Assignment

Substructure Design (CE7113)

Name: Manohar Mitta

KU Id: K2004168

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1)

Design of pad footing

i) Design of A_1 pad footing:

The assigned parameters for footing A_1.

Vertical Load (D.L) $V_{GK} = 455$ kN

Vertical Live Load (L.L) $V_{QK} = 273$ kN

V_{GK} eccentricity = 0 from both ways.

V_{QK} eccentricity = 0 from both ways.

Moment due to D.L (M_{GK}) for axis A-A = 87 kN.m

Moment due to D.L (M_{GK}) for axis 1-1 = 109 kN.m

Moment due to L.L (M_{QK}) for axis A-A = 84 kN.m

Moment due to L.L (M_{QK}) for axis 1-1 = 113 kN.m

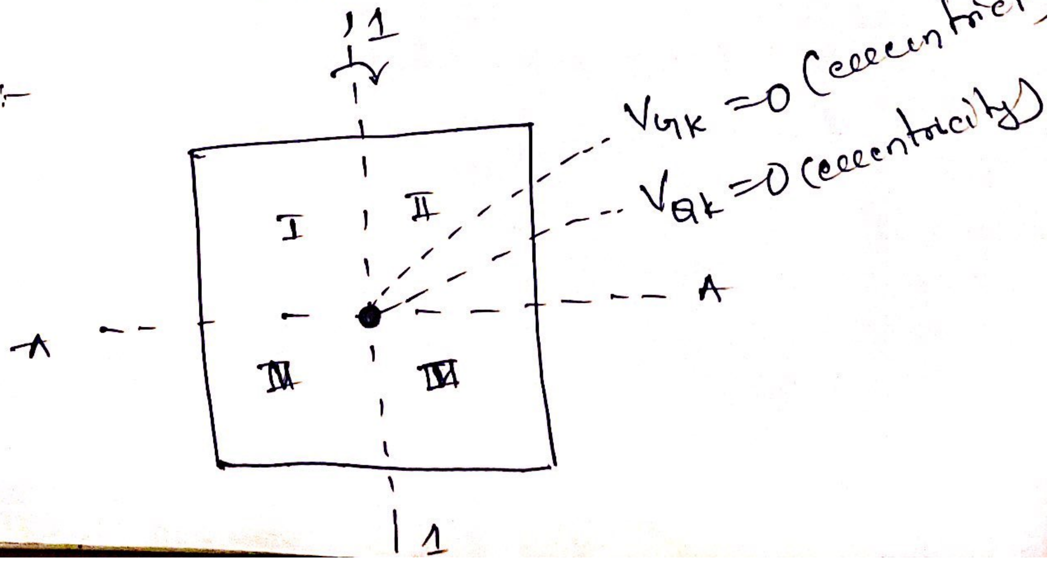
Unit weight of concrete = 25 kN/m^3

Unit weight of soil = 18 kN/m^3

Thickness of footing = 0.3m

Depth = 3m

Column A_1 :-



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Let assume pad ~~wi~~ length & width to be 2.3 m

=> Self weight $(W_{GK}) = 2.3 \times 2.3 \times 0.3 \times 25$

$= 39.68$ KN

=> Dead load $(B_{GK}) = (3-0.3) \times 2.30 \times 2.3 \times 18$

$= 257.09$ KN

* partial factors for design loads:-

Combination 1

$\gamma_{G_1} = 1.35$

$\gamma_{Q_1} = 1.5$

$\gamma_{Q_1,fav} = 0$

Combination 2

$\gamma_{G_2} = 1.0$

$\gamma_{Q_2} = 1.3$

$\gamma_{Q_2,fav} = 0$

$\therefore$ Total $V_{GK} = W_{GK} + B_{GK} + V_{GK(given)}$

$= 39.68 + 257.09 + 455$

$= 751.77$ KN

Now,

$$V_d = \begin{bmatrix} \text{combination 1} \\ \text{combination 2} \end{bmatrix} = \begin{bmatrix} \gamma_{G_1} \times (\text{Total } V_{GK}) + [\gamma_{Q_1} \times V_{QK}] - \gamma_{Q_1,fav} \times V_{Kb} \\ \gamma_{G_2} \times (\text{Total } V_{GK}) + (\gamma_{Q_2} \times V_{QK}) - \gamma_{Q_2,fav} \times V_{Kb} \end{bmatrix}$$

$$= \begin{bmatrix} 1.35 \times (751.77) + 1.5 \times 273 - 0 \\ 1 \times (751.77) + 1.3 \times 273 - 0 \end{bmatrix}$$

$$= \begin{bmatrix} 1424.39 \\ 1106.67 \end{bmatrix} \text{KN}$$

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Design moments based on load combination 1 & 2

Calculations of moments on I, II, III, IV with respect to A-A

About axis A-A	Combination 1	Combination 2
1) $M_1 = -\gamma_{G,fav} \times M_{GK} - \gamma_{Q,fav} \times M_{QK}$	$M_1 = -1.0 \times 87 - 0 \times 84$ $M_1 = -87$ kN.M	$M_1 = -1.0 \times 87 - 0 \times 84$ $= -87$ KNm
2) $M_2 = M_1$	$M_2 = M_1 = -87$ kN.M	$M_2 = M_1 = -87$ kN.M
3) $M_3 = \gamma_G \times M_{GK} + \gamma_Q \times M_{QK}$	$M_3 = 1.35 \times 87 + 1.5 \times 84$ $= 243.45$ KNM	$M_3 = 1 \times 87 + 1.3 \times 84$ $= 196.2$ KNM
4) $M_4 = M_3$	$M_4 = M_3 = 243.45$ KNM	$M_4 = M_3 = 196.2$ KNM

Calculations of moments on quadrant I, II, III, IV w.r.t 1-1 axis.

About axis 1-1	Combination 1	Combination 2
1) $M_1 = \gamma_{G,fav} \times M_{GK} - \gamma_{Q,fav} \times M_{QK}$	$M_1 = 1.0 \times 109 - 0 \times 113$ $= 109$ kNM	$M_1 = 1.0 \times 109 - 0 \times 113$ $= 109$ kNm
2) $M_2 = \gamma_G \times M_{GK} + \gamma_Q \times M_{QK}$	$M_2 = 1.35 \times 109 + 1.5 \times 113$ $= 316.65$ kNm	$M_2 = 1.0 \times 109 + 1.3 \times 113$ $= 255.9$ kNm
3) $M_3 = M_2$	$M_3 = M_2 = 316.65$ kNm	$M_3 = M_2 = 255.9$ kNm
4) $M_4 = M_1$	$M_4 = M_1 = 109$ kNm	$M_4 = M_1 = 109$ kNm

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Maximum moments about A-A axis

$$M_{d\,(A-A)} = \begin{bmatrix} 243.45 \\ 196.2 \end{bmatrix} \text{KNM}$$

Maximum moments about 1-1 axis

$$M_{d(1-1)} = \begin{bmatrix} 316.65 \\ 255.9 \end{bmatrix} \text{KNm}$$

Effective pad footing area based on load combinations 1 & 2

$$e_{(A-A)} = \left[\frac{M_{d(A-A)}}{V_d}\right]$$

$$= \begin{bmatrix} 243.45/1424.39 \\ 196.2/1106.67 \end{bmatrix}$$

$$= \begin{bmatrix} 0.17 \\ 0.18 \end{bmatrix} m$$

$$\therefore \quad e_{(A-A)} < \frac{B}{6} \quad \text{Hence ok} \left[\because \frac{B}{6} = \frac{2.3}{6} = 0.38\right]$$

Similarly,

$$e_{(1-1)} = \left[\frac{M_{d(1-1)}}{V_d}\right]$$

$$= \begin{bmatrix} 316.65/1424.39 \\ 255.9/1106.67 \end{bmatrix}$$

$$= \begin{bmatrix} 0.22 \\ 0.23 \end{bmatrix} m \quad \left(\because e_{(1-1)} < \frac{B}{6}\right)$$

Hence ok.

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	About A-A	About 1-1
* Effective length and width = (length and width in the direction of eccentricity) − 2×eccentricity	$\begin{bmatrix} (2.3-0.17)-2\times0.17 \\ (2.3-0.16)-2\times0.16 \end{bmatrix}$	$\begin{bmatrix} (2.3-0.22)-2\times0.22 \\ (2.3-0.23)-2\times0.23 \end{bmatrix}$
	$= \begin{bmatrix} 1.79 \\ 1.76 \end{bmatrix} = \begin{bmatrix} L'_1 \& B'_1 \\ L'_2 \& B'_2 \end{bmatrix} m$	$\begin{bmatrix} 1.64 \\ 1.61 \end{bmatrix} = \begin{bmatrix} L'_1 \& B'_1 \\ L'_2 \& B'_2 \end{bmatrix}$
* Smaller effective dimension $A' = L' \times B'$	$\begin{bmatrix} 3.2 \\ 3.09 \end{bmatrix} m^2$	$\begin{bmatrix} 2.68 \\ 2.59 \end{bmatrix} m^2$
* q_{design} (Q_{Ed}) $Q_{Ed} = \frac{V_d}{A'}$	$\begin{bmatrix} \frac{1424.39}{3.2} \\ \frac{1106.67}{3.09} \end{bmatrix}$	$\begin{bmatrix} \frac{1424.39}{2.68} \\ \frac{1106.67}{2.59} \end{bmatrix}$
	$= \begin{bmatrix} 445.12 \\ 358.15 \end{bmatrix}$	$\begin{bmatrix} 531.48 \\ 427.29 \end{bmatrix}$

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Bearing capacity (undrained condition)

$$Q_{ult} = (\pi+2)\, C_u b_c S_c^{o} i_c + q$$

C_u = SPT value x5

= 20x5 = 100.

	About A-A axis	About (1-1) axis
1) undrained strength (C_u)	$\begin{bmatrix}100\\100\end{bmatrix}$	$\begin{bmatrix}100\\100\end{bmatrix}$
2) $\frac{C_u}{\gamma_{cu}}$	$\begin{bmatrix}\frac{100}{1}\\\frac{100}{1.4}\end{bmatrix} = \begin{bmatrix}100\\71.42\end{bmatrix}$	$\begin{bmatrix}\frac{100}{1}\\\frac{100}{1.4}\end{bmatrix} = \begin{bmatrix}100\\71.42\end{bmatrix}$
3) $b_c = \frac{1-2\alpha}{\pi+2}$	$\begin{bmatrix}1\\1\end{bmatrix}$	$\begin{bmatrix}1\\1\end{bmatrix}$
4. S_c = 1.2 for square or circular footing	$\begin{bmatrix}1.2\\1.2\end{bmatrix}$	$\begin{bmatrix}1.2\\1.2\end{bmatrix}$
5. $i_c = 0.5\left(1+\sqrt{1-\frac{H}{A'C_u}}\right)$ Provided $H \le A'C_u$	$\begin{bmatrix}1\\1\end{bmatrix}$	$\begin{bmatrix}1\\1\end{bmatrix}$
6. q = dencity of soil x depth of footing	$\begin{bmatrix}18\times3.0=54\\18\times3.0=54\end{bmatrix}$ KN/M	$\begin{bmatrix}54\\54\end{bmatrix}$ KN/m
7) $Q_{ult} = (\pi+2) C_u b_c S_c i_c + q$	$\begin{bmatrix}(\pi+2)\times100\times1\times1.2\times1)+54\\(\pi+2)\times71.42\times1\times1.2\times1)+54\end{bmatrix} = \begin{bmatrix}670.8\\494.58\end{bmatrix}$ KPa	$\begin{bmatrix}670.8\\494.58\end{bmatrix}$ Kpa
8. Q_{ult}/γ_R	$\begin{bmatrix}670.8/1\\494.58/1\end{bmatrix} = \begin{bmatrix}670.8\\494.58\end{bmatrix}$	$\begin{bmatrix}670.8\\494.58\end{bmatrix}$
9. utilization factor $\frac{Q_{Ed}}{Q_{ult}}\times100$	$\begin{bmatrix}\frac{445.12}{670.8}\times100\\\frac{358.15}{494.58}\times100\end{bmatrix} = \begin{bmatrix}66.36\%\\72.41\%\end{bmatrix} < 100\%$	$\begin{bmatrix}\frac{531.48}{670.8}\times100\\\frac{427.29}{494.58}\times100\end{bmatrix} = \begin{bmatrix}79.23\\86.39\end{bmatrix} < 100\%$

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	About axis (A-A)	About axis (1-1)
$M = \frac{L'}{B'}$	$\begin{bmatrix} \frac{1.79}{1.79} \\ \frac{1.76}{1.76} \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$	$\begin{bmatrix} \frac{1.64}{1.64} \\ \frac{1.61}{1.61} \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$
$N = \frac{H}{B'}$ $(\because H = 4 \times B)$	$\begin{bmatrix} \frac{2.3 \times 4}{1.79} \\ \frac{2.3 \times 4}{1.76} \end{bmatrix} = \begin{bmatrix} 5.14 \\ 5.23 \end{bmatrix}$	$\begin{bmatrix} \frac{2.3 \times 4}{1.64} \\ \frac{2.3 \times 4}{1.61} \end{bmatrix} = \begin{bmatrix} 5.61 \\ 5.71 \end{bmatrix}$

$E_s = 1000 \times Q_{uni}/2$

$Q_{uni} = 2 \times C_u \left[\because C_u = 5 \times \text{SPT value}\right]$

$= 2 \times 5 \times \text{SPT value}$

$E_s = 1000 \times 5 \times \text{SPT value}$

E_s at $3.5 = 1000 \times 5 \times 20 = 1{,}00000$ kPa

E_s at $5.5 = 1000 \times 5 \times 54 = 270000$ kPa

E_s at $8.0 = 1000 \times 5 \times 50 = 250000$ kPa

$$E_s \text{ weighted average} = \frac{100000 \times 3.5 + 270000 \times 5.5 + 250000 \times 8}{17}$$

$$= 225588 \text{ kPa}$$

$$\Delta_H = q_0 B' \times \frac{1-\mu^2}{E_s}\left(I_1 + \frac{1-2\mu}{1-\mu} I_2\right) I_F$$

$$I_1 = \frac{1}{\pi}\left[M \times \ln \frac{(1+\sqrt{M^2+1})\sqrt{M^2+N^2}}{M(1+\sqrt{M^2+N^2+1})} + \ln \frac{(M+\sqrt{M^2+1})\sqrt{1+N^2}}{M+\sqrt{M^2+N^2+1}}\right]$$

$$I_2 = \frac{N}{2\pi} \tan^{-1}\left(\frac{M}{N\sqrt{M^2+N^2+1}}\right)$$

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About A-A axis

Combination 1:

$$I_1 = \frac{1}{\pi}\left[1\times \ln \frac{(1+\sqrt{1^2+1})\sqrt{1^2+5.14^2}}{1(1+\sqrt{1^2+(5.14)^2+1}} + \ln \frac{(1+\sqrt{1^2+1})\sqrt{1+(5.14)^2}}{1+\sqrt{1^2+(5.14)^2+1}}\right]$$

