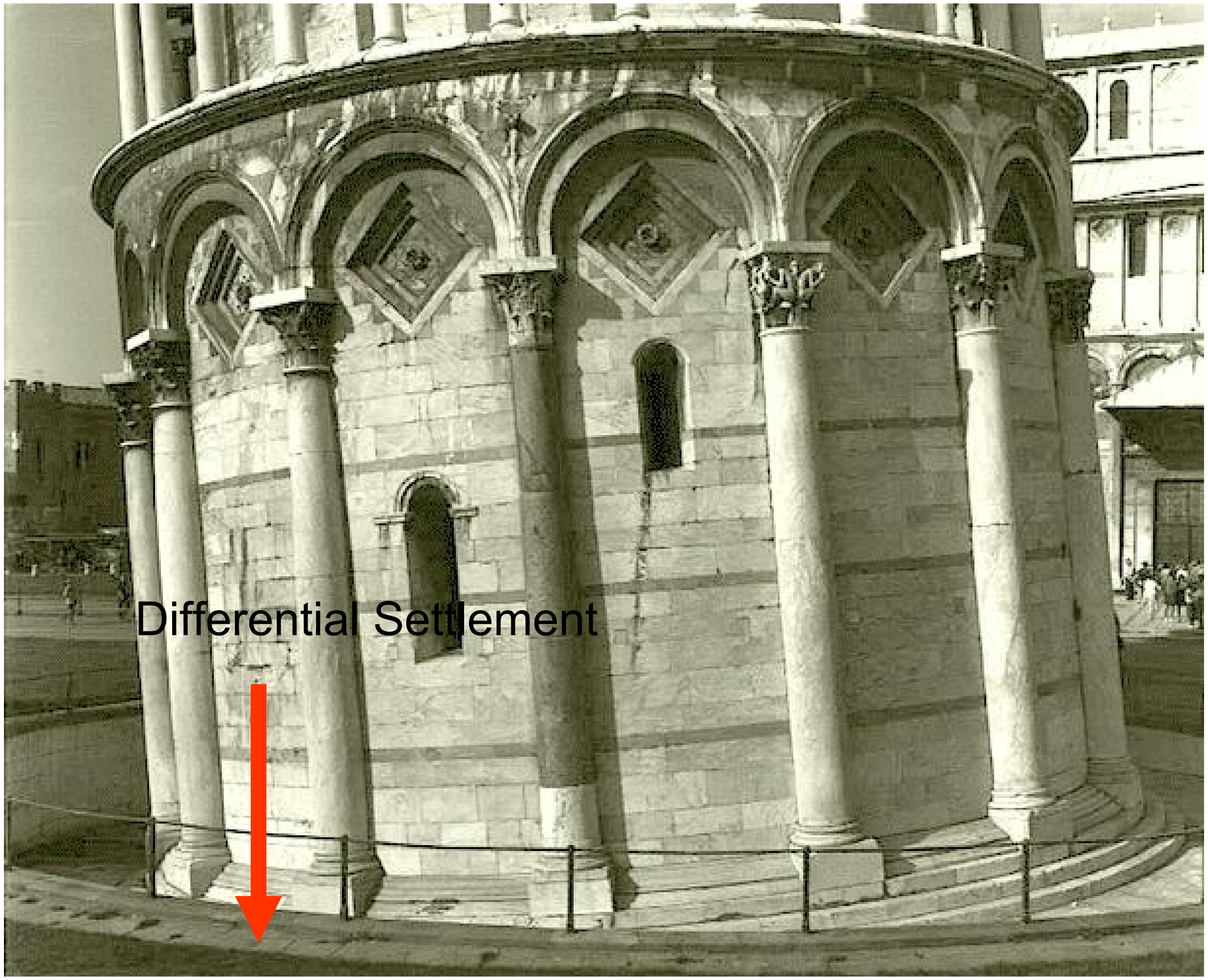
Foundation Design



Structural Foundations are grouped into two main groups.

1- Shallow Foundation
- Spread Footings
- Continuous Footings
- Combined Footings
- Mat Foundation

2- Deep Foundation
- Driven Piles
- Drilled Shaft
- Auger Cat Piles

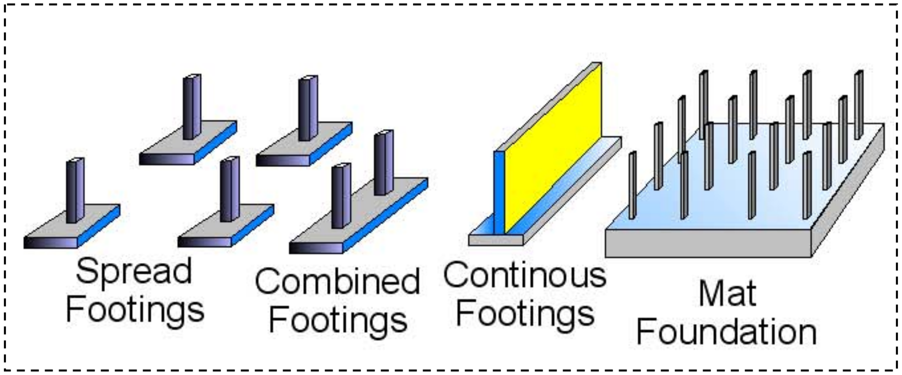
3- Compensated or floating foundations

Various foundation types:

(a) shallow foundations;

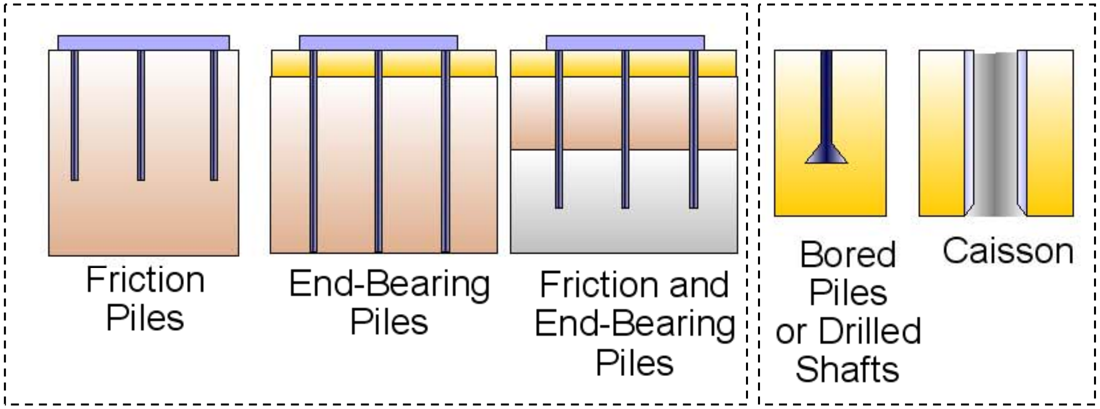
(b) deep foundations;

(c) compensated or floating foundations.

