# Shallow Foundations

**Q1** A continuous footing of 2 m width is located at a depth of 1.3 m ($D_f$) below the ground surface in a deposit of compacted sand ($c'$ = 0 kPa, $\phi'$ = 37°, $\gamma_1 = 16$ kN/m³, $\gamma_2 = 20$ kN/m³). The ground water table is 2 m below the ground surface ($D_w$). **i)** What type of failure conditions (i.e., general shear failure (GSF), local shear failure (LSF) or punching shear failure (PSF) do you expect for the given shear strength parameters. Give reasons. **ii)** Determine the allowable bearing capacity ($q_{all}$) for a factor of safety of 2.5.

***Use the equation below for solving the problem along with Table 2 (****Table 3.4 in the textbook: Meyerhof's bearing capacity, shape, depth, and inclination factors)* ***attached at the end of the questions***

**Meyerhof (1963)** equation: $q_{ult} = c'N_c F_{cs} F_{cd} F_{ci} + qN_q F_{qs} F_{qd} F_{qi} + \frac{1}{2}\gamma B N_\gamma F_{\gamma s} F_{\gamma d} F_{\gamma i}$

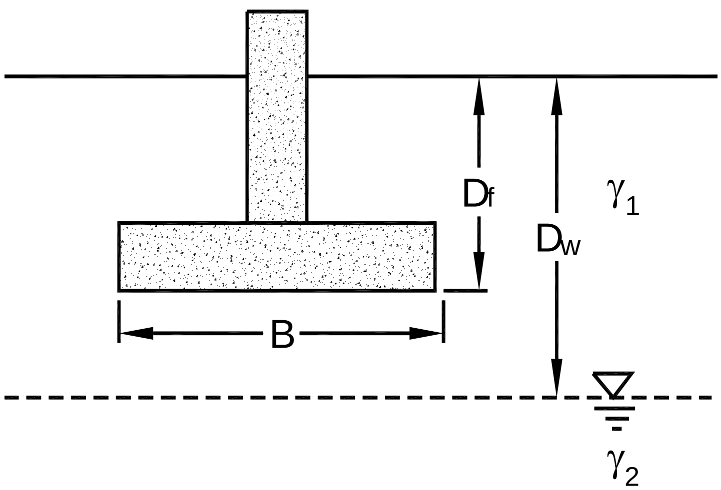


**Figure 1**

**iii)** What would be the allowable bearing capacity if you use **Terzaghi's (1943)** bearing capacity equation ($q_{ult} = c'N_c + qN_q + \frac{1}{2}\gamma B N_\gamma$) with the same bearing capacity factors. **Don't solve or calculate the bearing capacity** using this equation. Just discuss the reasons whether the bearing capacity value would be lower or higher. Which one of the equations (Terzaghi's or Meyerhof) do you recommend to use in engineering practice.

**Q2** A square footing located at a depth of 1.5 m ($D_f$) in a deposit of compacted sand ($c'$ = 0.7 kPa, $\phi'$ = 36°, $\gamma$ = 16.7 kN/m$^3$) must support a load of 300 kN. The load is inclined at an angle of 15° to the vertical. Determine the size of the footing required to support the load with a factor of safety of 3. The width of footing should be greater than the depth of the footing (i.e. $D_f / B < 1$). **(Use <u>Table 4</u> and <u>Table 5</u>** (Table 3.3 in the textbook: Bearing capacity factors).

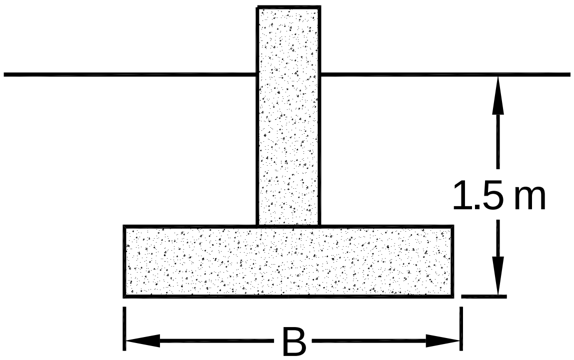


**Figure 2**

**Q3** Figure 3 shows the details of square footing. The gross allowable load, $Q_{all}$ with FS = 3 is 300 kN. The standard penetration resistance, $N_{60}$ values are shown in Table 1. **i)** What type of failure conditions do you expect for the soil conditions given in this problem? **ii)** Determine the width of the footing. The unit weight $\gamma$ = 16.5 kN/m$^3$, $\gamma_{sat}$ = 21 kN/m$^3$, $D_f$ = 1.5 m, and $D_1$ = 0.4 m. (**<u>Use Terzaghi (1943) equation</u>**: $q_{ult} = 1.3c'N_c + qN_q + 0.4\gamma BN_\gamma$ for determining the bearing capacity).