$= 0.44$

$$I_2 = \frac{5.14}{2\pi}\tan^{-1}\left(\frac{1}{5.14\sqrt{1^2+(5.14)^2+1}}\right) = 1.71$$

$$\Delta_H = 4.45\times 1.79 \times \frac{(1-(0.3)^2)}{225588}\left(0.44+\frac{1-2(0.3)}{1-0.3}\times 1.71\right)\times 0.623$$

$= 0.0000283687$

To limit settlement to 50mm $q = \dfrac{0.05}{0.0000283687}$

$= 1762.5\ kN/m^2$

Combination 2:

$$I_1 = \frac{1}{\pi}\left[1\times \ln \frac{(1+\sqrt{1^2+1})\sqrt{1^2+(5.23)^2}}{1(1+\sqrt{1^2+(5.23)^2+1}} + \ln \frac{(1+\sqrt{1^2+1})\sqrt{1+(5.23)^2}}{1+\sqrt{1^2+(5.23)^2+1}}\right.$$

$= 0.44$

$$I_2 = \frac{5.23}{2\pi}\tan^{-1}\left(\frac{1}{5.23\sqrt{1^2+(5.23)^2+1}}\right) = 1.68$$

$$\Delta_H = 356.15\times 1.79\times \frac{1-(0.3)^2}{225588}\left(0.44+\frac{1-2(0.3)}{1-0.3}\times 1.68\right)\times 0.6$$

$= 0.0002256$

To limit settlement to 50mm

$$q = \frac{0.05}{0.0002256} = 221.63\ kN/m^2$$

About 1-1 axis

Combination 1:

$$I_1 = \frac{1}{\pi}\left[1 \times \ln \frac{(1+\sqrt{1^2+1}\sqrt{1^2+(5.61)^2}}{1(1+\sqrt{1^2+(5.61)^2+1}} + \ln \frac{(1+\sqrt{1^2+1}\sqrt{1+(5.61)^2}}{1+\sqrt{1^2+(5.61)^2+1}}\right]$$

$$= 0.45$$

$$I_2 = \frac{5.61}{2\pi}\tan^{-1}\left(\frac{1}{5.61\sqrt{1^2+(5.61)^2+1}}\right) = 1.58$$

$$\Delta_H = 0.000296$$

To limit settlement to 50mm

$$q = \frac{0.05}{0.000296} = 168.91\ \text{kN/m}^2$$

Combination: 2

$$I_1 = \frac{1}{\pi}\left[1 \times \ln \frac{(1+\sqrt{1^2+1}\sqrt{1^2+(5.71)^2}}{1(1+\sqrt{1^2+(5.71)^2+1}} + \ln \frac{(1+\sqrt{1^2+1}\sqrt{1+(5.71)^2}}{1+\sqrt{1^2+(5.71)^2+1}}\right]$$

$$= 0.45$$

$$I_2 = \frac{5.71}{2\pi}\tan^{-1}\left(\frac{1}{5.71\sqrt{1^2+(5.23)^2+1}}\right) = 1.55$$

$$\Delta H = 427.29 \times 1.61 \times \frac{1-(0.3)^2}{22558.8}\left(0.45 + \frac{1-2(0.3)}{1-0.3} \times 1.55\right) \times 0.623$$

$$= 0.000228$$

To limit settlement to 50 mm

$$q = \frac{0.05}{0.00023} = 217\ \text{kN/m}^2$$

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ii) Design of A_2 pad footing:

The assigned parameters for footing A_2

Vertical load (D.L) (V_{GK}) = 314 KN

Vertical live load (V_{QK}) = 73 KN

V_{GK} eccentricity = 0 from both ways

V_{QK} eccentricity = 0 from both ways

Moment due to D.L (M_{GK}) for axis A-A = 98 KNM

Moment due to D.L (M_{GK}) for axis 2-2 = 101 KNM

Moment due to L.L (M_{QK}) for axis A-A = 23 KNM

Moment due to L.L (M_{QK}) for axis 2-2 = 32 KNM

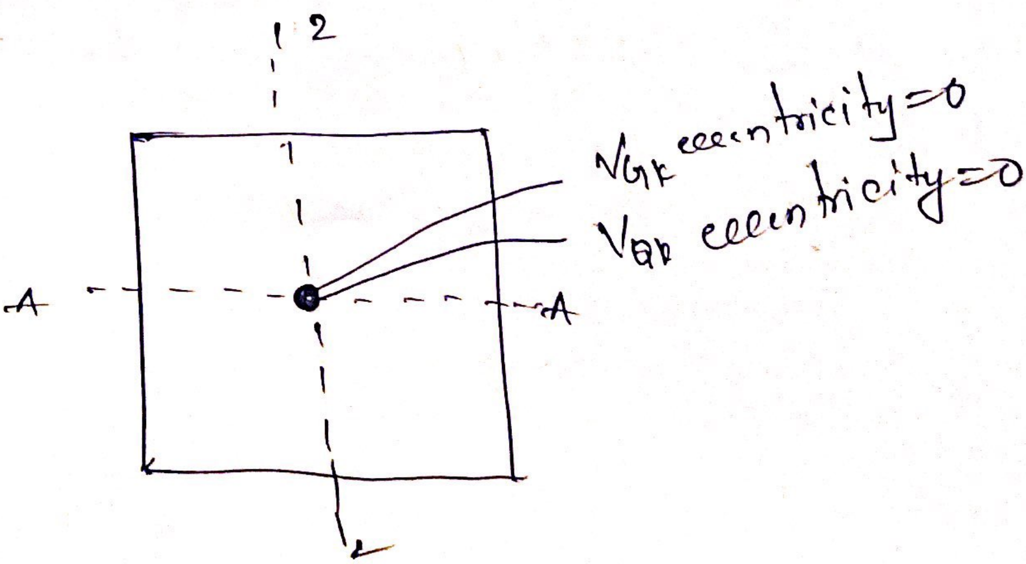
Unit weight of concrete = 25 KN/m^3

Unit weight of soil = 18 KN/m^3

Thickness of footing = 0.3m

Depth " = 3m

Column A_2 :



let assume pad length & width to be 2.3 m

$\Rightarrow$ self weight $(W_{GK}) = 2.3 \times 2.3 \times 0.3 \times 25$

$= 39.68$ KN

$\Rightarrow$ Dead load $(B_{GK}) = (3-0.3) \times 2.3 \times 2.3 \times 18$

$= 257.09$ KN

* partial factors for design loads :-

Combination 1

$\gamma_{G_1} = 1.35$

$\gamma_{Q_1} = 1.5$

$\gamma_{Q_1 fav} = 0$

Combination

$\gamma_{G_2} = 1.0$

$\gamma_{Q_2} = 1.3$

$\gamma_{Q_2 fav} = 0$

$\therefore$ Total $V_{GK} = W_{GK} + B_{GK} + V_{GK(given)}$

$= 39.68 + 257.09 + 314$

$= 610.77$ KN

Now,

$$V_d = \begin{bmatrix} \text{Combination 1} \\ \text{Combination 2} \end{bmatrix} = \begin{bmatrix} \gamma_{G_1} \times (\text{Total } V_{GK}) + [\gamma_{Q_1} \times V_{QK}] - \gamma_{Q_1 fav} \times V_{Qk,b} \\ \gamma_{G_2} \times (\text{Total } V_{GK}) + (\gamma_{Q_2} \times V_{QK}] - \gamma_{Q_2 fav} \times V_{Qk,b} \end{bmatrix}$$

$$= \begin{bmatrix} 1.35\,(610.77) + 1.5 \times 73 - 0 \\ 1 \times (610.77) + 1.3 \times 73 - 0 \end{bmatrix}$$

$$= \begin{bmatrix} 934.04 \\ 705.67 \end{bmatrix} \text{KN}$$

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Design moments based on load combination 1 & 2

* Calculations of moments on quadrant I, II, III, IV w.r.t axis (A – A)

About axis (A-A)	Combination 1	Combination 2
1) $M_1 = -\gamma_{Gfar} \times M_{Gk} - \gamma_{Qfar} \times M_{Qk}$	1) $= -1.0 \times 98 - 0 \times 23$ $M_1 = -98$ kNM	$M_1 = -1.0 \times 98 - 0 \times 23$ $M_1 = -98$ kNM
2) $M_2 = M_1$	2) $M_2 = M_1 = -98$ kNM	$M_2 = M_1 = -98$ kNM
3. $M_3 = \gamma_G \times M_{Gk} + \gamma_Q \times M_{Qk}$	3) $M_3 = 1.35 \times 98 + 1.5 \times 23$ $= 166.8$ kNM	$M_3 = 1 \times 98 + 1.3 \times 23$ $= 127.9$ kNM
4. $M_4 = M_3$	4) $M_4 = M_3 = 166.8$ kNM	$M_4 = M_3 = 127.9$ kNM

* Calculations of moments on quadrants I, II, III and IV w.r.t 2-2

About axis (2-2)	combination 1	Combination 2
1) $M_1 = \gamma_{Gfar} \times M_{Gk} - \gamma_{Qfar} \times M_{Qk}$	$M_1 = 1 \times 101 - 0 \times 32$ $= 101$ kNM	$M_1 = 1 \times 101 - 0 \times 32$ $= 101$ kNm
2) $M_2 = (\gamma_G \times M_{Gk}) + (\gamma_Q \times M_{Qk})$	$M_2 = 1.35 \times 101 + 1.5 \times 32$ $= 184.35$ kNM	$M_2 = 1 \times 101 + 1.3 \times 32$ $= 142.6$ kNM
3) $M_3 = M_2$	$M_3 = M_2 = 184.35$ kNm	$M_3 = M_2 = 142.6$ kNm
4) $M_4 = M_1$	$M_4 = M_1 = 109$ kNm	$M_4 = M_1 = 101$ kNm

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Maximum moments about A-A axis

$$M_{d(A-A)} = \begin{bmatrix} 166.8 \\ 127.9 \end{bmatrix} \text{KNM}$$

Maximum moments about 2-2 axis

$$M_{d(2-2)} = \begin{bmatrix} 184.35 \\ 142.6 \end{bmatrix} \text{KNM}$$

Effective pad footing area based on load combinations 1 & 2

$$e_{(A-A)} = \left[\frac{M_{d(A-A)}}{V_d}\right]$$

$$= \begin{bmatrix} 166.8/934.04 \\ 127.9/705.67 \end{bmatrix}$$

$$= \begin{bmatrix} 0.18 \\ 0.18 \end{bmatrix} m$$

$\therefore e_{(A-A)} < \frac{B}{6}$ Hence ok $\left[\because \frac{B}{6} = \frac{2.3}{6} = 0.38\right]$

Similarly

$$e_{(2-2)} = \left[\frac{M_{d(2-2)}}{V_d}\right]$$

$$= \begin{bmatrix} 184.35/934.04 \\ 142.6/705.67 \end{bmatrix}$$

$$= \begin{bmatrix} 0.20 \\ 0.20 \end{bmatrix} m$$

$\therefore e_{(2-2)} < \frac{B}{6}$ Hence ok.

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	About A-A axis	About 2-2 axis
* Effective length and width = (length and width in the direction of eccentricity) − 2 × eccentricity	$\begin{bmatrix} (2.3-0.18)-2\times 0.18 \\ (2.3-0.18)-2\times 0.18 \end{bmatrix}$ $= \begin{bmatrix} 1.76 \\ 1.76 \end{bmatrix} = \begin{bmatrix} L' \& B' \\ L' \& B' \end{bmatrix} m$	$\begin{bmatrix} (2.3-0.2)-2\times 0.2 \\ (2.3-0.2)-2\times 0.2 \end{bmatrix}$ $= \begin{bmatrix} 1.70 \\ 1.70 \end{bmatrix}$
* Smaller effective dimensions $A' = L' \times B'$	$= \begin{bmatrix} 3.1 \\ 3.1 \end{bmatrix}$	$= \begin{bmatrix} 2.89 \\ 2.89 \end{bmatrix}$
* q_{design} $(q_{Ed}) = \frac{V_d}{A'}$	$= \begin{bmatrix} \frac{934.04}{3.1} \\ \frac{705.67}{3.1} \end{bmatrix}$	$\begin{bmatrix} \frac{934.04}{2.89} \\ \frac{705.67}{2.89} \end{bmatrix}$
	$= \begin{bmatrix} 301.3 \\ 227.64 \end{bmatrix}$	$= \begin{bmatrix} 323.20 \\ 244.18 \end{bmatrix}$

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(6)

Bearing capacity (undrained condition)

$$Q_{ult} = (\pi+2)\, C_u b_c s_c i_c + q$$

$$C_u = \text{SPT value} \times 5$$

$$= 20 \times 5 = 100$$

	About A-A axis	About (2-2) axis
1. Undrained strength (C_u)	$\begin{bmatrix}100\\100\end{bmatrix}$	$\begin{bmatrix}100\\100\end{bmatrix}$
2) $\frac{C_u}{\gamma_{cu}}$	$\begin{bmatrix}100/1\\100/1.4\end{bmatrix} = \begin{bmatrix}100\\71.42\end{bmatrix}$	$\begin{bmatrix}100\\71.42\end{bmatrix}$
3. $b_c = \frac{1-2\alpha}{\pi+2}$	$\begin{bmatrix}1\\1\end{bmatrix}$	$\begin{bmatrix}1\\1\end{bmatrix}$
4. $S_c = 1.2$ for square or circular footing	$\begin{bmatrix}1.2\\1.2\end{bmatrix}$	$\begin{bmatrix}1.2\\1.2\end{bmatrix}$
5. $i_c = 0.5\left(1+\sqrt{1-\frac{H}{A'C_u}}\right)$ provid $H \le A'C_u$	$\begin{bmatrix}1\\1\end{bmatrix}$	$\begin{bmatrix}1\\1\end{bmatrix}$
6. q = density of soil × depth of footing	$\begin{bmatrix}18\times3.0=54\\18\times3.0=54\end{bmatrix}$ KN/m	$\begin{bmatrix}54\\54\end{bmatrix}$ KN/m
7. $Q_{ult} = (\pi+2)C_u b_c s_c i_c + q$	$\begin{bmatrix}(\pi+2)\times100\times(1\times1.2\times1)+54\\(\pi+2)+71.42\times(1\times1.2\times1)+54\end{bmatrix} = \begin{bmatrix}670.8\\494.58\end{bmatrix}$ kpa	$\begin{bmatrix}670.8\\494.58\end{bmatrix}$ kpa
8. Q_{ult}/γ_R	$\begin{bmatrix}670.8/1\\494.58/1\end{bmatrix} = \begin{bmatrix}670.8\\494.58\end{bmatrix}$	$\begin{bmatrix}670.8\\494.58\end{bmatrix}$
9. Utilization factor $= \frac{Q_{ed}}{Q_{ult}} \times 100$	$\begin{bmatrix}\frac{301.3}{670.8}\times100\\\frac{227.64}{494.58}\times100\end{bmatrix} = \begin{bmatrix}44.92\%\\46.03\%\end{bmatrix}$ $< 100\%$	$\begin{bmatrix}\frac{323.20}{670.8}\times100\\\frac{244.18}{494.58}\times100\end{bmatrix} = \begin{bmatrix}48.18\%\\49.37\%\end{bmatrix}$ $< 100\%$ Hence ok