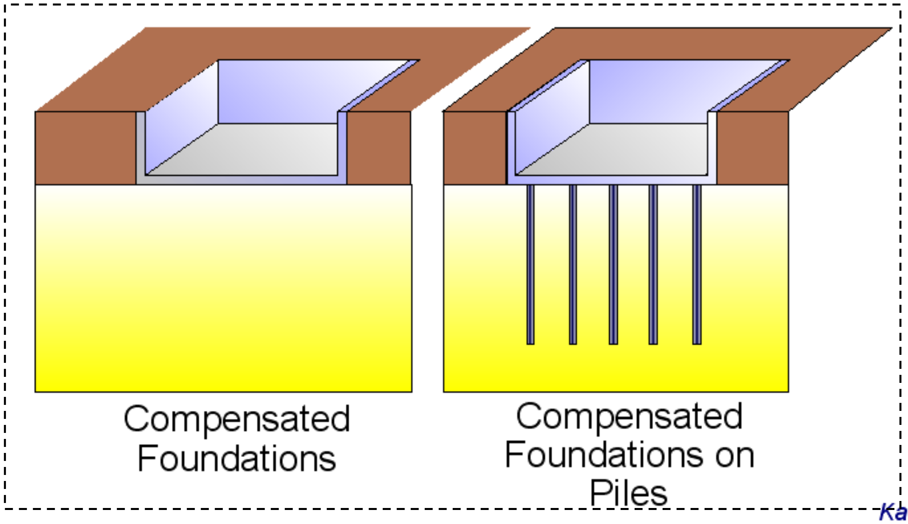


Shallow Foundation

Piles
&
Drilled Shafts

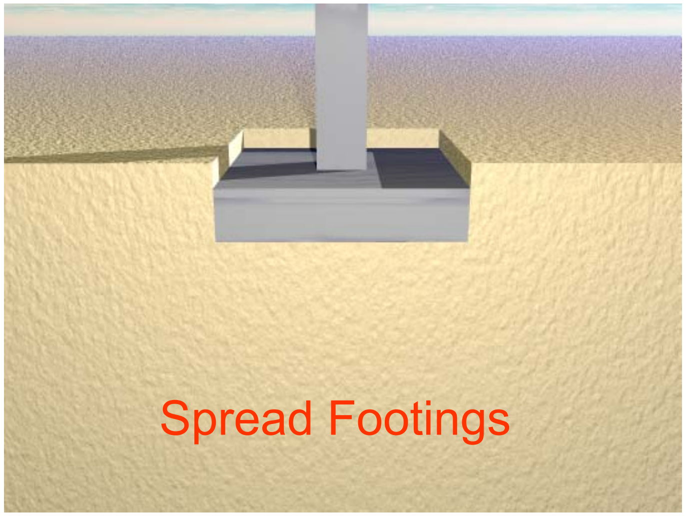


Compensated Foundation

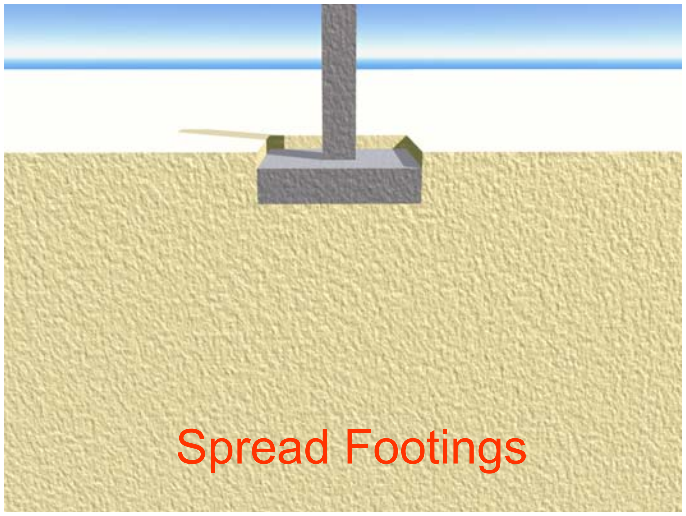


Kamal Tawfiq, Ph.D., P.E. 2002

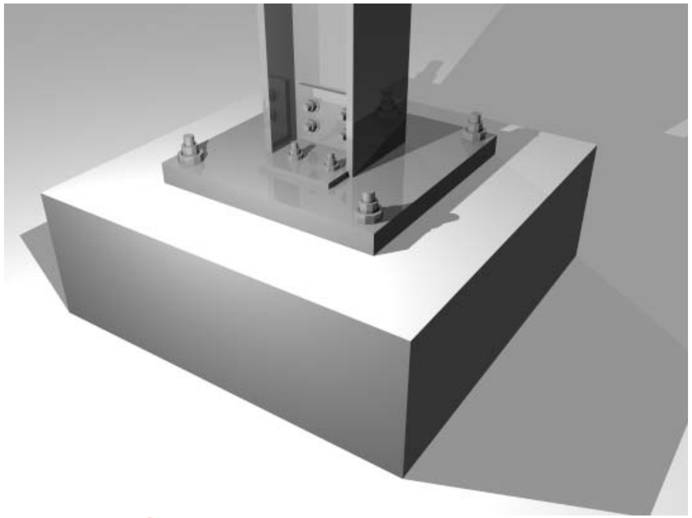
Shallow Foundation



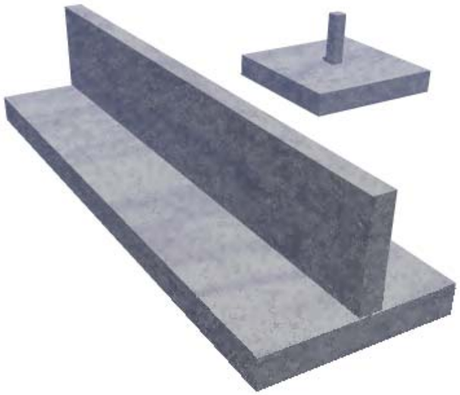
Spread Footings



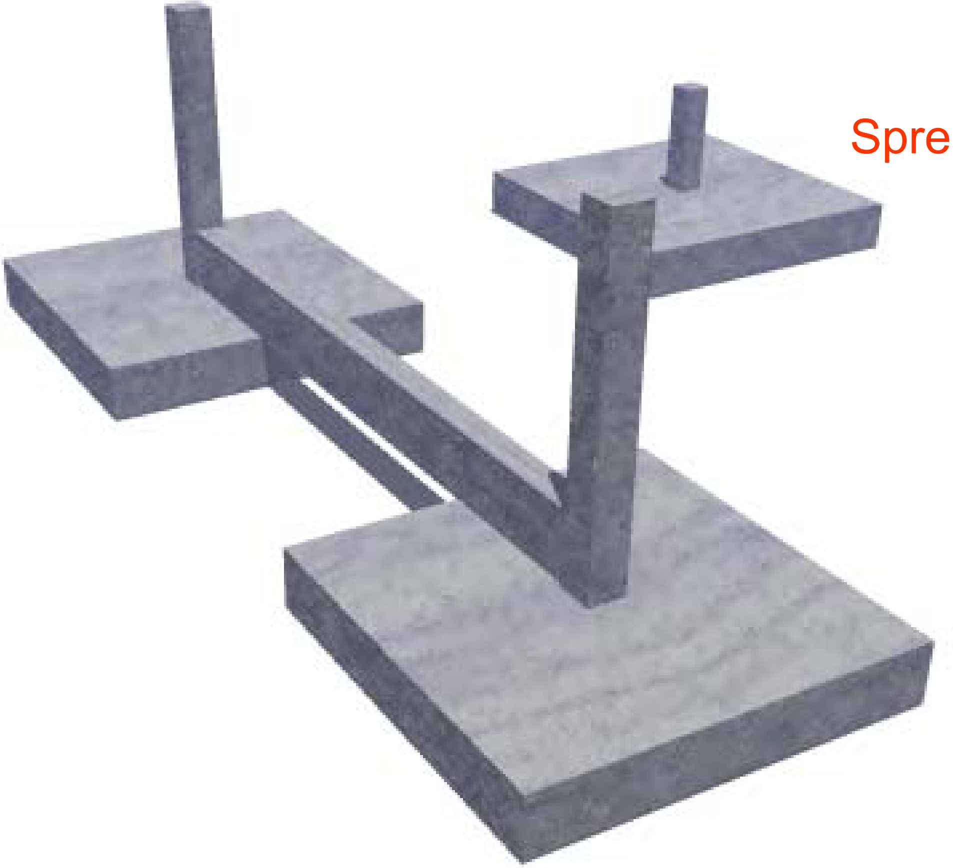
Spread Footings

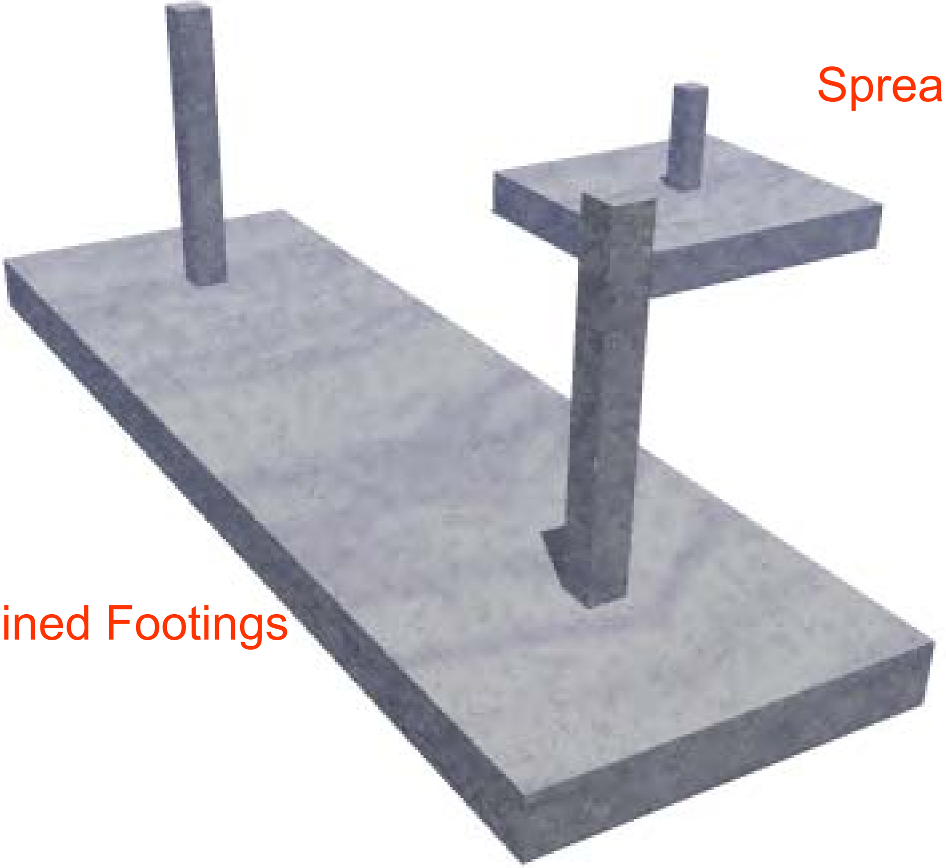


Spread Footings



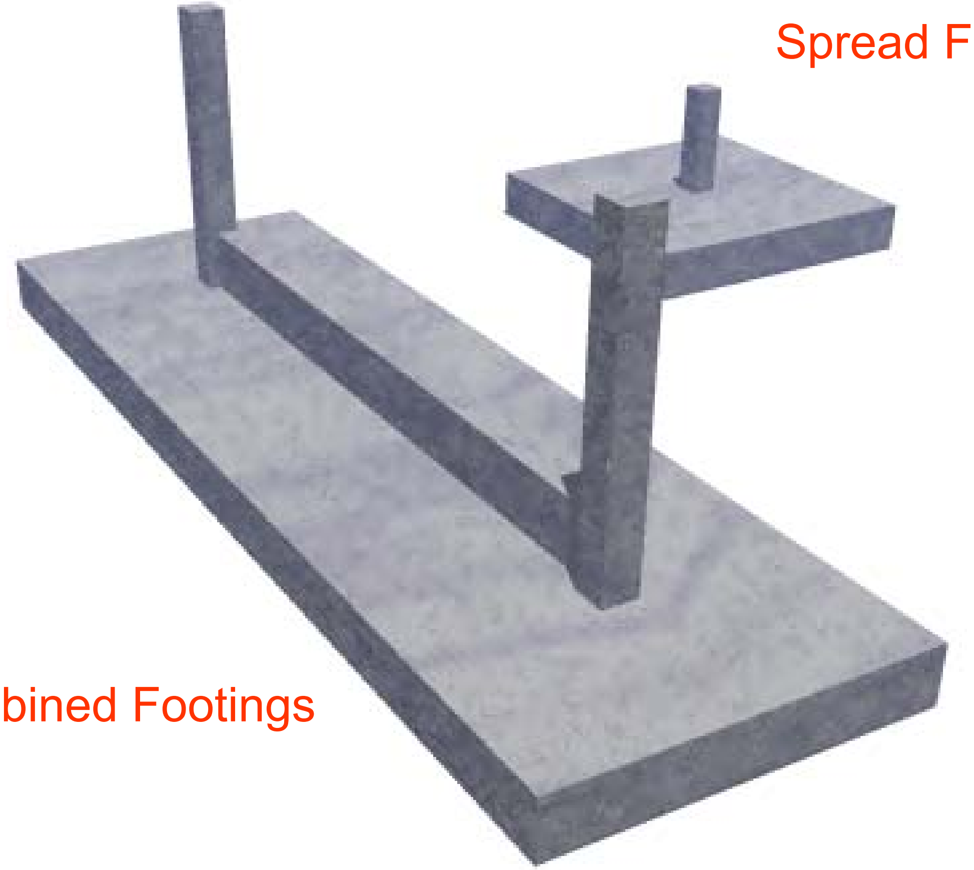
Continuous Footings


Spread Footings
Combined Footings



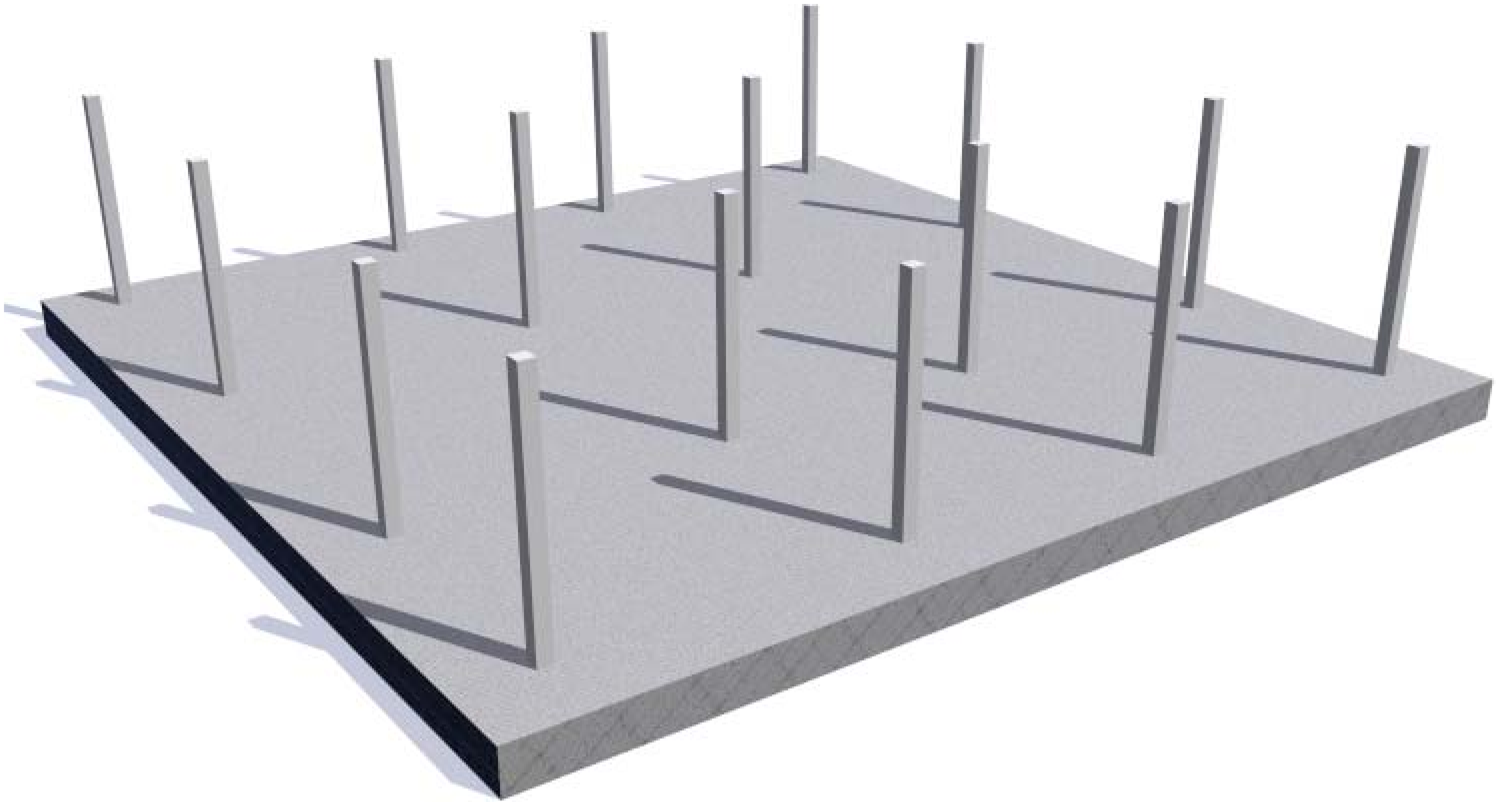
Spread Footings

