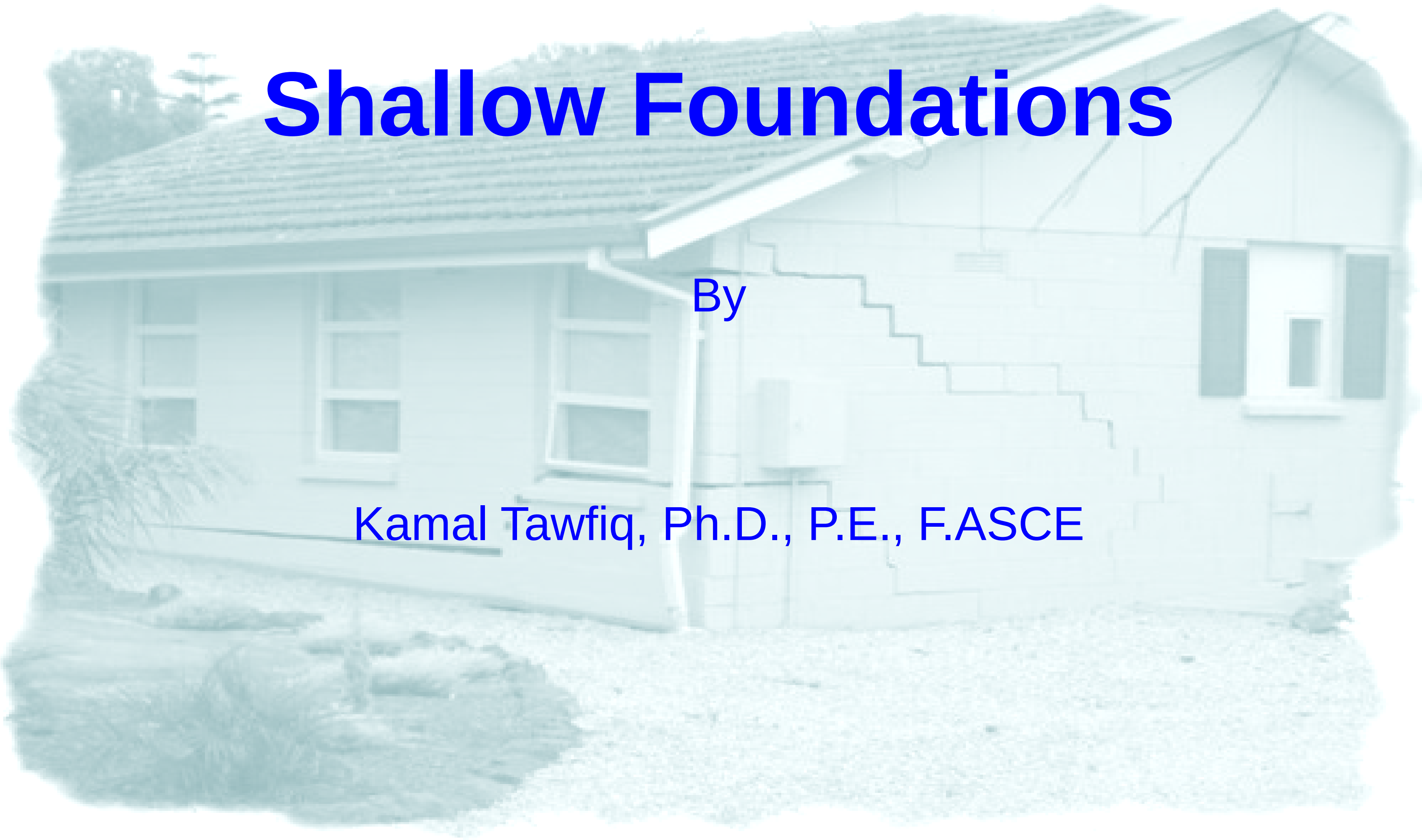
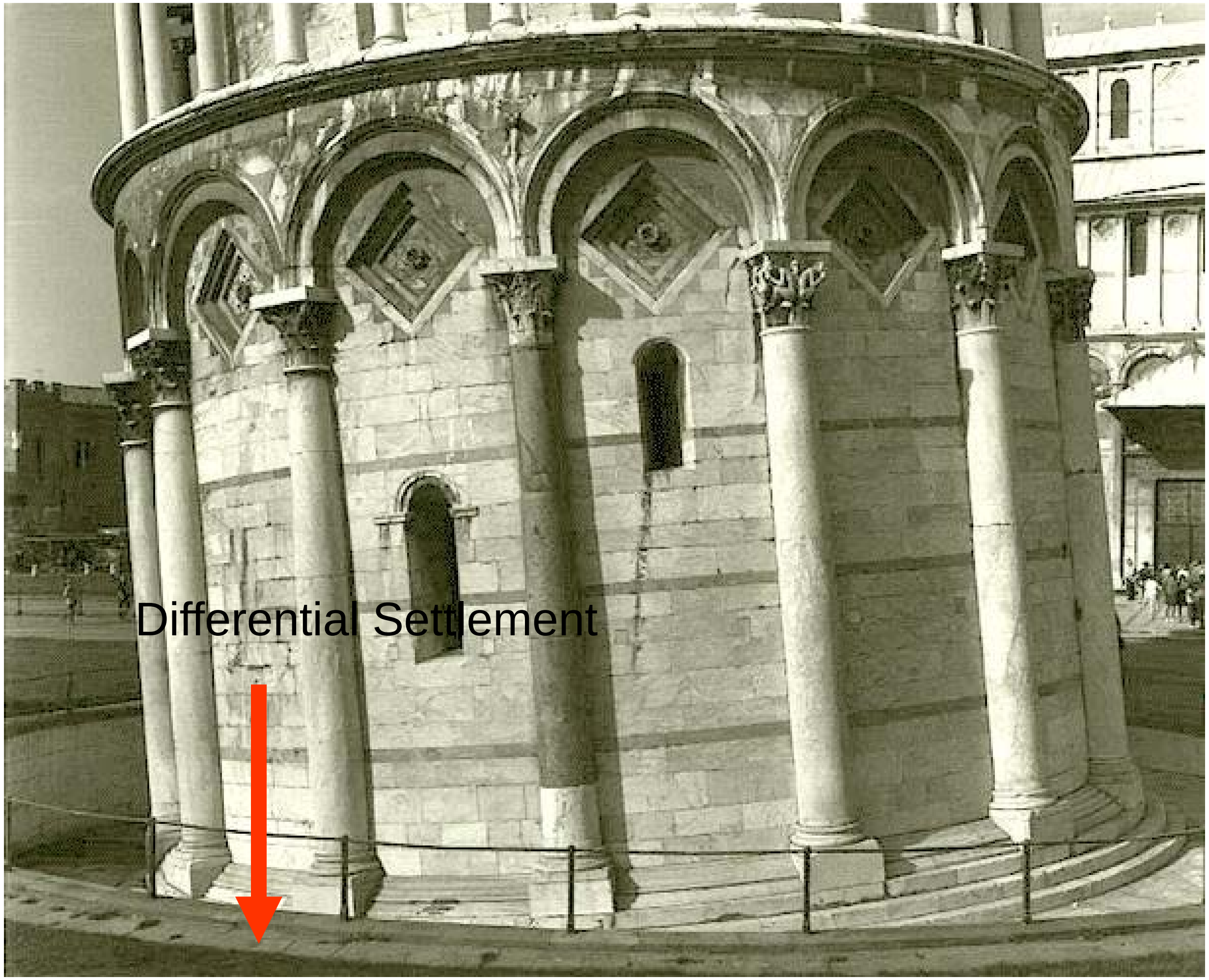


