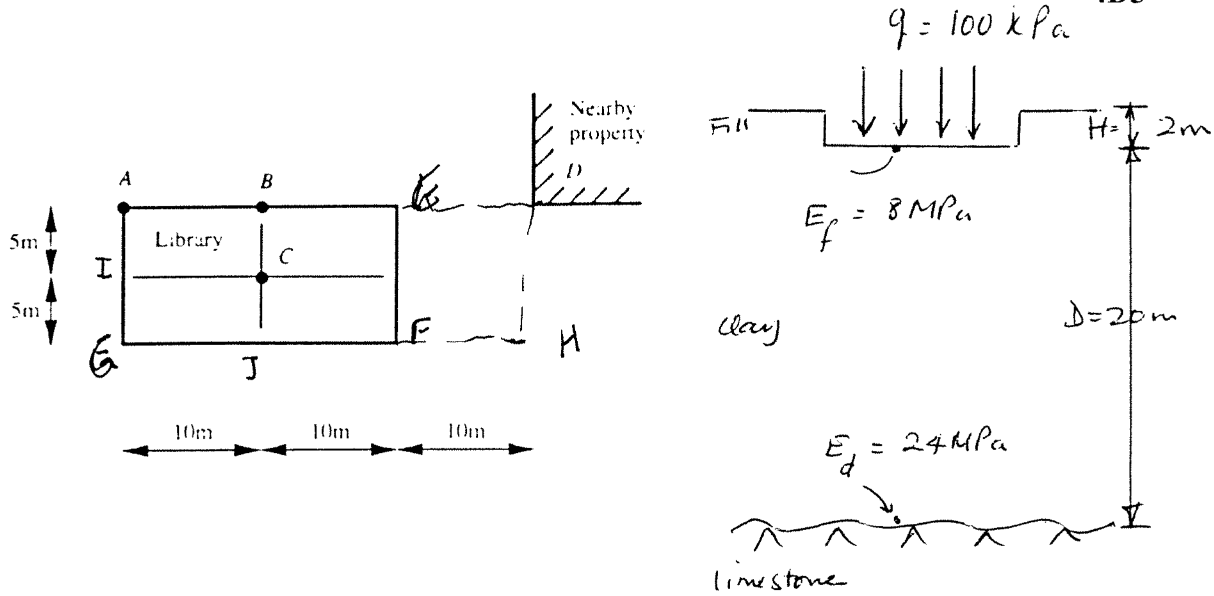
Module 4D5 – Foundation Engineering
2003 – Solutions.

IIB CRIBS
2003

1

4D5



(a)+(d)

Settlement beneath a corner of a rectangle (Meigh, 76)

$$w = \frac{q}{E_f} \cdot B \cdot I_p' \cdot F_B \cdot F_D \quad , \quad K = \frac{E_d - E_f}{E_f} \frac{B}{H}$$

Tabulate calculations – see table on next page.

∴ Settlements

w_A = 23mm.

w_B = 2x 21.8 = 43.6mm

w_c = 4 x 18.0 = 72.0 mm

w_D = 23.0 – 21.8 = 1.2mm [40%]

(b) A–C $\Delta w / \ell = \dfrac{\sqrt{(5)^2 + (10)^2}}{72 - 23} \times 10^3 = 1 : 228$

A–B $\Delta w / \ell = \dfrac{10 \times 10^3}{43.6 - 23} = 1 : 485$

B–C $\Delta w / \ell = \dfrac{5 \times 10^3}{72 - 43.6} = 1 : 176$

[10%]

(a) Cont'd. + (d) Cont'd

Area	L	B	4B	H	H/B	B/H	D/B	K	I_p'	F_D	F_H	W
GFEA	20	10	2	20	2	0.5	0.2	1	0.2	0.97	0.95	23.0
ICBA	10	5	2	"	4	0.25	0.4	0.5	0.31	0.93	1.00	18.0
GJBA	10	10	1	"	2	0.5	0.2	1	0.18	0.97	0.95	21.8
GHDA	30	10	3	"	2	0.5	0.2	1	0.2	0.97	0.95	23.0
FHDE	10	10	1	"	2	0.5	0.2	1	0.18	0.97	0.95	21.8

part of [25%]

(1)

(c) The angular distortions are too large for a structure that is likely to be sensitive to differential settlement. A flexible raft would be a bad choice.