Combined Footings

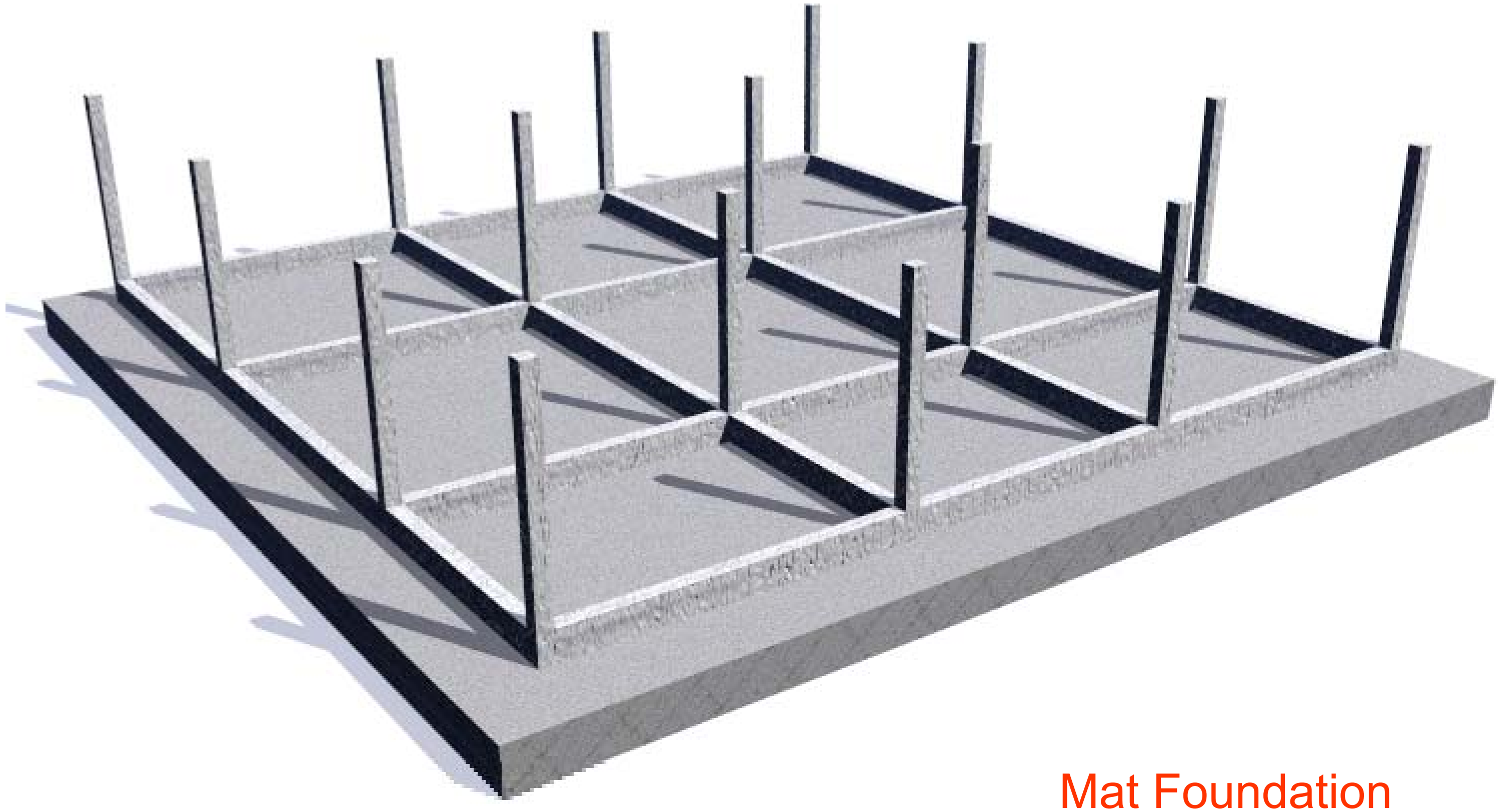


Spread Footings

Combined Footings

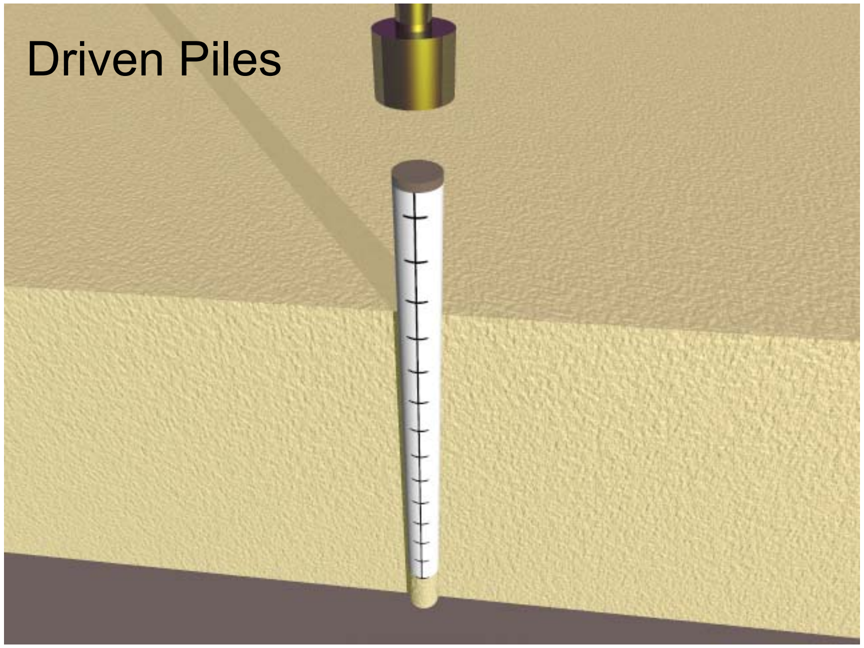


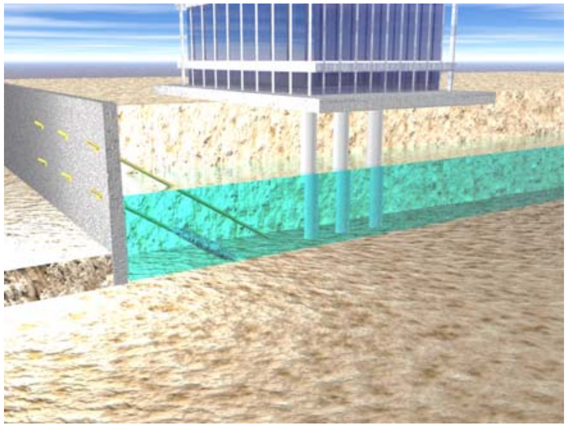
Mat Foundation

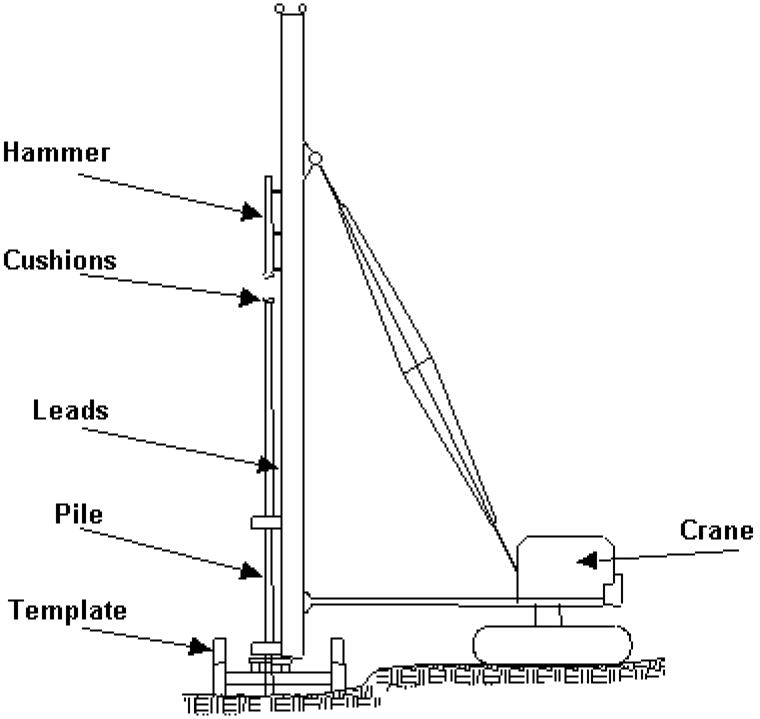


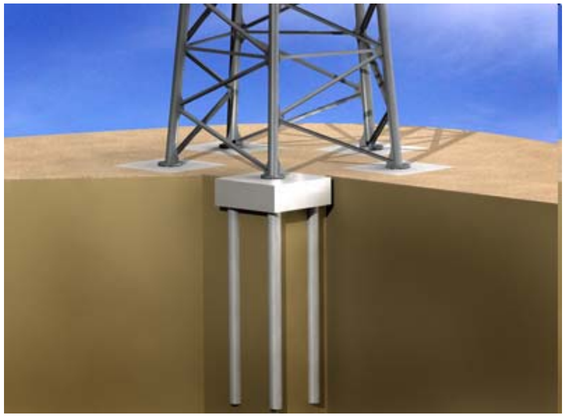
Mat Foundation

Deep Foundation


Driven Piles







Drilled Shafts

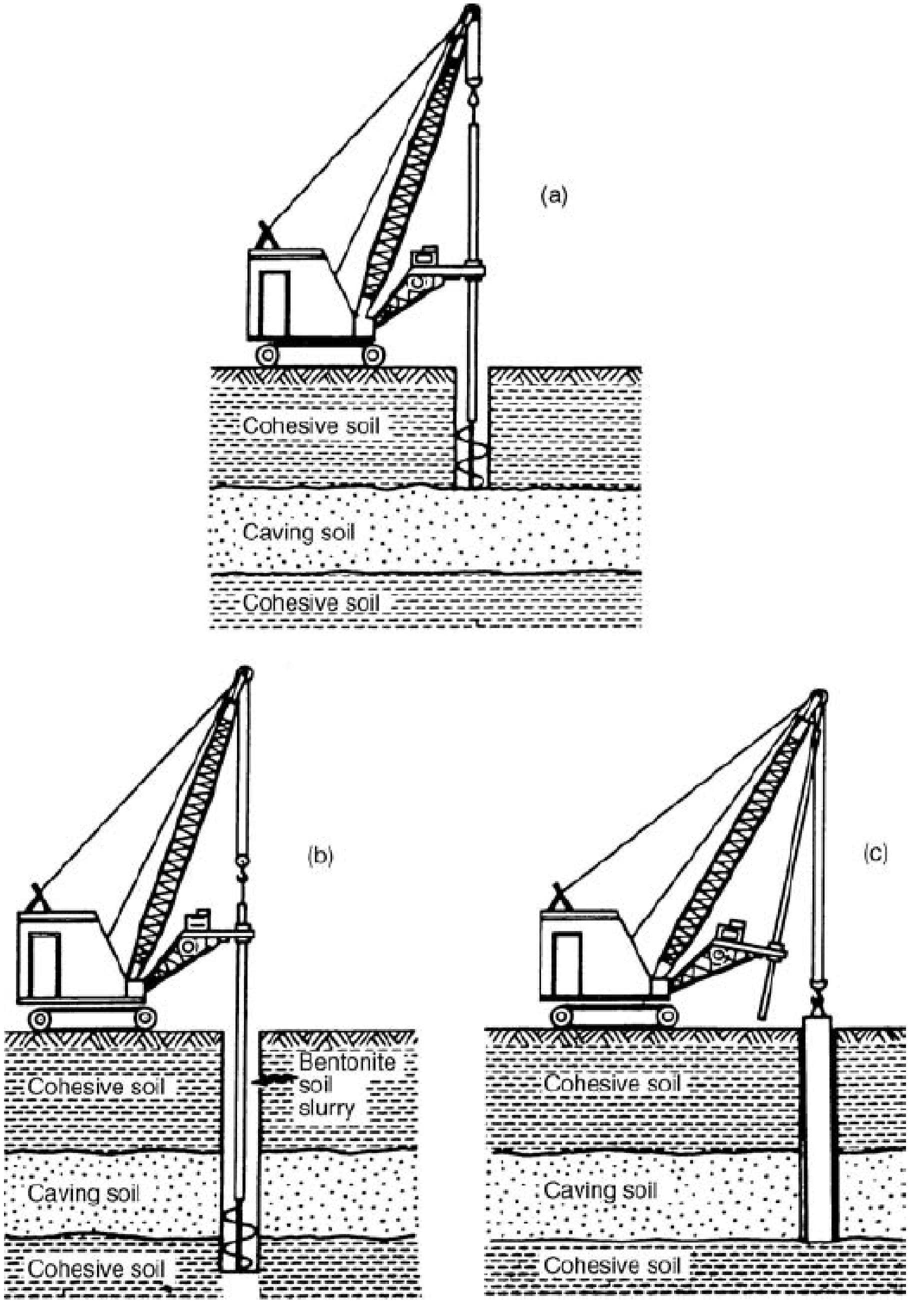


FIGURE 5.7 Typical steps in the construction of a drilled pier. (*a*) Dry augering through self-supporting cohesive soil; (*b*) augering through water-bearing cohesionless soil with aid of slurry; (*c*) setting the casing; (*d*) dry