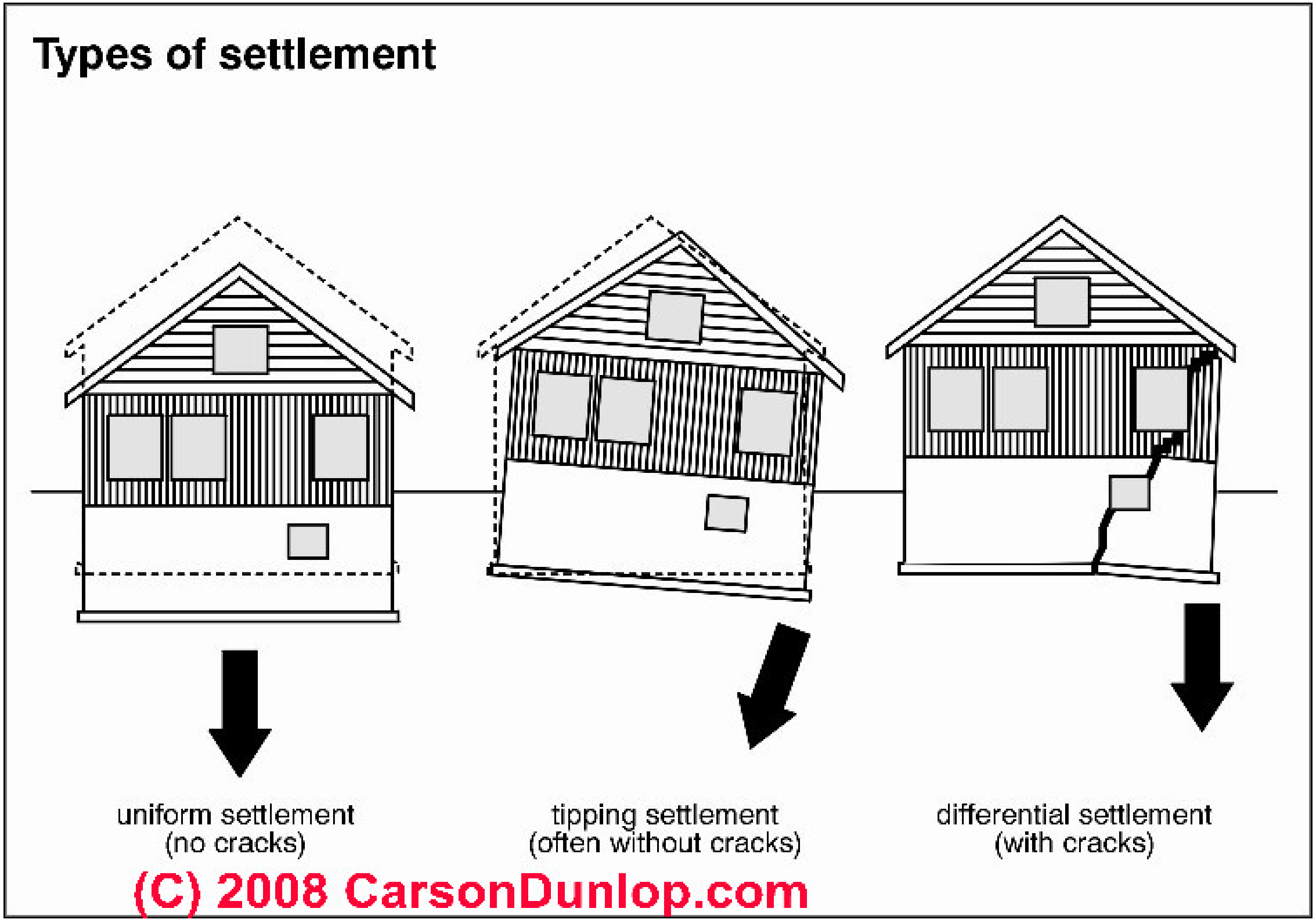
Shallow Foundations

By

Kamal Tawfiq, Ph.D., P.E., F.ASCE

3- Foundation Design

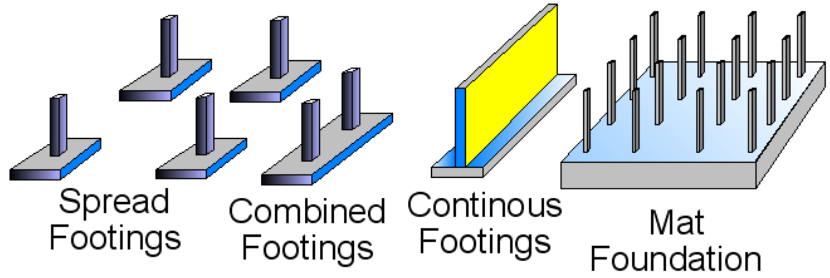



Types of settlement
uniform settlement
(no cracks)
tipping settlement
(often without cracks)
differential settlement
(with cracks)
(C) 2008 CarsonDunlop.com

Structural Foundations are grouped into two main groups.

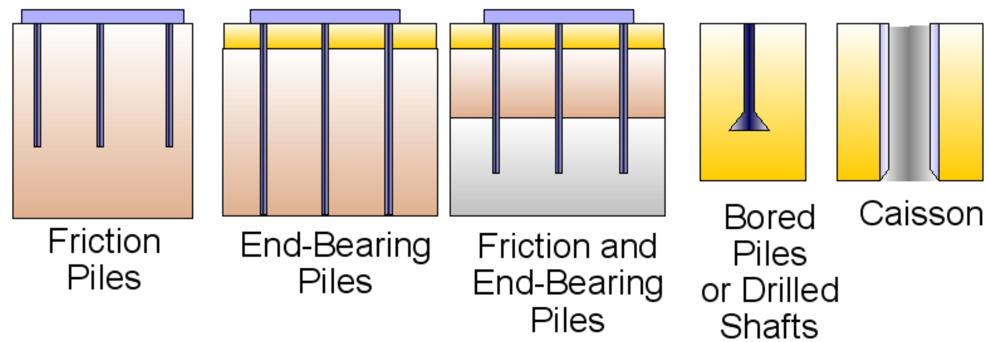
1- Shallow Foundation

- Spread Footings
- Continuous Footings
- Combined Footings
- Mat Foundation

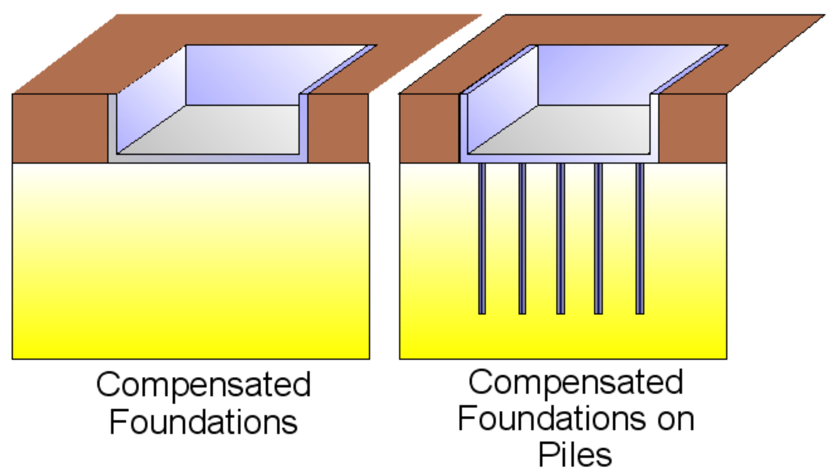


2- Deep Foundation

- Driven Piles
- Drilled Shaft
- Auger Cat Piles



3- Compensated or floating foundations

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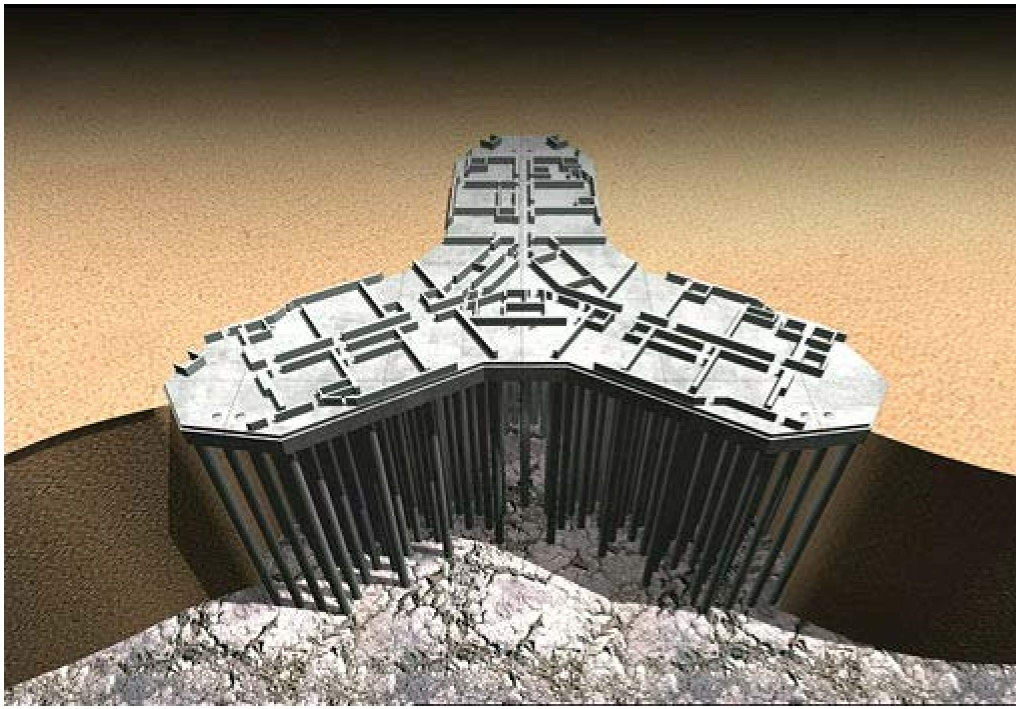
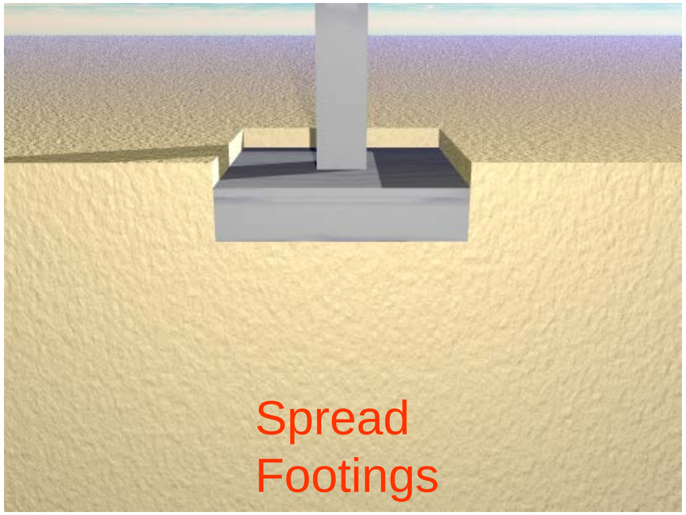
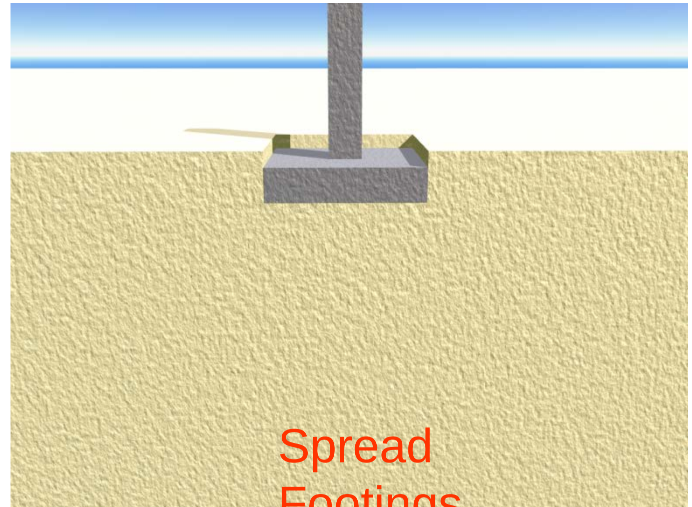