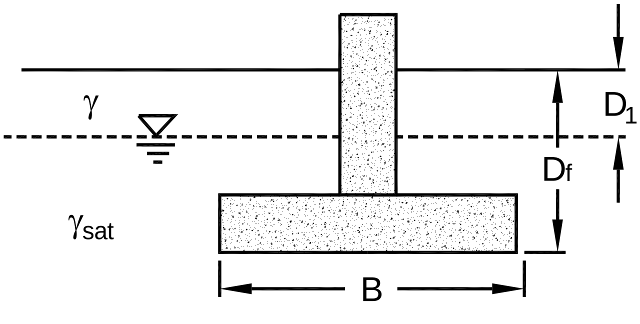


**Figure 3**

Table 1

| Depth (m) | $N_{60}$ |
|---|---|
| 1.5 | 7 |
| 3.0 | 9 |
| 4.5 | 9 |
| 6.0 | 13 |
| 7.5 | 8 |

**Q4** The proposed continuous footing shown in Figure 4 will support an axial vertical load of 100kN/m. The underlying soil is clay with $s_u$ = 120 kPa, $c'$ = 1.5 kPa, $\phi'$ = 23°, and $\gamma_2 = 18$ kN/m$^3$\. Compute **i)** the short-term and and **ii)** Determine FS.

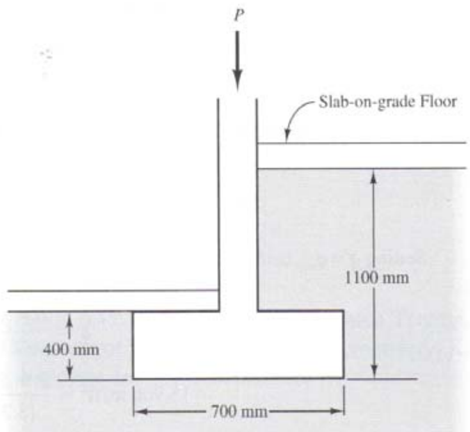


**Figure (4)**

**Q5** Repeat Q4 for **i)** long-term bearing capacity and **ii)** determine factor of safety for this continuous footing. (**Use Terzaghi's equation**).

**Table 2** Meyerhof's Bearing Capacity, Shape, Depth, and Inclination Factors [Eq. (3.23)]

| Factor | Relationship |
|---|---|
| **Bearing capacity** | |
| $N_c$ | **See Table 5** |
| $N_q$ | |
| $N_\gamma$ | $(N_q - 1)\tan(1.4\phi')$; **See Table 3** |
| **Shape** | |
| For $\phi = 0$, | |
| $F_{cs}$ | $1 + 0.2(B/L)$ |
| $F_{qs} = F_{\gamma s}$ | 1 |
| For $\phi' \geq 10°$, | |
| $F_{cs}$ | $1 + 0.2(B/L)\tan^2(45 + \phi'/2)$ |
| $F_{qs} = F_{\gamma s}$ | $1 + 0.1(B/L)\tan^2(45 + \phi'/2)$ |
| **Depth** | |
| For $\phi = 0$, | |
| $F_{cd}$ | $1 + 0.2(D_f/B)$ |
| $F_{qd} = F_{\gamma d}$ | 1 |
| For $\phi' \geq 10°$ | |
| $F_{cd}$ | $1 + 0.2(D_f/B)\tan(45 + \phi'/2)$ |
| $F_{qd} = F_{\gamma d}$ | $1 + 0.1(D_f/B)\tan(45 + \phi'/2)$ |
| **Inclination** | |
| $F_{ci} = F_{qi}$ | **See Table 4** |
| $F_{\gamma i}$ | |

**Table 3** Meyerhof's Bearing Capacity Factor $N_\gamma = (N_q - 1)\tan(1.4\phi')$

| $\phi'$ | $N_\gamma$ | $\phi'$ | $N_\gamma$ | $\phi'$ | $N_\gamma$ | $\phi'$ | $N_\gamma$ |
|---|---|---|---|---|---|---|---|
| 0 | 0.00 | 14 | 0.92 | 28 | 11.19 | 42 | 139.32 |
| 1 | 0.002 | 15 | 1.13 | 29 | 13.24 | 43 | 171.14 |
| 2 | 0.01 | 16 | 1.38 | 30 | 15.67 | 44 | 211.41 |
| 3 | 0.02 | 17 | 1.66 | 31 | 18.56 | 45 | 262.74 |
| 4 | 0.04 | 18 | 2.00 | 32 | 22.02 | 46 | 328.73 |
| 5 | 0.07 | 19 | 2.40 | 33 | 26.17 | 47 | 414.32 |
| 6 | 0.11 | 20 | 2.87 | 34 | 31.15 | 48 | 526.44 |
| 7 | 0.15 | 21 | 3.42 | 35 | 37.15 | 49 | 674.91 |
| 8 | 0.21 | 22 | 4.07 | 36 | 44.43 | 50 | 873.84 |
| 9 | 0.28 | 23 | 4.82 | 37 | 53.27 | 51 | 1143.93 |
| 10 | 0.37 | 24 | 5.72 | 38 | 64.07 | 52 | 1516.05 |
| 11 | 0.47 | 25 | 6.77 | 39 | 77.33 | 53 | 2037.26 |
| 12 | 0.60 | 26 | 8.00 | 40 | 93.69 | | |
| 13 | 0.74 | 27 | 9.46 | 41 | 113.99 | | |

