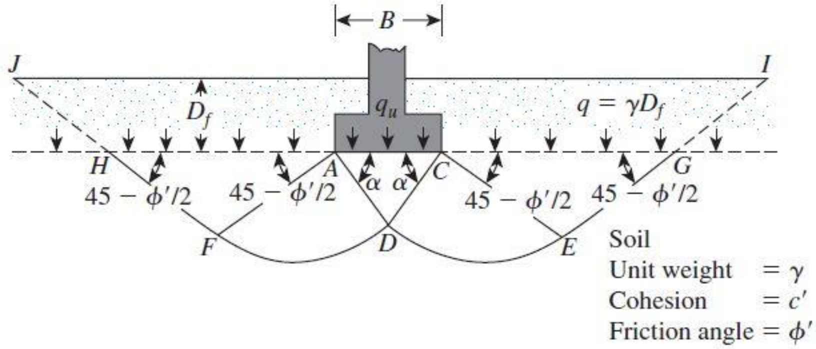
Terzaghi Bearing-Capacity Equation

One of the early sets of bearing-capacity equations was proposed by Terzaghi (1943) as shown bellow:-



Terzaqhi Equation (1843)

$$q_u = c'N_c + qN_q + \tfrac{1}{2}\gamma B N_\gamma \qquad \text{(continuous or strip foundation)} \tag{3.3}$$

where

c' = cohesion of soil
γ = unit weight of soil
$q = \gamma D_f$
N_c, N_q, N_γ = bearing capacity factors that are nondimensional and are functions only of the soil friction angle ϕ'

The bearing capacity factors N_c, N_q, and N_γ are defined by

$$N_c = \cot\phi'\left[\frac{e^{2(3\pi/4-\phi'/2)\tan\phi'}}{2\cos^2\left(\frac{\pi}{4}+\frac{\phi'}{2}\right)} - 1\right] = \cot\phi'(N_q - 1) \tag{3.4}$$

$$N_q = \frac{e^{2(3\pi/4-\phi'/2)\tan\phi'}}{2\cos^2\left(45+\frac{\phi'}{2}\right)} \tag{3.5}$$

and

$$N_\gamma = \frac{1}{2}\left(\frac{K_{p\gamma}}{\cos^2\phi'} - 1\right)\tan\phi' \tag{3.6}$$

where $K_{p\gamma}$ = passive pressure coefficient.

The variations of the bearing capacity factors defined by Eqs. (3.4), (3.5), and (3.6) are given in Table 3.1.

Where $N_C, N_q, and\ N_\gamma$ are Terzaghi factors, $S_C\ and\ S_\gamma$ shape factors, B and D are the width and depth of foundation respectively. q^- is an overburden pressure at the base of footing.

By substituting S_C and S_γ **in the above equation, we obtain:-**

$q_u = CN_C + q^- N_q + 0.5\gamma BN_\gamma$ **(for strip footing)**

$q_u = 1.3CN_C + q^- N_q + 0.3\gamma BN_\gamma$ **(round footing)**

$q_u = 1.3CN_C + q^- N_q + 0.4\gamma BN_\gamma$ **(Square footing)**

Table 3.1 Terzaghi's Bearing Capacity Factors—Eqs. (3.4), (3.5), and (3.6) a From Kumbhojkar (1993)