Two possibilities are:

(i) a rigid raft: This should greatly reduce the settlement differences. The likely uniform settlement would be about

$$\frac{1}{3}(w_A + w_B + w_C) = 46.2\,mm, \text{ say } 45\text{-}50\,mm.$$

(ii) Settlement reducing piles: A few piles (probably large diameter bored) would be located at areas of unacceptable raft deflections. In this case, this would be around the centre of the raft. The piles would act as props to the raft and the total load would be shared between raft and piles. [25%]

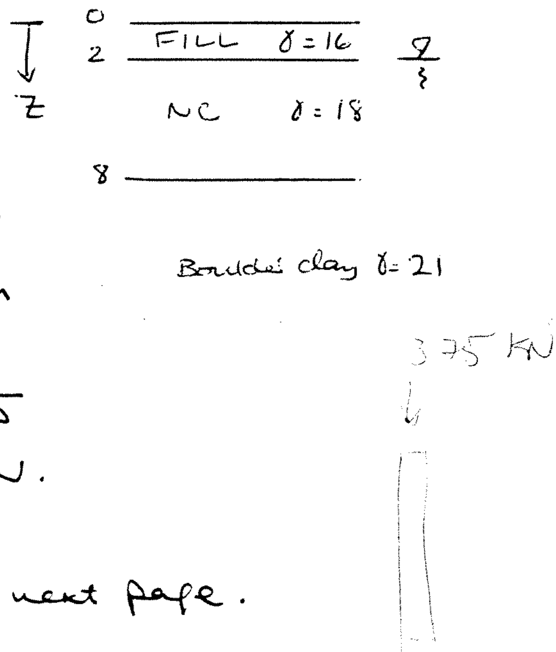
(d) $w_D = 1.2\,mm$ – as before.

This is well below the possible accuracy of prediction, and it is negligible. Nevertheless, the movement of the existing building should be monitored and recorded, and an initial and final damage survey should be made. [25%]

part of

③ (a)

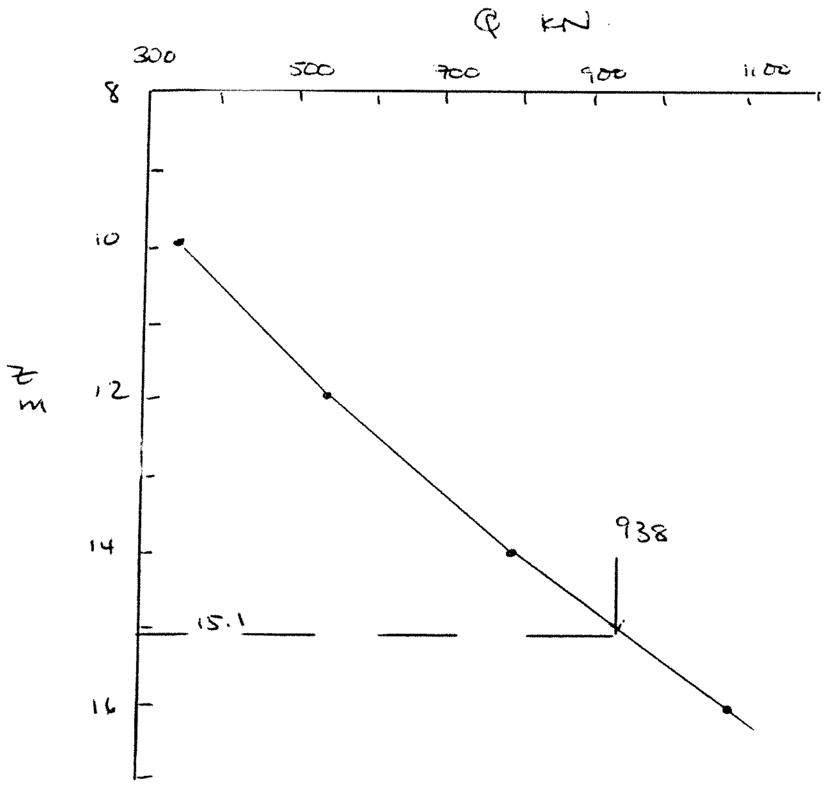
Ignore τ_s in fill.