## Table 4: Shape, Depth, and Inclination Factors Recommended for Use

| Factor | Relationship | Source |
|---|---|---|
| Shape[a] | $F_{cs} = 1 + \frac{B}{L}\frac{N_q}{N_c}$<br>$F_{qs} = 1 + \frac{B}{L}\tan\phi$<br>$F_{\gamma s} = 1 - 0.4\frac{B}{L}$<br>where $L$ = length of the foundation ($L > B$) | De Beer (1970)<br>Hansen (1970) |
| Depth[b] | *Condition (a)*: $D_f/B \le 1$<br>$F_{cd} = 1 + 0.4\frac{D_f}{B}$<br>$F_{qd} = 1 + 2\tan\phi(1-\sin\phi)^2\frac{D_f}{B}$<br>$F_{\gamma d} = 1$<br>*Condition (b)*: $D_f/B > 1$<br>$F_{cd} = 1 + (0.4)\tan^{-1}\left(\frac{D_f}{B}\right)$<br>$F_{qd} = 1 + 2\tan\phi(1-\sin\phi)^2\tan^{-1}\left(\frac{D_f}{B}\right)$<br>$F_{\gamma d} = 1$ | Hansen (1970) |
| Inclination | $F_{ci} = F_{qi} = \left(1 - \frac{\beta^\circ}{90^\circ}\right)^2$<br>$F_{\gamma i} = \left(1 - \frac{\beta}{\phi}\right)^2$<br>where $\beta$ = inclination of the load on the foundation with respect to the vertical | Meyerhof (1963); Hanna and Meyerhof (1981) |

[a] These shape factors are empirical relations based on extensive laboratory tests.
[b] The factor $\tan^{-1}(D_f/B)$ is in radians.

**Table 5: Variation of Bearing Capacity Factors with Friction Angle (Table 3.3 in the text book)**

| $\phi'$ | $N_c$ | $N_q$ | $N_\gamma$ | $\phi'$ | $N_c$ | $N_q$ | $N_\gamma$ |
|---|---|---|---|---|---|---|---|
| 0 | 5.14 | 1.00 | 0.00 | 26 | 22.25 | 11.85 | 12.54 |
| 1 | 5.38 | 1.09 | 0.07 | 27 | 23.94 | 13.20 | 14.47 |
| 2 | 5.63 | 1.20 | 0.15 | 28 | 25.80 | 14.72 | 16.72 |
| 3 | 5.90 | 1.31 | 0.24 | 29 | 27.86 | 16.44 | 19.34 |
| 4 | 6.19 | 1.43 | 0.34 | 30 | 30.14 | 18.40 | 22.40 |
| 5 | 6.49 | 1.57 | 0.45 | 31 | 32.67 | 20.63 | 25.99 |
| 6 | 6.81 | 1.72 | 0.57 | 32 | 35.49 | 23.18 | 30.22 |
| 7 | 7.16 | 1.88 | 0.71 | 33 | 38.64 | 26.09 | 35.19 |
| 8 | 7.53 | 2.06 | 0.86 | 34 | 42.16 | 29.44 | 41.06 |
| 9 | 7.92 | 2.25 | 1.03 | 35 | 46.12 | 33.30 | 48.03 |
| 10 | 8.35 | 2.47 | 1.22 | 36 | 50.59 | 37.75 | 56.31 |
| 11 | 8.80 | 2.71 | 1.44 | 37 | 55.63 | 42.92 | 66.19 |
| 12 | 9.28 | 2.97 | 1.69 | 38 | 61.35 | 48.93 | 78.03 |
| 13 | 9.81 | 3.26 | 1.97 | 39 | 67.87 | 55.96 | 92.25 |
| 14 | 10.37 | 3.59 | 2.29 | 40 | 75.31 | 64.20 | 109.41 |
| 15 | 10.98 | 3.94 | 2.65 | 41 | 83.86 | 73.90 | 130.22 |
| 16 | 11.63 | 4.34 | 3.06 | 42 | 93.71 | 85.38 | 155.55 |
| 17 | 12.34 | 4.77 | 3.53 | 43 | 105.11 | 99.02 | 186.54 |
| 18 | 13.10 | 5.26 | 4.07 | 44 | 118.37 | 115.31 | 224.64 |
| 19 | 13.93 | 5.80 | 4.68 | 45 | 133.88 | 134.88 | 271.76 |
| 20 | 14.83 | 6.40 | 5.39 | 46 | 152.10 | 158.51 | 330.35 |
| 21 | 15.82 | 7.07 | 6.20 | 47 | 173.64 | 187.21 | 403.67 |
| 22 | 16.88 | 7.82 | 7.13 | 48 | 199.26 | 222.31 | 496.01 |
| 23 | 18.05 | 8.66 | 8.20 | 49 | 229.93 | 265.51 | 613.16 |
| 24 | 19.32 | 9.60 | 9.44 | 50 | 266.89 | 319.07 | 762.89 |
| 25 | 20.72 | 10.66 | 10.88 | | | | |