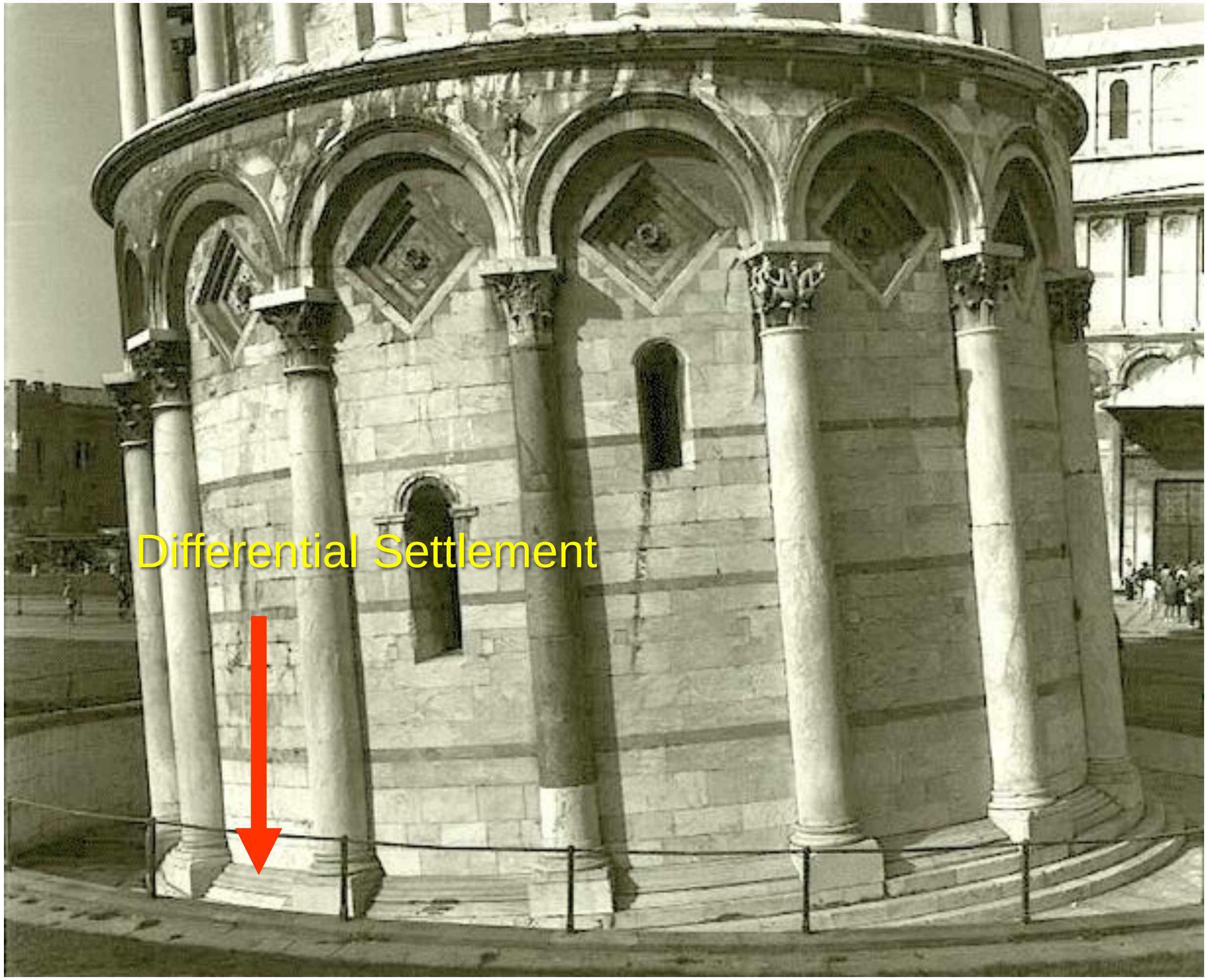
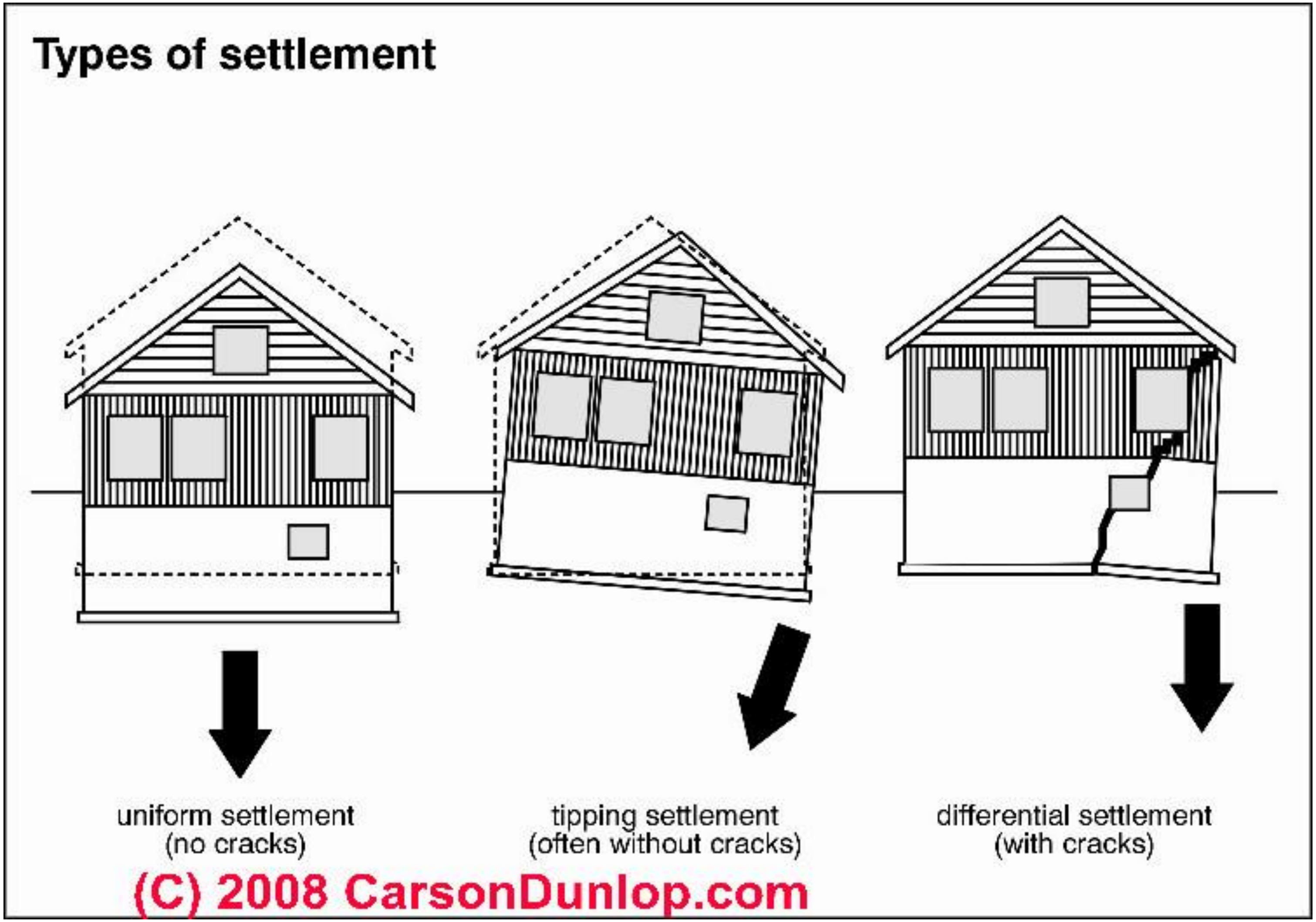
## 3- Foundation Design

Foundation design consists of two steps

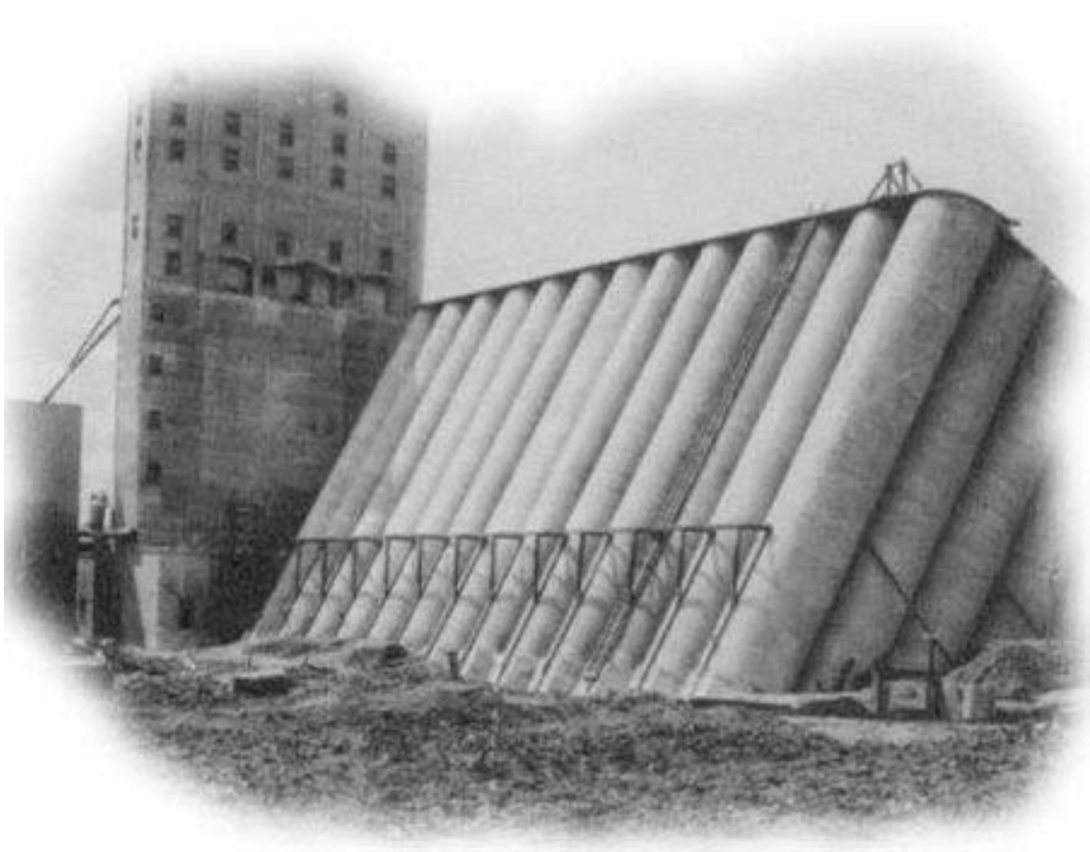
1- determine the bearing capacity of the foundation → You can get suitable size of the foundation from this step

2- determine the settlement of the foundation → Foundation settlement should not exceed allowable settlement