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	About axis (A-A)	About axis (2-2)
$M = \frac{L'}{B'}$	$\begin{bmatrix} \frac{1.76}{1.76} \\ \frac{1.76}{1.76} \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$	$\begin{bmatrix} \frac{1.7}{1.7} \\ \frac{1.7}{1.7} \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$
$N = \frac{H}{B'}$ $[\because H = 4 \times B]$	$\begin{bmatrix} \frac{9.2}{1.76} \\ \frac{9.2}{1.76} \end{bmatrix} = \begin{bmatrix} 5.23 \\ 5.23 \end{bmatrix}$	$\begin{bmatrix} \frac{9.2}{1.7} \\ \frac{9.2}{1.7} \end{bmatrix} = \begin{bmatrix} 5.41 \\ 5.41 \end{bmatrix}$

$$E_s = 1000 \times q_{uni}/2$$

$$q_{uni} = 2 \times C_u \quad [\because C_u = 5 \times \text{SPT value}]$$

$$= 2 \times 5 \times \text{SPT value}$$

E_s at 3.5 m $= 1000 \times 5 \times 20 = 100000$ kPa

E_s at 5.5 m $= 1000 \times 5 \times 54 = 2,70,000$ kPa

E_s at 8.0 m $= 1000 \times 5 \times 50 = 2,50,000$ kPa

$$E_s \text{ weighted average} = \frac{1,00000 \times 3.5 + 5.5 \times 2,70,000 + 8 \times 2,50,000}{12} = 22382 \text{ kPa}$$

$$\Delta_H = q_0 B' \times \frac{1-\mu^2}{E_s}\left(I_1 + \frac{1-2\mu}{1-\mu} I_2\right) I_F$$

$$I_1 = \frac{1}{\pi}\left[M \times \ln \frac{(1+\sqrt{1+m^2}\,\sqrt{m^2+N^2}}{M + (1+\sqrt{M^2+N^2+1}} + \ln \frac{(M+\sqrt{M^2+1}\,\sqrt{1+N^2}}{M+\sqrt{M^2+N^2+1}}\right]$$

$$I_2 = \frac{N}{2\pi}\tan^{-1}\left(\frac{M}{N\sqrt{(M^2+N^2+1)}}\right)$$

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About A-A axis :-

Combination 1 :-

$$I_1 = \frac{1}{\pi}\left[1\times \ln \frac{(1+\sqrt{1^2+1}\,\sqrt{1^2+(5.23)^2}}{1\,(1+\sqrt{1^2+(5.23)^2+1}} + \ln \frac{(1+\sqrt{1^2+1}\,\sqrt{1+(5.23)^2}}{1+\sqrt{1^2+(5.23)^2+1}}\right]$$

$$\doteq 0.44$$

$$I_2 = \frac{5.23}{2\pi}\tan^{-1}\left(\frac{1}{5.23\sqrt{1^2+(5.23)^2+1}}\right) = 01.68$$

$$\Delta_4 = 301.3\times 1.76\times \frac{1-0.3^2}{22382}\left(0.44+\frac{1-2(0.3)}{1-0.3}\times 01.68\right)0.623$$

$$= 0.0002066$$ ~~242.01 kN/m²~~

To limit settlement to 50mm $q = 242.01\ kN/m^2$

Combination 2:-

From above,

$$I_1 = 0.44$$

$$I_2 = 01.68$$

$$\Delta_4 = 0.00014$$

To limit settlement to 50mm $q = \frac{0.05}{0.00014}$

$$= 350\ kN/m^2$$

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About z-z axis :-

Combination 1 :

$$I_1 = \frac{1}{\pi}\left[1 \times \ln\frac{(1+\sqrt{1^2+1}\ \sqrt{1^2+(5.41)^2})}{1(1+\sqrt{1^2+(5.41)^2+1})} + \ln\frac{(1+\sqrt{1^2+1}\ \sqrt{1+(5.41)^2}}{1+\sqrt{1^2+(5.41)^2+1}}\right]$$

$$= 0.45$$

$$I_2 = \frac{5.41}{2\pi}\tan^{-1}\left(\frac{1}{5.41\sqrt{1^2+(5.41)^2+1}}\right) = 1.63$$

$$\Delta_H = 323.20 \times 1.7 \times \frac{1-0.3^2}{22382}\left(0.45 + \frac{1-2(0.3)}{1-0.3} \times 1.63\right) 0.623$$

$$= 0.000192$$

To limit settlement to 50mm $q = \frac{0.05}{0.000192} = 260.41\ kN/m^2$

Combination 2 =

similarly,

$$I_1 = 0.45$$

$$I_2 = 1.63$$

$$\Delta H = 244.18 \times 1.7 \times \frac{1-0.3^2}{22382}\left(0.45 + \frac{1-2(0.3)}{1-0.3} \times 1.63\right) 0.623$$

$$= \cancel{200}.000145$$

To limit settlement to 50mm

$$q = \frac{0.05}{0.000145} = 344.82\ kN/m^2$$

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iii) Design of B_1 Pad footing:

The assigned parameters for footing B_1

Vertical load (dead load) $V_{Gk} = 836$ KN

Vertical live load $V_{Qk} = 198$ KN

V_{Gk} eccentricity $= 0$ bothways

V_{Qk} eccentricity $= 0.1\,B$ bothways

Moment due to D.L (M_{Gk}) for axis 1-1 = 58 KNM

Moment due to L.L (M_{Qk}) for axis 1-1 = 52 KNM

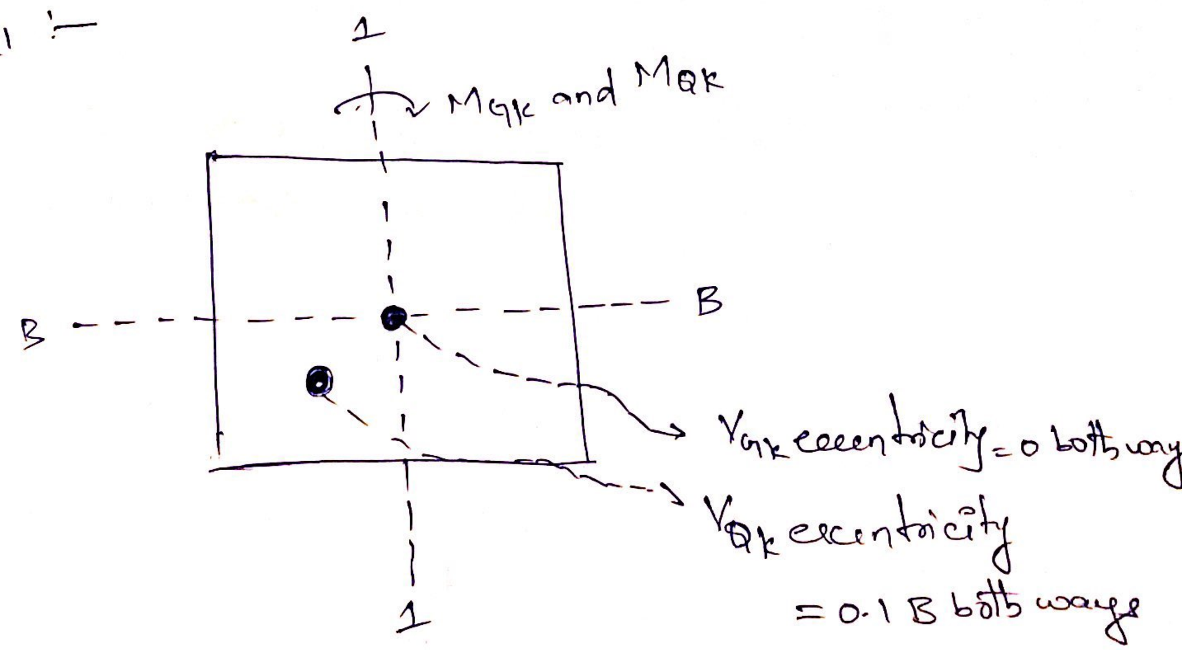
Unit weight of concrete = 25 KN/m³

Unit weight of soil = 18 KN/m³

Thickness of footing = 0.3 m

Depth = 3 m

Column B_1 :-



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②

Let assume pad length & width to be 2.3m

=> self weight $(W_{Gk}) = 2.3 \times 2.3 \times 0.3 \times 25$

$= 39.68$ kN

=> Dead load $(B_{Gk}) = (3-0.3) \times 2.3 \times 2.3 \times 18$

$= 257.09$ kN

* partial factors for design loads:-

$\gamma_{G_1} = 1.35$ $\gamma_{G_2} = 1.0$

$\gamma_{Q_1} = 1.5$ $\gamma_{Q_2} = 1.3$

$\gamma_{G_1,fav} = 1$ $\gamma_{G_1,fav} = 1$

$\gamma_{Q_1,fav} = 0$ $\gamma_{Q_1,fav} = 0$

∴ Total $V_{Gk} = W_{Gk} + B_{Gk} + V_{Gk}$(given)

$= 39.68 + 257.09 + 836$

$= 1132.77$ kN

Now,

$$V_d = \begin{bmatrix} \text{Combination 1} \\ \text{combination 2} \end{bmatrix} = \begin{bmatrix} \gamma_{G_1}(\text{total } V_{Gk}) + (\gamma_{Q_1} \times V_{Qk} - \gamma_{Q_1,fav} \times U_{kb}) \\ \gamma_{G_2}(\text{total } V_{Gk}) + (\gamma_{Q_2} \times V_{Qk} - \gamma_{Q_1,fav} \times U_{kb}) \end{bmatrix}$$

$$= \begin{bmatrix} 1.35(1132.77) + 1.5 \times 198 - 0 \\ 1.0(1132.77) + 1.3(198 - 0) \end{bmatrix}$$

$$= \begin{bmatrix} 1826.24 \\ 1390.17 \end{bmatrix} \text{kN}$$

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Design moments based on load Combination 1 & 2

* calculations of moments on quadrant I, II, III, IV w.r.t axis (B – B) and axis (1-1)

About axis (B-B)	Combination 1	Combination 2
1) $M_1 = -\gamma_{g\,fav}(0) + (0) - \gamma_q \times 0.1B \times V_{QK}$	$M_1 = -1.5 \times 0.1 \times 2.3 \times 198 = -68.3$ kN	$M_1 = -1.3 \times 0.1 \times 2.3 \times 198 = -59.2$ kN
2) $M_2 = M_1$	$M_2 = -68.3$ kN	$M_2 = -59.2$ kN
3. $M_3 = (0) \mp (0) + \gamma_q \times 0.1B \times V_{QK}$	$M_3 = 1.5 \times 0.1 \times 2.3 \times 198 = 68.31$ kN	$M_3 = +1.3 \times 0.1 \times 2.3 \times 198 = 59.2$ kN
4. $M_3 = M_4$	$M_4 = 68.31$ kN	$M_4 = 59.2$ kN

About axis (1-1)	Combination 1	Combination 2
1) $M_1 = -(\gamma_{g\,fav} M_{GK}) - (\gamma_{q\,fav} M_{QK}) + (\gamma_q \times 0.1B \times V_{QK})$	$M_1 = -1 \times 58 - 0 \times 52 + 1.5 \times 0.1 \times 2.3 \times 198$; $M_1 = 10.31$ kN	$M_1 = -1 \times 58 - 0 \times 52 + 1.3 \times 0.1 \times 2.3 \times 198 = 1.2$ kN
2) $M_2 = \gamma_{g\,fav} M_{QK} + \gamma_{q\,fav} M_{QK} - \gamma_q \times 0.1B \times V_{QK}$	$M_2 = -10.31$ kN	$M_2 = +1 \times 58 - 0 \times 52 - 1.3 \times 0.1 \times 2.3 \times 198 = -1.2$ kN
3) $M_3 = M_2$	$M_3 = -10.31$ kN	$M_3 = -1.2$ kN
4) $M_4 = M_1$	$M_4 = 10.31$ kN	$M_4 = 1.2$ kN

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Maximum moments about B-B axis

$$M_{d(B-B)} = \begin{bmatrix} 68.31 \\ 59.2 \end{bmatrix} kN$$

Maximum moments about 1-1 axis

$$M_{d(1-1)} = \begin{bmatrix} 10.31 \\ 1.2 \end{bmatrix} kN$$

Effective footing area based on load Combination 1 & 2

$$e_{(B-B)} = \begin{bmatrix} \dfrac{M_{d(B-B)}}{V_d} \end{bmatrix}$$

$$= \begin{bmatrix} \dfrac{68.31}{1826.24} \\ \dfrac{59.2}{1390.17} \end{bmatrix}$$

$$= \begin{bmatrix} 0.037 \\ 0.043 \end{bmatrix} m$$

$$\therefore e_{(B-B)} < \frac{B}{6} \left[\because \frac{B}{6} = \frac{2.3}{6} = 0.38\right] \text{ Hence ok.}$$