augering into cohesive soil after sealing; (*e*) forming a bell. (*After O'Neill and Reese 1970; reproduced from Peck, Hanson, and Thornburn 1974.*)

Auger Cast Pile

How Auger-Cast Piles are Installed

First the auger drills deep into the ground.

Then as the auger is brought back up, concrete flows out from its tip, filling the hole with concrete. To stabilize the top of the hole, a tube is placed in it and soil packed around it.

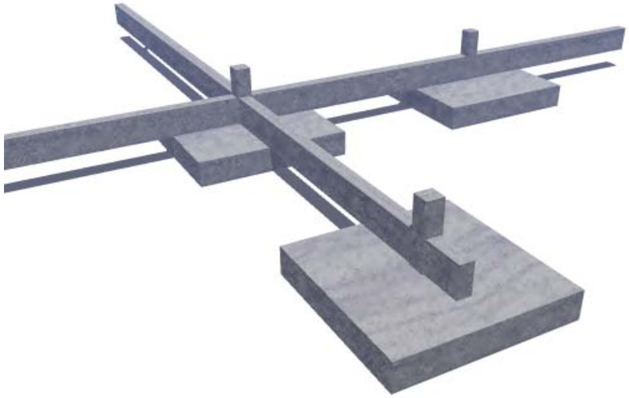
One last push to get the steel all the way in.

A steel rebar cage is lowered into the hole. The steel is guided all the way down the hole.