ϕ'	N_c	N_q	N_γ[a]	ϕ'	N_c	N_q	N_γ[a]
0	5.70	1.00	0.00	26	27.09	14.21	9.84
1	6.00	1.10	0.01	27	29.24	15.90	11.60
2	6.30	1.22	0.04	28	31.61	17.81	13.70
3	6.62	1.35	0.06	29	34.24	19.98	16.18
4	6.97	1.49	0.10	30	37.16	22.46	19.13
5	7.34	1.64	0.14	31	40.41	25.28	22.65
6	7.73	1.81	0.20	32	44.04	28.52	26.87
7	8.15	2.00	0.27	33	48.09	32.23	31.94
8	8.60	2.21	0.35	34	52.64	36.50	38.04
9	9.09	2.44	0.44	35	57.75	41.44	45.41
10	9.61	2.69	0.56	36	63.53	47.16	54.36
11	10.16	2.98	0.69	37	70.01	53.80	65.27
12	10.76	3.29	0.85	38	77.50	61.55	78.61
13	11.41	3.63	1.04	39	85.97	70.61	95.03
14	12.11	4.02	1.26	40	95.66	81.27	115.31
15	12.86	4.45	1.52	41	106.81	93.85	140.51
16	13.68	4.92	1.82	42	119.67	108.75	171.99
17	14.60	5.45	2.18	43	134.58	126.50	211.56
18	15.12	6.04	2.59	44	151.95	147.74	261.60
19	16.56	6.70	3.07	45	172.28	173.28	325.34
20	17.69	7.44	3.64	46	196.22	204.19	407.11
21	18.92	8.26	4.31	47	224.55	241.80	512.84
22	20.27	9.19	5.09	48	258.28	287.85	650.67
23	21.75	10.23	6.00	49	298.71	344.63	831.99
24	23.36	11.40	7.08	50	347.50	415.14	1072.80
25	25.13	12.72	8.34				

[a]From Kumbhojkar (1993)

Factor of Safety

Calculating the gross *allowable load-bearing capacity* of shallow foundations requires the application of a factor of safety (FS) to the gross ultimate bearing capacity, or

$$q_{all} = \frac{q_u}{FS} \qquad (3.12)$$

Modification of Bearing Capacity Equations for Water Table

Equations (3.3) and (3.7) through (3.11) give the ultimate bearing capacity, based on the assumption that the water table is not existed. However, if the water table is close to the foundation, some modifications of the bearing capacity equations will be necessary. (See Figure 3.6.)

Case I. If the water table is located so that $0 \le D_1 \le D_f$, the factor q in the bearing capacity equations takes the form

$$q = \text{effective surcharge} = D_1\gamma + D_2(\gamma_{sat} - \gamma_w) \tag{3.16}$$

where

γ_{sat} = saturated unit weight of soil
γ_w = unit weight of water

Also, the value of γ in the last term of the equations has to be replaced by $\gamma' = \gamma_{sat} - \gamma_w$.

Case II. For a water table located so that $0 \le d \le B$,

$$q = \gamma D_f \tag{3.17}$$

In this case, the factor γ in the last term of the bearing capacity equations must be replaced by the factor

$$\bar{\gamma} = \gamma' + \frac{d}{B}(\gamma - \gamma') \tag{3.18}$$

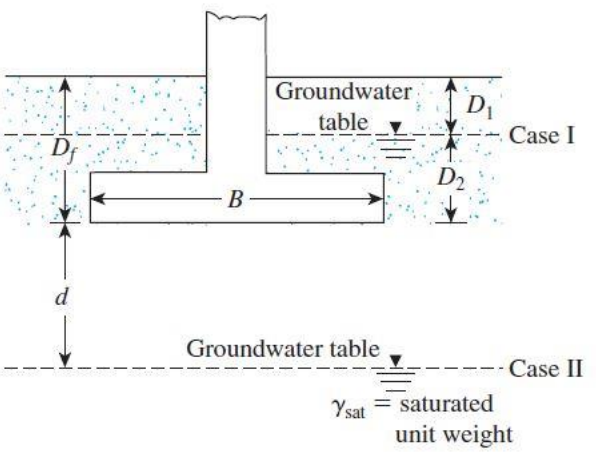


Figure 3.6 Modification of bearing capacity equations for water table

Case III. When the water table is located so that $d \geq B,$ the water will have no effect on the ultimate bearing capacity.

Example 3.1. A square foundation is $2^m * 2^m$ in plan. The soil supporting the foundation has a friction angle $\emptyset = 25^o$ of and $C = 20\ KN/m2$ The unit weight of soil, is $\gamma = 16.5 KN/m3$. Determine the allowable gross load on the foundation with a factor of safety (FS) of 3. Assume that the depth of the foundation is 1.5 m and that general shear failure occurs in the soil.