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

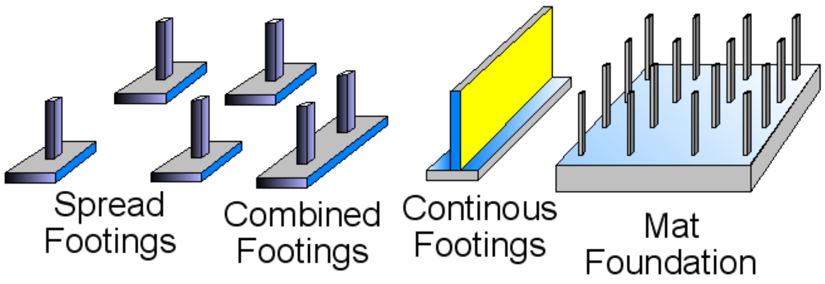


Bearing Capacity Failure

# Structural Foundations are grouped into two main groups.

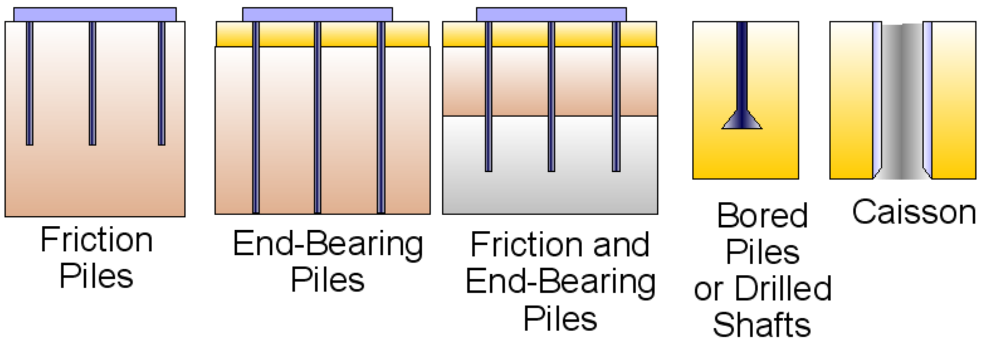
1- Shallow Foundation

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

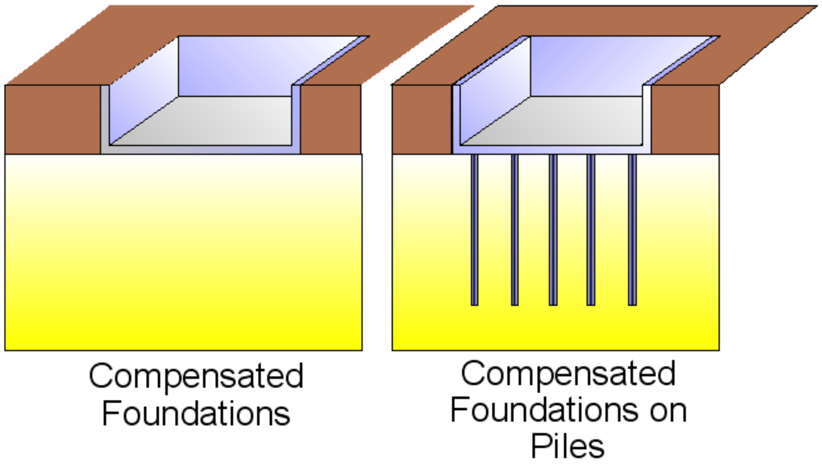



2- Deep Foundation

- Driven Piles
- Drilled Shaft
- Auger Cat Piles




3- Compensated or floating foundations

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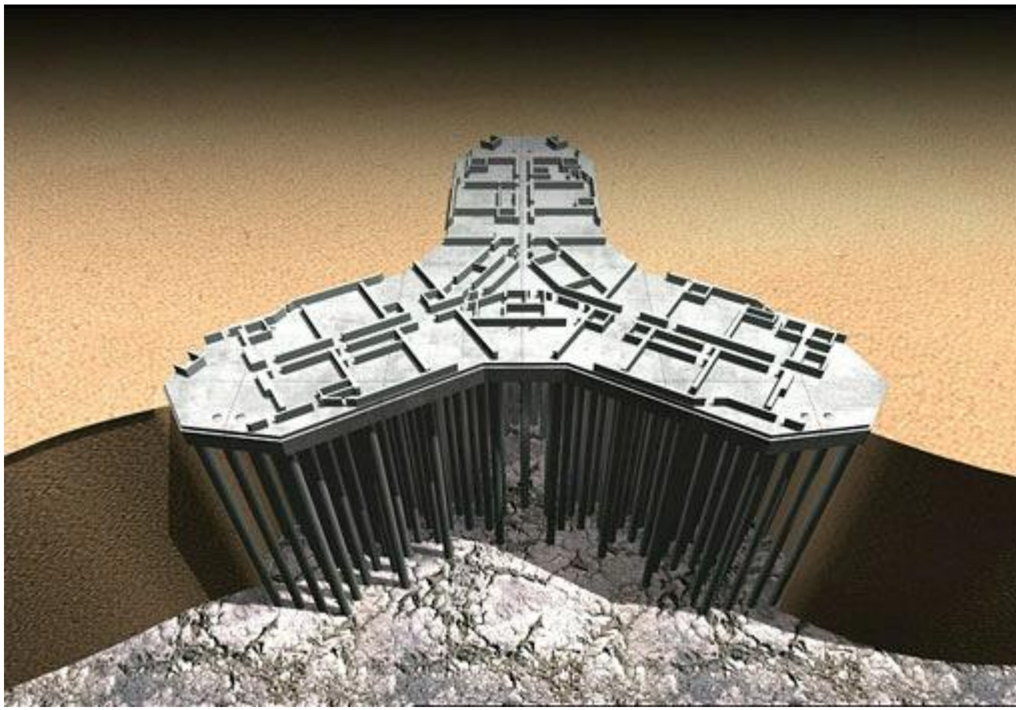
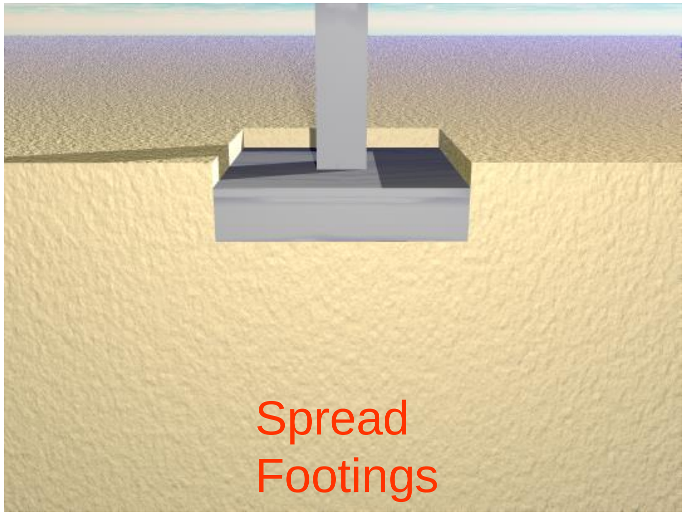
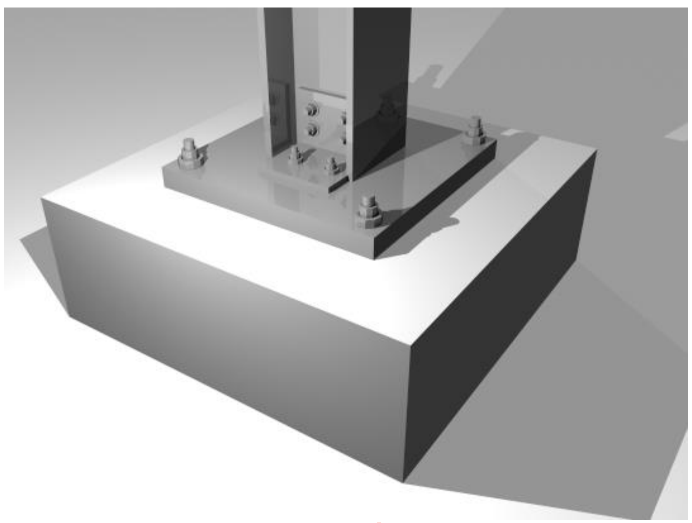