Similarly,

$$e_{(1-1)} = \begin{bmatrix} \dfrac{M_{d(1-1)}}{V_d} \end{bmatrix} = \begin{bmatrix} \dfrac{10.31}{1826.24} \\ \dfrac{1.2}{1390.17} \end{bmatrix}$$

$$= \begin{bmatrix} 0.0056 \\ 0.0009 \end{bmatrix}$$

$$\therefore e_{(1-1)} < \frac{B}{6} \quad [\because \text{ Hence ok}]$$

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	About B-B axis	About 1-1 axis
* Effective length and width = (length and width in the direction of eccentricity − 2 × eccentricity	$\begin{bmatrix} (2.3-0.037)-2\times0.037 \\ (2.3-0.043)-2\times0.043 \end{bmatrix}$ $= \begin{bmatrix} 2.19 \\ 2.7 \end{bmatrix}$	$\begin{bmatrix} (2.3-0.0056)-2\times0.0056 \\ (2.3-0.0009)-2\times0.0009 \end{bmatrix}$ $= \begin{bmatrix} 2.28 \\ 2.30 \end{bmatrix}$
* Smaller effective dimensions $A' = L' \times B'$	$= \begin{bmatrix} 4.8 \\ 4.71 \end{bmatrix}$	$\begin{bmatrix} 5.2 \\ 5.29 \end{bmatrix}$
* Q design $Q_{Ed} = \frac{V_d}{A1}$	$= \begin{bmatrix} \frac{1826.24}{4.8} \\ \frac{1390.17}{4.71} \end{bmatrix}$ $= \begin{bmatrix} 380.47 \\ 295.15 \end{bmatrix}$	$\begin{bmatrix} \frac{1826.24}{5.2} \\ \frac{1390.17}{4.71} \end{bmatrix}$ $= \begin{bmatrix} 351.2 \\ 262.79 \end{bmatrix}$

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Bearing capacity (undrained condition)

$Q_{ult} = (\pi+2) C_u b_c S_c i_c + q$

$C_u =$ SPT value $\times 5$

$= 2\times5 = 100$

	About axis B–B	About (1–1)
1) undrained strength (C_u)	$\begin{bmatrix}100\\100\end{bmatrix}$	$\begin{bmatrix}100\\100\end{bmatrix}$
2) C_u/γ_{Cu}	$\begin{bmatrix}100/1\\100/1.4\end{bmatrix} = \begin{bmatrix}100\\71.43\end{bmatrix}$	$\begin{bmatrix}100\\71.43\end{bmatrix}$
3) $b_c = \dfrac{1-2\alpha}{\pi+2}$	$\begin{bmatrix}1\\1\end{bmatrix}$	$\begin{bmatrix}1\\1\end{bmatrix}$
4) $S_c = 1.2$ for square or circular footing	$\begin{bmatrix}1.2\\1.2\end{bmatrix}$	$\begin{bmatrix}1.2\\1.2\end{bmatrix}$
5) $i_c = 0.5\left(1+\sqrt{1-\frac{H}{A'C_u}}\right)$ provided $H \le A'C_u$	$\begin{bmatrix}1\\1\end{bmatrix}$	$\begin{bmatrix}1\\1\end{bmatrix}$
6.) q = density of soil $\times$ depth of footing	$\begin{bmatrix}18\times3=54\\18\times3=54\end{bmatrix}$ KNM	$\begin{bmatrix}18\times3=54\\18\times3=54\end{bmatrix}$ KNM
7) $Q_{ult} = (\pi+2)C_u b_c S_c i_c + q$	$\begin{bmatrix}(\pi+2)\times100\times1\times1.2\times1)+5.4\\(\pi+2)\times100\times1\times1.2\times1)+5.4\end{bmatrix}$ $= \begin{bmatrix}670.8\\494.58\end{bmatrix}$ kpa	similarly, $= \begin{bmatrix}670.8\\494.58\end{bmatrix}$ kpa
8.) Q_{ult}/γ_R	$\begin{bmatrix}670.8/1\\494.58/1\end{bmatrix} = \begin{bmatrix}670.8\\494.58\end{bmatrix}$	$\begin{bmatrix}670.8\\494.58\end{bmatrix}$
9) utilization factor $= \dfrac{Q_{Ed}}{Q_{ult}}\times100$	$\begin{bmatrix}[380.47/670.8]\times100\\\dfrac{295.15}{494.58}\times100\end{bmatrix}$ $= \begin{bmatrix}56.72\%\\59.68\%\end{bmatrix} < 100\%$	$\begin{bmatrix}[351.2/670.8]\times100\\\left[\dfrac{262.79}{494.58}\right]\times100\end{bmatrix}$ $= \begin{bmatrix}52.35\%\\53.13\%\end{bmatrix} < 100\%$

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	About axis (B-B)	about Axis (1-1)
* $M = \frac{L'}{B'}$	$\begin{bmatrix} \frac{2.19}{2.19} \\ \frac{2.17}{2.17} \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$	$\begin{bmatrix} \frac{2.28}{2.28} \\ \frac{2.3}{2.3} \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$
* $N = \frac{H}{B'}$ [$\because H = 4 \times B$]	$\begin{bmatrix} \frac{4 \times 2.3}{2.19} \\ \frac{4 \times 2.3}{2.17} \end{bmatrix} = \begin{bmatrix} 4.2 \\ 4.24 \end{bmatrix}$	$\begin{bmatrix} \frac{4 \times 2.3}{2.28} \\ \frac{4 \times 2.3}{2.3} \end{bmatrix} = \begin{bmatrix} 4.03 \\ 4 \end{bmatrix}$

$$E_s = 100 \times \frac{Q_{uni}}{2}$$

$$Q_{uni} = 2 \times C_u$$

$$= 2 \times 5 \times \text{SPT value} \; [\because C_u = 5 \times \text{SPT value}]$$

E_s at 3.5 $= 1000 \times 5 \times 20 = 1,00,000$ kpa

E_s at 5.5 $= 1000 \times 5 \times 54 = \cancel{2,50}\,70,000$ kpa

E_s at 8.0 $= 1000 \times 5 \times 50 = 2,50,000$ kpa

$$E_s \text{ (weighted average)} = \frac{1,00,000 \times 3.5 + 2,70,000 \times 5.5 + 2,50000 \times 8.0}{12} = 22382 \text{ kpa}$$

$$A_H = q_0 B' \times \frac{1-\mu^2}{E_s}\left(I_1 + \frac{1-2\mu}{1-\mu} I_2\right) I_F$$

$$I_1 = \frac{1}{\pi}\left[M \times \ln \frac{(1+\sqrt{1+m^2}\sqrt{M^2+N^2})}{M(1+\sqrt{M^2+N^2+1})} + \ln \frac{(M+\sqrt{M^2+1}\sqrt{1+N^2})}{(M+\sqrt{M^2+N^2+1})}\right]$$

$$I_2 = \frac{N}{2\pi}\tan^{-1}\left[\frac{M}{N\sqrt{M^2+N^2+1}}\right]$$

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About B-B axis :

Combination 1 :

$$I_1 = \frac{1}{\pi}\left[1 \times \ln \frac{(1+\sqrt{1^2+1})\sqrt{1^2+(4.2)^2}}{1+\sqrt{1^2+(4.2)^2+1}} + \ln \frac{(1+\sqrt{1^2+1})\sqrt{1+(4.2)^2}}{1+\sqrt{1^2+(4.2)^2+1}}\right]$$

$= 0.42$

$$I_2 = \frac{4.2}{2\pi}\tan^{-1}\left(\frac{1}{4.2\sqrt{1^2+(4.2)^2+1}}\right) = 2.06$$

$$\Delta_H = 380.47 \times 2.19 \times \frac{1-0.3^2}{22382}\left[0.42 + \frac{1-2\times0.3}{1-0.3}\times 2.06\right] 0.632$$

$= 0.0003419$

To limit settlement to 50mm $q = \frac{0.05}{0.0003149} = 158.78\ kN/m^2$

Combination 2 :

$$I_1 = \frac{1}{\pi}\left[1\times \ln \frac{(1+\sqrt{1^2+1})\sqrt{1^2+(4.24)^2}}{1(1+\sqrt{1^2+(4.24)^2+1}} + \ln \frac{(1+\sqrt{1^2+1})\sqrt{1^2+(4.24)^2}}{1(1+\sqrt{1^2+(4.24)^2+1}}\right]$$

$= 0.42$

$$I_2 = \frac{4.24}{2\pi}\tan^{-1}\left(\frac{1}{4.24\sqrt{1^2+(4.24)^2+1}}\right) = 2.04$$

$$\Delta_H = 295.15 \times 2.17 \times \frac{1-0.3^2}{22382}\left[0.42 + \frac{1-2\times0.3}{1-0.3}\times 2.04\right]\times 0.632$$

$= 0.000164$

To limit settlement to 50 mm $q = \frac{0.05}{0.000164}$

$= 304.8\ kN/m^2$

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About 1-1 axis

Combination 1 :-

$$I_1 = \frac{1}{\pi}\left[1 \times \ln \frac{(1+\sqrt{1^2+1}\sqrt{1^2+(4.03)^2}}{(1+\sqrt{1^2+(4.03)^2+1}} + \ln \frac{(1+\sqrt{1^2+1}\sqrt{1+(4.03)^2}}{1+\sqrt{1^2+(4.03)^2+1}}\right]$$

$$= 0.41$$

$$I_2 = \frac{4.03}{2\pi}\tan^{-1}\left[\frac{1}{(4.03)\sqrt{1^2+(4.03)^2+1}}\right) = 2.13$$

$$\Delta_H = 351.2 \times 2.28 \times \frac{1-0.3^2}{22382}\left[0.41 + \frac{1-2\times0.3}{1-0.3} \times 2.13\right] \times 0.632$$

$$= 0.000348$$

To limit settlement to 50mm $q = \frac{0.05}{0.000348}$

$= 143.68 \ kN/m^2$

Combination 2:

$$I_1 = \frac{1}{\pi}\left[1\times \ln \frac{(1+\sqrt{1^2+1}\sqrt{1^2+4^2}}{(1+\sqrt{1^2+(4)^2+1}} + \ln \frac{(1+\sqrt{1^2+1}\sqrt{1+4^2}}{1+\sqrt{1^2+4^2+1}}\right]$$

$$= 0.41$$

$$I_2 = \frac{4}{2\pi}\tan^{-1}\left[\frac{1}{(4)\sqrt{1^2+4^2+1}}\right] = 2.15$$

$$\Delta_H = 262.79 \times 2.3 \times \frac{1-0.3^2}{22382}\left[0.41 + \frac{1-2\times0.3}{1-0.3}\times 1.25\right] \times 0.632$$

$$= 0.0001746$$

To limit settlement to 50 mm $q = 286.38 \ kN/m^2$

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IV) Design of B_2 pad footing:

The assigned parameters for footing B_2

Vertical load (Dead load) V_{Gk} = 319 KN

Vertical live load (V_{Qk}) = 99 KN

V_{Gk} eccentricity = 0 both ways

V_{Qk} eccentricity = 0.1B both ways

Moment due to D.L (M_{Gk}) for axis 2-2 = 69 KNM

Moment due to LL (M_{Qk}) for axis 2-2 = 46 KNM

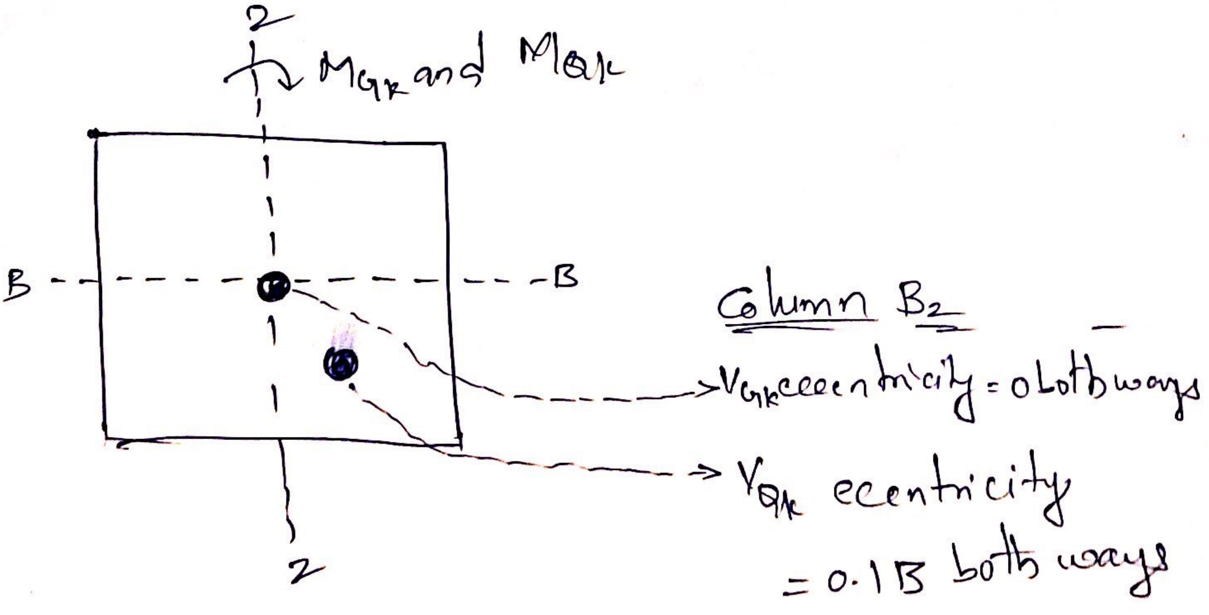
Unit weight of concrete = 25 KN/m³

unit weight of soil = 18 KN/m³

Thickness of footing = 0.3 m

Depth = 3 m

Column B_2 :-



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let assume pad length & width to be 2.3 m ②

=> self weight (W_{GK}) = 2.3×2.3×0.3×25

= 39.68 kN

=> Dead load (B_{GK}) = (3−0.3)×2.3×2.3×18

= 257.09 kN

* partial factors for design loads:-

Combination 1

$\gamma_{G_1} = 1.35$

$\gamma_{Q_1} = 1.5$

$\gamma_{Q_1,fav} = 0$

Combination 2

$\gamma_{G_2} = 1.0$

$\gamma_{Q_2} = 1.3$

$\gamma_{Q_2,fav} = 0$

→ Total $V_{GK} = W_{GK} + B_{GK} + V_{GK}$(given)

= 39.68 + 257.09 + 319

= 615.77 kN

Now

$$V_d = \begin{bmatrix} \text{combination 1} \\ \text{combination} \end{bmatrix} = \begin{bmatrix} \gamma_{G_1}(\text{total } V_{GK}) + (\gamma_{Q_1} \times V_{QK}) - \gamma_{Q_1,fav} \times V_{Kb} \\ \gamma_{G_1}(\text{total } V_{GK}) + (\gamma_{Q_2} \times V_{QK}) - \gamma_{Q_1,fav} \times V_{Kb} \end{bmatrix}$$

$$= \begin{bmatrix} 1.35(615.77) + 1.5 \times 99 - 0 \\ 1 \times (615.77) + 1.3 \times 99 - 0 \end{bmatrix}$$

$$= \begin{bmatrix} 979.79 \\ 744.47 \end{bmatrix} \text{kN}$$

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Design moments based on load combination 1 & 2

