# CHAPTER-3

## Understand the bearing capacity of soil.

3.1 Define the bearing capacity of soil.
3.2 Explain the ultimate bearing capacity of soil.
3.3 Mention the Tarzaghi’ s bearing capacity factors.
3.4 Express the equations for determination of 3.5ultimate bearing capacity of soil for square and circular footing.
3.6Calculate the ultimate bearing capacity of sandy soil.
3.7 Explain the allowable bearing capacity of clay.
3.8 Explain the allowable bearing capacity of sand.
3.9 Describe the method of plate bearing test.
3.10 Calculate the allowable bearing capacity of soil.
3.11 Explain the methods for improving bearing capacity of soil.

# FOUNDATION ENGINEERING

# BEARING CAPACITY OF SHALLOW FOUNDATIONS

# *DEFINITION OF SOIL*

*Soil is a mixture of irregularly shaped mineral particles of various sizes containing voids between particles. The particles are a by-product of mechanical and chemical weathering of rock and described as gravels, sands, silts, and clays..*

*Any manmade structure should, one way or another, rest and/or transmit its load to the underlying soil*

# BEARING CAPACITY OF SOILS

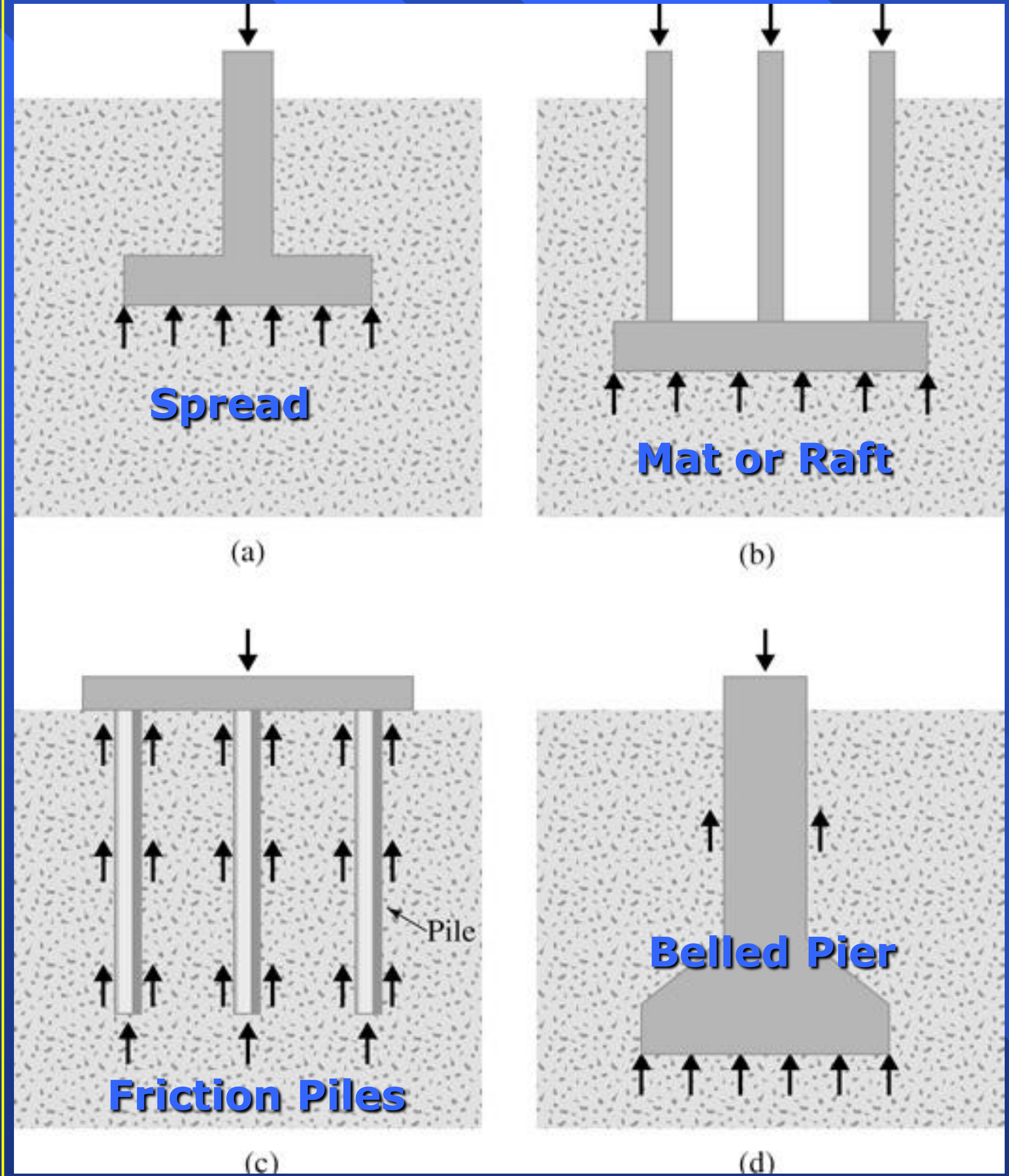
***Bearing capacity*** *is the ability of soil to safely carry the pressure placed on the soil from any engineered structure without undergoing a shear failure with accompanying large settlements.*