Solution:

Ultimate bearing capacity may be obtained by general Terzaqhi's Equation for square footing:-

$$q_U = 1.3CN_C + qN_q + 0.4\gamma BN_\gamma$$

For $\emptyset = 25^o$

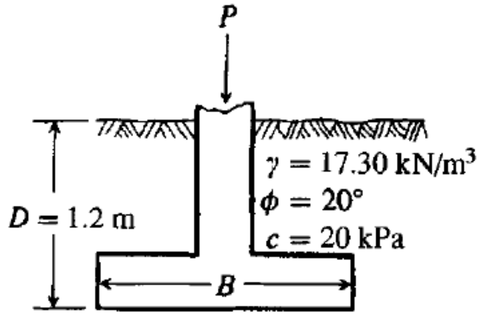
$$N_C = 25.13, \qquad N_q = 12.72, \qquad N_\gamma = 8.34$$

$$q_U = 1.3 * 20 * 25.13 + 1.5 * 16.5 * 12.72 + 0.4 * 16.5 * 2 * 8.34 = 1{,}078 KN/m2$$

$q_{all} = \frac{q_U}{F} = \frac{1078}{3} = 359.4KN/m2$

Thus the total allowable gross load, $Q = 359.4 * 2^2 = 1437KN$

Example 2. Compute the allowable bearing pressure using the Terzaghi equation for the footing and soil parameters shown in the figure. Use a safety factor of 3 to obtain q_a.



$N_c = 17.7 \quad N_q = 7.4 \quad N_\gamma = 5.0$

$s_c = 1.3 \quad s_\gamma = 0.8$

1. Find the bearing capacity

$q_u = 1.3CN_C + q^- N_q + 0.4\gamma BN_\gamma$ **(Square footing)**

$q_u = 1.3 * 20 * 17.7 + 1.2 * 17.3 * 7.4 + 0.4 * 17.3 * B * 5$

$= 613.8 + 34.6B$

$q_a = \frac{613.8+34.6B}{3} = 205 + 11.5B$ **KN/m2**

Assume B =1.5, $q_a = 222$

The General Bearing Capacity Equation

The ultimate bearing capacity equations (3.3), (3.7), and (3.8) are for continuous, square, and circular foundations only; they do not address the case of rectangular foundations ($0 < B/L < 1$). Also, the equations do not take into account the shearing resistance along the failure surface in soil above the bottom of the foundation (the portion of the failure surface marked as *GI* and *HJ* in Figure 3.5). In addition, the load on the foundation may be inclined. To account for all these shortcomings, Meyerhof (1963) suggested the following form of the general bearing capacity equation:

$$q_u = c'N_c F_{cs} F_{cd} F_{ci} + qN_q F_{qs} F_{qd} F_{qi} + \tfrac{1}{2}\gamma B N_\gamma F_{\gamma s} F_{\gamma d} F_{\gamma i} \qquad (3.19)$$

In this equation:

c' = cohesion
q = effective stress at the level of the bottom of the foundation
γ = unit weight of soil
B = width of foundation (= diameter for a circular foundation)
$F_{cs}, F_{qs}, F_{\gamma s}$ = shape factors
$F_{cd}, F_{qd}, F_{\gamma d}$ = depth factors
$F_{ci}, F_{qi}, F_{\gamma i}$ = load inclination factors
N_c, N_q, N_γ = bearing capacity factors

Meyerhof Equation (1963) for shape, depth, and inclination factors.

Vertical load: $q_{ult} = cN_c s_c d_c + \bar{q} N_q s_q d_q + 0.5\gamma B' N_\gamma s_\gamma d_\gamma$

Inclined load: $q_{ult} = cN_c d_c i_c + \bar{q} N_q d_q i_q + 0.5\gamma B' N_\gamma d_\gamma i_\gamma$

$$N_q = e^{\pi \tan\phi} \tan^2\left(45 + \frac{\phi}{2}\right)$$

$$N_c = (N_q - 1)\cot\phi$$

$$N_\gamma = (N_q - 1)\tan(1.4\phi)$$

Table 3.3 Bearing Capacity Factors

ϕ'	N_c	N_q	N_γ	ϕ'	N_c	N_q	N_γ
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				

Shape, depth, and inclination factors for the Meyerhof bearing-capacity equations

Table 3.4 Shape, Depth and Inclination Factors (DeBeer (1970); Hansen (1970); Meyerhof (1963); Meyerhof and Hanna (1981))