* calculation of moments on quadrant I, II, III, IV w.r.t axis (B-B) and axis (2-2)

About axis (2-2)	Combination 1	Combination 2
1) $M_1 = -\gamma_{G,favourable} \times M_{GK} - \gamma_{Q,fav} \times M_{QK} - (\gamma_Q \times 0.1B \times V_{QK})$	$= -1\times69 - 0\times46 - (1.5\times0.1\times2.3\times99)$ $M_1 = -103.16$	$= -1\times69 - 0\times46 - (1.3\times0.1\times2.3\times99)$ $M_1 = -98.6$
2) $M_2 = \gamma_{G,fav}(M_{GK}) + \gamma_{Q,fav} M_{QK} + \gamma_Q \times 0.1B \times V_{QK}$	$M_2 = 1\times69 + 0\times46 + (1.5\times0.1\times2.3\times99)$ $= 103.16$	$M_2 = 1\times69 + 0\times46 + 1.3\times0.1\times2.3\times99$ $M_2 = 98.6$
3) $M_3 = M_2$	$M_3 = 103.16$	$M_3 = M_2 = 98.6$
4) $M_4 = M_1$	$M_4 = -103.16$	$M_4 = -98.6$

About axis (B-B)	Combination 1	Combination 2
1) $M_1 = 0 + 0 - (\gamma_Q \times 0.1B \times V_{QK})$	$M_1 = -(1.5\times0.1\times2.3\times99)$ $= 34.155$	$M_1 = 1.3\times0.1\times2.3\times99$ $= -29.6$
2) $M_2 = M_1$	$M_2 = -34.155$	$M_2 = -29.6$
3) $M_3 = 0 + 0 + (\gamma_Q \times 0.1B \times V_{Qfav})$	$M_3 = 1.5\times0.1\times2.3\times99$ $= 34.155$	$M_3 = 1.3\times0.1\times2.3\times99$ $= 29.6$
4) $M_3 = M_4$	$M_4 = 34.155$	$M_4 = 29.6$

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Maximum moments about B-B axis

$$M_{d\,(B-B)} = \begin{bmatrix} 34.155 \\ 29.6 \end{bmatrix} kN$$

Maximum moments about 2-2 axis

$$M_{d\,(2-2)} = \begin{bmatrix} 103.16 \\ 98.6 \end{bmatrix} kN$$

Effective footing area based on load combination 1 & 2

$$e_{(B-B)} = \begin{bmatrix} \dfrac{M_{d(B-B)}}{V_d} \end{bmatrix}$$

$$= \begin{bmatrix} \dfrac{34.155}{979.79} \\ \dfrac{29.6}{744.47} \end{bmatrix}$$

$$= \begin{bmatrix} 0.035 \\ 0.04 \end{bmatrix} m$$

$\therefore\ e_{(B-B)} < \frac{B}{6}$ Hence ok $\left[\because\ \frac{B}{6} = \frac{2.3}{6} = 0.38\right]$

Similarly,

$$e_{(2-2)} = \begin{bmatrix} \dfrac{M_{d(2-2)}}{V_d} \end{bmatrix}$$

$$= \begin{bmatrix} 103.16/979.79 \\ 98.6/744.47 \end{bmatrix} = \begin{bmatrix} 0.11 \\ 0.13 \end{bmatrix}$$

$\therefore\ e_{(2-2)} < \frac{B}{6}$ Hence ok

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	About B-B axis	About 2-2 axis
* Effective length and width = (length and width in the direction of eccentricity) − 2x eccentricity	$\begin{bmatrix} (2.3-0.035)-2\times0.035 \\ (2.3-0.04)-2\times0.04 \end{bmatrix}$	$\begin{bmatrix} (2.3-0.11)-2\times0.11 \\ (2.3-0.13-2\times0.13 \end{bmatrix}$
	$\begin{bmatrix} 2.195 \\ 2.18 \end{bmatrix}$	$\begin{bmatrix} 1.97 \\ 1.91 \end{bmatrix}$
* smaller effective dimensions $A' = L' \times B'$	$= \begin{bmatrix} 4.82 \\ 4.75 \end{bmatrix}$	$\begin{bmatrix} 3.88 \\ 3.65 \end{bmatrix}$
* q design $q_{Ed} = \frac{V_d}{A'}$	$\begin{bmatrix} \frac{979.79}{4.82} \\ \frac{744.42}{4.75} \end{bmatrix}$	$\begin{bmatrix} \frac{979.79}{3.88} \\ \frac{744.42}{3.65} \end{bmatrix}$
	$\begin{bmatrix} 203.28 \\ 156.73 \end{bmatrix}$	$\begin{bmatrix} 252.52 \\ 203.96 \end{bmatrix}$

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Bearing capacity (undrained condition)

$Q_{ult} = (\pi+2)\, C_u b_c s_c i_c + q$

C_u = SPT value × 5

= 20×5 = 100

	About axis B-B	About axis (2-2)
1) undrained strength (C_u)	$\begin{bmatrix}100\\100\end{bmatrix}$	$\begin{bmatrix}100\\100\end{bmatrix}$
2) $\frac{C_u}{\gamma_{cu}}$	$\begin{bmatrix}100/1\\100/1.4\end{bmatrix} = \begin{bmatrix}100\\71.43\end{bmatrix}$	$\begin{bmatrix}100\\71.42\end{bmatrix}$
3) $b_c = \frac{1-2\alpha}{\pi+2}$	$\begin{bmatrix}1\\1\end{bmatrix}$	$\begin{bmatrix}1\\1\end{bmatrix}$
4. $S_c = 1.2$ for square or circular footing	$\begin{bmatrix}1.2\\1.2\end{bmatrix}$	$\begin{bmatrix}1.2\\1.2\end{bmatrix}$
5. $i_c = 0.5\left(1+\sqrt{1-\frac{H}{A'c_u}}\right)$ provided $H \le A'c_u$	$\begin{bmatrix}1\\1\end{bmatrix}$	$\begin{bmatrix}1\\1\end{bmatrix}$
6. q = density of soil × depth of footing	$\begin{bmatrix}18\times3.0 = 54\\18\times3 = 54\end{bmatrix}$ kN/m	$\begin{bmatrix}54\\54\end{bmatrix}$ kN/m
7. $Q_{ult} = (\pi+2)C_u b_c s_c i_c + q$	$\begin{bmatrix}(\pi+2)\times100\times1\times1.2\times1)+54\\(\pi+2)+71.42\times1\times1.2\times1)+54\end{bmatrix}$ $= \begin{bmatrix}670.8\\494.58\end{bmatrix}$ kpa	$\begin{bmatrix}670.8\\494.58\end{bmatrix}$ kpa
8. Q_{ult}/γ_R	$\begin{bmatrix}670.8/1\\494.58/1\end{bmatrix} = \begin{bmatrix}670.8\\494.58\end{bmatrix}$	$\begin{bmatrix}670.8\\494.58\end{bmatrix}$
9. utilization factor $= \frac{Q_{Ed}}{Q_{ult}} \times 100$	$\begin{bmatrix}203.28/670.8\times100\\\frac{156.73}{494.58}\times100\end{bmatrix} = \begin{bmatrix}30.3\%\\31.6\%\end{bmatrix}$	$\begin{bmatrix}\frac{252.52}{670.8}\times100\\\frac{203.9}{494.58}\times100\end{bmatrix} = \begin{bmatrix}37.6\%\\41.2\%\end{bmatrix}$
	< 100%	< 100% Hence ok

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	About axis B-B	About axis 2-2
* $M = \frac{L'}{B'}$	$\begin{bmatrix} \frac{2.195}{2.195} \\ \frac{2.18}{2.18} \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$	$\begin{bmatrix} \frac{1.97}{1.97} \\ \frac{1.97}{1.97} \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$
* $N = \frac{H}{B'}$ [$\because H = 4 \times B$]	$\begin{bmatrix} \frac{4 \times 2.3}{2.195} \\ \frac{4.23}{2.18} \end{bmatrix} = \begin{bmatrix} 4.19 \\ 4.22 \end{bmatrix}$	$\begin{bmatrix} \frac{4 \times 2.3}{1.97} \\ \frac{4 \times 2.3}{1.97} \end{bmatrix} = \begin{bmatrix} 4.67 \\ 4.82 \end{bmatrix}$

$$E_s = 1000 \times Q_{uni}/2$$

$$Q_{uni} = 2 \times C_u \quad [\because C_u = 5 \times \text{SPT value}]$$

$$= 2 \times 5 \times \text{SPT value}$$

E_s at 3.5 m $= 1000 \times 5 \times 20 = 100000$ kpa

E_s at 5.5 m $= 1000 \times 5 \times 54 = 2,70,000$ kpa

E_s at 8.0 m $= 1000 \times 5 \times 50 = 2,50,000$ kpa

$$E_s \text{ (weighted average)} = \frac{100000 \times 3.5 + 2,70,000 \times 5.5 + 2,500000 \times 8.0}{10}$$

$$= 22382 \text{ kpa}$$

$$A_H = q_o B' \times \frac{1-M^2}{E_s}\left(I_1 + \frac{1-2M}{1-M} I_2\right) I_F$$

$$I_1 = \frac{1}{\pi}\left[M \times \ln \frac{(1+\sqrt{1+m^2}\sqrt{m^2+N^2}}{M(1+\sqrt{M^2+N^2+1}} + \ln \frac{(M+\sqrt{M^2+1}\sqrt{1+N^2}}{(M+\sqrt{M^2+N^2+1}}\right]$$

$$I_2 = \frac{N}{2\pi} \tan^{-1}\left[\frac{M}{N\sqrt{M^2+N^2+1}}\right]$$

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About B–B axis

Combination 1:

$$I_1 = \frac{1}{\pi}\left[1\times \ln \frac{(1+\sqrt{1^2+1}\sqrt{1^2+(4.19)^2}}{1(1+\sqrt{1^2+(4.19)^2+1}} + \ln \frac{(1+\sqrt{1^2+1}\sqrt{1+(4.19)^2}}{1+\sqrt{1^2+(4.19)^2+1}}\right.$$

$= 0.41$

$$I_2 = \frac{4.19}{2\pi}\tan^{-1}\left(\frac{1}{4.19\sqrt{1^2+(4.19)^2+1}}\right) = 2.06$$

$$\Delta_H = 203.28\times 2.198\times \frac{1-0.3^2}{22382}\left[0.41 + \frac{1-(0.3)2}{1-0.3}\times 2.06\right]0.623$$

$= 0.00133$

To limit settlement to 30mm $q = 375$ kN/m2

Combination 2:

$$I_1 = \frac{1}{\pi}\left[1\times \ln \frac{(1+\sqrt{1^2+1}\sqrt{1^2+(4.22)^2}}{1(1+\sqrt{1^2+(4.22)^2+1}} + \ln \frac{(1+\sqrt{1^2+1}\sqrt{1+(4.22)^2}}{1(1+\sqrt{1^2+(4.22)^2+1}}\right]$$

$= 0.42$

$$I_2 = \frac{4.22}{2\pi}\tan^{-1}\left(\frac{1}{4.22\sqrt{1^2+(4.22)^2+1}}\right) = 2.05$$

$$\Delta_H = 156.73\times 2.18\times \frac{1-0.3^2}{22582}\left[0.42 + \frac{1-2\times 0.3}{1-0.3}\times 2.05\right]\times 0.623$$

$=$

$= 0.000138$

To limit settlement to 50mm $q = 362.31$ kN/m2

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About 2-2 axis

Combination 1 :-

$$I_1 = \frac{1}{\pi}\left[1\times \ln \frac{(1+\sqrt{1^2+1}\sqrt{1^2+(4.67)^2}}{(1+\sqrt{1^2+(4.67)^2+1}} + \ln \frac{(1+\sqrt{1^2+1}\sqrt{1+(4.67)^2}}{1+\sqrt{1^2+(4.67)^2+1}}\right]$$

$= 0.43$

$$I_2 = \frac{4.67}{2\pi}\tan^{-1}\left(\frac{1}{4.67\sqrt{1^2+(4.67)^2+1}}\right) = 1.87$$

$$\Delta_H = 252.52\times 1.97\times \frac{1-0.3^2}{22382}\times\left[0.43+\frac{1-2\times0.3}{1-0.3}\times 1.87\right]\times 0.632$$

$= 0.0009915$

To limit settlement to 50mm $q = 263.15$

Combination 2 :

$$I_1 = \frac{1}{\pi}\left[1\times \ln \frac{(1+\sqrt{1^2+1}\times\sqrt{1^2+(4.82)^2}}{(1+\sqrt{1^2+(4.82)^2+1}} + \ln \frac{(1+\sqrt{1^2+1}\times\sqrt{1+(4.82)^2}}{1+\sqrt{1^2+(4.82)^2+1}}\right]$$

$= 0.43$

$$I_2 = \frac{4.82}{2\pi}\tan^{-1}\left(\frac{1}{4.82\sqrt{1^2+(4.82)^2+1}}\right) = 1.82$$

$$\Delta_H = 203.9\times 1.9\times \frac{1-0.3^2}{22382}\times\left[0.43+\frac{1-2\times0.3}{1-0.3}\times 1.82\right]0.632$$

$= 0.00014627$

To limit settlement to 50 mm $q = 341.83$ kN/m²

2) # Design of Raft footing

* Dimensions of Raft foundation.