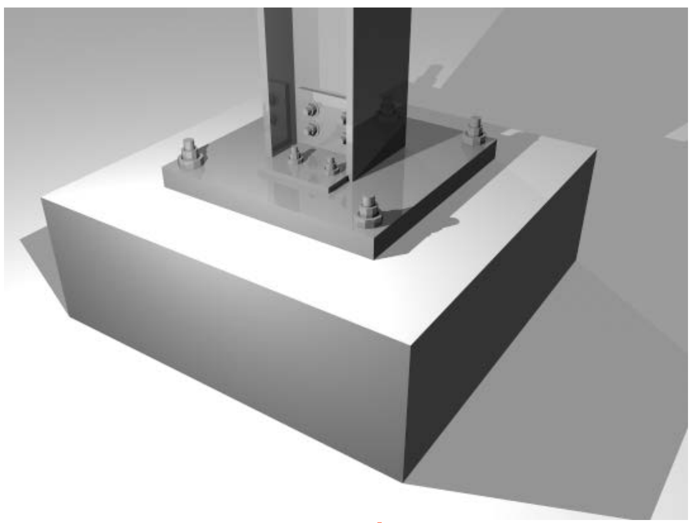

Shallow Foundation



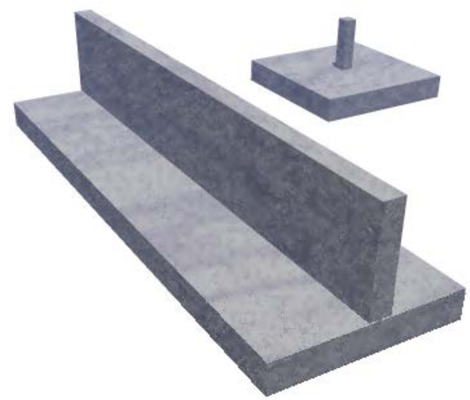
Spread Footings



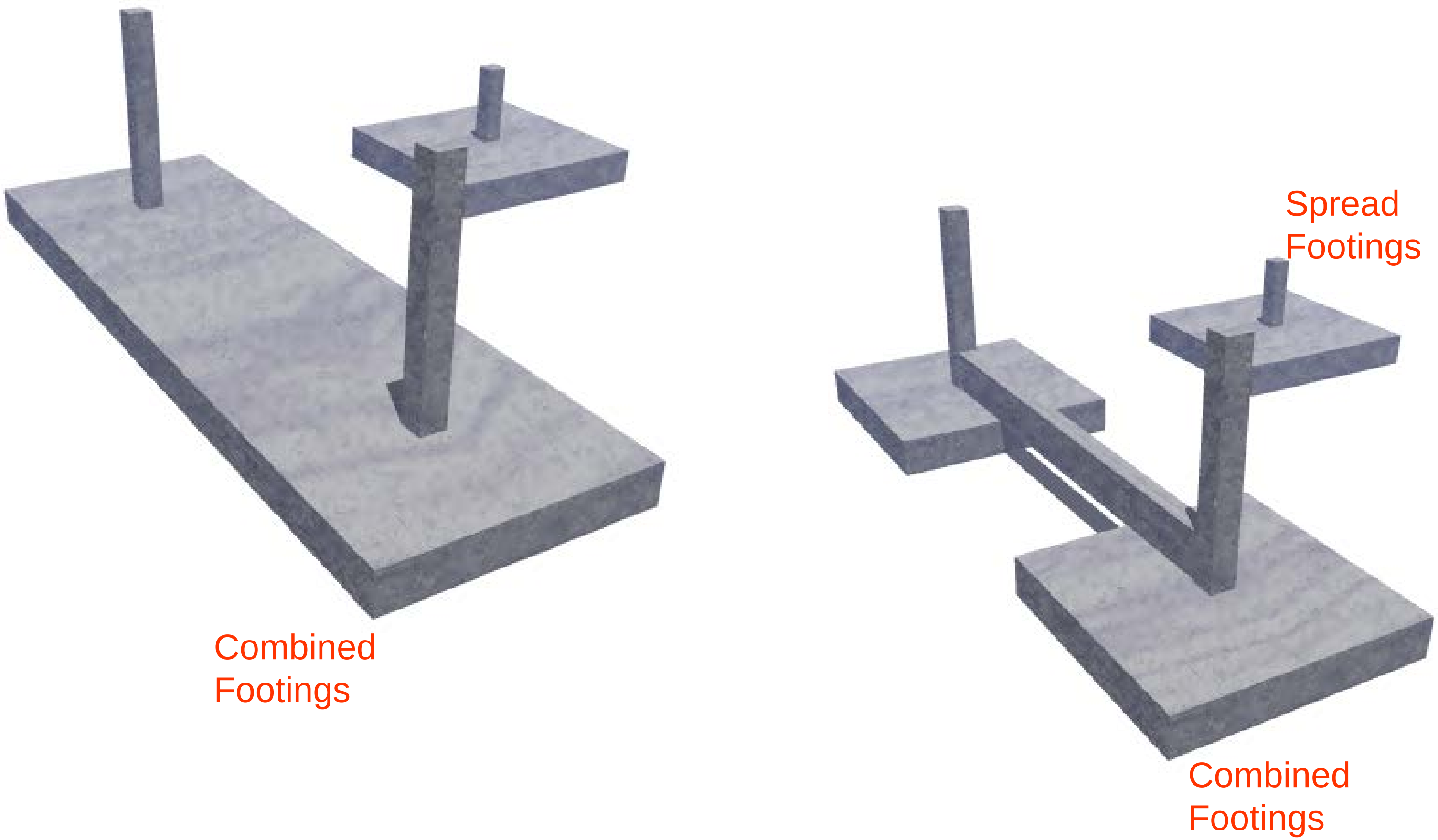
Spread Footings

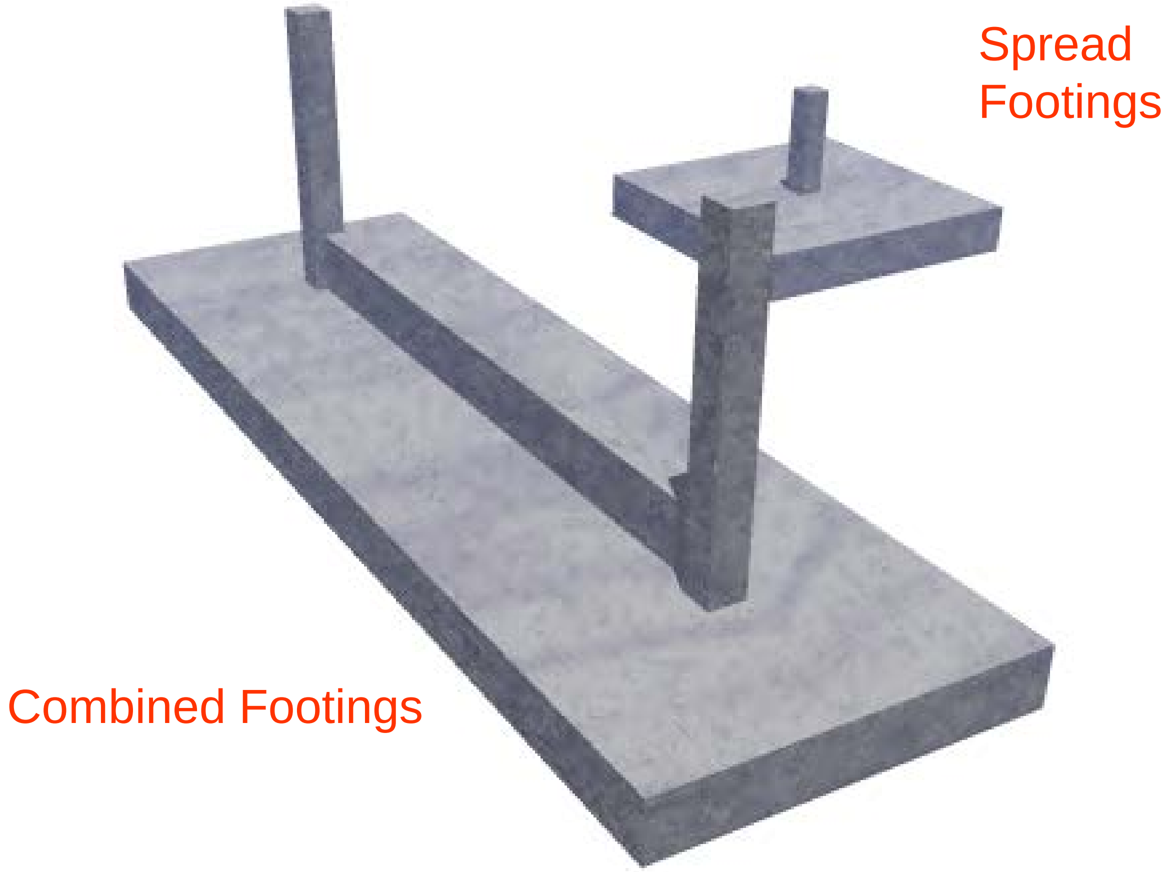


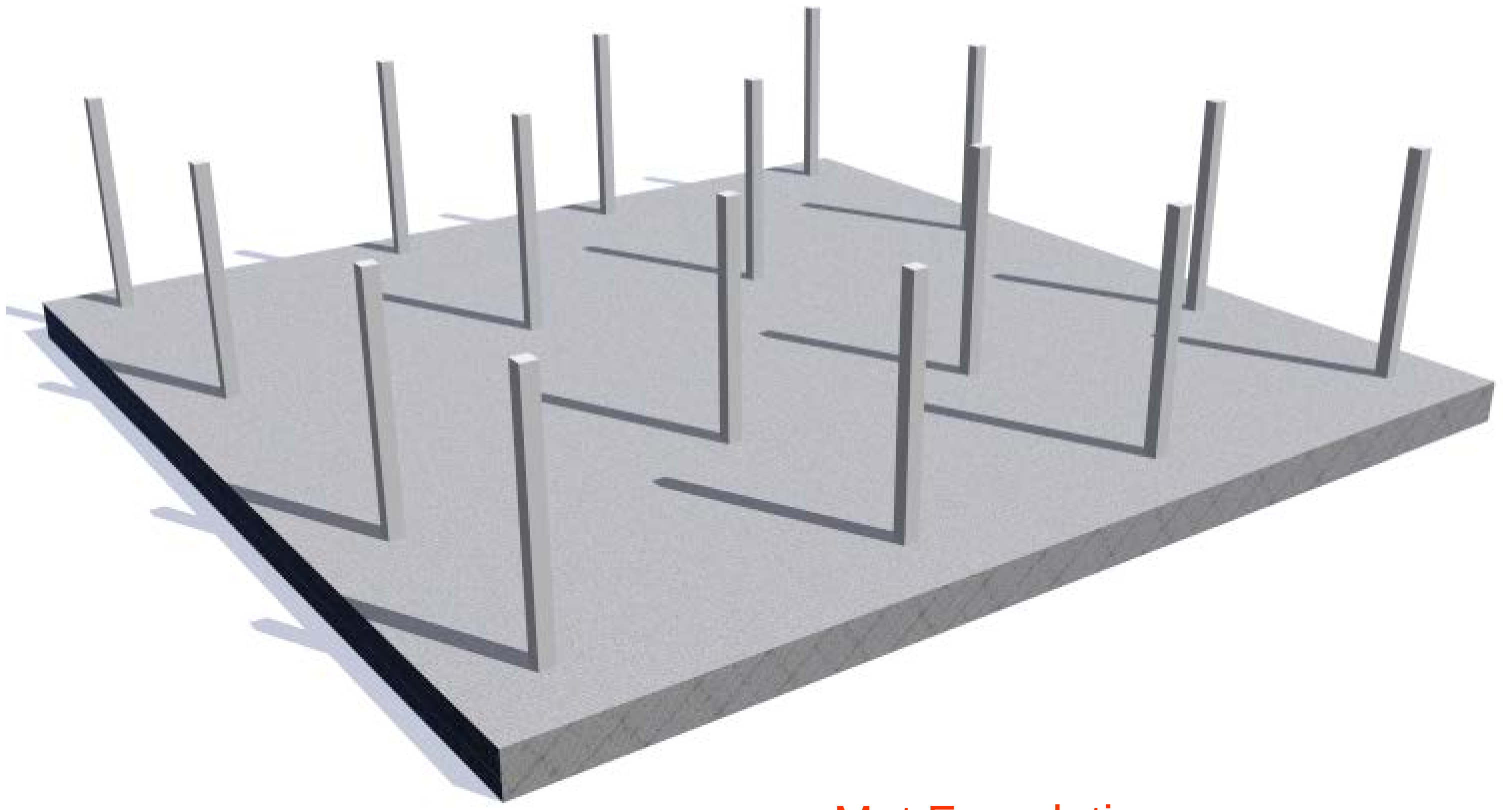
Spread Footings



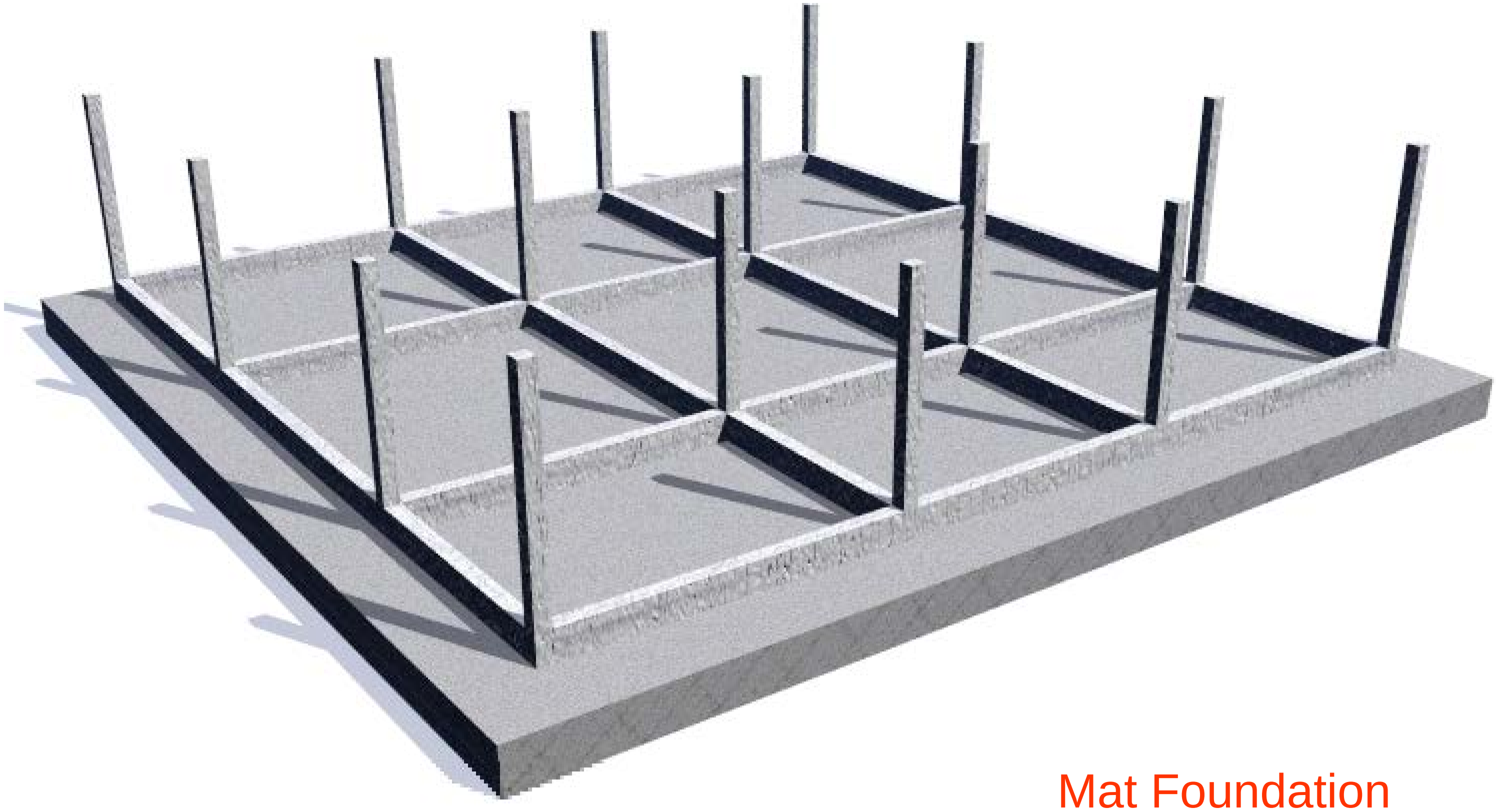
Continuous Footings


Combined