Factor	Relationship	Reference
Shape	$F_{cs} = 1 + \left(\frac{B}{L}\right)\left(\frac{N_q}{N_c}\right)$ $F_{qs} = 1 + \left(\frac{B}{L}\right)\tan\phi'$ $F_{\gamma s} = 1 - 0.4\left(\frac{B}{L}\right)$	DeBeer (1970)
Depth	$\frac{D_f}{B} \leq 1$ For $\phi = 0$: $F_{cd} = 1 + 0.4\left(\frac{D_f}{B}\right)$ $F_{qd} = 1$ $F_{\gamma d} = 1$ For $\phi' > 0$: $F_{cd} = F_{qd} - \frac{1 - F_{qd}}{N_c \tan\phi'}$ $F_{qd} = 1 + 2\tan\phi'(1 - \sin\phi')^2\left(\frac{D_f}{B}\right)$ $F_{\gamma d} = 1$ $\frac{D_f}{B} > 1$ For $\phi = 0$: $F_{cd} = 1 + 0.4\underbrace{\tan^{-1}\left(\frac{D_f}{B}\right)}_{\text{radians}}$ $F_{qd} = 1$ $F_{\gamma d} = 1$ For $\phi' > 0$: $F_{cd} = F_{qd} - \frac{1 - F_{qd}}{N_c \tan\phi'}$ $F_{qd} = 1 + 2\tan\phi'(1 - \sin\phi')^2 \underbrace{\tan^{-1}\left(\frac{D_f}{B}\right)}_{\text{radians}}$ $F_{\gamma d} = 1$	Hansen (1970)
Inclination	$F_{ci} = F_{qi} = \left(1 - \frac{\beta^\circ}{90^\circ}\right)^2$ $F_{\gamma i} = \left(1 - \frac{\beta}{\phi'}\right)$ β = inclination of the load on the foundation with respect to the vertical	Meyerhof (1963); Hanna and Meyerhof (1981)

Example 3.1. **A square foundation is 2^m * 2^m in plan. The soil supporting the foundation has a friction angle $\emptyset = 25^o$ of and $C = 20\ KN/m2$ The unit weight of soil, is $\gamma = 16.5 KN/m3$. Determine the allowable gross load on the foundation with a factor of safety (FS) of 3. Assume that the depth of the foundation is 1.5 m and that general shear failure occurs in the soil.**

Example 3.2. **Solve Example Problem 3.1 using Eq. (3.19).**

From Eq. (3.19),

$$q_u = c' N_c F_{cs} F_{cd} F_{ci} + q N_q F_{qs} F_{qd} F_{qt} + \frac{1}{2} \gamma B N_\gamma F_{\gamma s} F_{\gamma d} F_{\gamma t}$$

Since the load is vertical, $F_{ci} = F_{qi} = F_{\gamma i} = 1$. From Table 3.3 for $\phi' = 25°$, $N_c = 20.72$, $N_q = 10.66$, and $N_\gamma = 10.88$.

Using Table 3.4,

$$F_{cs} = 1 + \left(\frac{B}{L}\right)\left(\frac{N_q}{N_c}\right) = 1 + \left(\frac{2}{2}\right)\left(\frac{10.66}{20.72}\right) = 1.514$$

$$F_{qs} = 1 + \left(\frac{B}{L}\right)\tan\phi' = 1 + \left(\frac{2}{2}\right)\tan 25 = 1.466$$

$$F_{\gamma s} = 1 - 0.4\left(\frac{B}{L}\right) = 1 - 0.4\left(\frac{2}{2}\right) = 0.6$$

$$F_{qd} = 1 + 2\tan\phi' (1 - \sin\phi')^2\left(\frac{D_f}{B}\right)$$

$$= 1 + (2)(\tan 25)(1 - \sin 25)^2\left(\frac{1.5}{2}\right) = 1.233$$

$$F_{cd} = F_{qd} - \frac{1 - F_{qd}}{N_c \tan\phi'} = 1.233 - \left[\frac{1 - 1.233}{(20.72)(\tan 25)}\right] = 1.257$$