Length = 22.4 m

width = 12.4 m

Thickness = 0.75 m

Area = $22.4 \times 12.4 = 277.76\ m^2$

Yeild strength = 400 MPa

Concrete cover = 50mm

Conkrete clamps = 30

* Given parameter values of column A_1, A_2, B_1, B_2 are :-

	A_1	A_2	B_1	B_2
V_{GK}	455	314	836	319
V_{QK}	273	73	198	99

	V_{GK}	V_{QK}
$A_1 = A_4 = C_1 = C_4$	$4 \times 455 = 1820$	$4 \times 273 = 1092$
$A_2 = A_3 = C_2 = C_3$	$4 \times 314 = 1256$	$4 \times 73 = 292$
$B_1 = B_4$	$2 \times 836 = 1672$	$2 \times 198 = 396$
$B_2 = B_3$	$2 \times 319 = 638$	$2 \times 99 = 198$
Total	5386	~~2764~~ 1978

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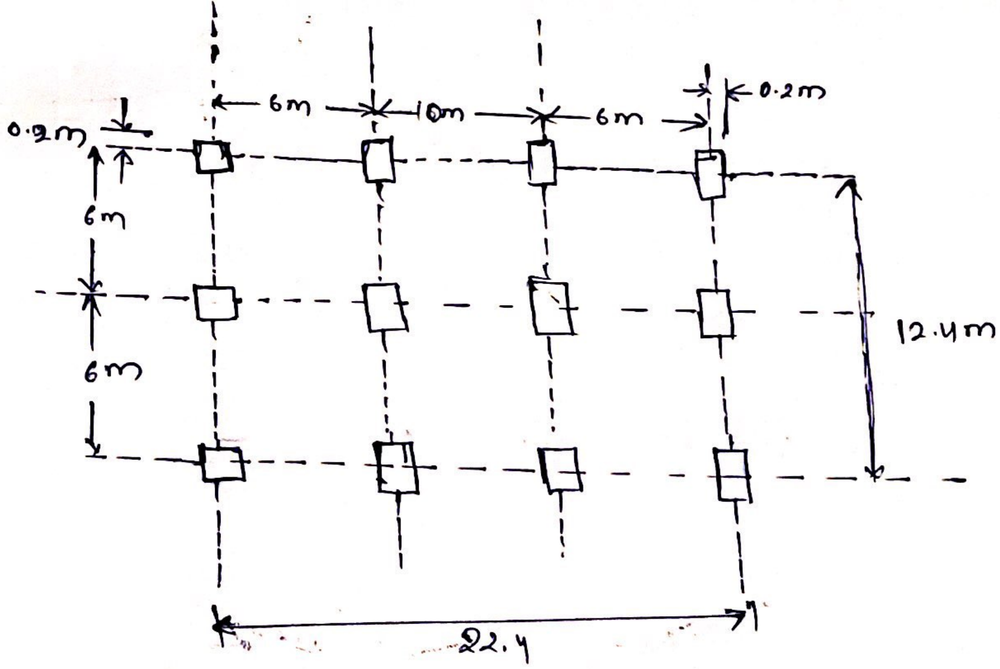
(2)



self weight of raft $= 22.4 \times 12.4 \times 0.75 \times 25$

$W_{gk} = 5208$ kN/m

Permanent actions = self weight of raft (W_{gk}) + ~~Total~~ ΣV_{gk} (all actions)

$= 5208 + 5386$

$\therefore$ Total $V_{gk} = 10594$

$\therefore$ Total $V_{Qk} = \cancel{2788}\ 1978$

Total factored load as per combinations 1 & 2

$$V_d = \begin{bmatrix} 1.35(W_{gk} + V_{gk}) + 1.5\, V_{Qk} \\ 1(W_{gk} + V_{gk}) + 1.3\, V_{Qk} \end{bmatrix}$$

$$= \begin{bmatrix} 1.35(10594) + 1.5(\overset{1978}{\cancel{2788}}) \\ 1(10594) + 1.3(\overset{1978}{\cancel{2788}}) \end{bmatrix}$$

$$V_d = \begin{bmatrix} \cancel{18483.9} \\ 14218.4 \end{bmatrix} \text{kN} = \begin{bmatrix} 17268.9 \\ 13165.4 \end{bmatrix} \text{kN}$$

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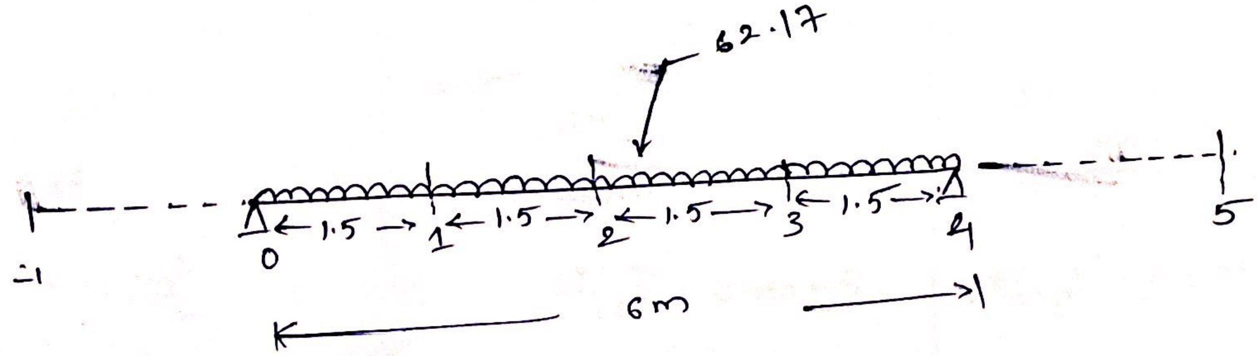
∴ Factored based on the lf $r_d = \dfrac{\text{Total factored load}}{\text{Area of raft}}$ ③

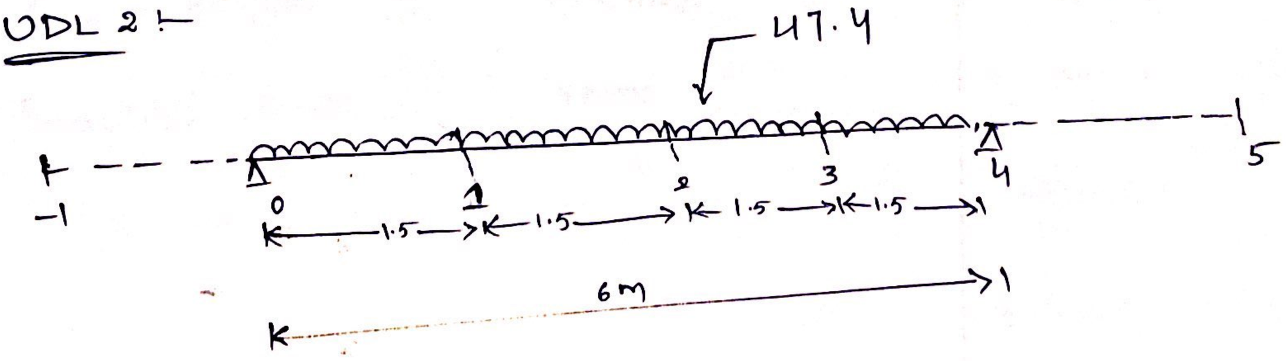
$$UDL_{1\&2} = \begin{bmatrix} \dfrac{17266.9}{277.76} \\ \dfrac{13165.4}{277.76} \end{bmatrix} kN/m^2$$

$$= \begin{bmatrix} 62.17 \\ 47.4 \end{bmatrix} kN/m^2$$

UDL 1 :-



UDL 2 :-



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	Combination 1	Combination 2
1. $V_d = \gamma_g \times total V_{gk} + \gamma_Q \times total (V_{Qk})$	$= 1.35 \times 10594 + 1.5 \times 1978$ $= 17268.9$ kN	$= 1.0 \times 10594 + 1.3 \times 1978$ $= 13165.4$ kN
2. $Q_{design}(Q_{Ed}) = \frac{V_d}{A}$	$\frac{17268.9}{277.76} = 62.17$ kN/m²	$\frac{13165.4}{277.76} = 47.4$ kN/m²
3. Type of soil k (0.3x0.3)	clay (25,000 kN/m3)	clay (25,000 kN/m3)
4. $K_s = K_{(0.3 \times 0.3)} \left[\frac{\frac{L}{B} + 0.5}{1.5 \frac{L}{B}}\right]$	$= 25,000 \left[\frac{\frac{22.4}{12.4} + 0.5}{1.5 \times \frac{22.4}{12.4}}\right] = 21296.29$ kN/m³	$= 25000 \left[\frac{\frac{22.4}{12.4} + 0.5}{1.5 \times \frac{22.4}{12.4}}\right] = 21296.29$ kN/m³
5. b	1m	1m
6. d	0.75m	0.75m
7. $I = \frac{bd^3}{12}$	$\frac{1 \times 0.75^3}{12} = 0.035$ m⁴	$\frac{1 \times 0.75^3}{12} = 0.035$ m⁴
8. $f_{cm} = 33$ MPA	33 MPA	33 MPA
9. E_{cm} [MPa] = 22000	22,000	22000
10. [f_{cm}/10mpa]	31475.8	31475.8
11. E	31475806 kN/m²	31475806 kN/m²
12. $h = \frac{L}{4}$	6/4 = 1.5m	6/4 = 1.5m
13. h^4 / EI	$\frac{1.5^4}{31475806 \times 0.035} = 0.00000459$ m²	$\frac{1.5^4}{31475806 \times 0.035} = 0.00000459$ m²
14. $\frac{q h^4}{EI}$	$\frac{62.17 \times 1.5^4}{31475806 \times 0.035} = 0.000285$ kN	$\frac{47.4 \times 1.5^4}{31475806 \times 0.035}$ $= 0.000285$
15. $\frac{k h^4}{EI}$	$\frac{21296.29 \times 1.5^4}{31475806 \times 0.035} = 0.0978$ kN/m	$= 0.0978$ kN/m²

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	Combination 1	Combination 2
16. $y_2 = \dfrac{\left(\frac{qh^4}{EI}\right)\left(1+\frac{8}{\left(6+\frac{kh^4}{EI}\right)}\right)}{\left[\left(6+\frac{kh^4}{EI}\right)-\left(\frac{32}{6+\frac{kh^4}{EI}}\right)\right]}$	$\dfrac{0.000286\left[1+\frac{8}{6+0.0978}\right]}{[(6+0.0978)]-\left[\frac{32}{6+0.09786642}\right]}$ $= 0.000778\,m$	$\dfrac{0.000218\left[1+\frac{8}{0.09786}\right]}{(6+0.09786)-\frac{32}{6+0.097664}}$ $= 0.000593\,m$
17. $y_1 = \dfrac{y_2\left(6+\frac{kh^4}{EI}\right)-\left(\frac{qh^4}{EI}\right)}{8}$	$= \dfrac{0.000778(6+0.0978)-(0.000286)}{8}$ $= 0.000557\,m$	$= \dfrac{0.000593(6+0.09786)-(0.000218)}{8}$ $= 0.000425\,m$
18. $y_1 = \dfrac{\frac{qh^4}{EI}+4y_2}{\left(6+\frac{kh^4}{EI}\right)}$	$= \dfrac{(0.000286)+4\times0.000778}{6+0.0978}$ $= 0.000557\,m$	$= \dfrac{(0.000218)+4\times0.000593}{6+0.0978}$ $= 0.000425\,m$
19. Y_2	0.77mm	0.59mm
20 $Y_1 = Y_3$	= 0.55mm	0.42mm
21. $Y_{-1} = Y_5 = -Y_1$	−0.55mm	−0.42mm
23 $Y_0 = Y_4$	0	0

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Bearing capacity (undrained condition)

$Q_{ult} = (\pi+2)\, c_u b_c s_c i_c + q$

c_u = SPT value × 5

= 26 × 5 = 130

	Combination 1	Combination 2
1) undrained strength (c_u)	130	130
2. c_u / γ_{cu}	$\frac{130}{1} = 130$	$\frac{130}{1.4} = 92.85$
3. $b_c = 1 - \frac{2\alpha}{(\pi+2)}$	1	1
4. s_c	1.11	1.01
5. i_c	1	1
6. q = density of soil × depth of footing	18 × 0.75 = 13.50 kN/m²	13.50 kN/m²
7. $Q_{ult} = (\pi+2) c_u b_c s_c i_c + q$	$(\pi+2) \times 130 \times 1 \times 1.1 \times 1 + 13.5$ = 755.91 kN/m²	$(\pi+2) \times 92.85 \times 1 \times 1.01 \times 1 + 13.5$ 496.67 kN/m²
8. utilization $\left(\frac{Q_{ult}}{\gamma_R}\right)$	$\frac{755.91}{1} = 755.91$	$\frac{496.67}{1} = 496.67$
9. utilization ratio $\frac{Q_{Ed}}{Q_{ult}} \times 100$	$\frac{62.17}{755.91} \times 100 = 8.23\%$ < 100%	$\frac{47.4}{496.67} \times 100 = 9.54\%$ < 100%

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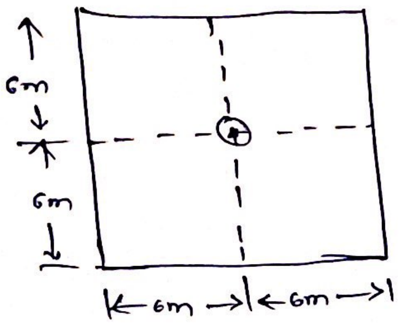
settlement check combination 1 & 2



Combination 1 | Combination 2

$M = \frac{L'}{B'}$ | $\frac{6}{6} = 1$ | $\frac{6}{6} = 1$

$N = \frac{H}{B'}$ | $\frac{15}{6} = 2.5$ | $\frac{15}{6} = 2.5$

$H < 4 \times B$ | 15 m | 15m

$E_s = 1000 \times \frac{Q_{uni}}{2}$

$Q_{uni} = 2 \times S_u$

$= 5 \times$ spt value $\times 2$

$E_s = \frac{1000 \times 2 \times 5 \times \text{SPT value}}{2}$

E_s at 2.0 m = $1000 \times 5 \times 26 = 130000$ kPa

E_s at 3.0 m = $1000 \times 5 \times 23 = 115000$ kPa

E_s at 5.0m = $1000 \times 5 \times 20 = 1000\,000$ kPa

E_s at 6.0m = $1000 \times 5 \times 54 = 270000$ kPa

E_s at 9.5m = $1000 \times 5 \times 50 = 250000$ kPa

E_s at 11m = $1000 \times 5 \times 43 = 215000$ kPa

E_s at 13m = $1000 \times 5 \times 59 = 295000$ kPa

E_s at 15m = $1001 \times 5 \times 64 = 320000$ kPa

E_s weighted average $= \frac{130000 \times 2.0 + 115000 \times 3 + 100000 \times 5 + 270000 \times 6 + 250000 \times 9.5 + 215000 \times 11 + 295000 \times 13 + 320000 \times 15}{64.5}$

8

$$I_1 = \frac{1}{\pi}\left(m \cdot \ln \frac{(1+\sqrt{m^2+1})\sqrt{m^2+N^2}}{m(1+\sqrt{m^2+N^2+1})}\right) + \ln \frac{(m\sqrt{m^2+1}\sqrt{1+N^2}}{M+\sqrt{M^2+N^2+1}}\Bigg)$$