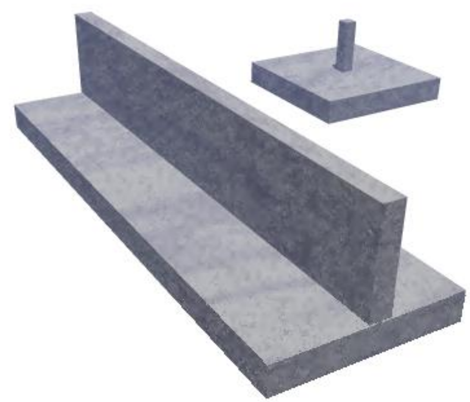

# Shallow Foundation



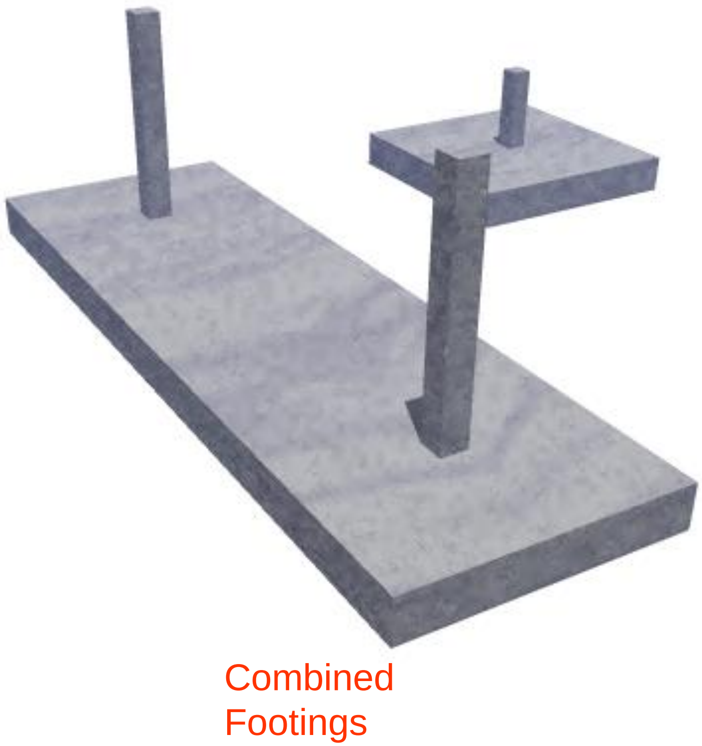


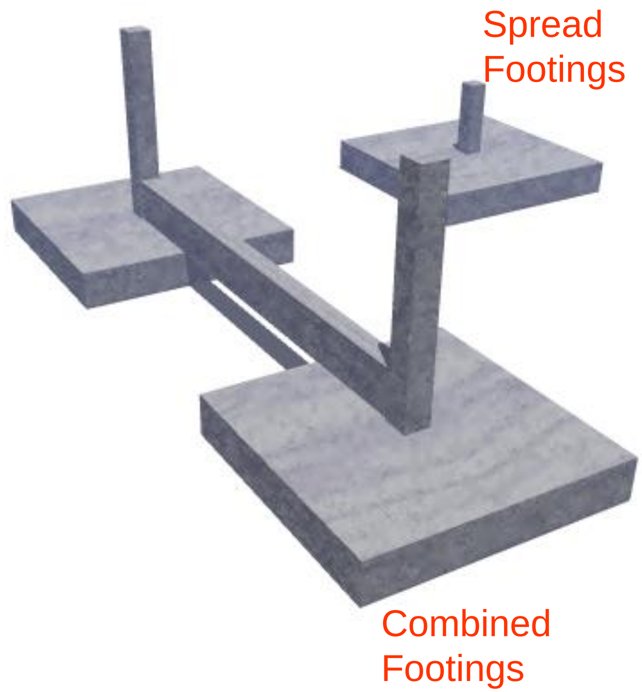


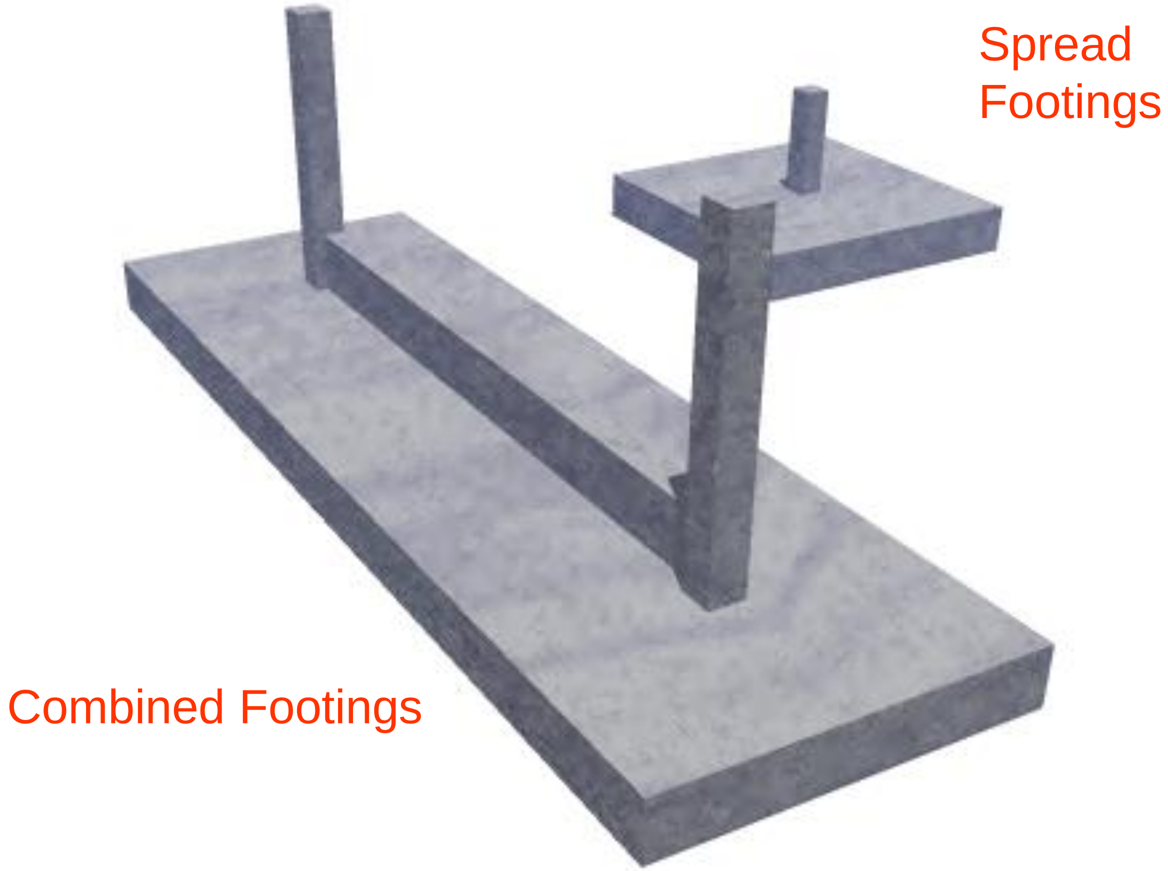
Spread
Footings

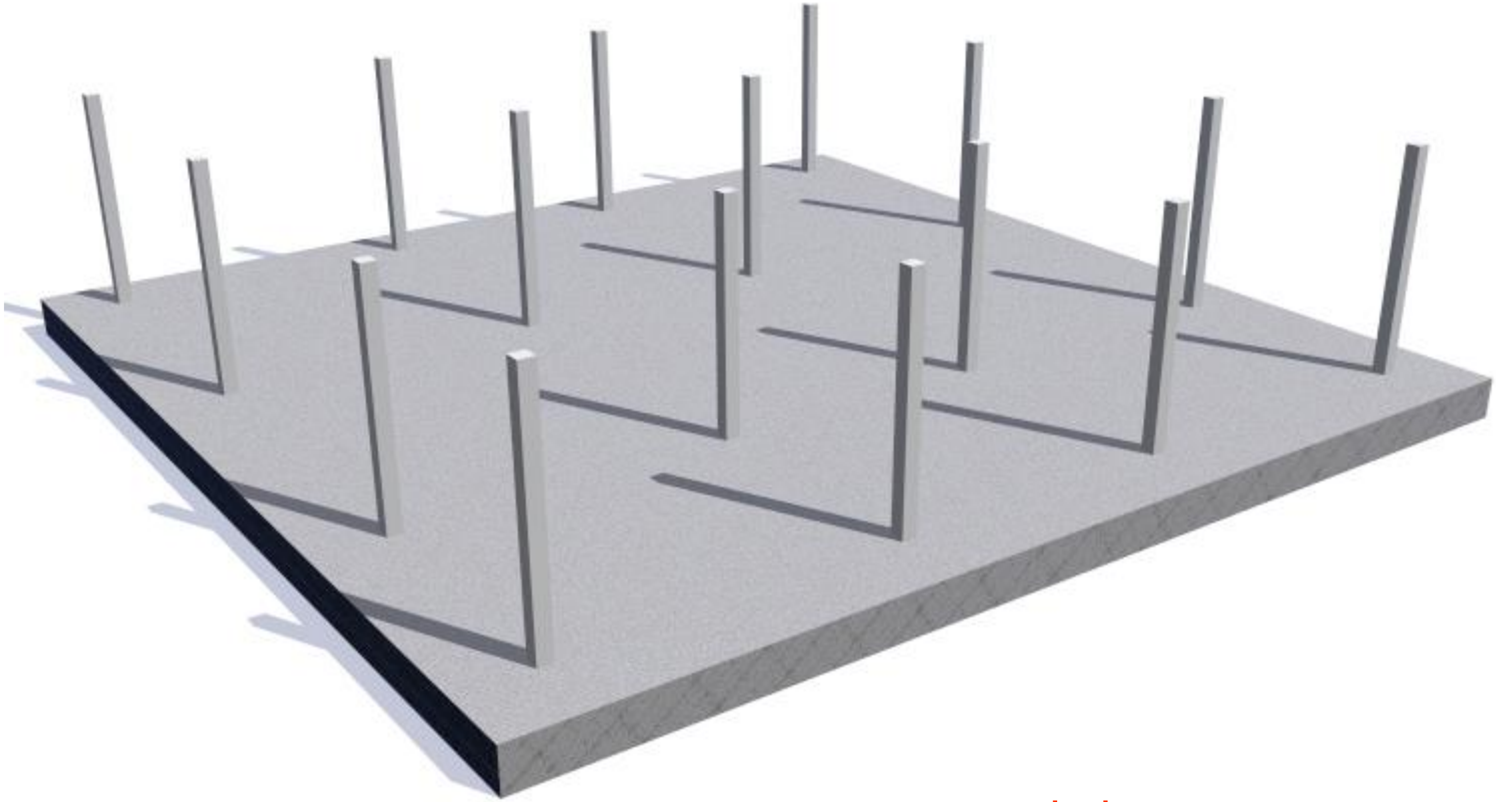


Continuous
Footings

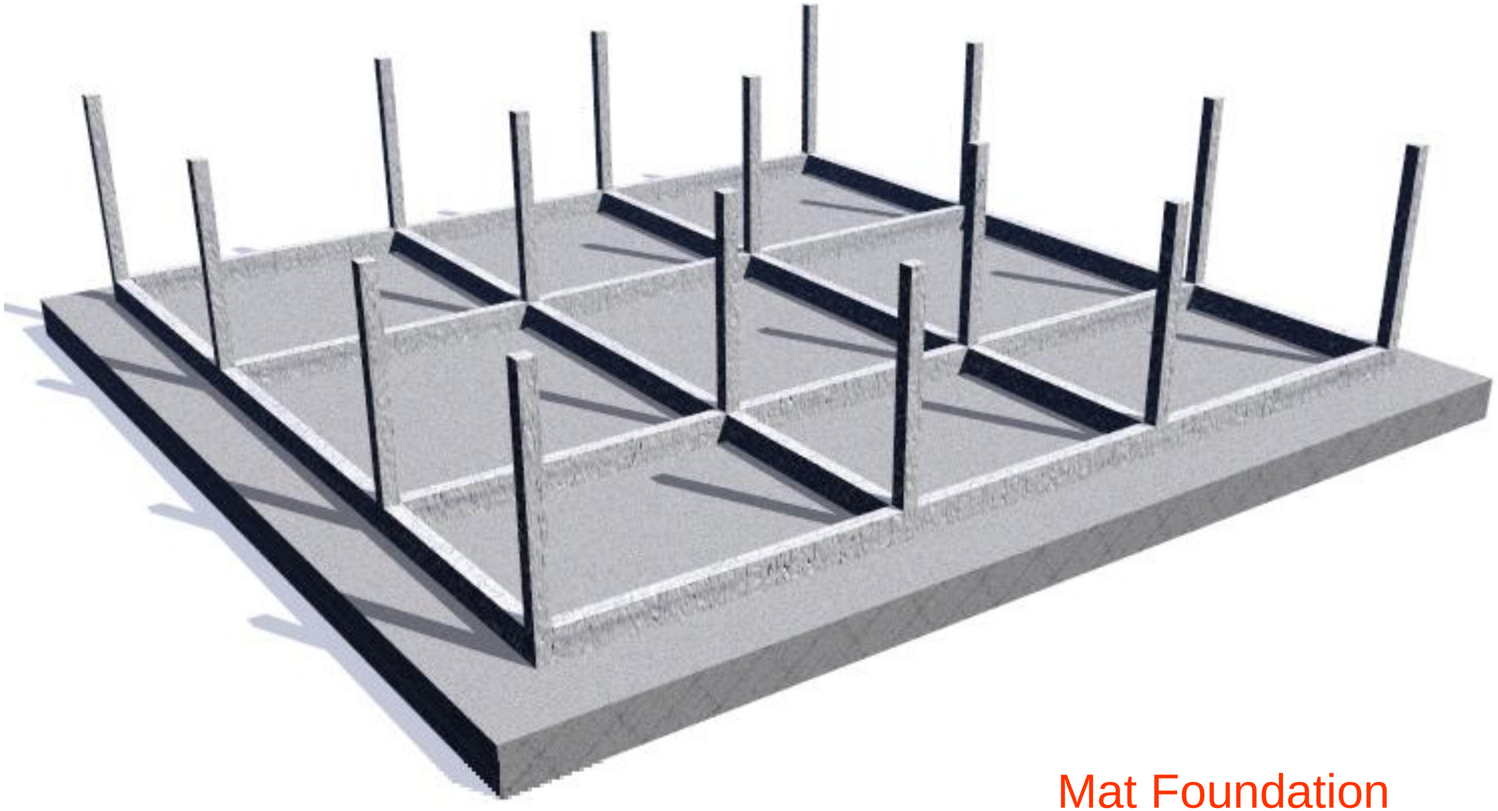

Combined
Footings


Spread
Footings
Combined
Footings


Spread
Footings
Combined Footings

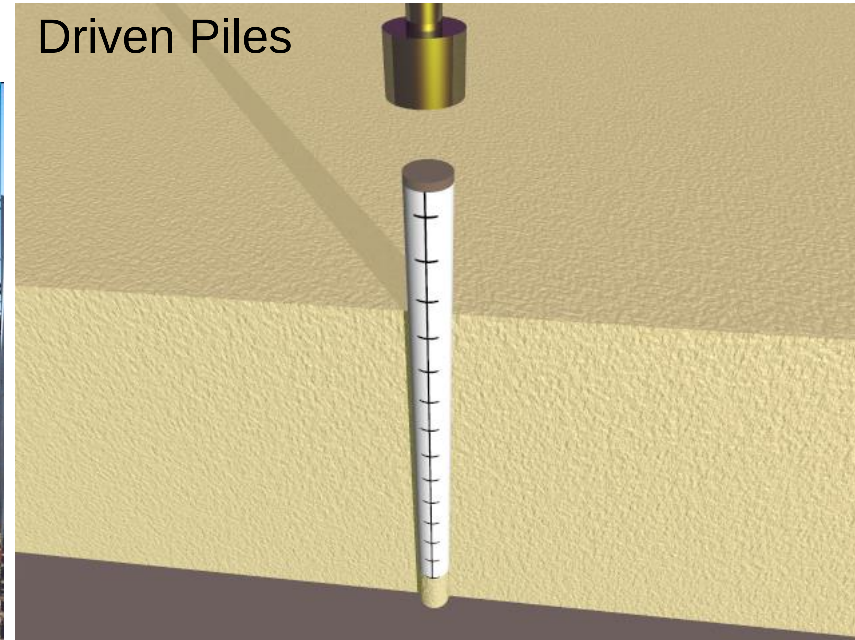


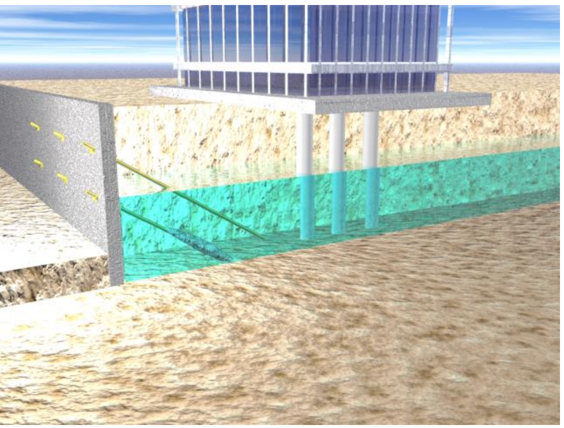
Mat Foundation