*Therefore, **settlement analysis** should generally be performed since most structures are sensitive to excessive settlement.*

# Bearing Capacity of Shallow Foundations

- ***Soil Bearing Capacity is Controlled by:***
  - ***Bearing Capacity Analysis:***
    - » *Terzaghi's Theory (1943), based on Prandtl theory (1920).*
    - » *General B.C. Equation.*
  - ***Settlement Analysis:***
    - » *Immediate Settlement*
    - » *Consolidation Settlement*

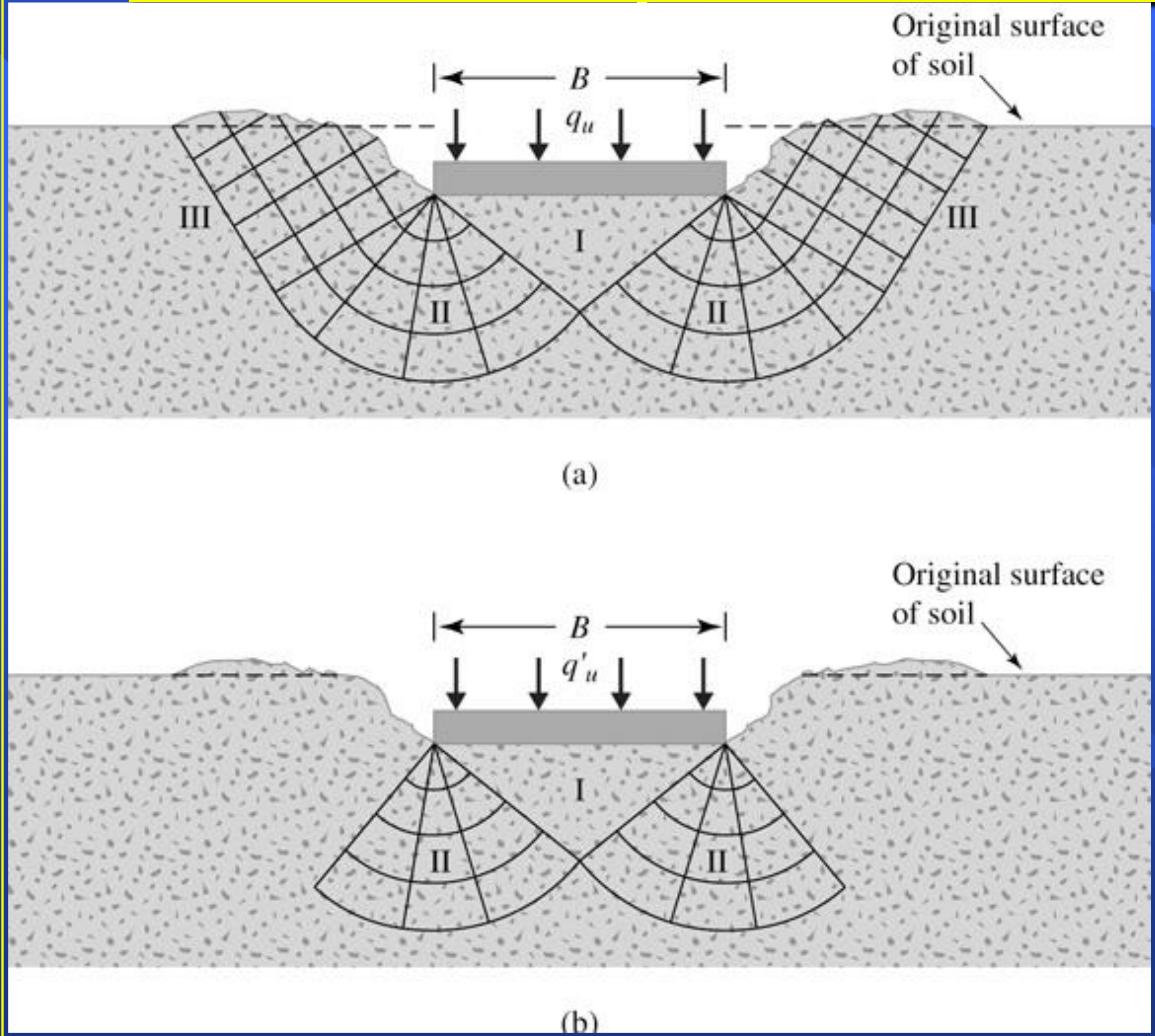
# Types of Foundations




**Shallow Foundations**

**Deep Foundations**

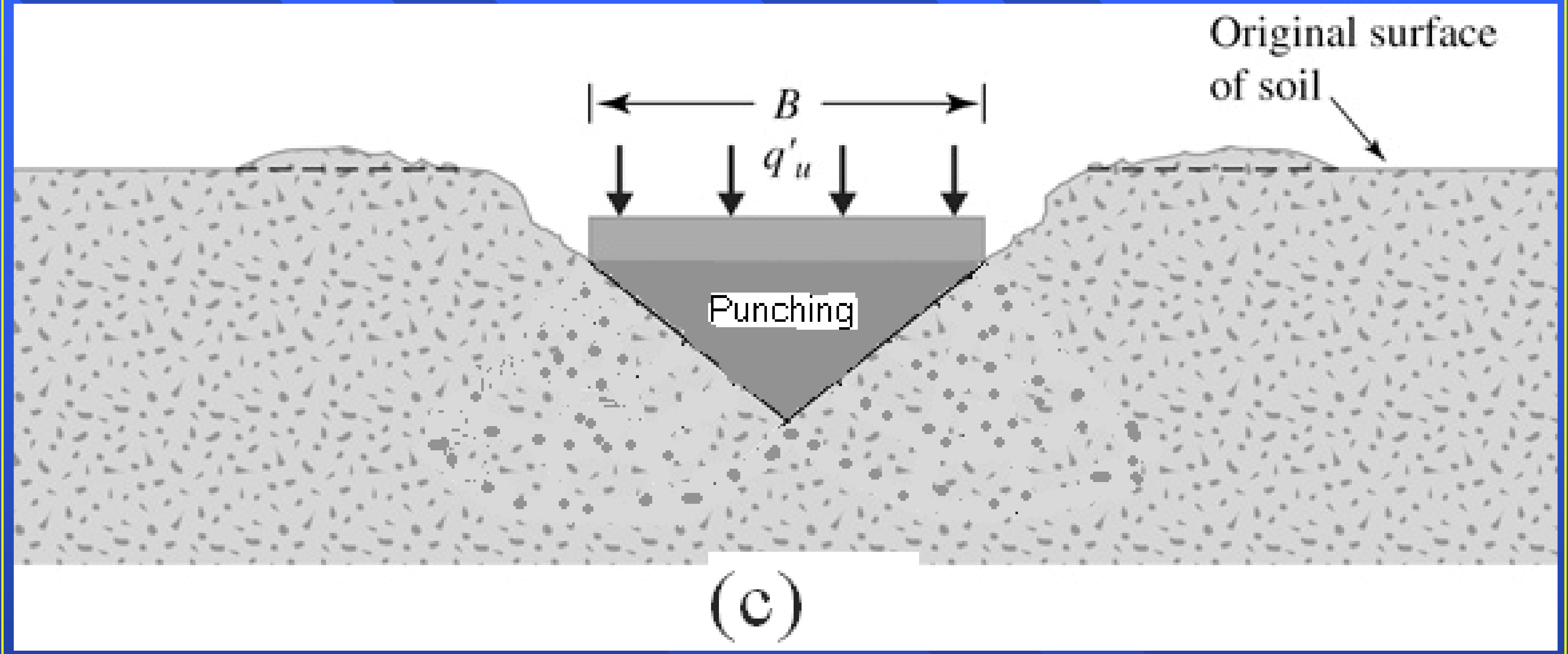
# Failure Modes for Shallow Foundations




*General Shear Failure, Zones I, II, III, Dense Sand*