Footings
Spread
Footings
Combined
Footings


Spread
Footings
Combined Footings

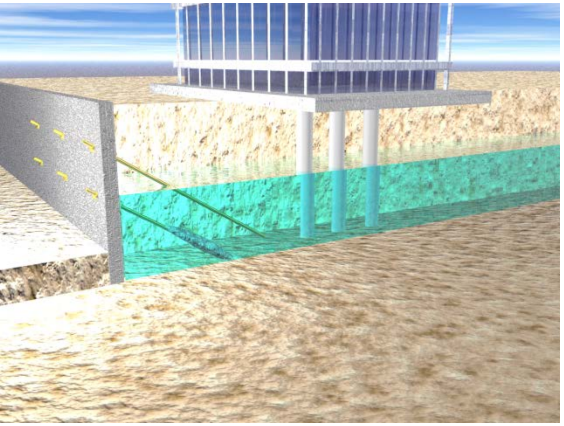


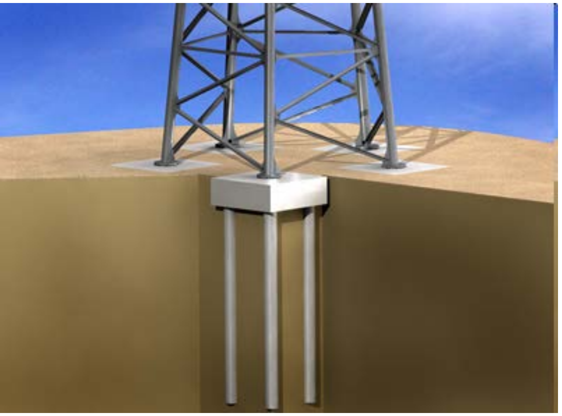
Mat Foundation

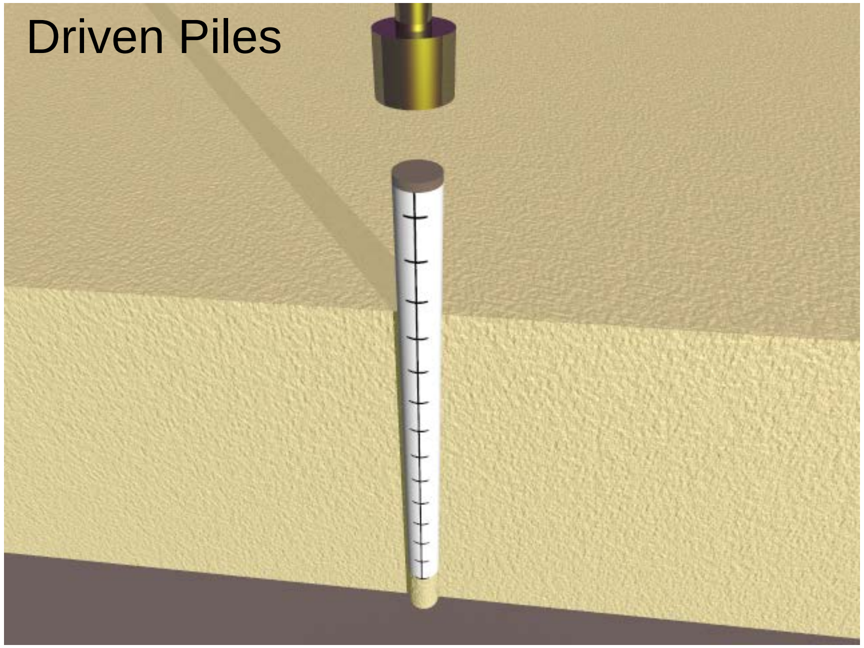


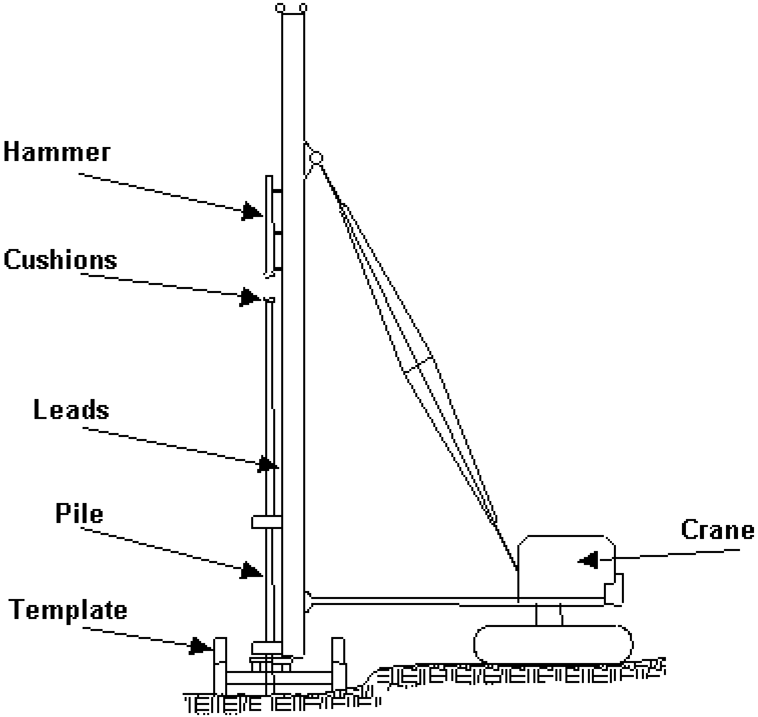
Mat Foundation

Deep Foundation









Drilled Shafts

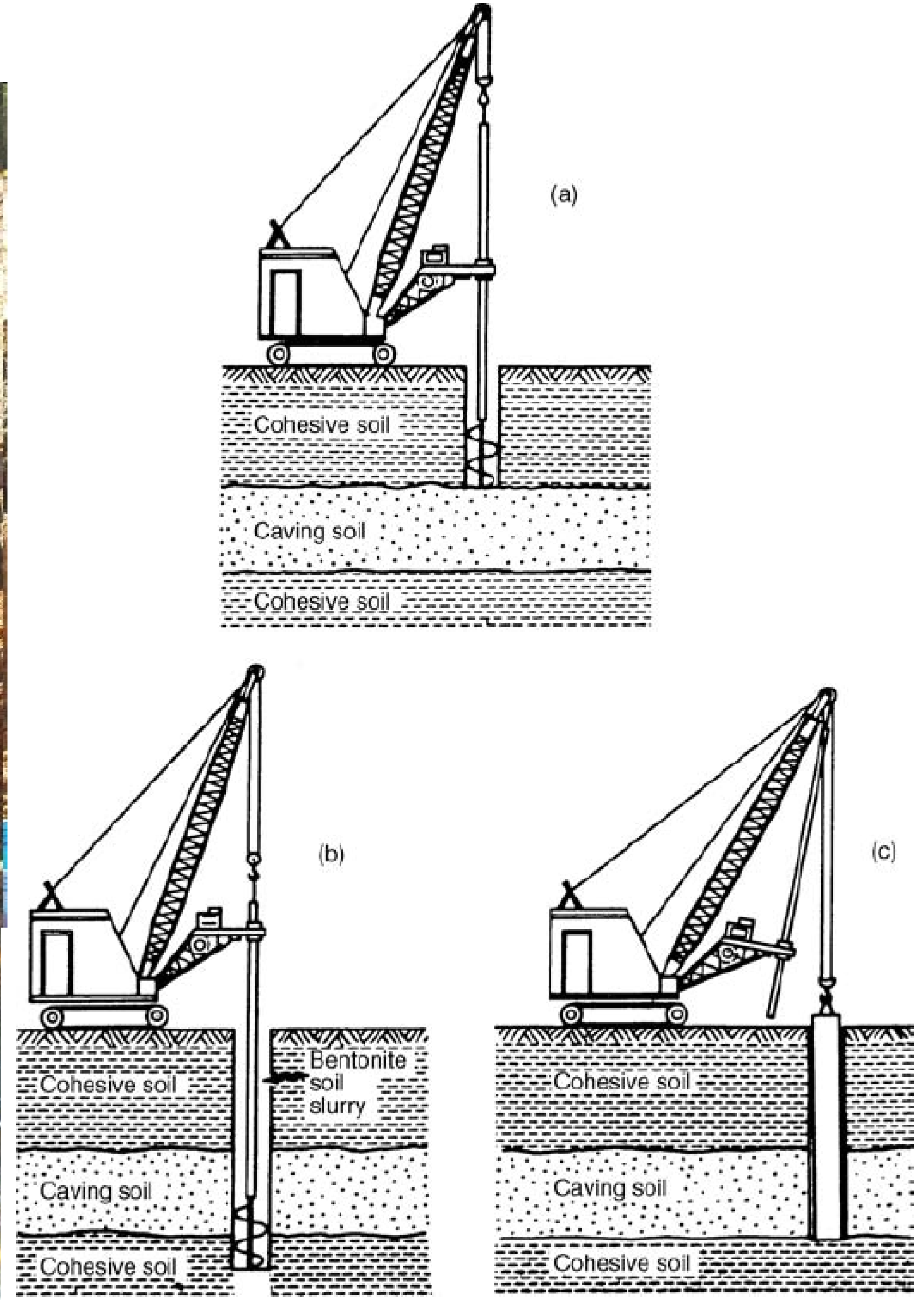


FIGURE 5.7 Typical steps in the construction of a drilled pier. (*a*) Dry augering through self-supporting cohesive soil; (*b*) augering through water-bearing cohesionless soil with aid of slurry; (*c*) setting the casing; (*d*) dry augering into cohesive soil after sealing; (*e*) forming a bell. (*After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