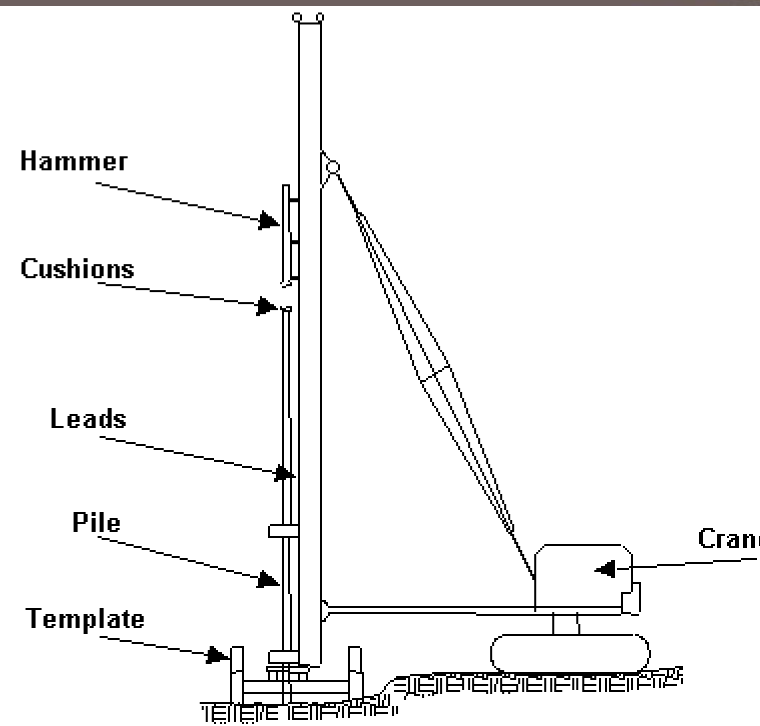


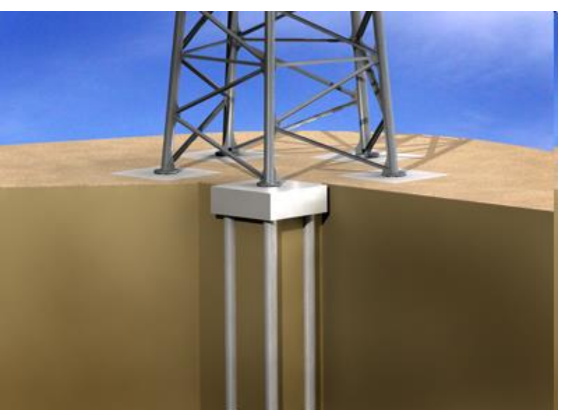
Mat Foundation

# Deep Foundation





# Drilled Shafts

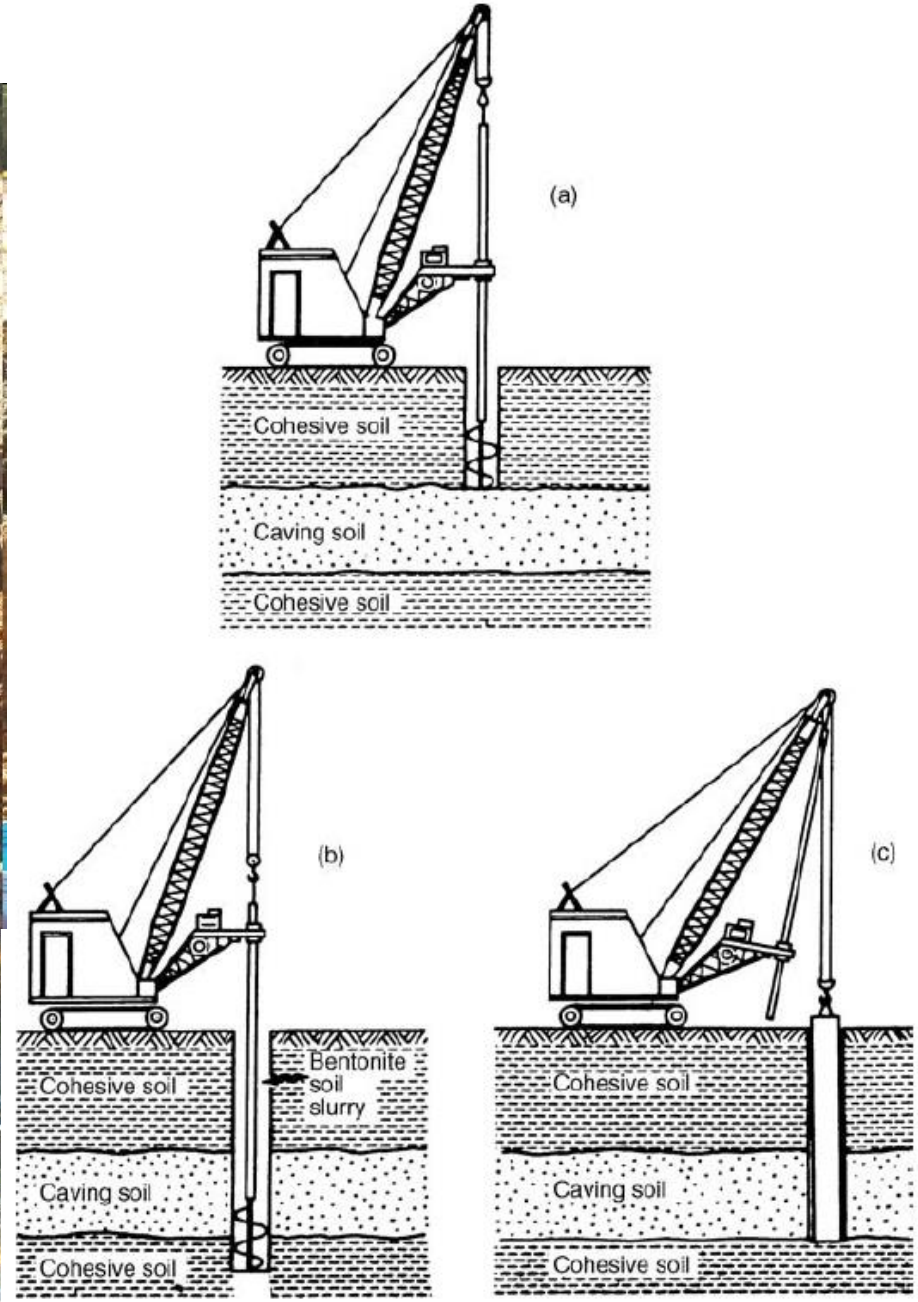



**FIGURE 5.7** Typical steps in the construction of a drilled pier. (*a*) Dry augering through self-supporting cohesive soil; (*b*) augering through water-bearing cohesionless soil with aid of slurry; (*c*) setting the casing; (*d*) dry augering into cohesive soil after sealing; (*e*) forming a bell.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