Pile $0.4\text{m}\,\square$, $A_b = 0.16\text{m}^2$
$A_s = 1.6\text{m}^2/\text{m}$

$P_w = 375$ kN, $\therefore\ Q = 2.5 \times 375$
$= 938$ kN.

See table of calculations on next page.



② (a) cont'd.

z	$\bar{z}$	σ'_v	$\bar{c}_u$	$\overline{c_u}/\sigma'_v$	$\bar{\alpha}$	τ_s	ΔA_s	ΔQ_s	c_{ub}	Q_b	Q
2											
	5	56	16.8	0.30	0.90	15.1	9.6	145.2			
8											
	9	91	50	0.55	0.80	33.0	3.2	105.6			
10									65	93.6	344
	11	113	80	0.71	0.75	47.2	3.2	151.0			
12									100	144.0	546
	13	135	120	0.89	0.52	67.4	3.2	199.7			
14									135	194.4	796
	15	157	150	0.96	0.50	75.0	3.2	240.0			
16									175	252.0	1094
	17	179	200	1.12	0.48	96.0	3.2	307.2			
18											

[50%]

2(b) (i) In normally consolidated clay pile driving causes positive excess pore water pressure around the shaft. Dissipation causes lateral consolidation and a local rise in c_u. Also, lateral stresses are sufficient to ensure complete contact between the clay and the pile, so α value are usually high and around 0.9-1.0.

(ii) In overconsolidated clay pile driving probably causes a small positive excess pore water pressure, but pile-clay gaps are likely to stay open indefinitely. The gap fills with water, the clay softens locally (and very readily) and α falls. Hence α for heavily oversoncolidated clay can be as low as 0.3-0.2.

[20%]

(c) Reasons for preliminary pile tests:

(i) to confirm design values for the soils and hence to prove pile capacity and settlement characteristics.
(ii) to confirm workmanship is suitable
(iii) to develop construction practice.
(iv) to refine design to produce savings. [10%]

(d) Use of polymer vs bentonite:

Bentonite	Polymer
Naturally occurring mined clay	Industrially produced chemical
Raw material is relatively cheap	Very expensive material
Large plant requirements for mixing and cleaning	Smaller storage and no desander
Takes time to clean before concreting	deflocculant added to clean polymer
Site can become a quagmire	Site cleaner but sticky puddles
Large disposal costs	Lower disposal costs
Inexpensive fluid loss/waste	very costly to waste
Higher specific gravity	lower specific gravity creates only small imbalance with high water levels
Known science, no health hazards	steep learning curve, multi level personal protective equipment required

[20%]

Module 4D5: Foundation Engineering
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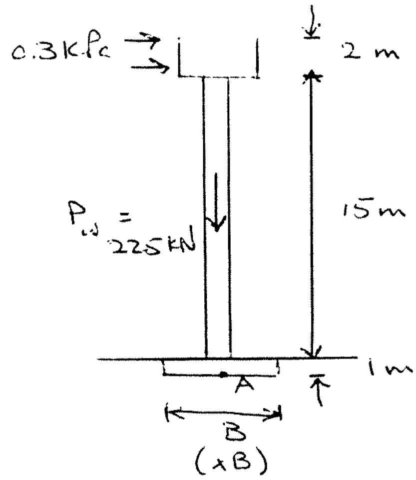
(a)
③ Three ways of design are possible:

(a) Linear method



$M_A = 0.3 \times 2 \times 15 \times 17 = 153\ kNm$

$P_w = 225\ kN$

$e = M_A / P_w = 0.68\ m.$

If vertical resultant is at end of middle third,

$B = 6 \times 0.68 = 4.08$ say $4.1\ m$; $q_{max} = 26.8\ kPa$

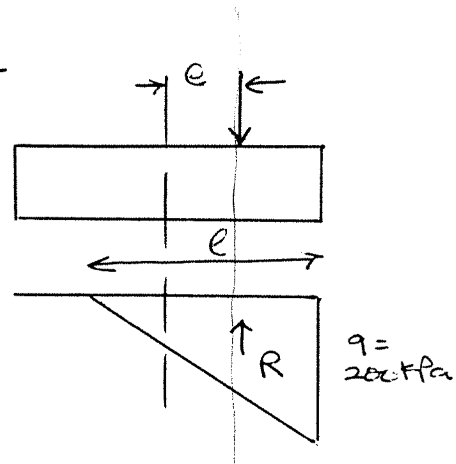
(b) Reduced base width

$R = \frac{1}{2} \ell B \times 200 = 100 \ell B$

triple

$\ell = 3 \left\{ \frac{B}{2} - 0.68 \right\} = 1.5B - 2.04$

$R = P_w = 225\ kN$



$225 = 100B(1.5B - 2.04)$
$225 = 150B^2 - 204B.$

$$B = \frac{204 \pm \sqrt{(204)^2 + 4(150)(225)}}{300}$$

$= 2.08\ m$; $q_{max} = 200\ kPa$

(C) <u>Limit state method</u>

Base area $A = B(B - 2e) = B^2 - 1.36B$

$$q = \frac{225}{B^2 - 1.36B} = 200$$

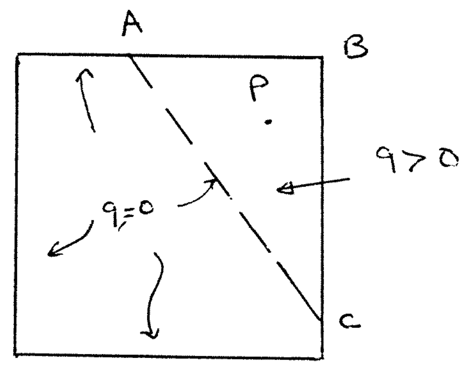
$$225 = 200B^2 - 272B.$$

$$B = \frac{272 \pm \sqrt{(272)^2 + 4(200)(225)}}{400}$$

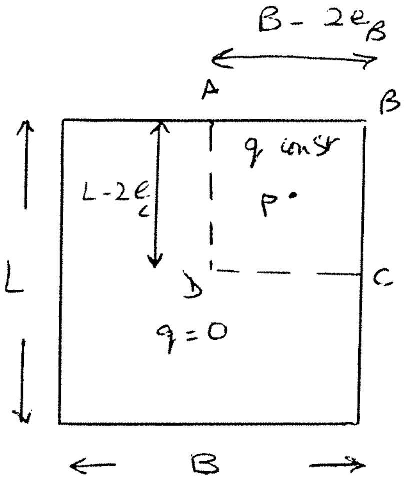
$$= 1.94\text{m}.$$

Method (a) is too conservative : the available bearing capacity is grossly underused.
Methods (b) and (c) give similar answers (2.08m and 1.97m) so take $B = 2.00$m.
[45 %]

(b) The doubly-eccentric load case is tedious to solve by either the linear method or the limit state method if the resultant vertical force is outside the middle-third core.
An area ABC must be found such that P is at the centroid of the stress block, and this is a lengthy calculation.
With the linear method an added complication is that q is zero along AC and increases towards B.



In the limit-state method q is constant over ABC. An approximation is possible with the limit state method. Over ABCD q is taken as constant; elsewhere it is zero. The calculation is then trivial : $q = \dfrac{P}{(B-2e_B)(L-2e_L)}$.