Auger Cast Pile

How Auger-Cast Piles are Installed



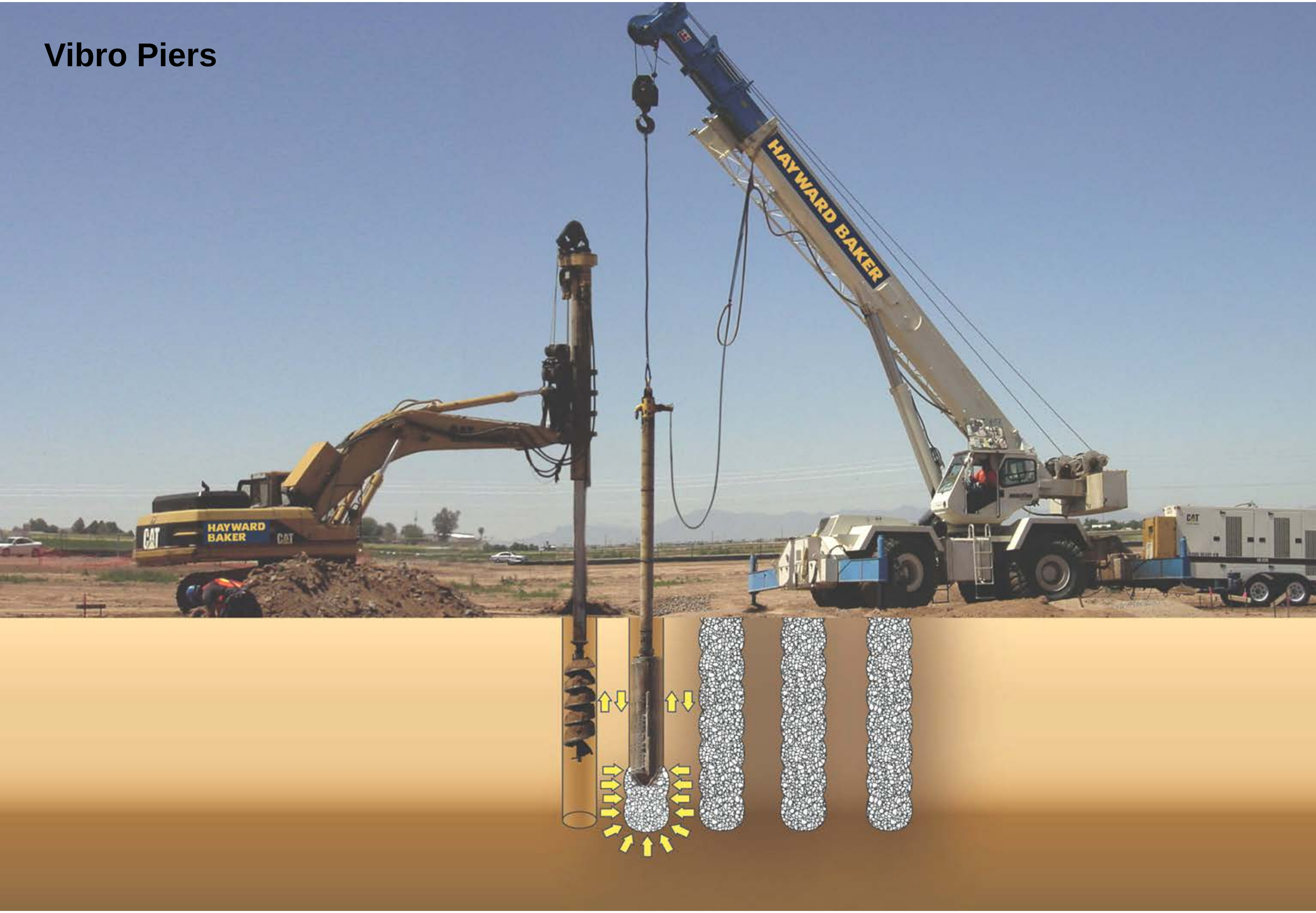

First the auger drills deep into the ground.

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.