Analysis and Design of Shallow Foundation

I- Bearing Capacity

II- Settlement

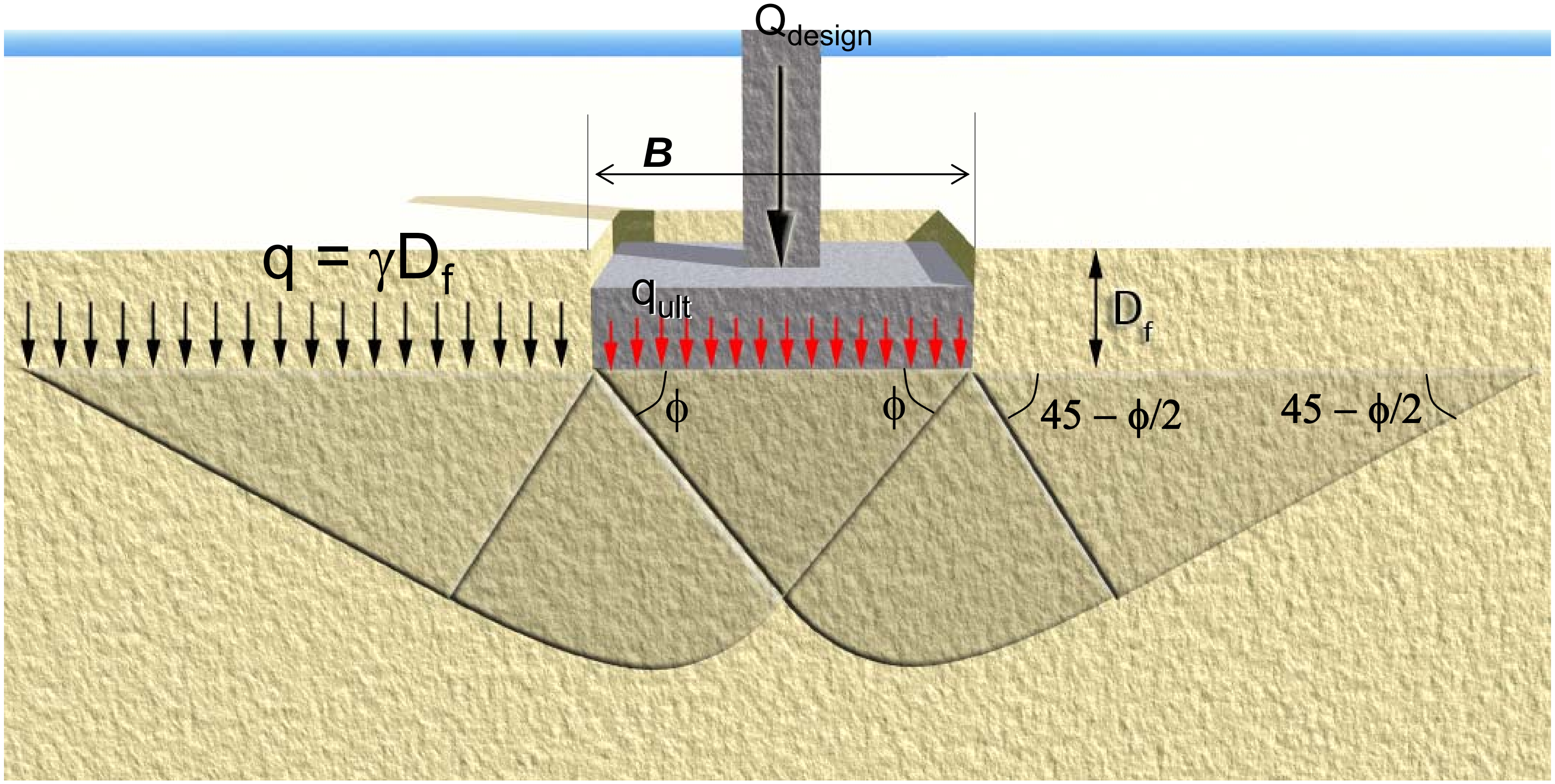


I- ULTIMATE BEARING CAPACITY THEORIES:

- **TERZAGHI'S BEARING CAPACITY THEORY**
- **GENERAL BEARING CAPACITY EQUATION**

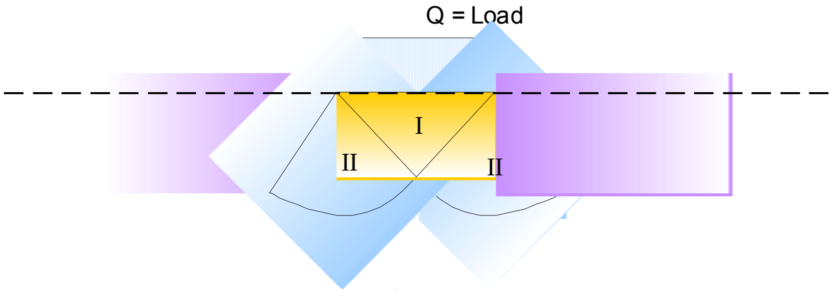
I- Bearing Capacity

TERZAGHI'S BEARING CAPACITY THEORY

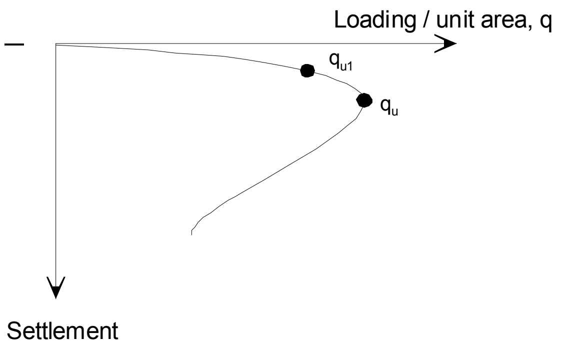


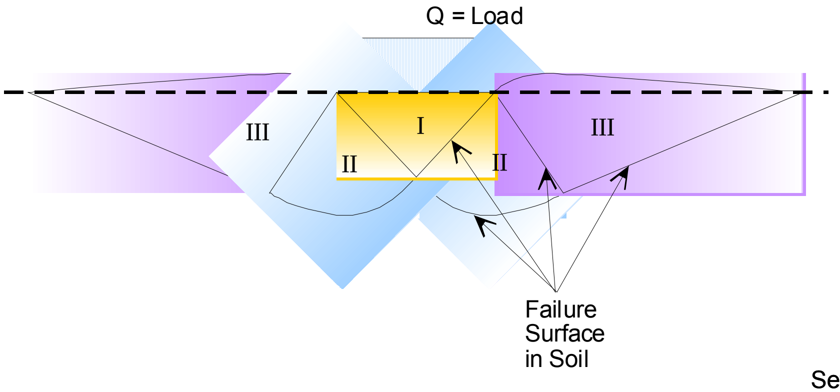
I- Bearing Capacity

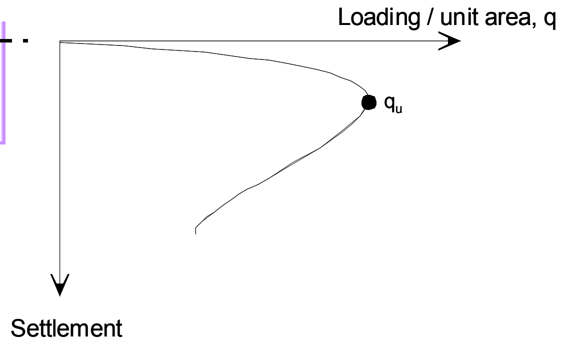
TERZAGHI'S BEARING CAPACITY THEORY



Local Shear Failure







General Shear Failure

By: Kamal Tawfiq, Ph.D.,P.E. 2001

I- Bearing Capacity

TERZAGHI’S BEARING CAPACITY THEORY

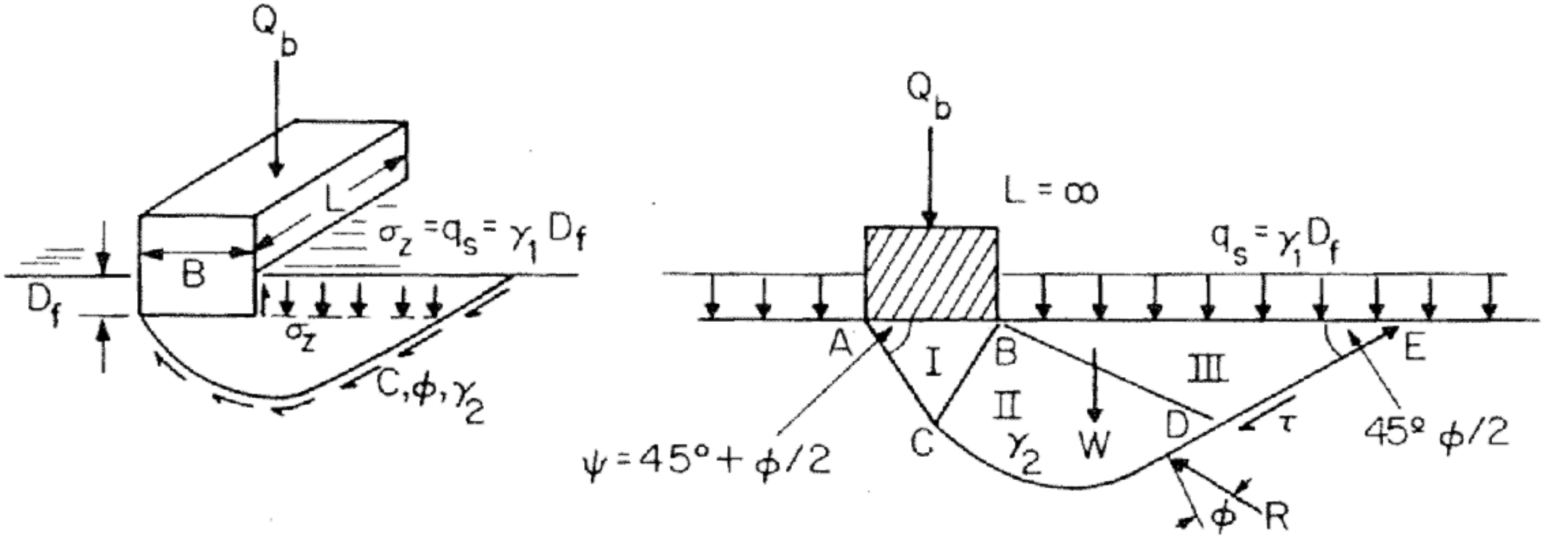
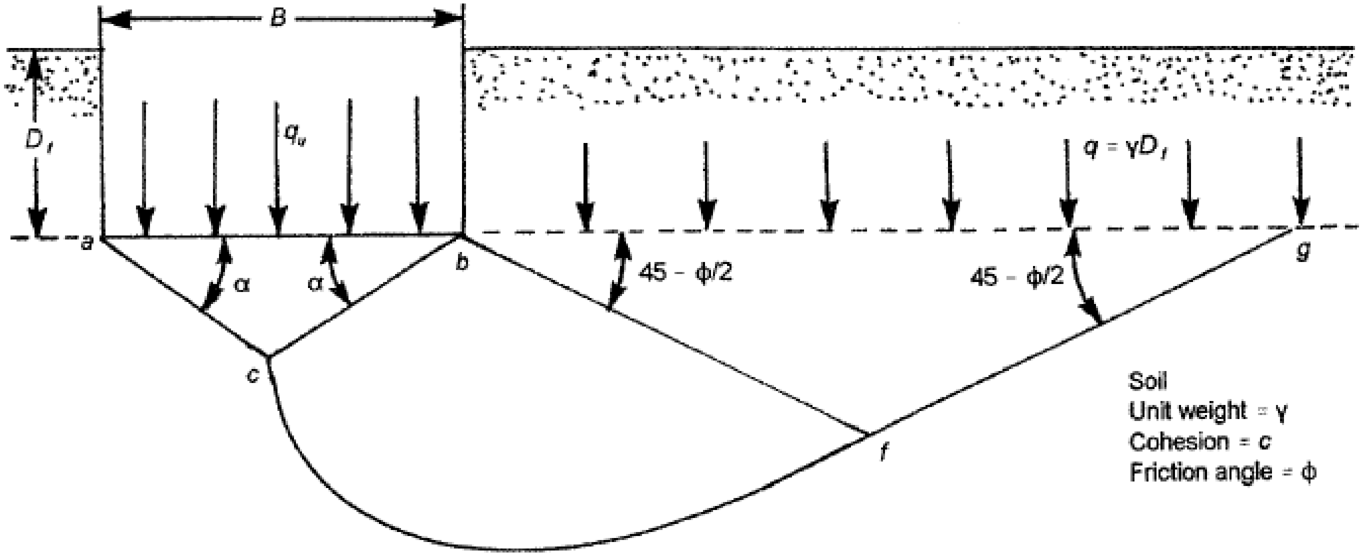


FIG. 6.28 The problem of the bearing capacity of shallow foundations failing in general shear with parameters *c* and ϕ. Boundaries are simplified. I = active Rankine zone; II = Prandtl zone; III = passive Rankine zone.

I- ULTIMATE BEARING CAPACITY THEORIES:

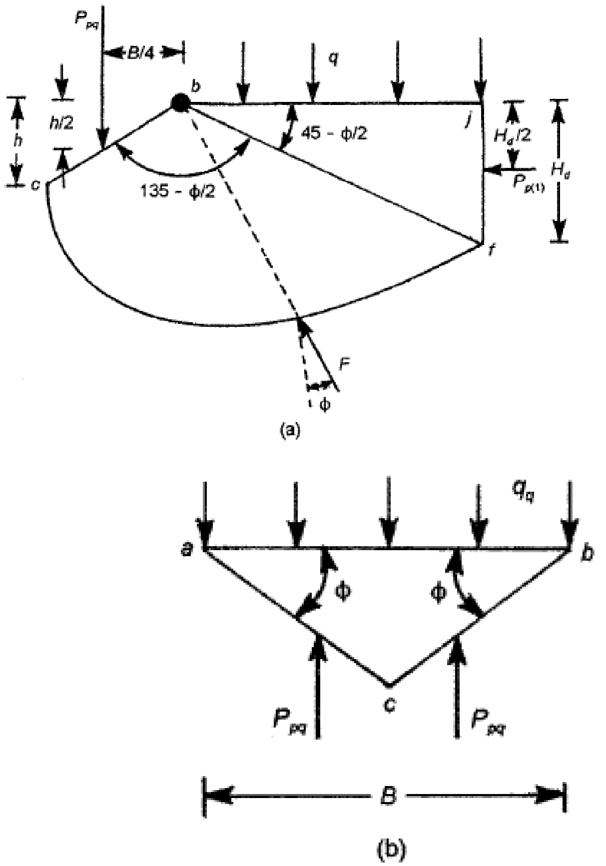
1- TERZAGHI'S BEARING CAPACITY THEORY



Failure surface in soil at ultimate load for a continuous rough rigid foundation as assumed by Terzaghi

I- Bearing Capacity

TERZAGHI'S BEARING CAPACITY THEORY



(a)

(b)

FIGURE 2.3 Determination of P_{pq} ($\phi \neq 0$, $\gamma = 0$, $q \neq 0$, $c = 0$)

$$q_u = q_c + q_q + q_\gamma$$

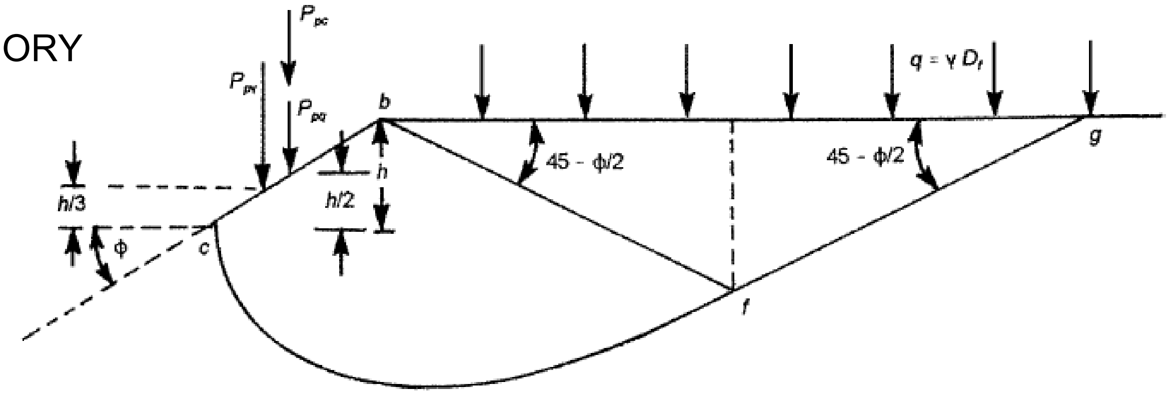
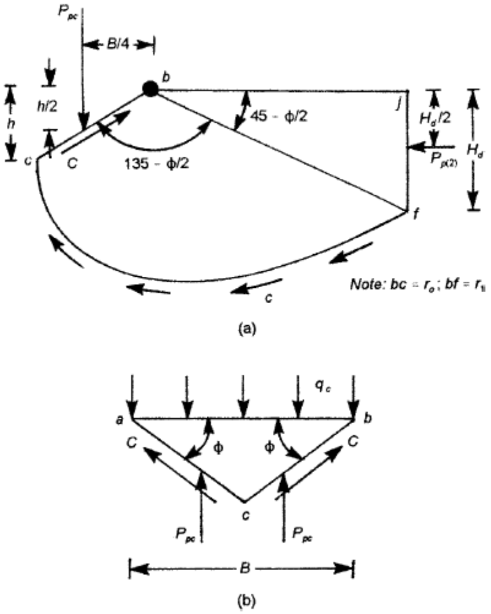


FIGURE 2.2 Passive force on the face *bc* of wedge *abc* shown in Fig. 2.1



(a)

(b)

FIGURE 2.4 Determination of P_{pc} ($\phi \neq 0$, $\gamma = 0$, $q = 0$, $c \neq 0$)

Ultimate Bearing Capacity

$$q_u = q_c + q_q + q_\gamma$$

$$q_u = cN_c + qN_q + \frac{1}{2}\gamma BN_\gamma$$

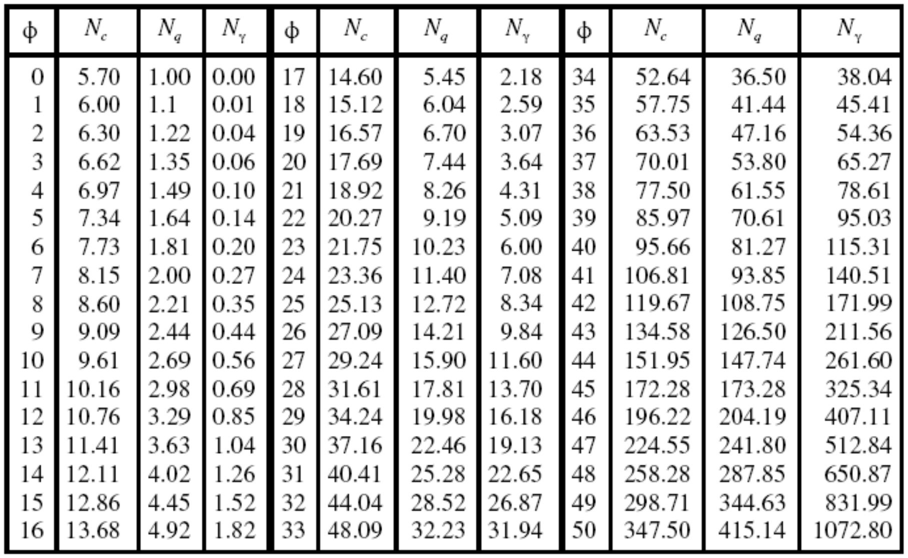
where N_c, N_q, and N_γ = bearing capacity factors, and