$$F_{\gamma d} = 1$$

Hence,

$$q_u = (20)(20.72)(1.514)(1.257)(1)$$
$$+(1.5 \times 16.5)(10.66)(1.466)(1.233)(1)$$
$$+\frac{1}{2}(16.5)(2)(10.88)(0.6)(1)(1)$$
$$= 788.6 + 476.9 + 107.7 = 1373.2\ \text{kN/m}^2$$

$$q_{\text{all}} = \frac{q_u}{\text{FS}} = \frac{1373.2}{3} = 457.7\ \text{kN/m}^2$$

$$Q = (457.7)(2 \times 2) = \mathbf{1830.8\ kN}$$

Example 3.3

A square foundation ($B \times B$) has to be constructed as shown in Figure 3.7. Assume that $\gamma = 16.5\ \text{kN/m}^3$, $\gamma_{sat} = 18.55\ \text{kN/m}^3$, $\phi' = 34°$, $D_f = 1.22$ m, and $D_1 = 0.61$ m. The gross allowable load, Q_{all}, with FS = 3 is 667.2 kN. Determine the size of the footing. Use Eq. (3.19).

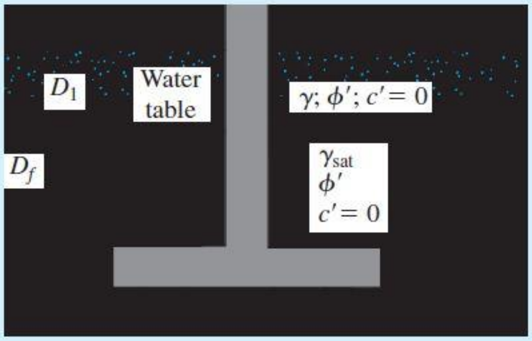


Figure 3.7 A square foundation

Solution

We have

$$q_{all} = \frac{Q_{all}}{B^2} = \frac{667.2}{B^2}\ \text{kN/m}^2 \tag{a}$$

From Eq. (3.19) (with $c' = 0$), for vertical loading, we obtain

$$q_{all} = \frac{q_u}{\text{FS}} = \frac{1}{3}\left(qN_qF_{qs}F_{qd} + \frac{1}{2}\gamma' BN_\gamma F_{\gamma s}F_{\gamma d}\right)$$

For $\phi' = 34°$, from Table 3.3, $N_q = 29.44$ and $N_\gamma = 41.06$. Hence,

$$F_{qs} = 1 + \frac{B}{L}\tan\phi' = 1 + \tan 34 = 1.67$$

$$F_{\gamma s} = 1 - 0.4\left(\frac{B}{L}\right) = 1 - 0.4 = 0.6$$

$$F_{qd} = 1 + 2\tan\phi'(1 - \sin\phi')^2\frac{D_f}{B} = 1 + 2\tan 34\,(1 - \sin 34)^2\frac{4}{B} = 1 + \frac{1.05}{B}$$

$$F_{\gamma d} = 1$$

and

$$q = (0.61)(16.5) + 0.61\,(18.55 - 9.81) = 15.4\ \text{kN/m}^2$$

So

$$q_{all} = \frac{1}{3}\left[(15.4)(29.44)(1.67)\left(1 + \frac{1.05}{B}\right) + \left(\frac{1}{2}\right)(18.55 - 9.81)(B)(41.06)(0.6)(1)\right] \quad \text{(b)}$$

$$= 252.38 + \frac{265}{B} + 35.89B$$

Combining Eqs. (a) and (b) results in

$$\frac{667.2}{B^2} = 252.38 + \frac{265}{B} + 35.89B$$

By trial and error, we find that $B \approx \mathbf{1.3\ m}$.