# Auger Cast Pile

**How Auger-Cast Piles are Installed**

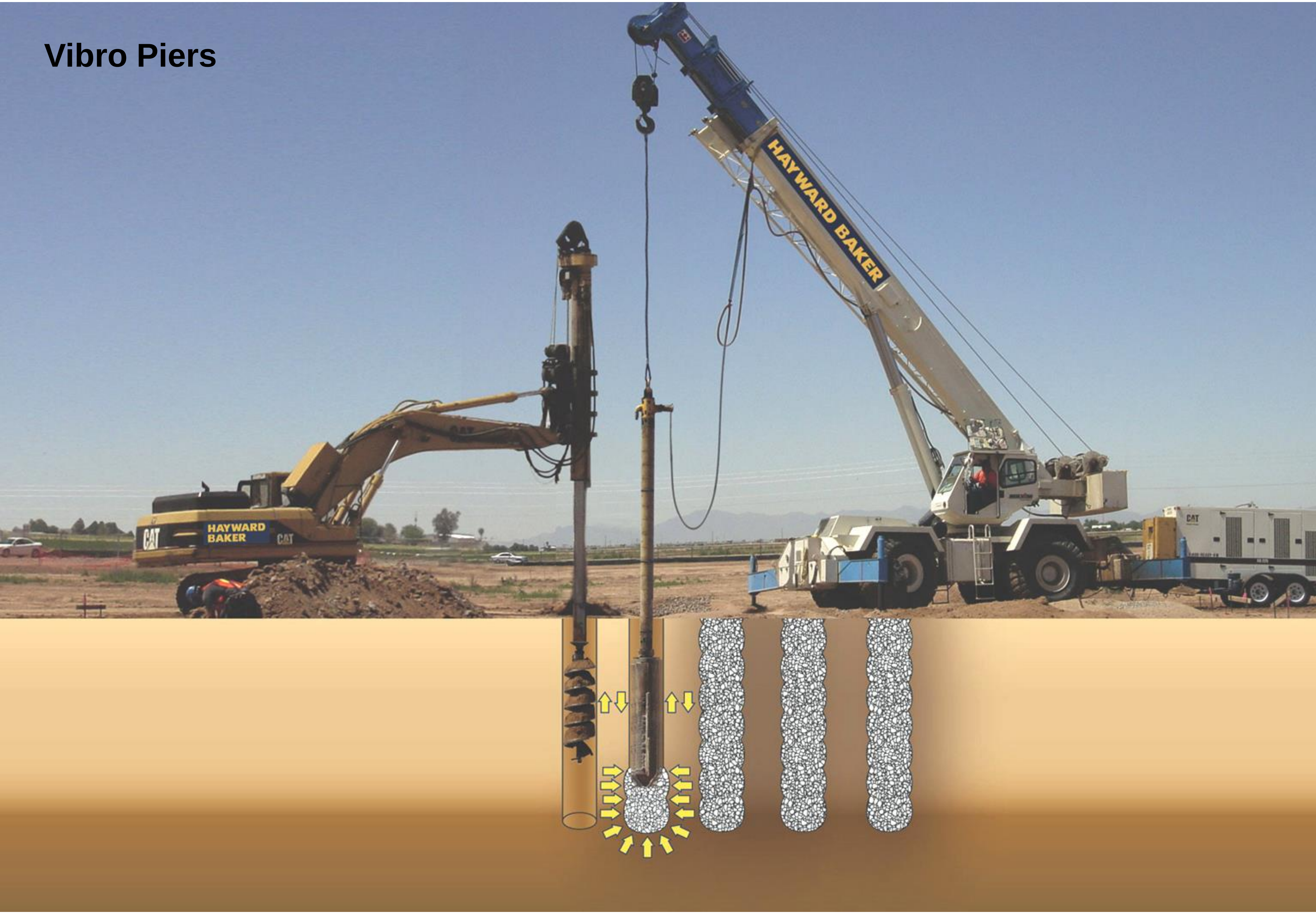
First the auger drills deep into the ground.

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.

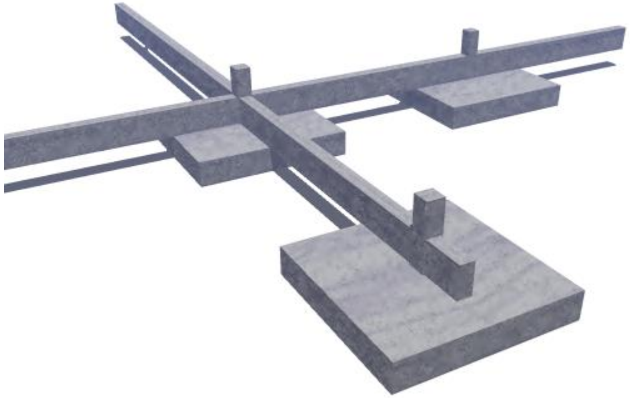
# Vibro Piers



# 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

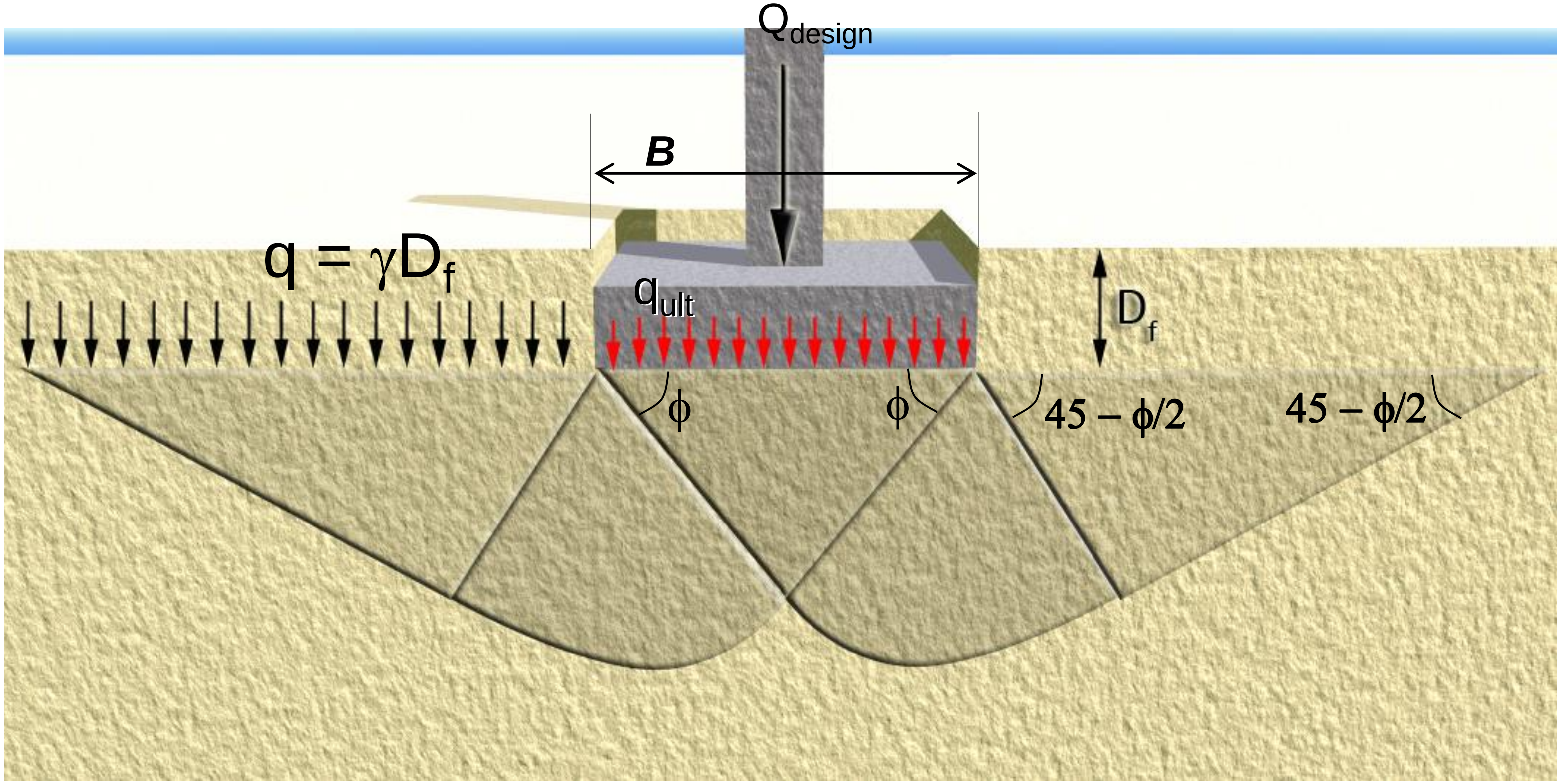
# I- Bearing Capacity

## TERZAGHI'S BEARING CAPACITY THEORY

**Terzaghi's Equation (1943)**

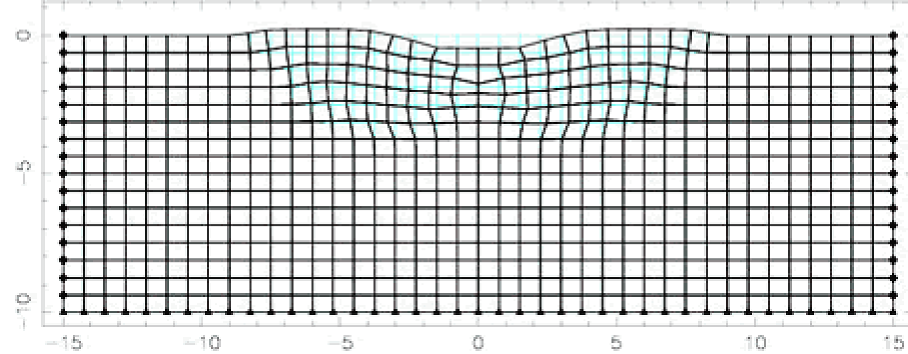
-Utilizing Prandtl's theory, Buisman (1940) expressed the maximum bearing capacity of soils by superimposing the contribution of cohesion, overburden pressure, and density of the soil, His expression is commonly referred to as Terzaghi's equation. Presumably, it was associated with Terzaghi's in the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

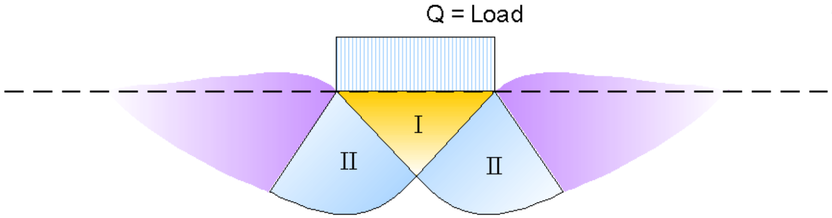
- Based on Prandtl's theory of plastic failure, Terzaghi presented a modified system as illustrated below.