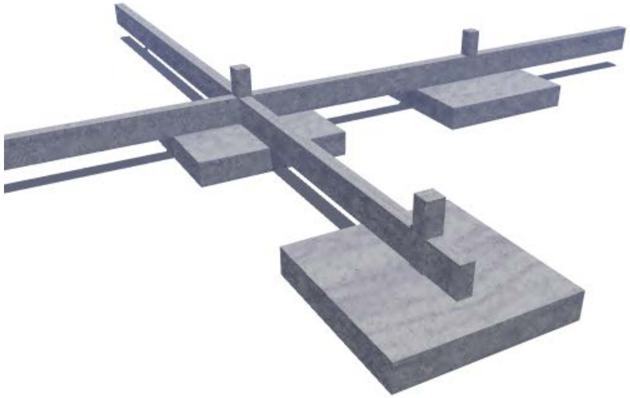
Vibro Piers



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

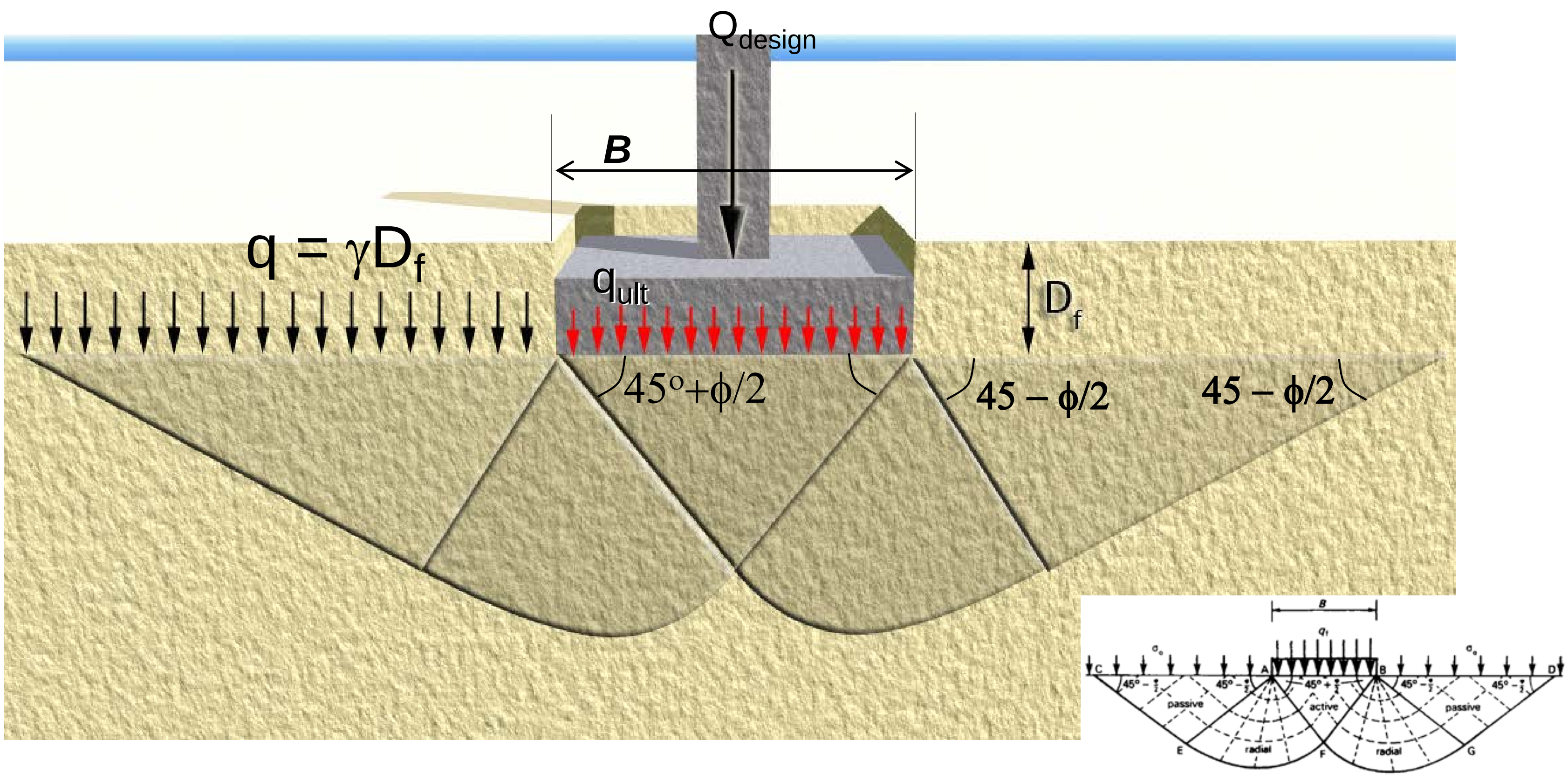
I- Bearing Capacity

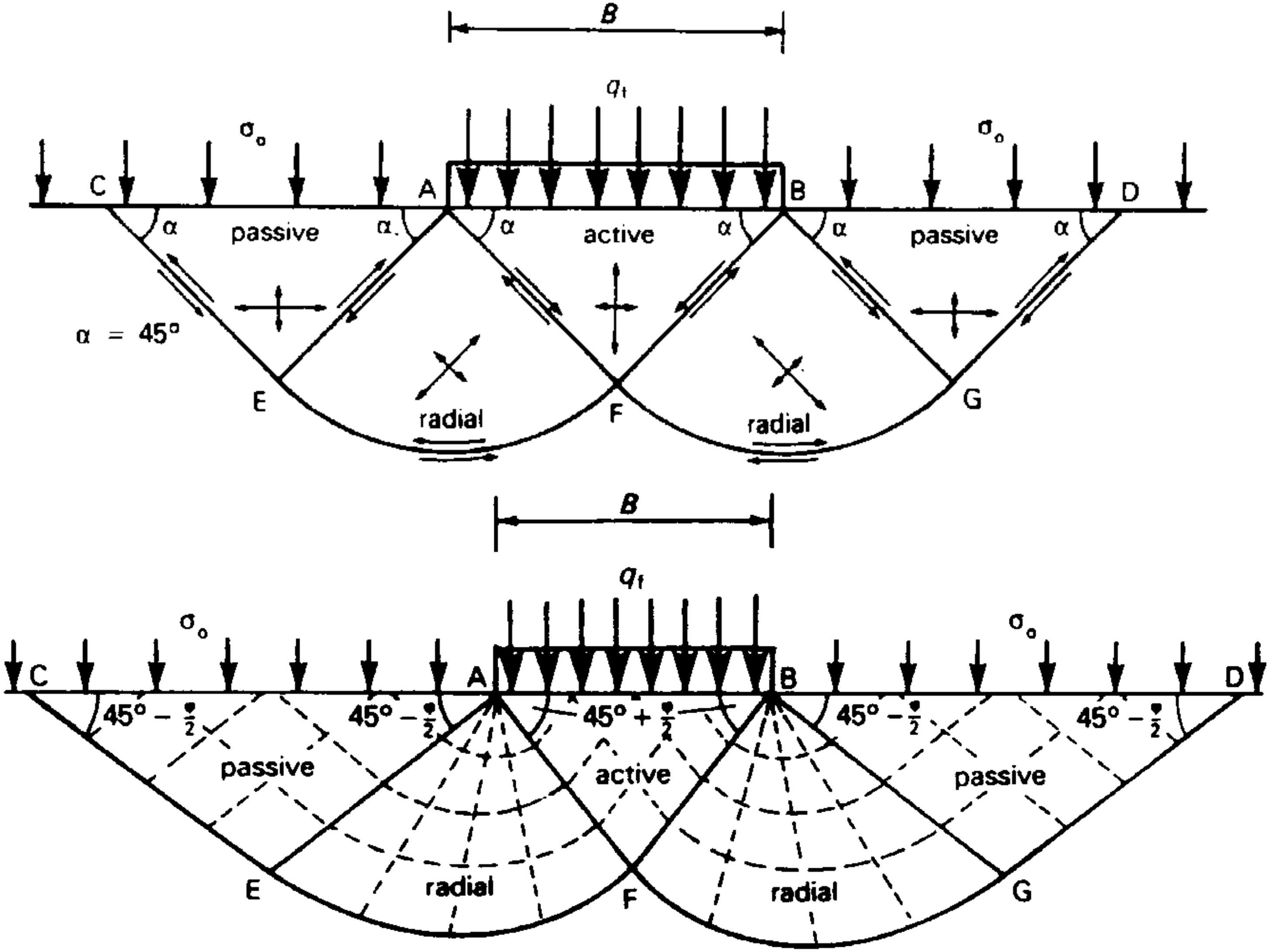
TERZAGHI’S BEARING CAPACITY THEORY

Terzaghi's Equation (1943)

-Utilizing Prandtl's theory, Buisman (1940) expressed the maximum bearing capacity of soils by superimposing the contribution of cohesion, overburden pressure, and density of the soil, His expression is commonly referred to as Terzaghi's equation. Presumably, it was associated with Terzaghi's in the English speaking countries following the publication of his book (Theoretical Soil Mechanics) in 1943.

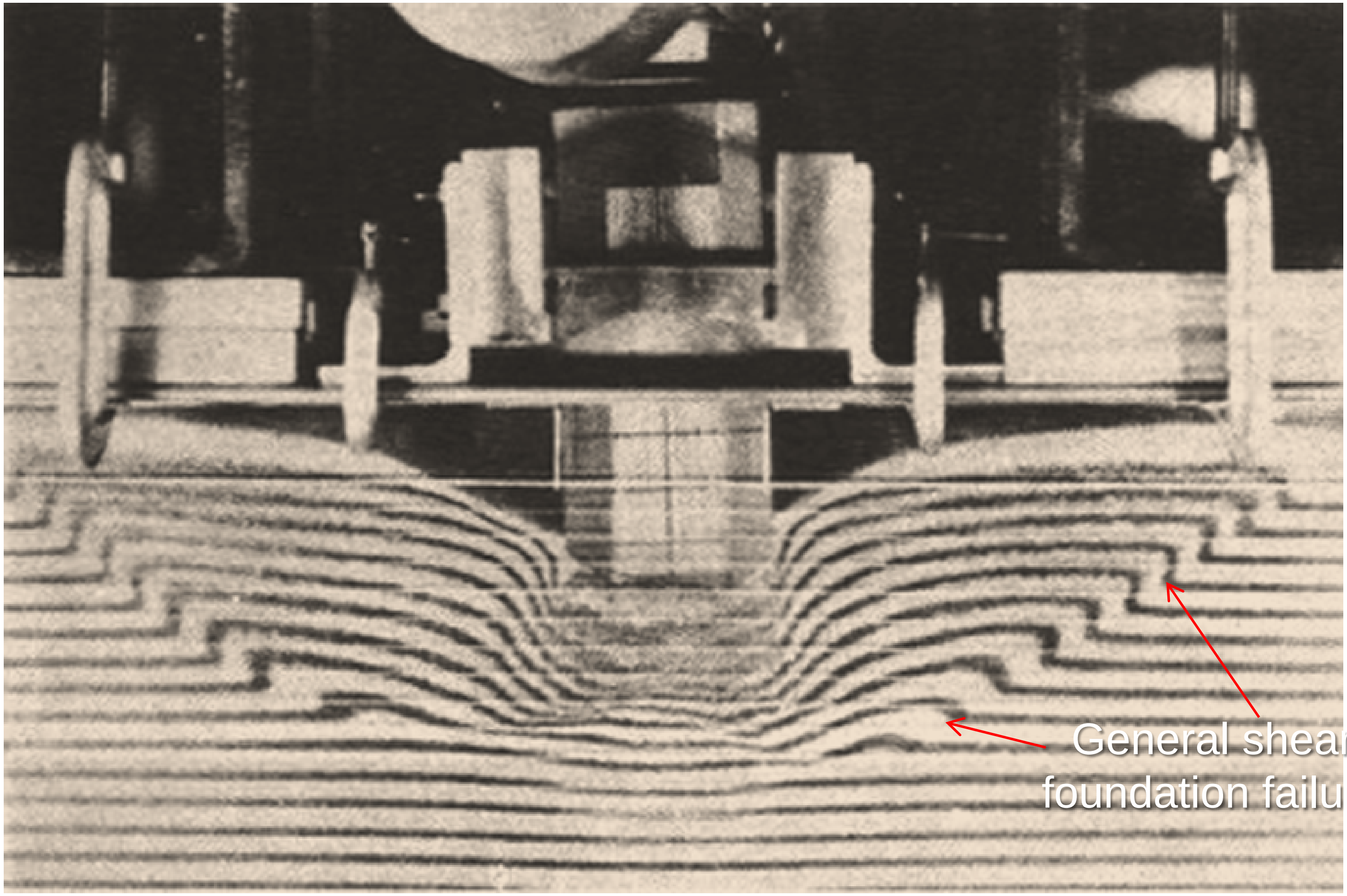
- Based on Prandtl's theory of plastic failure, Terzaghi presented a modified system as illustrated below.





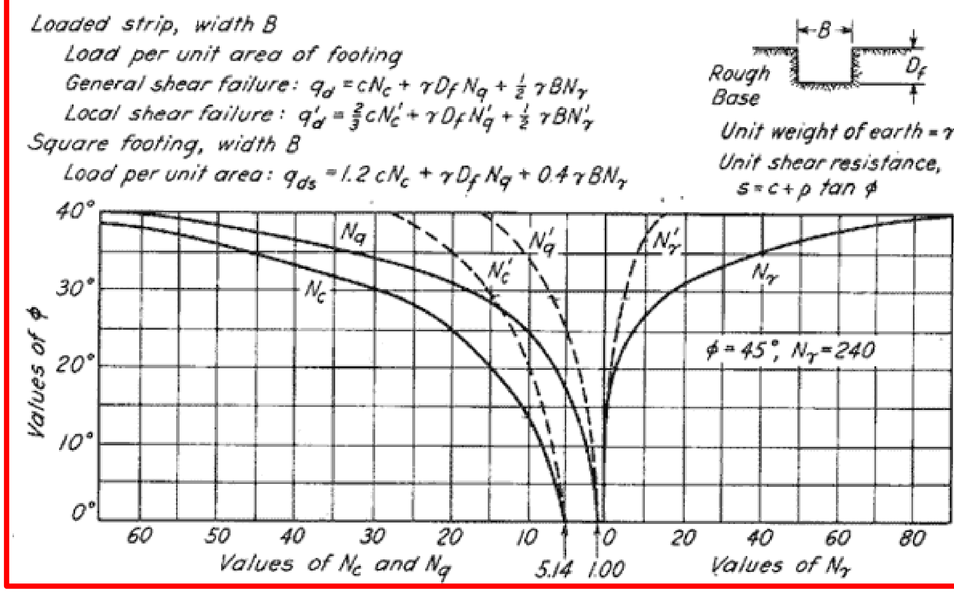
$$q_u = q_c + q_q + q_\gamma$$

Laboratory Testing on Bearing capacity failures of foundations



Ultimate Bearing Capacity

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



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

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)

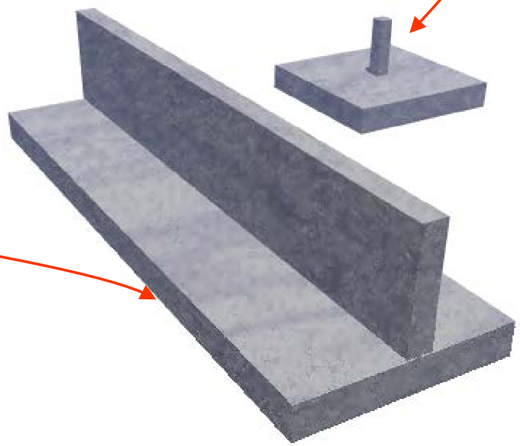
ϕ	N_c	N_q	N_γ	ϕ	N_c	N_q	N_γ	ϕ	N_c	N_q	N_γ
0	5.70	1.00	0.00	17	14.60	5.45	2.18	34	52.64	36.50	38.04
1	6.00	1.1	0.01	18	15.12	6.04	2.59	35	57.75	41.44	45.41
2	6.30	1.22	0.04	19	16.57	6.70	3.07	36	63.53	47.16	54.36
3	6.62	1.35	0.06	20	17.69	7.44	3.64	37	70.01	53.80	65.27
4	6.97	1.49	0.10	21	18.92	8.26	4.31	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