For combination 1&2 :-

$$I_1 = \frac{1}{\pi}\left[1.0 \ln \frac{(1+\sqrt{1^2+1}\sqrt{1^2+2.5^2})}{1+(1+\sqrt{1^2+2.5^2+1}} + \ln \frac{(1+\sqrt{1^2+1}\sqrt{1+2.5^2})}{1+\sqrt{1+2.5^2+1}}\right)$$

$$= 0.330$$

$$I_2 = \frac{N}{2\pi}\tan^{-1}\left(\frac{m}{N(\sqrt{M^2+N^2+1})}\right)$$

$$= \frac{2.5}{2\pi}\tan^{-1}\left(\frac{1}{2.5\sqrt{1^2+2.5^2+1}}\right)$$

$$= 3.16$$

$$\frac{D}{B} = \frac{0.75}{12.40} = 0.060$$

$$\frac{L}{B} = \frac{22.40}{12.40} = 1.806$$

$$I_F = 0.780$$

$$\mu = 0.3$$

Combination 1!

$$q = 755.91$$

$$\Delta H = q_0 B' \frac{1-\mu^2}{E_s}\left(I_1 + \frac{1-2\mu}{1-\mu} I_2\right) I_F =$$

$$\Delta H = 7.574\,mm$$

combination 2 :

$$q = 496.67$$

$$\Delta H = q_0 B' \frac{1-\mu^2}{E_s}\left(I_1 + \frac{1-2\mu}{1-\mu} I_2\right) I_F =$$

$$\Delta H = 5.71\,mm$$

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3 Design of pile footing

i) Design of pile located at A1

$V_{Gk} = 455$ kN

$V_{qk} = 273$ kN

Assume length $L = 14m$

pile diameter $D = 0.6m$

self weight of pile $(W_{Gk}) = \pi \times \left(\frac{D}{4}\right)^2 \times h \times \gamma_c$

$= \pi \times \frac{0.6^2}{4} \times 14 \times 25$

$W_{Gk} = 98.9$ kN

calculatons of design loads based on combination 1 & 2

$$V_d = \begin{bmatrix} 1.35(455 + 98.9) + 1.5 \times 273 \\ 1(455 + 98.9) + 1.3 \times 273 \end{bmatrix}$$

$$= \begin{bmatrix} 1157.265 \\ 908.8 \end{bmatrix} \text{ kN}$$

pile shaft area $(A_s) = \pi \times D \times L$

$= \pi \times 0.6 \times 14$

$= 26.38 m^2$

pile base area

$$A_b = \frac{\pi \times D^2}{4} = \frac{\pi \times 0.6^2}{4}$$

$= 0.282 m^2$

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Bearing capacity factor $N_c = 9$

soil strata	layer depth (m)
layer 1	3m
layer 2	6m
layer 3	8m
layer 4	12m
layer 5	14m

* Average SPT value for layer 1 = $\left(\frac{23+26}{2}\right) = 24.5$
* Avarage SPT value for layer 2 = $\left(\frac{20+20+54}{3}\right) = 31.33$
* Avarage SPT value for layer 3 = $\frac{50}{1} = 50$
* Avarage SPT value for layer 4 = $\frac{43+49}{2} = 51$
* Avarage SPT value for layer 5 = $\frac{64}{1} = 64$
* undrained shear strength $C_u = SPT \times 5$

$C_{u_1} = 24.5 \times 5 = 122.5 \ kN/m^2$

$C_{u_2} = 31.33 \times 5 = 156.65 \ kN/m^2$

$C_{u_3} = 50 \times 5 = 265 \ kN/m^2$

$C_{u_4} = 51 \times 5 = 255 \ kN/m^2$

$\boxed{\therefore C_{u_5} = 64 \times 5 = 320 \ kN/m^2}$

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From the graph adhension factor at layer 5

$$f_{ss} = \bar{C}_u \times 0.45 \times \left(\frac{\bar{\sigma}_v}{\bar{C}_u}\right)^{0.45}$$

$$= 320 \times 0.45 \times \left(\frac{87.33}{320}\right)^{0.45}$$

$$\boxed{\therefore f_{ss} = 50.27\,kN/m^2}$$

* pile shaft area $A_s = \pi \times D \times L$

$$= \pi \times 0.6 \times 14$$

$$= 26.38\,m^2$$

* Maximum shaft resistance $(Q_s) = A_s \times f_{ss}$

$$= 26.38 \times 80.27$$

$$= 2117.52\,kN$$

* pile base area $= \frac{\pi \times D^2}{4} = \frac{\pi \times 0.6^2}{4}$

$$= 0.2827\,m^2$$

* Unit base resistance $q_b = N \times C_{u5}$

$$= 9 \times 320$$

$$= 2880\,kN/m^2$$

* Maximum base resistance $Q_b = \frac{\pi D^2}{4} \times q_b$

$$= \frac{\pi \times 0.6^2}{4} \times 2880$$

$$Q_b = 816.56\,kN$$

For bored pile the design resistance V_{Rd}:-

ultimate bearing resistance ~~combination~~

$$VRD1 = \begin{bmatrix} \frac{Q_b}{1.25} + \frac{Q_s}{1} \\ \\ \frac{Q_b}{1.6} + \frac{Q_s}{1.3} \end{bmatrix}$$

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$$= \begin{bmatrix} \frac{816.56}{1.25} + \frac{2117.52}{1} \\ \frac{816.56}{1.6} + \frac{2117.52}{1.3} \end{bmatrix}$$

$$= \begin{bmatrix} 2770.76 \\ 2139.2 \end{bmatrix} kN$$

$$AGE_0 = \begin{bmatrix} 1157.26/2770.76 \\ 908.8/2139.2 \end{bmatrix} \times 100 = \begin{bmatrix} 41.77\% \\ 42.48\% \end{bmatrix}$$

Ultimate ~~total~~ resistance ~~of combination~~ of

$$VRD2 = \begin{bmatrix} \frac{Q_b + Q_s}{1.15} \\ \frac{Q_b + Q_s}{1.5} \end{bmatrix} = \begin{bmatrix} \frac{816.56 + 2117.52}{1.15} \\ \frac{816.56 + 2117.52}{1.5} \end{bmatrix}$$

$$= \begin{bmatrix} 2551.37 \\ 1956.05 \end{bmatrix} kN$$

$$\therefore \quad AGE_6 = \frac{V_d}{VRD2} \times 100\%$$

$$AGE_6 = \begin{bmatrix} 1157.26/2551.37 \\ 906.8/1956.05 \end{bmatrix} \times 100\%$$

$$= \begin{bmatrix} 45.35\% \\ 46.46\% \end{bmatrix}$$

Settlement calculation :

$Q_s = 2117.52$ kN

$Q_b = 816.56$ kN

$A_b = 0.2827\ m^2$

$A_s = 26.38\ m^2$

$E_p = 33 \times 10^6\ kN/m^2$

$E_b = 122500\ kN/m^2$.

poison's ratio $\mu = 0.35$

Influence factor of $\frac{L}{B}$ ratio $I_p = 0.55$

* Pile head settlement based on combination 1

$$W_{s1} = \frac{Q_s}{1} = \frac{2117.52}{1} = 2117.52 \text{ kN}$$

$$w_{b1} = \frac{Q_b}{1} = \frac{816.56}{1.25} = 653.24 \text{ kN}$$

* pile head settlement $(P_1) = \frac{(w_s + 2w_b)}{2A_s \times E_p} + \left(\frac{\pi w_{b1}}{4A_b}\right) \times \left(\frac{D(1-\nu^2)I_p}{E_b}\right)$

$$= \left(\frac{(2117.52 + 2\times 653.24)\times 14}{2\times 26.38\times 33\times 10^6}\right) + \left(\frac{\pi\times 653.24}{4\times 0.2822}\right) \times \left(\frac{0.6(1-0.35^2)\,0.55}{1225000}\right)$$

$$= 4.3\times 10^{-3} m$$

$$P_1 = 4.3 m$$

* pile head settlement based on head combination 2

$$w_{s2} = \frac{Q_s}{1.3} = \frac{2117.52}{1.3} = 1628.86 \text{ kN}$$

$$w_{b2} = \frac{Q_b}{1.6} = \frac{816.56}{1.6} = 510.35 \text{ kN}$$

Pile head settlement P_2 :

$$= \frac{(w_{s2} + 2b_2)L}{2A_s E_p} + \left(\frac{\pi w_{b2}}{4A_b}\right) \times \left(\frac{D(1-\mu^2)}{E_b} I_p\right)$$

$$= \left(\frac{(1628.86 + 2\times 510.35)\times 14}{2\times 26.38\times 33\times 10^6}\right) + \left(\frac{\pi\times 510.35}{4\times 0.2822}\right) \times \left(\frac{0.6(1-0.35^2)\times 0.55}{122500}\right)$$

$$= 2.13\times 10^{-5} + 1417.85\times 2.36\times 10^{-6}$$

$$P_2 = 3.3\times 10^{-3} m = 3.3 mm$$

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Both settlements P_1 & P_2 are less than 50mm

$\therefore$ This pile design is safe and acceptable

PILE HEAD RESISTANCE

Scanned with CamScanner

ii) Design of pile located at A_2 :-

Given data

$V_{Gk} = 314$ KN

$V_{Qk} = 73$ KN

∴ Assume length L = 14m

pile diameter D = 0.75m

weight of pile $(W_{pile}) = \pi \times \frac{D^2}{4} \times h \times \gamma_c$

$= \pi \times \frac{0.75^2}{4} \times 14 \times 25$

$= 154.59$

∴ calculating design loads based on combination

$$V_d = \begin{bmatrix} 1.35(314 + 154.59) + 1.5 \times 73 \\ 1(314 + 154.59) + 1.3 \times 73 \end{bmatrix}$$

$$= \begin{bmatrix} 742.1 \\ 563.49 \end{bmatrix} \text{kN}$$

Bearing capacity factor $N_c = 9$

Average SPT layer 1 at $\left(\frac{23+26}{2}\right) = 24.5$

SPT layer 2 $\left(\frac{20+20+54}{3}\right) = 31.33$

SPT layer 3 $\left(\frac{50}{1}\right) = 50$

SPT layer 4 $\left(\frac{43+54}{2}\right) = 51$

SPT layer 5 $\left(\frac{64}{1}\right) = 64$

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$\therefore$ undrained shear strength $C_u = SPT \times 5$

$C_{u_1} = 14.5 \times 5 = 122.5\ kN/m^2$

$C_{u_2} = 31.33 \times 5 = 156.65\ kN/m^2$

$C_{u_3} = 50 \times 5 = 250\ kN/m^2$

$C_{u_4} = 57 \times 5 = 265\ kN/m^2$

$\boxed{\therefore C_{u_5} = 64 \times 5 = 320\ kN/m^2}$

From the graph adhension factor at layer 5

$$f_s = \bar{C_u} \times 0.45 \times \left(\frac{\bar{\sigma_v}}{\bar{C_u}}\right)^{0.45}$$

$$= 320 \times 0.45 \times \left(\frac{87.33}{320}\right)^{0.45}$$

$$= 80.27\ kN/m^2$$

pile shaft area $A_s = \pi \times D \times L$

$$= \pi \times 0.75 \times 14$$

$$= 32.98\ m^2$$

Maximum shaft resistance

$$Q_s = A_s \times f_s$$

$$= 32.98 \times 80.27$$

$$Q_s = 2647.30\ kN$$

~~pile~~ For bored pile design resistance :

ultimate bearing resistance

$$V_{Rd1} = \begin{bmatrix} \frac{Q_b}{1.25} + \frac{Q_s}{1} \\ \frac{Q_b}{1.6} + \frac{Q_s}{1.3} \end{bmatrix}$$

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pile base area $= \frac{\pi \times D^2}{4} = \frac{\pi \times 0.75^2}{4}$

$= 0.4417 \, m^2$

Unit base resistance $q_b = N \times C_{ur}$

$= 9 \times 320$

$= 2880 \; kN/m^2$

Maximum base resistance $Q_b = \frac{\pi D^2}{4} \times q_b$

$\boxed{Q_b = 1272 \; kN}$

$\therefore$ ultimate bearing resistance

$$VRD1 = \begin{bmatrix} \frac{1272}{1.25} + \frac{2647.30}{1} \\ \frac{1272}{1.6} + \frac{2647.30}{1.3} \end{bmatrix}$$

$$= \begin{bmatrix} 3664.9 \\ 2831.38 \end{bmatrix} kN$$

$$\therefore \; \Delta GE_0 = \begin{bmatrix} 742.1/3664.9 \\ 563.49/2831.38 \end{bmatrix} \times 100 = \begin{bmatrix} 20.25\% \\ 19.9\% \end{bmatrix}$$

ultimate total resistance

$$= \begin{bmatrix} \frac{Q_b + Q_s}{1.15} \\ \frac{Q_b + Q_s}{1.5} \end{bmatrix} = \begin{bmatrix} \frac{1272 + 2647.30}{1.15} \\ \frac{1272 + 2647.30}{1.5} \end{bmatrix}$$

$$= \begin{bmatrix} 3574 \\ 3036.88 \end{bmatrix} kN$$

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$$\therefore \Delta GE_0 = \begin{bmatrix} 742.1/3574.0 \\ 563.49/3036.86 \end{bmatrix} \times 100 = \begin{bmatrix} 20.76\% \\ 18.56\% \end{bmatrix}$$

settlement check:

Obtained values

$Q_s = 2647.30\,kN$

$Q_b = 1272\,kN$

$A_b = 0.4412\,m^2$

$A_s = 32.96\,m^2$

$E_p = 33 \times 10^6\,kN/m^2$

$E_b = 132500\,kN/m^2$

possion's ratio $\nu = 0.35$

Influence factor of $\frac{L}{B}$ ratio $I_p = 0.55$

∴ pile head settlement based on combination 1

$$W_{S1} = \frac{Q_s}{1} = \frac{2647.30}{1} = 2647.30\,kN$$

$$W_{B1} = \frac{Q_b}{1.25} = \frac{1272}{1.25} = 1017.6\,kN$$

$$\text{pile head settlement } (\delta_1) = \frac{(W_s + 2W_b)}{2A_s \times E_p} + \frac{\pi W_{b1}}{4A_b} \times \left(\frac{D(1-\nu^2)I_p}{E_b}\right)$$

$$= \frac{(2647.30 + 2 \times 1017.6) \times 14}{2 \times 32.96 \times 33 \times 10^6} + \left(\frac{\pi \times 1017.6}{4 \times 0.4412}\right) \times \left[\frac{0.75(1-0.35^2) \times 0.55}{122500}\right]$$

$\delta_1 = 5.32\,mm$

pile head settlement based on load combination 2

$$W_{S2} = \frac{Q_s}{1.3} = \frac{2647.30}{1.3} = 2036.76\,kN$$

$$wb_2 = \frac{Q_b}{1.6} = \frac{1017.6}{1.6} = 636\ kN$$

$$P_2 = \frac{(Ws_2 + 2W_b)\times L}{2A_s E_p} + \frac{\pi wb_2}{4A_b} \times \left(\frac{D(1-\nu^2) I_p}{E_b}\right)$$

$$= \left[\left(\frac{(2036.38 + 2\times 636)\times 14}{2\times 32.98\times 33\times 10^6}\right) + \left(\frac{\pi\times 636}{4\times 0.4417}\right)\times\left(\frac{0.75\times(1-0.35^2)\ 0.55}{12250}\right)\right]$$

$$P_2 = 3.3\times 10^{-3}\ m$$

Both settlement P_1 & P_2 are less than 50mm

$\therefore$ The pile design is safe and acceptable.