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

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

$$N_\gamma = \frac{1}{2}K_{p\gamma}\tan^2\phi - \frac{\tan\phi}{2}$$

TABLE 2.1 Terzaghi's Bearing Capacity Factors—Eqs. (2.32), (2.33), and (2.34)



ϕ	N_c	N_q	N_γ	ϕ	N_c	N_q	N_γ	ϕ	N_c	N_q	N_γ
0	5.70	1.00	0.00	17	14.60	5.45	2.18	34	52.64	36.50	38.04
1	6.00	1.1	0.01	18	15.12	6.04	2.59	35	57.75	41.44	45.41
2	6.30	1.22	0.04	19	16.57	6.70	3.07	36	63.53	47.16	54.36
3	6.62	1.35	0.06	20	17.69	7.44	3.64	37	70.01	53.80	65.27
4	6.97	1.49	0.10	21	18.92	8.26	4.31	38	77.50	61.55	78.61
5	7.34	1.64	0.14	22	20.27	9.19	5.09	39	85.97	70.61	95.03
6	7.73	1.81	0.20	23	21.75	10.23	6.00	40	95.66	81.27	115.31
7	8.15	2.00	0.27	24	23.36	11.40	7.08	41	106.81	93.85	140.51
8	8.60	2.21	0.35	25	25.13	12.72	8.34	42	119.67	108.75	171.99
9	9.09	2.44	0.44	26	27.09	14.21	9.84	43	134.58	126.50	211.56
10	9.61	2.69	0.56	27	29.24	15.90	11.60	44	151.95	147.74	261.60
11	10.16	2.98	0.69	28	31.61	17.81	13.70	45	172.28	173.28	325.34
12	10.76	3.29	0.85	29	34.24	19.98	16.18	46	196.22	204.19	407.11
13	11.41	3.63	1.04	30	37.16	22.46	19.13	47	224.55	241.80	512.84
14	12.11	4.02	1.26	31	40.41	25.28	22.65	48	258.28	287.85	650.87
15	12.86	4.45	1.52	32	44.04	28.52	26.87	49	298.71	344.63	831.99
16	13.68	4.92	1.82	33	48.09	32.23	31.94	50	347.50	415.14	1072.80

TABLE 2.1 Terzaghi's Bearing Capacity Factors—Eqs. (2.32), (2.33), and (2.34)

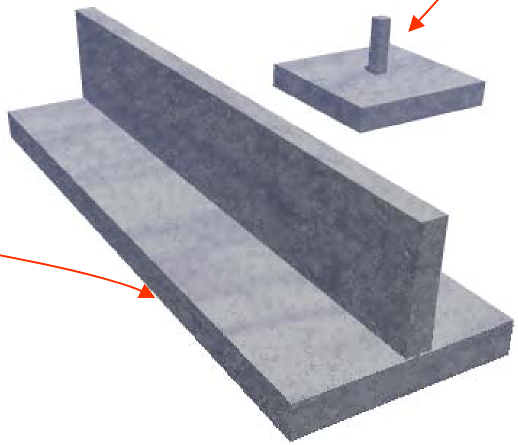
ϕ	N_c	N_q	N_γ	ϕ	N_c	N_q	N_γ	ϕ	N_c	N_q	N_γ
0	5.70	1.00	0.00	17	14.60	5.45	2.18	34	52.64	36.50	38.04
1	6.00	1.1	0.01	18	15.12	6.04	2.59	35	57.75	41.44	45.41
2	6.30	1.22	0.04	19	16.57	6.70	3.07	36	63.53	47.16	54.36
3	6.62	1.35	0.06	20	17.69	7.44	3.64	37	70.01	53.80	65.27
4	6.97	1.49	0.10	21	18.92	8.26	4.31	38	77.50	61.55	78.61
5	7.34	1.64	0.14	22	20.27	9.19	5.09	39	85.97	70.61	95.03
6	7.73	1.81	0.20	23	21.75	10.23	6.00	40	95.66	81.27	115.31
7	8.15	2.00	0.27	24	23.36	11.40	7.08	41	106.81	93.85	140.51
8	8.60	2.21	0.35	25	25.13	12.72	8.34	42	119.67	108.75	171.99
9	9.09	2.44	0.44	26	27.09	14.21	9.84	43	134.58	126.50	211.56
10	9.61	2.69	0.56	27	29.24	15.90	11.60	44	151.95	147.74	261.60
11	10.16	2.98	0.69	28	31.61	17.81	13.70	45	172.28	173.28	325.34
12	10.76	3.29	0.85	29	34.24	19.98	16.18	46	196.22	204.19	407.11
13	11.41	3.63	1.04	30	37.16	22.46	19.13	47	224.55	241.80	512.84
14	12.11	4.02	1.26	31	40.41	25.28	22.65	48	258.28	287.85	650.87
15	12.86	4.45	1.52	32	44.04	28.52	26.87	49	298.71	344.63	831.99
16	13.68	4.92	1.82	33	48.09	32.23	31.94	50	347.50	415.14	1072.80

1- TERZAGHI'S BEARING CAPACITY THEORY

$$q_u = cN_c + qN_q + \frac{1}{2}\gamma B N_\gamma$$

$$q_u = 1.3cN_c + qN_q + 0.4\gamma B N_\gamma \quad \text{(square foundation; plan } B \times B\text{)}$$

$$q_u = 1.3cN_c + qN_q + 0.3\gamma B N_\gamma \quad \text{(circular foundation; plan } B \times B\text{)}$$



EFFECT OF WATER TABLE

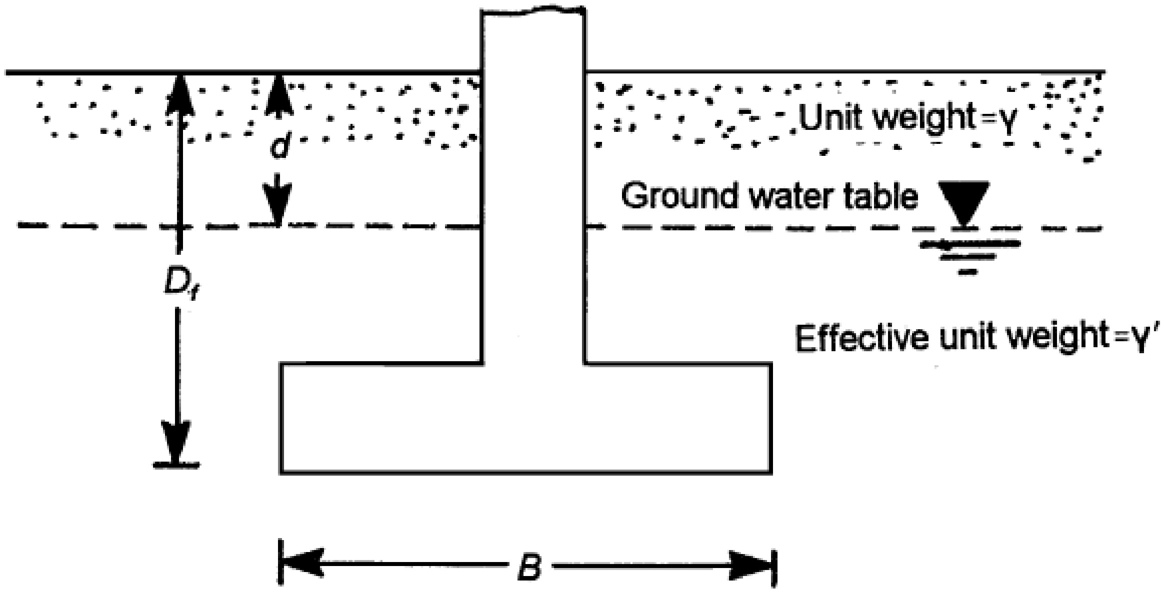


FIGURE 2.22 Effect of ground water table on ultimate bearing capacity

MEYERHOF'S BEARING CAPACITY THEORY

$$q_u = cN_c + qN_q + \frac{1}{2}\gamma B N_\gamma$$

where N_c', N_q', and N_γ' = bearing capacity factors
B = width of the foundation

$$N_q = e^{\pi \tan\phi}\left(\frac{1+\sin\phi}{1-\sin\phi}\right)$$

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

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

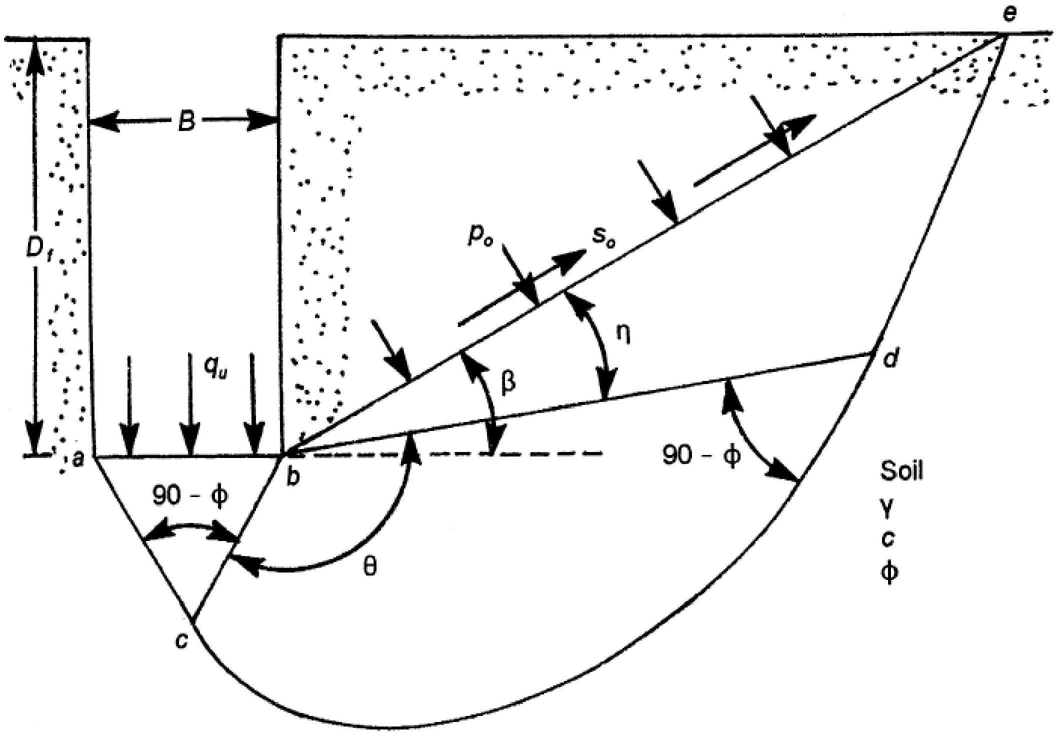


FIGURE 2.7 Slip line fields for a rough continuous foundation

TABLE 2.3 Variation of Meyerhof's Bearing Capacity Factors N_c, N_q, and N_γ [Eqs. (2.66), (2.67), and (2.72)]