Eccentrically Loaded Foundations

In several instances, as with the base of a retaining wall, foundations are subjected to moments in addition to the vertical load, as shown in Figure 3.13a. In such cases, the distribution of pressure by the foundation on the soil is not uniform. The nominal distribution of pressure is

$$q_{max} = \frac{Q}{BL} + \frac{6M}{B^2L} \quad (3.33)$$

and

$$q_{min} = \frac{Q}{BL} - \frac{6M}{B^2L} \quad (3.34)$$

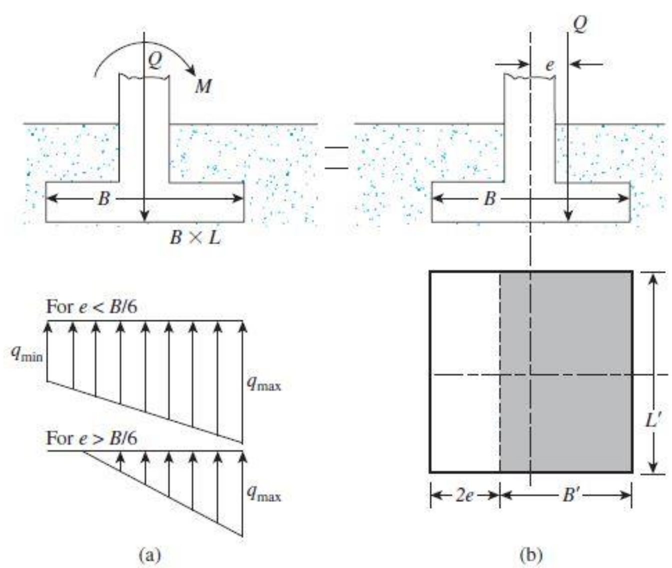


Figure 3.13 Eccentrically loaded foundations

where

Q = total vertical load
M = moment on the foundation

Figure 3.13b shows a force system equivalent to that shown in Figure 3.13a. The distance

$$e = \frac{M}{Q} \tag{3.35}$$

is the eccentricity. Substituting Eq. (3.35) into Eqs. (3.33) and (3.34) gives

$$q_{\text{max}} = \frac{Q}{BL}\left(1 + \frac{6e}{B}\right) \tag{3.36}$$

and

$$q_{\text{min}} = \frac{Q}{BL}\left(1 - \frac{6e}{B}\right) \tag{3.37}$$

Note that, in these equations, when the eccentricity e becomes $B/6$, q_{min} is zero. For $e > B/6$, q_{min} will be negative, which means that tension will develop. Because soil cannot take any tension, there will then be a separation between the foundation and the soil underlying it. The nature of the pressure distribution on the soil will be as shown in Figure 3.13a.

Ultimate Bearing Capacity under Eccentric Loading—One-Way Eccentricity

Effective Area Method (Meyerhoff, 1953)

In 1953, Meyerhof proposed a theory that is generally referred to as the *effective area method*.

The following is a step-by-step procedure for determining the ultimate load that the soil can support and the factor of safety against bearing capacity failure:

Step 1. Determine the effective dimensions of the foundation (Figure 3.13b):

$$B' = \text{effective width} = B - 2e$$
$$L' = \text{effective length} = L$$

Note that if the eccentricity were in the direction of the length of the foundation, the value of L' would be equal to $L - 2e$. The value of B' would equal B. The smaller of the two dimensions (i.e., L' and B') is the effective width of the foundation.

Step 2. Use Eq. (3.19) for the ultimate bearing capacity:

$$q'_u = c'N_cF_{cs}F_{cd}F_{ci} + qN_qF_{qs}F_{qd}F_{qi} + \tfrac{1}{2}\gamma B'N_\gamma F_{\gamma s}F_{\gamma d}F_{\gamma i} \tag{3.40}$$

To evaluate F_{cs}, F_{qs}, and $F_{\gamma s}$, use the relationships given in Table 3.4 with *effective length* and *effective width* dimensions instead of L and B, respectively. To determine F_{cd}, F_{qd}, and $F_{\gamma d}$, use the relationships given in Table 3.4. However, do not replace B with B'.

Step 3. The total ultimate load that the foundation can sustain is

$$Q_{\text{ult}} = q'_u \overbrace{(B')(L')}^{A'} \tag{3.41}$$

where A' = effective area.

Step 4. The factor of safety against bearing capacity failure is

$$\text{FS} = \frac{Q_{\text{ult}}}{Q}$$

Example 3.5

A continuous foundation is shown in Figure 3.18. If the load eccentricity is 0.2 m, determine the ultimate load, Q_{ult}, per unit length of the foundation. Use Meyerhof's effective area method.