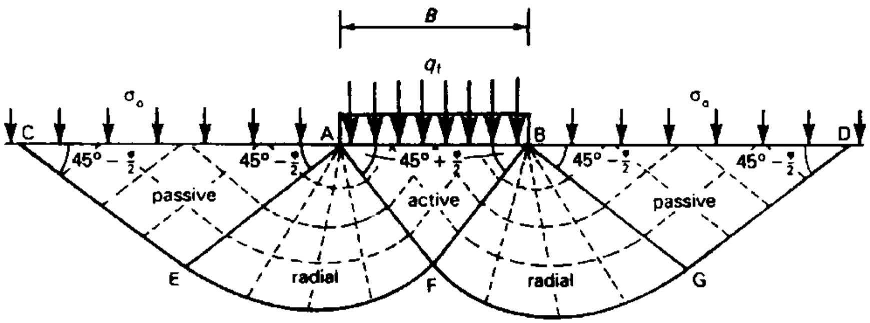
1- TERZAGHI'S BEARING CAPACITY THEORY

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

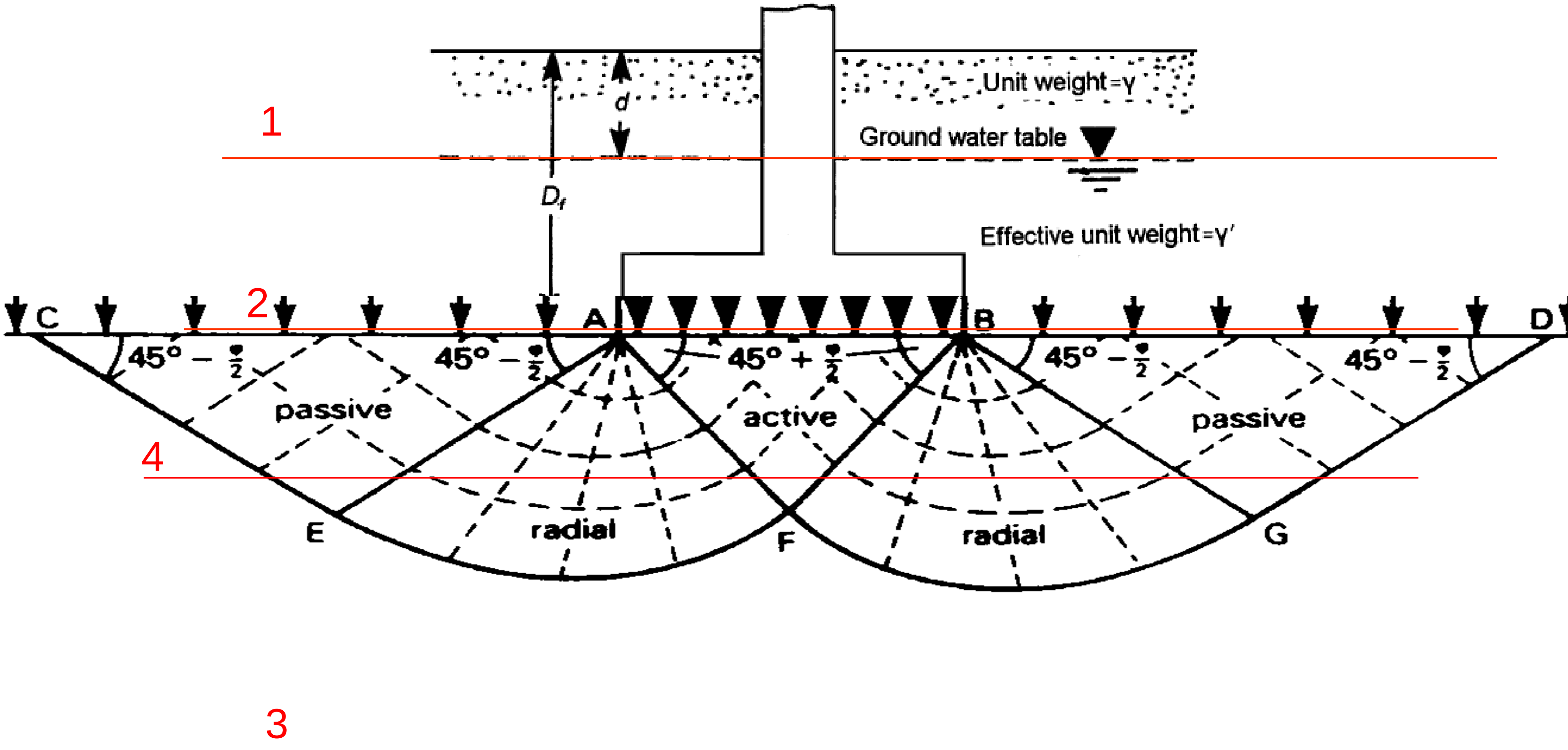
$$q_u = 1.3cN_c + qN_q + 0.4\gamma B N_\gamma \quad \text{(square foundation; plan } B \times B\text{)}$$

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





EFFECT OF WATER TABLE



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

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

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

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

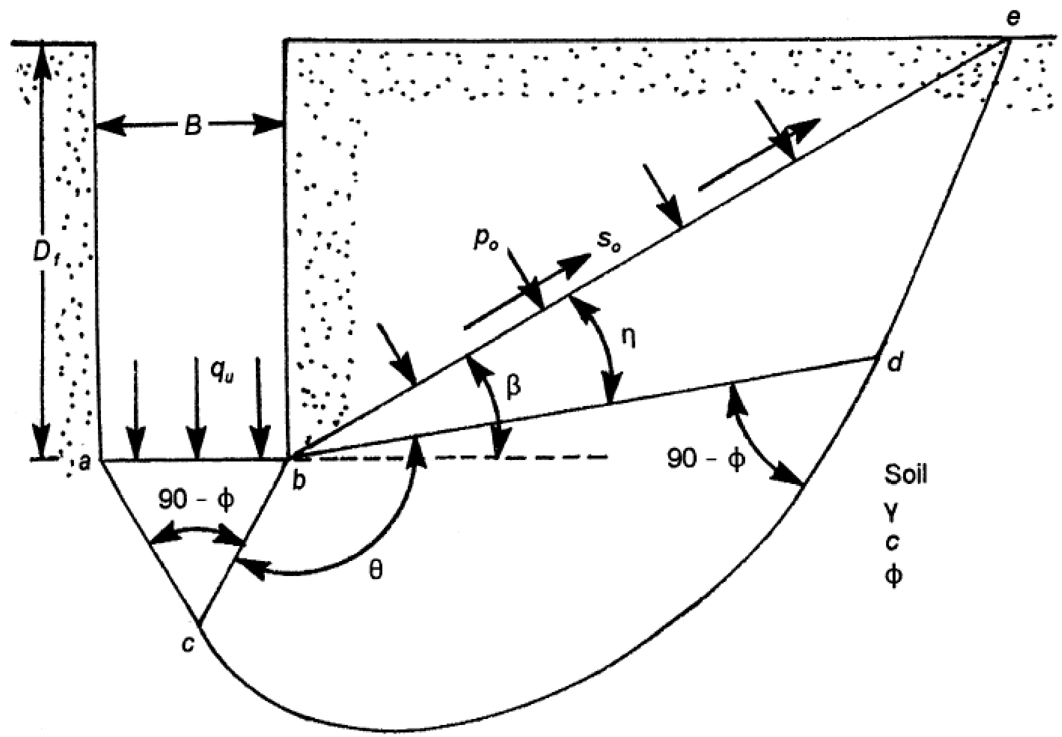


FIGURE 2.7 Slip line fields for a rough continuous foundation

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

λ_{cd}, λ_{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]

Factor | Relationship | Reference

Factor	Relationship	Reference
	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

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

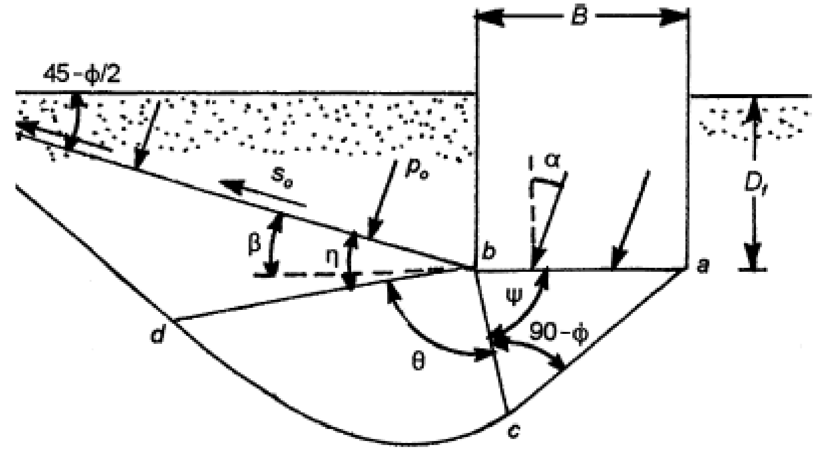


FIGURE 3.1 Plastic zones in soil near a foundation with inclined load

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

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

$$\lambda_{ci} = \lambda_{qi} - \left(\frac{1 - \lambda_{qi}}{N_q - 1}\right) \tag{3.17}$$

↑ Table 2.3

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

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