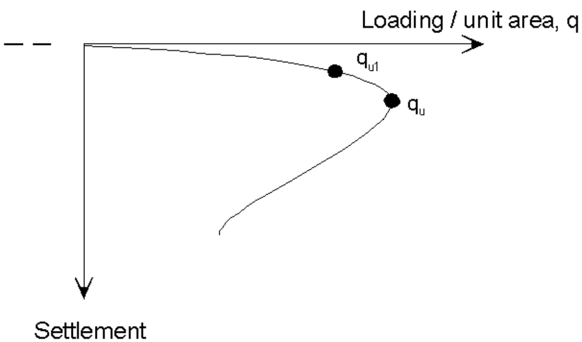


# I- Bearing Capacity

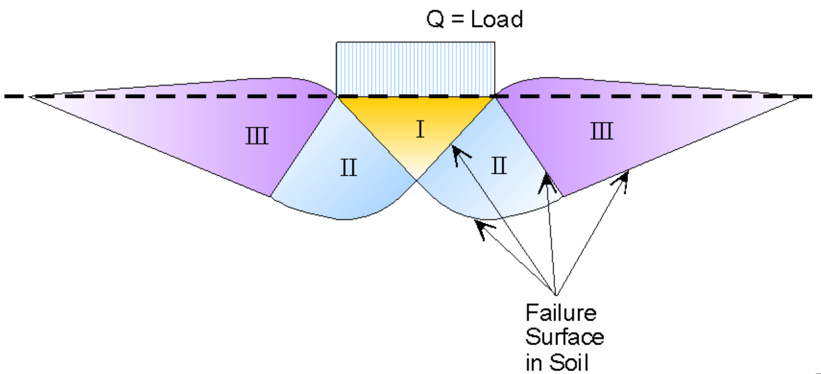
## TERZAGHI'S BEARING CAPACITY THEORY

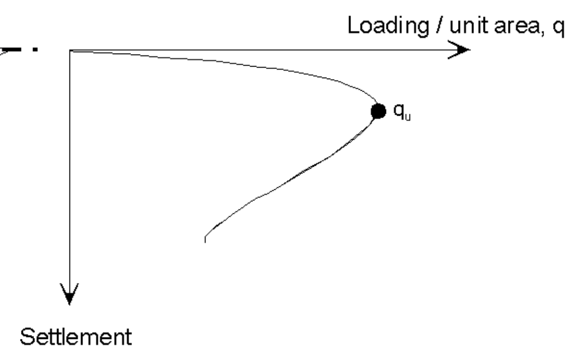


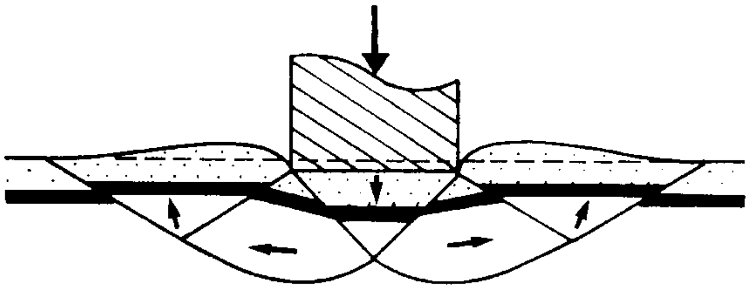



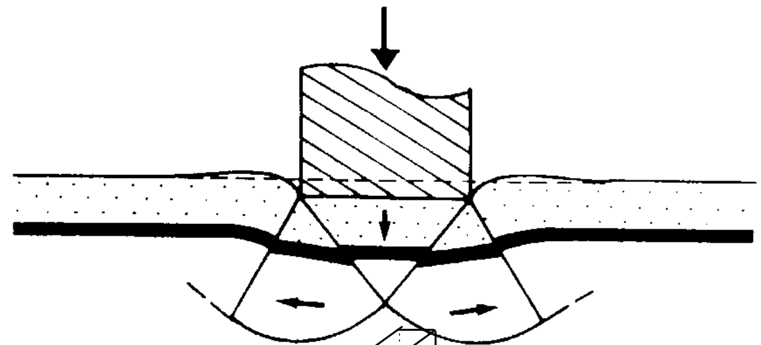

**Local Shear Failure**

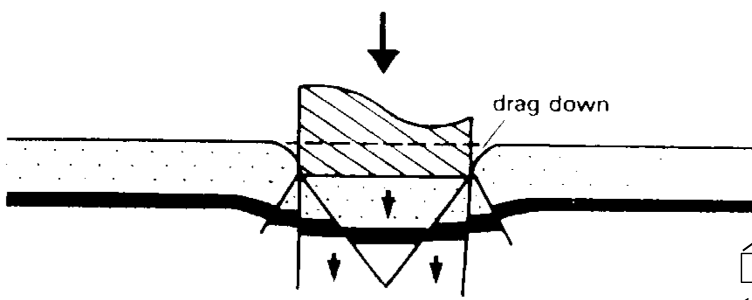


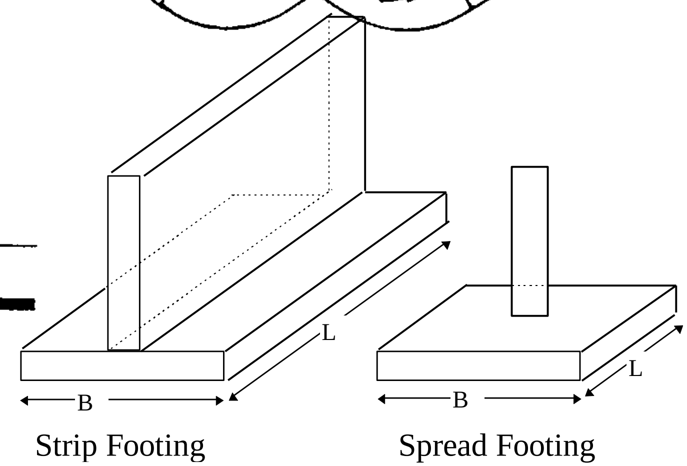




**General Shear Failure**






drag down


L
B
L
B
Strip Footing
Spread Footing

# I- Bearing Capacity

## TERZAGHI'S BEARING CAPACITY THEORY

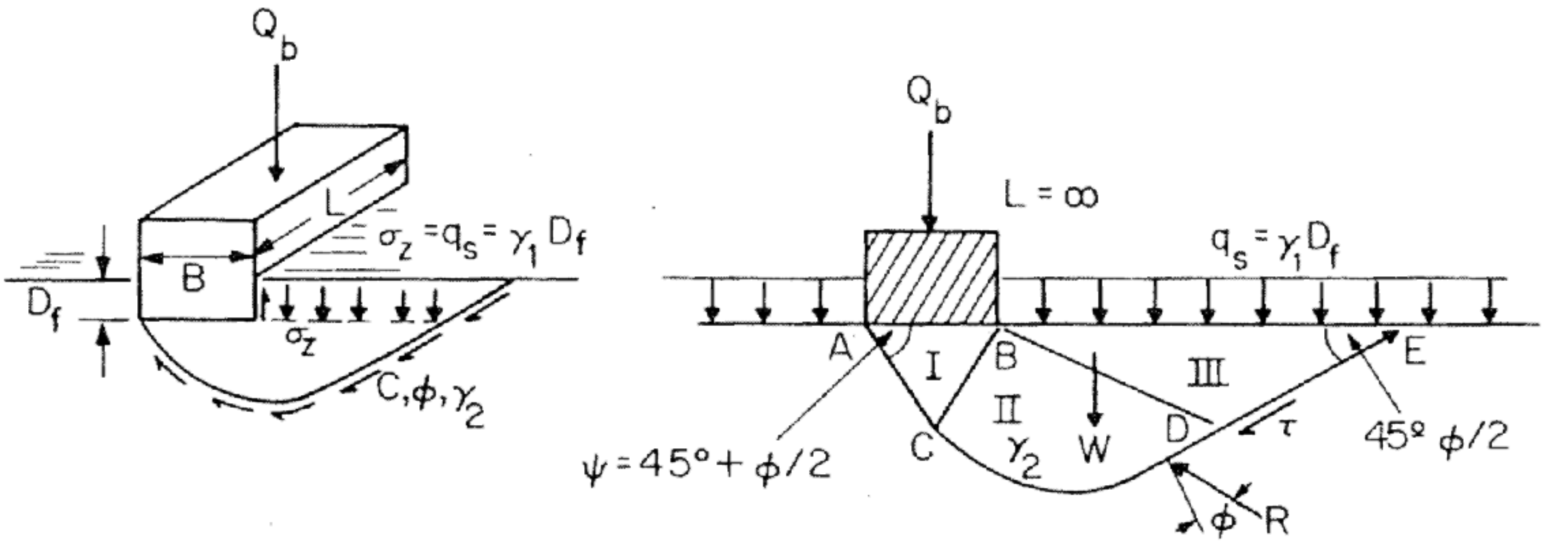
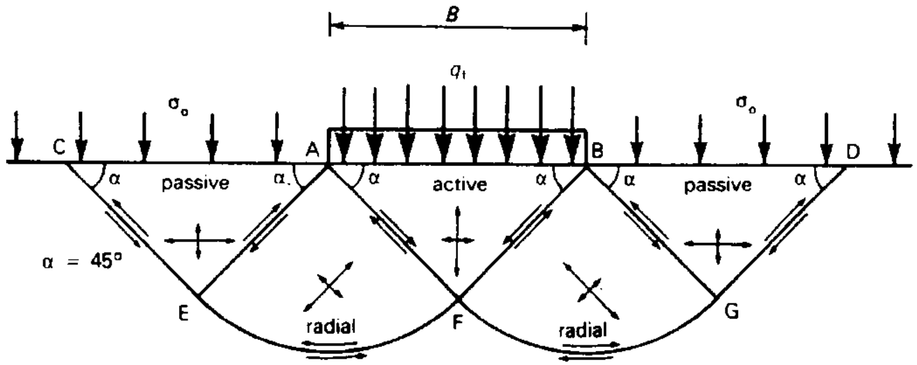
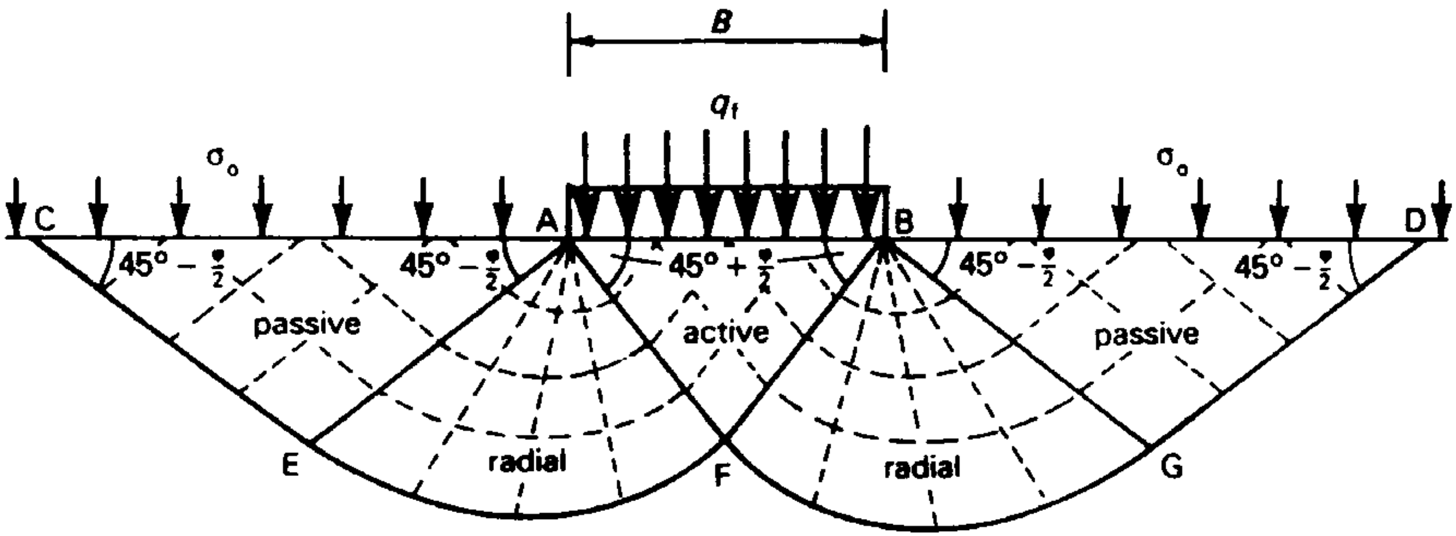



**FIG. 6.28** **The problem of the bearing capacity of shallow foundations failing in general shear with parameters *c* and *φ*. Boundaries are simplified. I = active Rankine zone; II = Prandtl zone; III = passive Rankine zone.**