Solution

For $c' = 0$, Eq. (3.40) gives

$$q'_u = qN_q F_{qs} F_{qd} F_{qi} + \frac{1}{2}\gamma' B' N_\gamma F_{\gamma s} F_{\gamma d} F_{\gamma i}$$

where $q = (16.5)(1.5) = 24.75 \text{ kN/m}^2$.

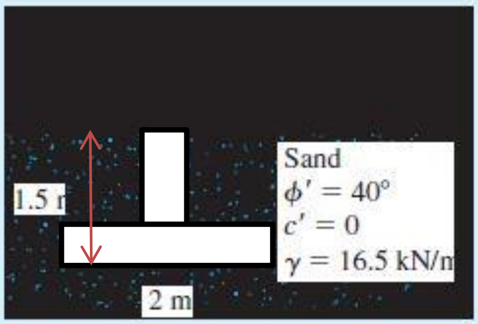


Figure 3.18 A continuous foundation with load eccentricity

For $\phi' = 40°$, from Table 3.3, $N_q = 64.2$ and $N_\gamma = 109.41$. Also,

$$B' = 2 - (2)(0.2) = 1.6 \text{ m}$$

Because the foundation in question is a continuous foundation, B'/L' is zero. Hence, $F_{qs} = 1$, $F_{\gamma s} = 1$. From Table 3.4,

$$F_{qi} = F_{\gamma i} = 1$$

$$F_{qd} = 1 + 2\tan\phi'(1 - \sin\phi')^2 \frac{D_f}{B} = 1 + 0.214\left(\frac{1.5}{2}\right) = 1.16$$

$$F_{\gamma d} = 1$$

and

$$q'_u = (24.75)(64.2)(1)(1.16)(1) + \left(\frac{1}{2}\right)(16.5)(1.6)(109.41)(1)(1)(1) = 3287.39 \text{ kN/m}^2$$

Consequently,

$$Q_{ult} = (B')(1)(q'_u) = (1.6)(1)(3287.39) \approx \mathbf{5260 \text{ kN}}$$ ■

Bearing Capacity—Two-way Eccentricity

Consider a situation in which a foundation is subjected to a vertical ultimate load Q_{ult} and a moment M, as shown in Figures 3.19a and b. For this case, the components of the moment M about the x- and y-axes can be determined as M_x and M_y, respectively. (See Figure 3.19.) This condition is equivalent to a load Q_{ult} placed eccentrically on the foundation with $x = e_B$ and $y = e_L$ (Figure 3.19d). Note that

$$e_B = \frac{M_y}{Q_{ult}} \tag{3.52}$$

and

$$e_L = \frac{M_x}{Q_{ult}} \tag{3.53}$$

If Q_{ult} is needed, it can be obtained from Eq. (3.41); that is,

$$Q_{ult} = q'_u A'$$

where, from Eq. (3.40),

$$q'_u = c' N_c F_{cs} F_{cd} F_{ci} + q N_q F_{qs} F_{qd} F_{qi} + \tfrac{1}{2} \gamma B' N_\gamma F_{\gamma s} F_{\gamma d} F_{\gamma i}$$

and

$$A' = \text{effective area} = B'L'$$

As before, to evaluate F_{cs}, F_{qs}, and $F_{\gamma s}$ (Table 3.4), we use the effective length L' and effective width B' instead of L and B, respectively. To calculate F_{cd}, F_{qd}, and $F_{\gamma d}$, we do