ϕ	N_c	N_q	N_γ	ϕ	N_c	N_q	N_γ	ϕ	N_c	N_q	N_γ
0	5.14	1 00	0.00	17	12.34	4.77	1.66	34	42.16	29.44	31.15
1	5.38	1.09	0.002	18	13.10	5.26	2.00	35	46.12	33.30	37.15
2	5.63	1.20	0.01	19	13.93	5.80	2.40	36	50.59	37.75	44.43
3	5.90	1.31	0.02	20	14.83	6.40	2.87	37	55.63	42.92	53.27
4	6.19	1.43	0.04	21	15.82	7.07	3.42	38	61.35	48.93	64.07
5	6.49	1.57	0.07	22	16.88	7.82	4.07	39	67.87	55.96	77.33
6	6.81	1.72	0.11	23	18.05	8.66	4.82	40	75.31	64.20	93.69
7	7.16	1.88	0.15	24	19.32	9.60	5.72	41	83.86	73.90	113.99
8	7.53	2.06	0.21	25	20.72	10.66	6.77	42	93.71	85.38	139.32
9	7.92	2.25	0.28	26	22.25	11.85	8.00	43	105.11	99.02	171.14
10	8.35	2.47	0.37	27	23.94	13.20	9.46	44	118.37	115.31	211.41
11	8.80	2.71	0.47	28	25.80	14.72	11.19	45	133.88	134.88	262.74
12	9.28	2.97	0.60	29	27.86	16.44	13.24	46	152.10	158.51	328.73
13	9.81	3.26	0.74	30	30.14	18.40	15.67	47	173.64	187.21	414.32
14	10.37	3.59	0.92	31	32.67	20.63	18.56	48	199.26	222.31	526.44
15	10.98	3.94	1.13	32	35.49	23.18	22.02	49	229.93	265.51	674.91
16	11.63	4.34	1.38	33	38.64	26.09	26.17	50	266.89	319.07	873.84

2- GENERAL BEARING CAPACITY EQUATION

$$q_u = cN_c \lambda_{cs} \lambda_{cd} + qN_q \lambda_{qs} \lambda_{qd} + \frac{1}{2} \gamma B N_\gamma \lambda_{\gamma s} \lambda_{\gamma d}$$

where $\lambda_{cs}, \lambda_{qs}, \lambda_{\gamma s}$ = shape factors

$\lambda_{cd}, \lambda_{qd}, \lambda_{\gamma d}$ = depth factors

TABLE 2.5 Summary of Shape and Depth Factors

Factor	Relationship	Reference
Shape	For $\phi = 0°$: $\lambda_{cs} = 1 + 0.2\left(\frac{B}{L}\right)$ $\lambda_{qs} = 1$ $\lambda_{\gamma s} = 1$ For $\phi \geq 10°$: $\lambda_{cs} = 1 + 0.2\left(\frac{B}{L}\right)\tan^2\left(45 + \frac{\phi}{2}\right)$ $\lambda_{qs} = \lambda_{\gamma s} = 1 + 0.1\left(\frac{B}{L}\right)\tan^2\left(45 + \frac{\phi}{2}\right)$	Meyerhof [8]
	$\lambda_{cs} = 1 + \left(\frac{N_q}{N_c}\right)\left(\frac{B}{L}\right)$ [*Note:* Use Eq. (2.67) for N_c and Eq. (2.66) for N_q as given in Table 2.3] $\lambda_{qs} = 1 + \left(\frac{B}{L}\right)\tan\phi$ $\lambda_{\gamma s} = 1 - 0.4\left(\frac{B}{L}\right)$	DeBeer [19]
Depth	For $\phi = 0°$: $\lambda_{cd} = 1 + 0.2\left(\frac{D_f}{B}\right)$ $\lambda_{qd} = \lambda_{\gamma d} = 1$ For $\phi \geq 10°$: $\lambda_{cd} = 1 + 0.2\left(\frac{D_f}{B}\right)\tan\left(45 + \frac{\phi}{2}\right)$ $\lambda_{qd} = \lambda_{\gamma d} = 1 + 0.1\left(\frac{D_f}{B}\right)\tan\left(45 + \frac{\phi}{2}\right)$	Meyerhof [8]
	For $D_f/B \leq 1$: $\lambda_{cd} = 1 + 0.4\left(\frac{D_f}{B}\right)$ $\lambda_{qd} = 1 + 2\tan\phi(1 - \sin\phi)^2\left(\frac{D_f}{B}\right)$ $\lambda_{\gamma d} = 1$ For $D_f/B > 1$: $\lambda_{cd} = 1 + 0.4\tan^{-1}\left(\frac{D_f}{B}\right)$ $\lambda_{qd} = 1 + 2\tan\phi(1 - \sin\phi)^2\tan^{-1}\left(\frac{D_f}{B}\right)$ $\lambda_{\gamma d} = 1$ $\left[\text{Note: } \tan^{-1}\left(\frac{D_f}{B}\right) \text{is in radians}\right]$	Hansen [9]

ULTIMATE BEARING CAPACITY UNDER INCLINED AND ECCENTRIC LOADS

$$q_u = cN_c \lambda_{cs} \lambda_{cd} \lambda_{ci} + qN_q \lambda_{qs} \lambda_{qd} \lambda_{qi} + \frac{1}{2} \gamma B N_\gamma \lambda_{\gamma s} \lambda_{\gamma d} \lambda_{\gamma i}$$

where N_c, N_q, N_γ = bearing capacity factors

$\lambda_{cs}, \lambda_{qs}, \lambda_{\gamma s}$ = shape factors
$\lambda_{cd}, \lambda_{qd}, \lambda_{\gamma d}$ = depth factors
$\lambda_{ci}, \lambda_{qi}, \lambda_{\gamma i}$ = inclination factors

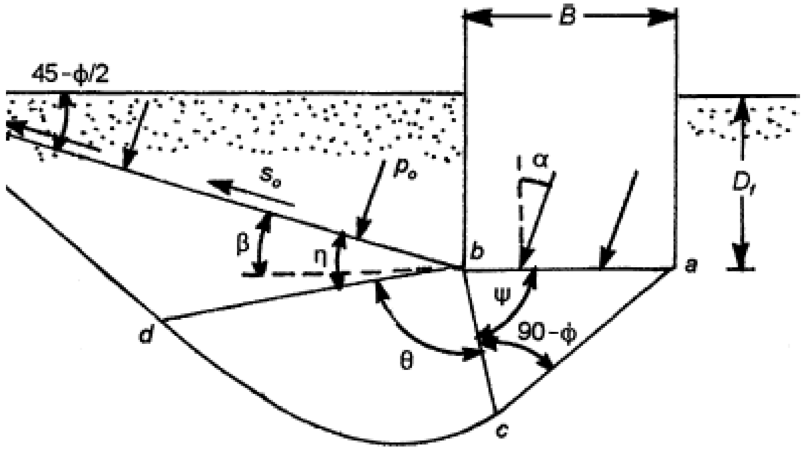


FIGURE 3.1 Plastic zones in soil near a foundation with inclined load

Meyerhof [4] provided the following inclination factor relationships

$$\lambda_{ci} = \lambda_{qi} = \left(1 - \frac{\alpha^\circ}{90^\circ}\right)^2 \tag{3.14}$$

$$\lambda_{\gamma i} = \left(1 - \frac{\alpha^\circ}{\phi^\circ}\right)^2 \tag{3.15}$$

Hansen [5] also suggested the following relationships for inclination factors

$$\lambda_{qi} = \left(1 - \frac{0.5Q_u \sin\alpha}{Q_u \cos\alpha + BLc\cot\phi}\right)^5 \tag{3.16}$$

$$\lambda_{ci} = \lambda_{qi} - \left(\frac{1-\lambda_{qi}}{\underset{\substack{\uparrow \\ \text{Table 2.3}}}{N_q} - 1}\right) \tag{3.17}$$

$$\lambda_{\gamma i} = \left(1 - \frac{0.7Q_u \sin\alpha}{Q_u \cos\alpha + BLc\cot\phi}\right)^5 \tag{3.18}$$

where, in Eqs. (3.14) to (3.18)

α = inclination of the load on the foundation with the vertical
Q_u = ultimate load on the foundation = $q_u BL$
B = width of the foundation
L = length of the foundation

Ground Factors:

$$F_{c\,g} = i_q - \frac{1-i_q}{5.14\tan\phi}$$

$$F_{q\,g} = F_{\gamma\,g} = (1-\tan\beta)^2$$

$$i_q = \left[1.0 - \frac{H}{V - A_f\, c\cot\phi}\right]^{1.5}$$

A_f = Area of the foundation
V = Vertical Load
H = Horizontal load
c = cohesion