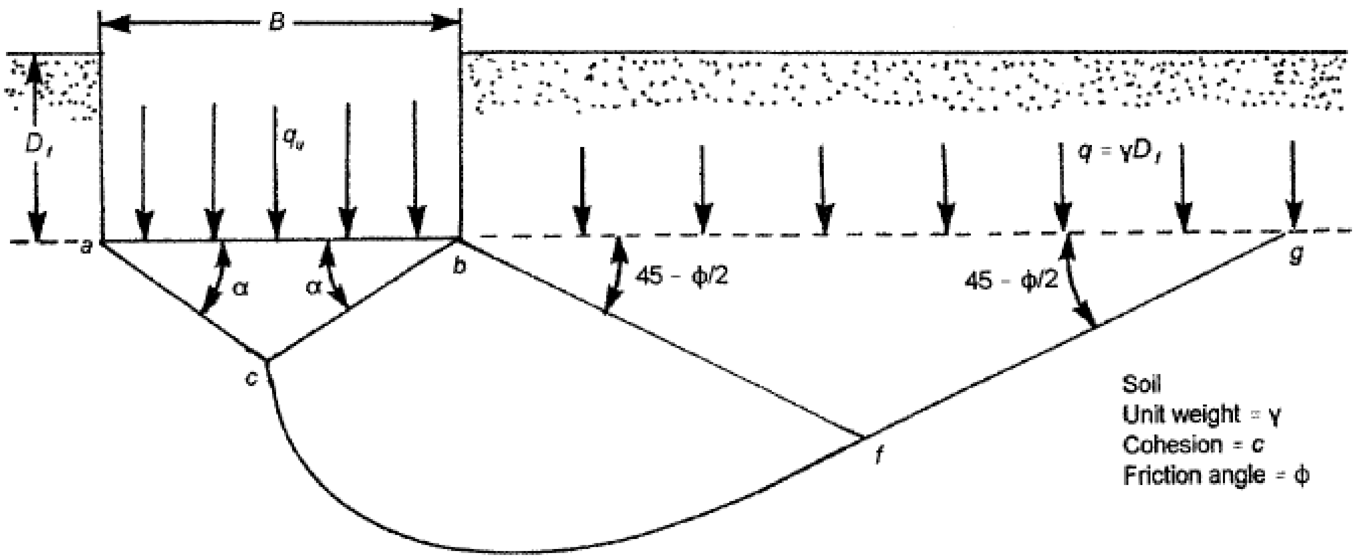
B
q_f
σ_o
C
A
B
D
α
passive
active
passive
α = 45°
E
F
G
radial
radial

B
q_f
σ_o
C
A
B
D
45° − φ/2
45° + φ/2
passive
active
passive
E
F
G
radial
radial

# 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

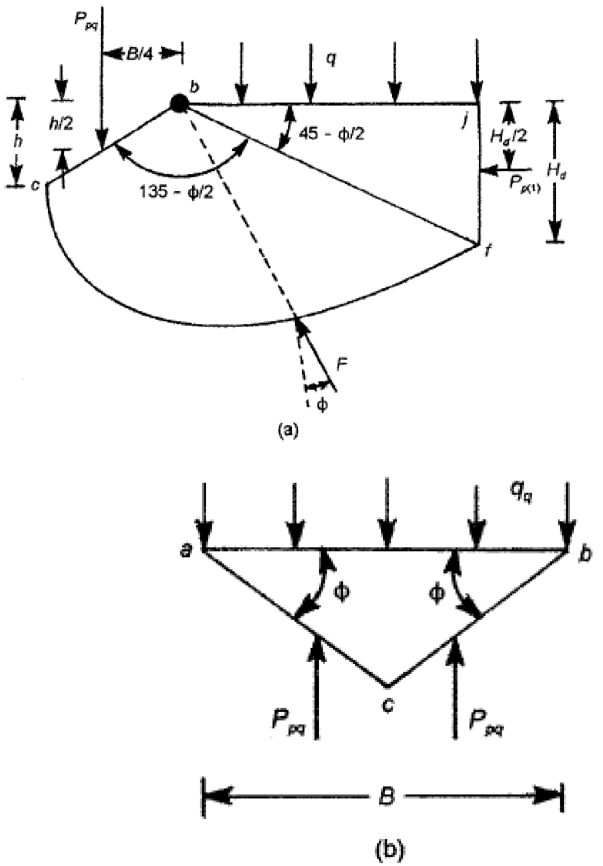



FIGURE 2.3 Determination of $P_{pq}$ ($\phi \neq 0$, $\gamma = 0$, $q \neq 0$, $c = 0$)

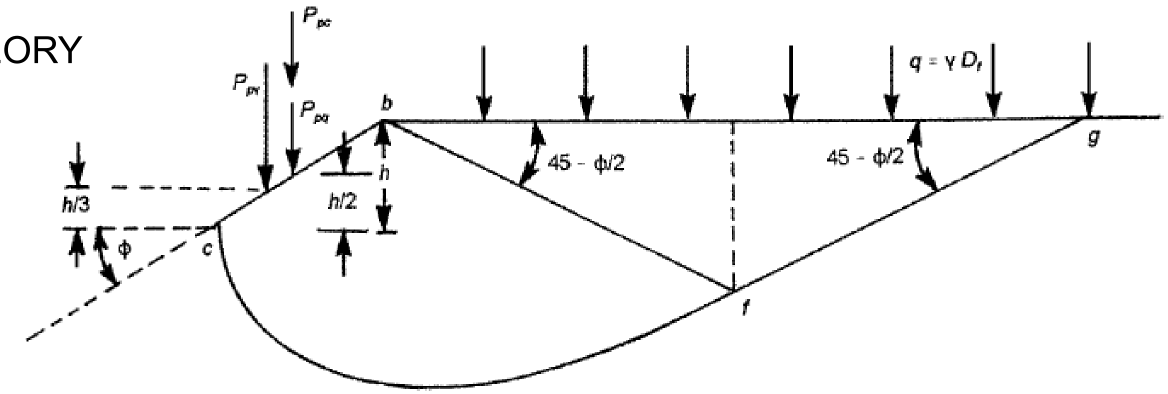



FIGURE 2.2 Passive force on the face *bc* of wedge *abc* shown in Fig. 2.1

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

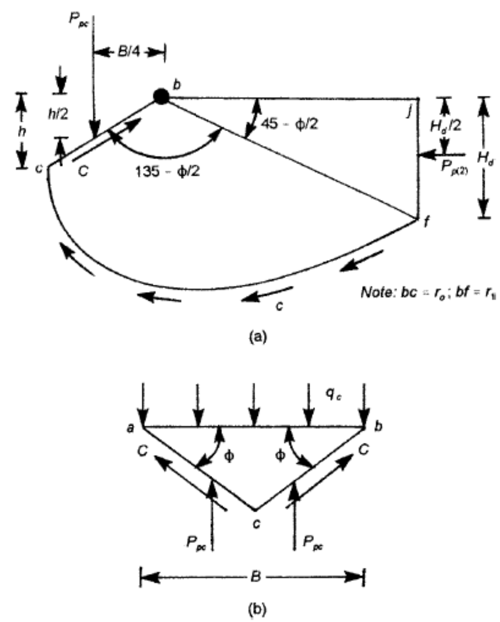
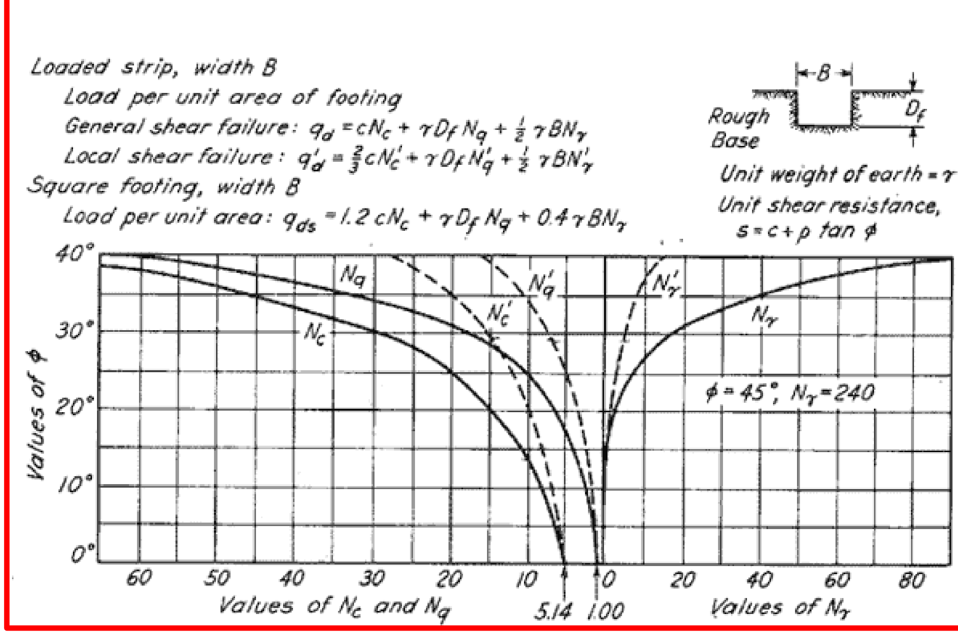



FIGURE 2.4 Determination of $P_{pc}$ ($\phi \neq 0$, $\gamma = 0$, $q = 0$, $c \neq 0$)

# Ultimate Bearing Capacity

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




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

where $N_c$, $N_q$, and $N_\gamma$ = 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)

| $\phi$ | $N_c$ | $N_q$ | $N_\gamma$ | $\phi$ | $N_c$ | $N_q$ | $N_\gamma$ | $\phi$ | $N_c$ | $N_q$ | $N_\gamma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 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)

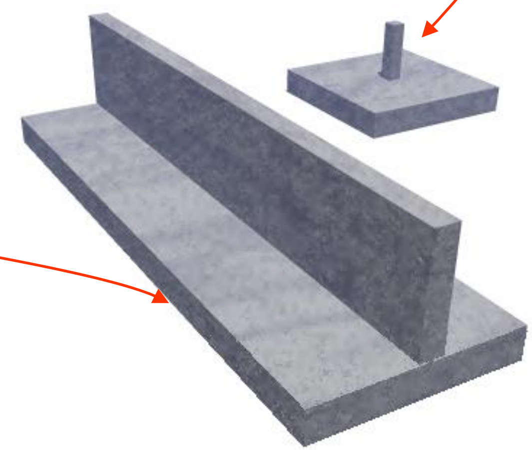
| $\phi$ | $N_c$ | $N_q$ | $N_\gamma$ | $\phi$ | $N_c$ | $N_q$ | $N_\gamma$ | $\phi$ | $N_c$ | $N_q$ | $N_\gamma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 5.70 | 1.00 | 0.00 | 17 | 14.60 | 5.45 | 2.18 | 34 | 52.64 | 36.50 | 38.04 |
| 1 | 6.00 | 1.1 | 0.01 | 18 | 15.12 | 6.04 | 2.59 | 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 |