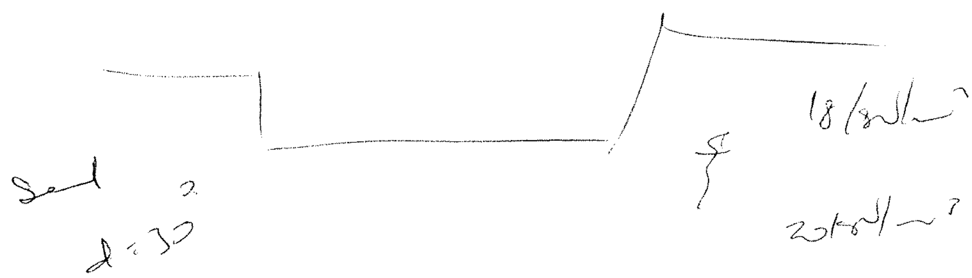
This approximation does not model the conditions at failure, though the solution is acceptable. [30%]

(c) $q_{ult} = \gamma D N_q + \beta \gamma B N_\gamma$

$= 18 \times 2 \times 18 + 0.4 \times 10 \times 2 \times 18$

$= 792$

F.o.S. $= \dfrac{792 - 36}{200} = 3.78.$ [25%]



53

4 (a)

$$\frac{P}{w\, r_o\, G_\ell} = \frac{4}{(1-\nu)}\frac{\eta}{\xi} + \frac{2\pi}{\zeta}\rho\frac{\ell}{r_o}$$

$P = 400\,kN$, $r_o = 0.25m$, $G_\ell = 8750 kPa$,
$\nu = 0.2$, $\eta = r_b/r_o = 1.0$, $\xi = G_\ell/G_b = 1.0$,
$\zeta = \ln r_m/r_o = \ln 15/0.25 = 4.1$,
$\rho = \bar{G}/G_\ell = 0.5$.

$$\therefore \frac{400}{w \times 0.25 \times 8750} = \frac{4}{0.8}\frac{1}{1} + \frac{2\pi}{4.1} \times \frac{1}{2} \times \frac{12.5}{0.25}$$

$$\frac{0.182}{w} = (5 + 38.3)$$

$\Rightarrow w = 4.2mm.$ [25%]

(b) $\frac{w}{P} = \frac{4.2}{400} = 0.0105\ mm/kN.$

$K = \infty$, $\frac{L}{d} = 25.$

use pile interaction chart (Poulos & Davis, 1980).

Pile j	s/d	α
1	–	–
2	3.0	0.54
3	4.24	0.47
4	3.0	0.54
		$\Sigma = 1.55$

$w_k = w\{P_k + \Sigma P_j\,\alpha\} = 0.0105\{400 + (400 \times 1.55)\}$
$= 10.5mm$

[25%]

(c)

Method (1)

$$\text{Settlement efficiency} = \frac{K_Q}{n K_s}$$

K_Q is stiffness of the pile group of n piles and K_s is the stiffness of a single pile.

$$\text{Settlement efficiency} = \frac{1600/10.5}{4(400/4.2)}$$

$$= \underline{0.4}$$

Method (2): using the graphs obtained by Randolph et al from finite element analyses:

$L/d = 25 \Rightarrow$ Efficiency exponent $e = 0.544$.

$\nu = 0.2 \Rightarrow e_1 = 1.03$

$\rho = 0.5 \Rightarrow e_2 = 0.925$

$E_p/G_\ell = \infty \Rightarrow e_3 = 1.1$

$S/d = 3 \Rightarrow e_4 = 1.0$

$$\therefore \text{Settlement efficiency} = n^{-e}$$

$$= 4^{-[0.544 \times 1.03 \times 0.925 \times 1.1 \times 1.0]}$$

$$= \underline{0.453}$$

The results calculated using methods (1) and (2) are similar.
Method (2) is based on the results of finite element analyses. It does not take into account interaction between the various variables considered. The analysis is also based on an elastic solution. In addition pile cap rigidity is not take into account. [40%]

(d) (i) As pile spacing increases, settlement efficiency increases for the same pile nos.
(ii) As no. of piles increase at the same spacing the settlement efficiency decreases. [10%]