Scanned with CamScanner

ii) Design of located at B_1

Vertical load $V_{Gk} = \cancel{344}\ 836$ kN

Vertical load $V_{Qk} = 198$ kN

Assume length $L = 14m$

pile diameter $D = 0.9m$

weight of pile $(W_{Gk}) = \pi \times \frac{D^2}{4} \times h \times \gamma_c$

$= \pi \times \frac{0.9^2}{4} \times 14 \times 25$

$W_{Gk} = 222.66$

∴ calculating design loads based on combination 1 & 2

$$V_d = \begin{bmatrix} 1.35(836 + 222.66) + 1.5(198) \\ 1(836 + 222.66) + 1.3(198) \end{bmatrix}$$

$$= \begin{bmatrix} 1726.19 \\ 1316.06. \end{bmatrix} kN$$

Bearing capacity factor $N_c = 9$

Avg SPT layer 1 $\left(\frac{23+26}{2}\right) = 24.5$

SPT layer 2 $\left(\frac{20+20+54}{3}\right) = 31.33$

SPT layer 3 $\left(\frac{50}{1}\right) = 50$

SPT layer 4 $\left(\frac{43+54}{2}\right) = 57$

SPT layer 5 $\left(\frac{64}{1}\right) = 64$

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∴ undrained shear strength

$$C_u = SPT \times 5$$

$$C_{u1} = 14.5 \times 5 = 122.5\ kN/m^2$$

$$C_{u2} = 31.33 \times 5 = 156.65\ kN/m^2$$

$$C_{u3} = 50 \times 5 = 250\ kN/m^2$$

$$C_{u4} = 53 \times 5 = 265\ kN/m^2$$

$$C_{u5} = 64 \times 5 = 320\ kN/m^2$$

From the graph adhension factor at layer 5

$$f_{s5} = \bar{C_u} \times 0.45 \times \left(\frac{\bar{\sigma_v}}{\bar{C_u}}\right) \times 0.45$$

$$f_{s5} = 320 \times 0.45 \times \left(\frac{87.33}{320}\right)^{0.45}$$

$$f_{s5} = 80.27\ kN/m^2$$

∴ pile shaft area $A_s = \pi \times D \times L$

$$= \pi \times 0.9 \times 14$$

$$= 39.58\ m^2$$

∴ Maximum shaft resistance

$$Q_s = A_s \times f_{s5}$$

$$= 39.58 \times 80.27$$

$$= 3177.08\ kN$$

pile base area $= \frac{\pi \times D^2}{4} = \frac{\pi \times 0.9^2}{4} = 0.636\ m^2$

unit base recistance $q/b = N \times C_{u5}$

$$= 9 \times 320$$

$$= 2880\ kN/m^2$$

∴ Maximum base resistance $Q_b = \frac{\pi D^2}{4} \times q/b$

$$= 0.636 \times 2880$$

$$Q_b = 1831.68\ kN$$

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For bored pile design resistance:

ultimate bearing resistance

$$V_{Rd1} = \begin{bmatrix} \frac{Q_b}{1.25} + \frac{Q_s}{1} \\ \frac{Q_b}{1.6} + \frac{Q_s}{1.3} \end{bmatrix} = \begin{bmatrix} \frac{1831.6}{1.25} + \frac{3177.08}{1} \\ \frac{1831.6}{1.6} + \frac{3177.08}{1} \end{bmatrix}$$

$$= \begin{bmatrix} 4642.52 \\ 4321.75 \end{bmatrix}$$

$$\therefore AGE_o = \begin{bmatrix} 1726.19/4642.52 \\ 1316.06/4321.75 \end{bmatrix} \times 100 = \begin{bmatrix} 37.18\% \\ 30.45\% \end{bmatrix}$$

ultimate total resistance at combination 1 & 2

$$VRD_2 = \begin{bmatrix} \frac{Q_b + Q_s}{1.15} \\ \frac{Q_b + Q_s}{1.5} \end{bmatrix} = \begin{bmatrix} \frac{1831.68 + 3177.08}{1.15} \\ \frac{1831.68 + 3177.08}{1.5} \end{bmatrix}$$

$$= \begin{bmatrix} 4594.35 \\ 3949.73 \end{bmatrix} \text{kN}$$

$$\therefore AGE_o = \begin{bmatrix} 1726.19/4594.35 \\ 1316.06/3949 \end{bmatrix} \times 100 = \begin{bmatrix} 37.57\% \\ 33.32\% \end{bmatrix}$$

∴ settlement calculation:

obtained values: $Q_s = 3177.08$ kN

$Q_b = 1831.68$ kN

$A_b = 0.636\ m^2$

$A_s = 39.58\ m^2$

$E_p = 33 \times 10^6\ kN/m^2$

$E_b = 12250\ kN/m^2$

poisson's ratio $\nu = 0.35$

Influence factor of L/B ratio $I_p = 0.55$

pile head settlement based on combination 1

$$w_{s1} = \frac{Q_s}{1} = \frac{3177.08}{1} = 3177.08\ kN$$

$$w_{B1} = \frac{Q_b}{1.25} = \frac{1831.68}{1.25} = 1465.34\ kN$$

$$\text{pile head settlement } (P_1) = \frac{(w_s + 2w_{b1}) \times L}{2 \times A_s \times E_p} + \frac{\pi w_{b1}}{4A_b} \times \left(\frac{D(1-\nu^2)I_p}{E_b}\right)$$

$$= \left(\frac{(3177.08 + 2 \times 1465.34) \times 14}{2 \times 39.58 \times 33 \times 10^6}\right) + \left(\frac{\pi \times 1465.34}{4 \times 0.636}\right) \times \left(\frac{0.9(1-0.35^2) \times 0.55}{122500}\right)$$

$= 6.4 \times 10^{-3}\ m$

$P_1 = 6.4\ mm$

pile head settlement based on load combination 1 & 2

$$w_{s2} = \frac{Q_s}{1.3} = \frac{3177.08}{1.3} = 2443.9\ kN$$

$$w_{B2} = \frac{Q_b}{1.6} = \frac{1831.68}{1.6} = 1144.8\ kN$$

$$P_2 = \left(\frac{(w_{s2} + 2b_2)L}{2A_s E_p}\right) + \left(\frac{\pi w b_2}{4A_b}\right) \times \left(\frac{P(1-\nu^2) I_p}{E_b}\right)$$

$$= \left[\left(\frac{(2443.9 + 2 \times 1144.8) \times 14}{2 \times 39.58 \times 33 \times 10^6}\right) + \left(\frac{\pi \times 1144.8}{4 \times 0.636}\right) \times \left(\frac{0.9(1-0.35^2)0.55}{122500}\right)\right]$$

$P_2 = 5 \times 10^{-3}\ m = 5\ mm$

both settlements P_1 & P_2 are less than 50mm

∴ The pile design is safe and acceptable.

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iv) Design of pile located at B_2:-

Vertical load $V_{Gk} = 319$ kN

Vertical load $V_{Qk} = 99$ kN

Assume length $L = 14$m

pile diameter $D = 1.05$m

weight of pile $(W_{Gk}) = \pi \times \frac{D^2}{4} \times h \times \gamma_c$

$= \pi \times \frac{1.05^2}{4} \times 14 \times 25$

$= 302.37$ kN

* calculating design loads based on combination 1&2

$$V_d = \begin{bmatrix} 1.35(319 + 302.37) + 1.5 \times 99 \\ 1(319 + 302.37) + 1.3 \times 99 \end{bmatrix}$$

$$= \begin{bmatrix} 987.35 \\ 750.07 \end{bmatrix} \text{kN}$$

Bearing capacity factor $N_c = 9$

Avg SPT layer 1 $\left(\frac{23+26}{2}\right) = 24.5$

SPT layer 2 $\left(\frac{20+20+54}{3}\right) = 31.33$

SPT layer 3 $\left(\frac{50}{1}\right) = 50$

SPT layer 4 $\left(\frac{42+54}{3}\right)$ = 3[illegible]57

SPT layer 5 $\left(\frac{64}{1}\right) = 64$

∴ undrained shear strength

$C_u = SPT \times 5$

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$C_{u_1} = 14.5 \times 5 = 122.5\ kN/m^2$

$C_{u_2} = 31.33 \times 5 = 156.5\ kN/m^2$

$C_{u_3} = 50 \times 5 = 250\ kN/m^2$

$C_{u_4} = 51 \times 5 = 265\ kN/m^2$

$C_{u_5} = 64 \times 5 = 320\ kN/m^2$

From the graph adhension factor at layer 5

$$f_{ss} = \bar{C_u} \times 0.45 \times \left(\frac{\bar{\sigma_v}}{C_u}\right) 0.45$$

$$f_{ss} = 320 \times 0.45 \times \left(\frac{87.33}{320}\right) \times 0.45$$

$$= 80.27\ kN/m^2$$

pile shaft area $A_s = \pi \times D \times L$

$$= \pi \times 1.05 \times 14$$

$$= 46.18\ m^2$$

Maximum shaft resistance

$$Q_s = A_s \times f_{ss}$$

$$= 46.18 \times 80.27$$

$$= 37069\ kN$$

pile base area $= \frac{\pi \times D^2}{4} = 0.865\ m^2$

unit base resistance $q_b = N \times C_{u_5}$

$$= 9 \times 320$$

$$q_b = 2880\ kN/m^2$$

maximum base resistance $Q_b = \frac{\pi D^2}{4} \times q_b$

$$= 0.865 \times 2880$$

$$Q_b = 2491.2\ kN$$

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For bored pile resistance V_{Rd}

ultimate bearing resistance combination 1 & 2

$$VRD(1) = \begin{bmatrix} \frac{Q_b}{1.25} + \frac{Q_s}{1} \\ \frac{Q_b}{1.6} + \frac{Q_s}{1.3} \end{bmatrix} = \begin{bmatrix} \frac{2491.2}{1.25} + \frac{3706.9}{1} \\ \frac{2491.2}{1.6} + \frac{3706.9}{1.3} \end{bmatrix}$$

$$= \begin{bmatrix} 5699.86 \\ 4408.46 \end{bmatrix} kN$$

$$\Delta GE_o = \begin{bmatrix} 987.35/5699.86 \\ 750.07/4408.46 \end{bmatrix} \times 100 = \begin{bmatrix} 17.32\ \% \\ 17.01\ \% \end{bmatrix}$$

ultimate total resistance at combination 1 & 2

$$VRD(2) = \begin{bmatrix} \frac{Q_b + Q_s}{1.15} \\ \frac{Q_b + Q_s}{1.5} \end{bmatrix} = \begin{bmatrix} \frac{2491.2 + 3706.9}{1.15} \\ \frac{2491.2 + 3706.9}{1.5} \end{bmatrix}$$

$$= \begin{bmatrix} 5389.6 \\ 4132.06 \end{bmatrix} kN$$

$$\therefore \quad \Delta GE_o = \begin{bmatrix} 987.35/5389.6 \\ 750.07/4132.06 \end{bmatrix} \times 100 = \begin{bmatrix} 18.32\ \% \\ 18.15\ \% \end{bmatrix}$$

Settlement calculation:-

we have
$Q_s = 3706.9\ kN$

$Q_b = 2491.2\ kN$

$A_b = 0.865\ m^2$

$A_s = 46.18\ m^2$

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$E_p = 33 \times 10^6 \, kN/m^2$

$E_b = 122500 \, kN/m^2$

poisson's ratio $v = 0.35$

Influence factor of L/B ratio $I_p = 0.55$

pile head settlement based on combination 1

$$W_{S1} = \frac{Q_s}{1} = \frac{3706.69}{1} = 3706.91 \, kN$$

$$W_{B1} = \frac{Q_b}{1.25} = \frac{2491.2}{1.25} = 1992.96 \, kN$$

$$\text{pile head settlement } (P_1) = \frac{(W_S + 2W_b) \times L}{2 A_S \times E_p} + \left(\frac{\pi W_{b1}}{4 A_b}\right) \times \left(\frac{D(1-v^2) I_p}{E_b}\right)$$

$$= \left(\frac{3706.9 + 2 \times 1992.96 \times 14}{2 \times 46.18 \times 33 \times 10^6}\right) + \left(\frac{\pi \times 1992.96}{4 \times 0.865}\right) \times \left(\frac{1.05(1-0.35^2)0.55}{122500}\right)$$

$= 75 \times 10^{-3} \, m$

$= 7.5 \, mm$

pile head settlement based on load combination 2

$$W_{S2} = \frac{Q_s}{1.3} = \frac{3706.9}{1.3} = 2851.46 \, kN$$

$$W_{B2} = \frac{Q_b}{1.6} = \frac{2491.2}{1.6} = 1557 \, kN$$

$$P_2 = \left(\frac{(W_{S2} + 2b_2) L}{2 A_S E_p}\right) + \frac{\pi W_{b2}}{4 A_b} \times \frac{D(1-v^2) I_p}{E_b}$$

$$= \left(\frac{(2851.46 + 2 \times 1557) \times 14}{2 \times 46.18 \times 10^6}\right) + \left(\frac{\pi \times 1557}{4 \times 0.865}\right)\left(\frac{1.05(1-0.35^2)0.55}{122500}\right)$$

$= 5.8 \times 10^{-3} \, m$

$P_2 = 5.8 \, mm$

Both settlement P_1 & P_2 are less than 50 mm

$\therefore$ The pile design is safe and acceptable.

Scanned with CamScanner