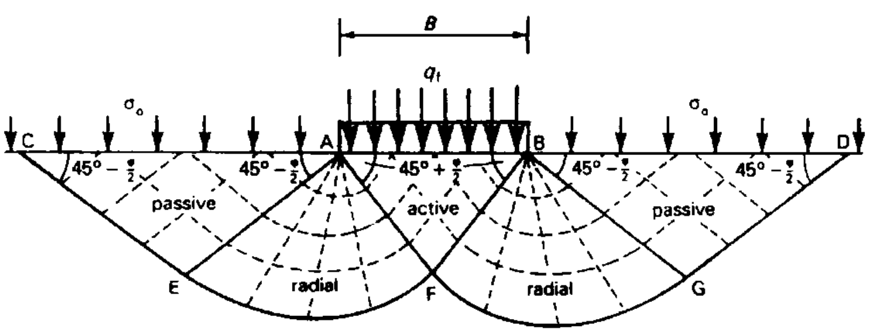
# 1- TERZAGHI'S BEARING CAPACITY THEORY

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

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

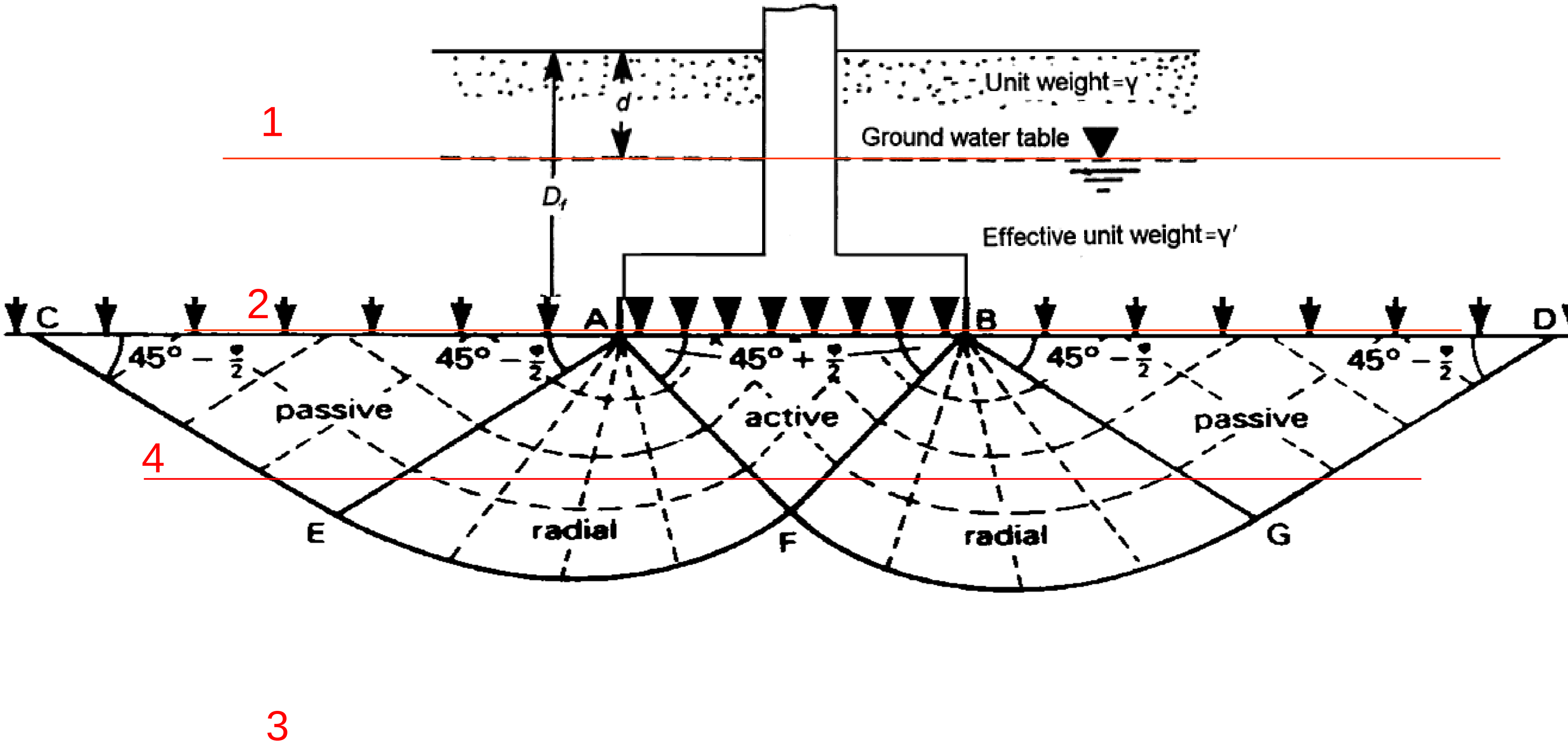
$$q_u = 1.3cN_c + qN_q + 0.3\gamma BN_\gamma \quad \text{(circular foundation; plan } B \times B\text{)}$$





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

# EFFECT OF WATER TABLE

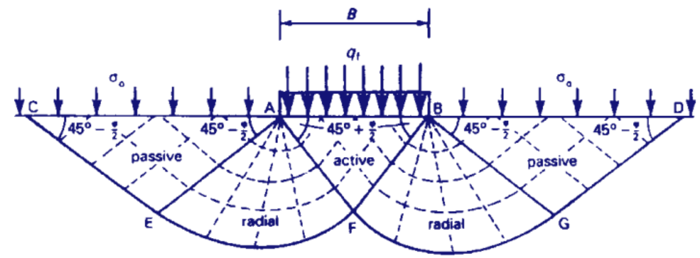


# MEYERHOF'S BEARING CAPACITY THEORY

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

where $N_c'$, $N_q'$, and $N_\gamma'$ = bearing capacity factors

$B$ = width of the foundation




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

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

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

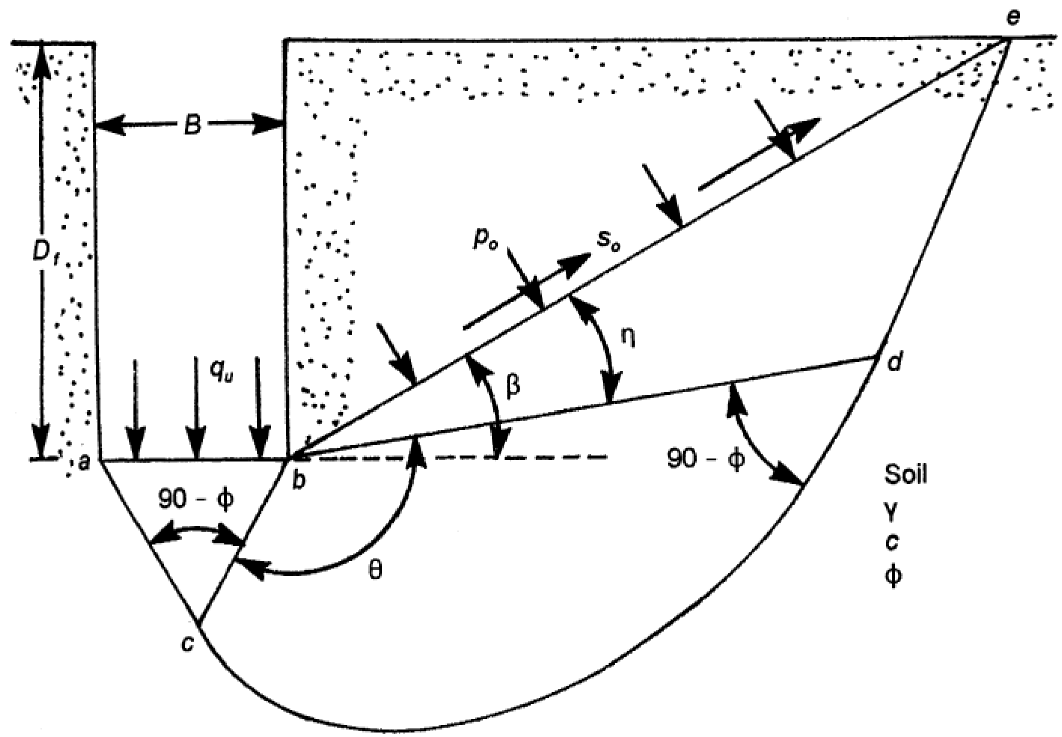



FIGURE 2.7 Slip line fields for a rough continuous foundation

**TABLE 2.3** **Variation of Meyerhof's Bearing Capacity Factors $N_c$, $N_q$, and $N_\gamma$ [Eqs. (2.66), (2.67), and (2.72)]**

| $\phi$ | $N_c$ | $N_q$ | $N_\gamma$ | $\phi$ | $N_c$ | $N_q$ | $N_\gamma$ | $\phi$ | $N_c$ | $N_q$ | $N_\gamma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 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

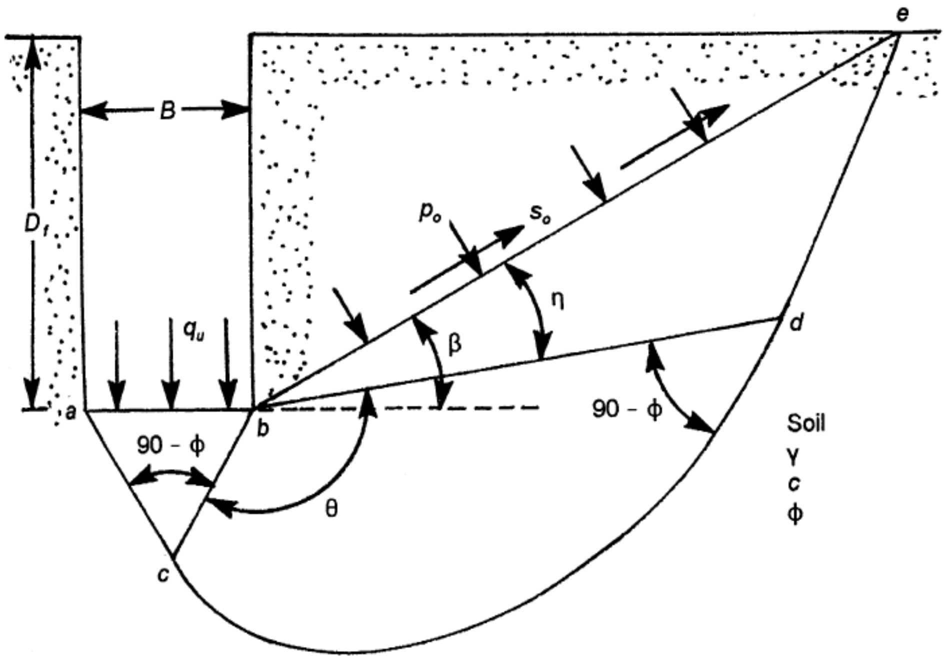



FIGURE 2.7 Slip line fields for a rough continuous foundation

**TABLE 2.5** Summary of Shape and Depth Factors

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

## ULTIMATE BEARING CAPACITY UNDER INCLINED AND ECCENTRIC LOADS

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

where $N_c$, $N_q$, $N_\gamma$ = 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

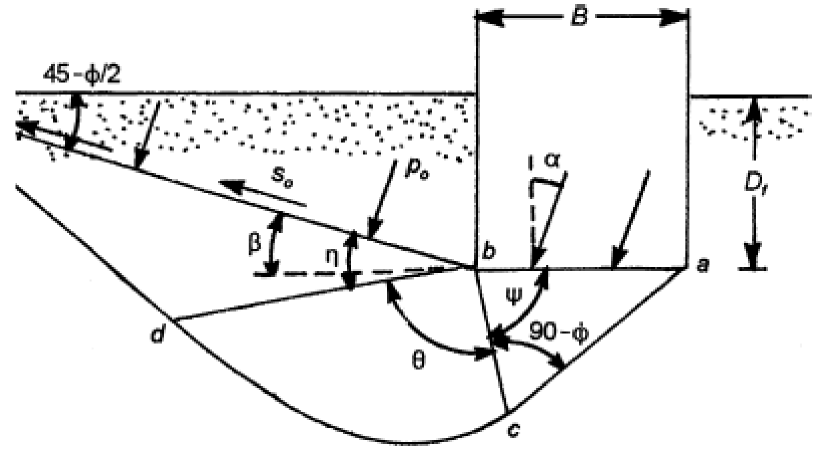



FIGURE 3.1 Plastic zones in soil near a foundation with inclined load

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

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

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

↑ 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)

$\alpha$ = 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