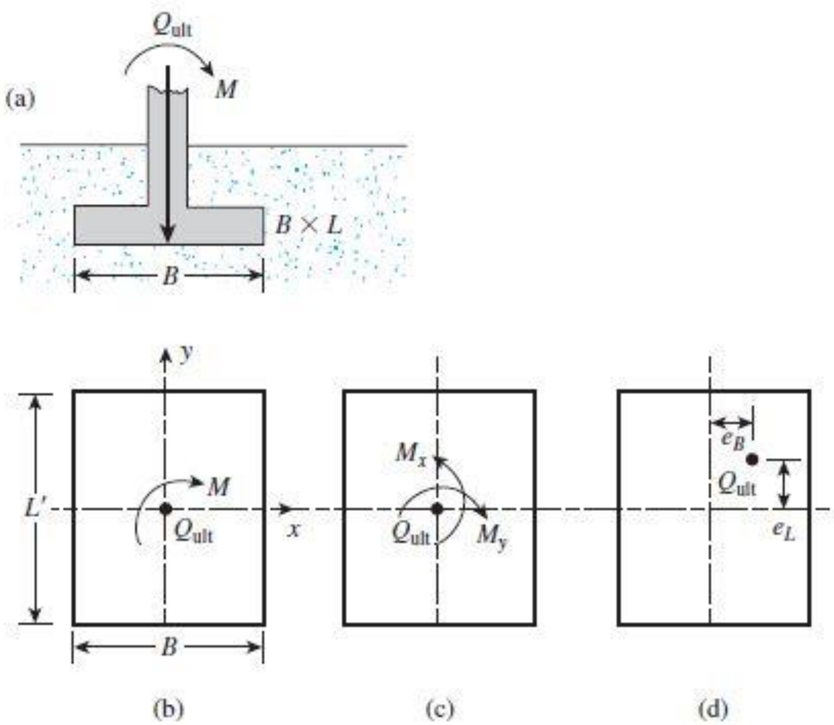


Figure 3.19 Analysis of foundation with two-way eccentricity

Problems

3.1 For the following cases, determine the allowable gross vertical load-bearing capacity of the foundation. Use Terzaghi's equation and assume general shear failure in soil. Use FS = 4.

Part	B	D_f	ϕ'	c'	γ	Foundation type
a.	1.22 m	0.91 m	25°	28.75 kN/m^2	17.29 kN/m^3	Continuous
b.	2 m	1 m	30°	0	17 kN/m^3	Continuous
c.	3 m	2 m	30°	0	16.5 kN/m^3	Square

3.2 A square column foundation has to carry a gross allowable load of 1805 kN (FS = 3). Given: $D_f = 1.5$ m, $\gamma = 15.9$ kN/m^3, $\phi' = 34°$, and $c' = 0$. Use Terzaghi's equation to determine the size of the foundation (B). Assume general shear failure.

3.3 Use the general bearing capacity equation [Eq. (3.19)] to solve the following:

a. Problem 3.1a
b. Problem 3.1b
c. Problem 3.1c

3.4 The applied load on a shallow square foundation makes an angle of 15° with the vertical. Given: $B = 1.83$ m, $D_f = 0.9$ m, $\gamma = 18.08$ kN/m^3, $\phi' = 25°$, and $c' = 23.96$ kN/m^2. Use FS = 4 and determine the gross allowable load. Use Eq. (3.19).

3.5 A column foundation (Figure P3.5) is 3 m × 2 m in plan. Given: $D_f = 1.5$ m, $\phi' = 25°$, $c' = 70$ kN/m^2. Using Eq. (3.19) and FS = 3, determine the net allowable load [see Eq. (3.15)] the foundation could carry.

3.6 For a square foundation that is $B \times B$ in plan, $D_f = 2$ m; vertical gross allowable load, $Q_{all} = 3330$ kN, $\gamma = 16.5$ kN/m^3; $\phi' = 30°$; $c' = 0$; and FS = 4. Determine the size of the foundation. Use Eq. (3.19).

3.8 An eccentrically loaded foundation is shown in Figure P3.8. Use FS of 4 and determine the maximum allowable load that the foundation can carry. Use Meyerhof's effective area method.

3.9 Repeat Problem 3.8 using Prakash and Saran's method.

3.10 For an eccentrically loaded continuous foundation on sand, given $B = 1.8$ m, $D_f = 0.9$ m, $e/B = 0.12$ (one-way eccentricity), $\gamma = 16$ kN/m^3, and $\phi' = 35°$. Using the reduction factor method, estimate the ultimate load per unit length of the foundation.

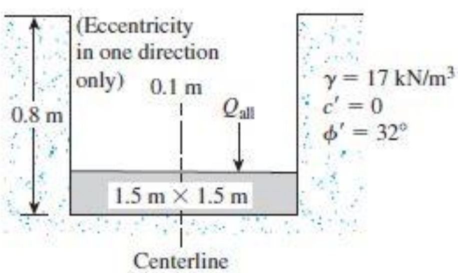


Figure P3.8