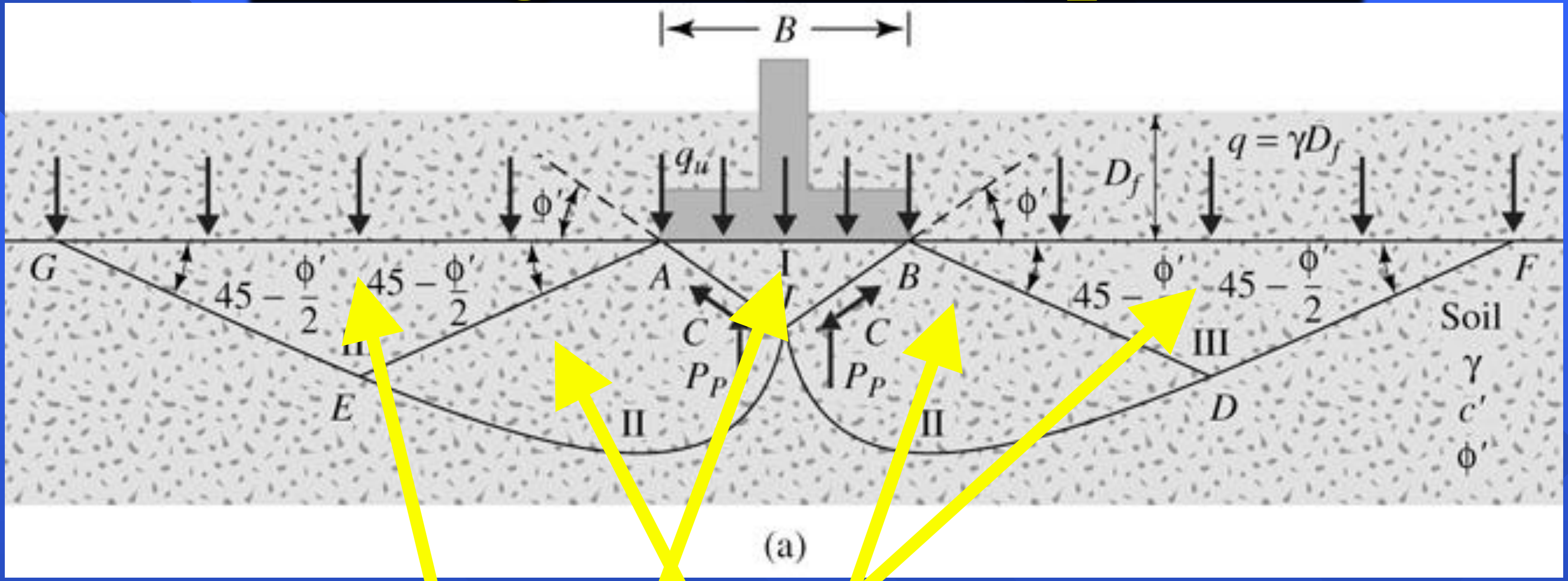
*Local Shear Failure, Zones I, II, Medium Dense Sand*

# Failure Modes, Continued




***Punching Failure, Zone I Only, Loose Sand and Soft Clay***

# Terzaghi's Assumptions




***Zone I, Active.***

***Zones II, Transition.***

***Zones III, Passive.***

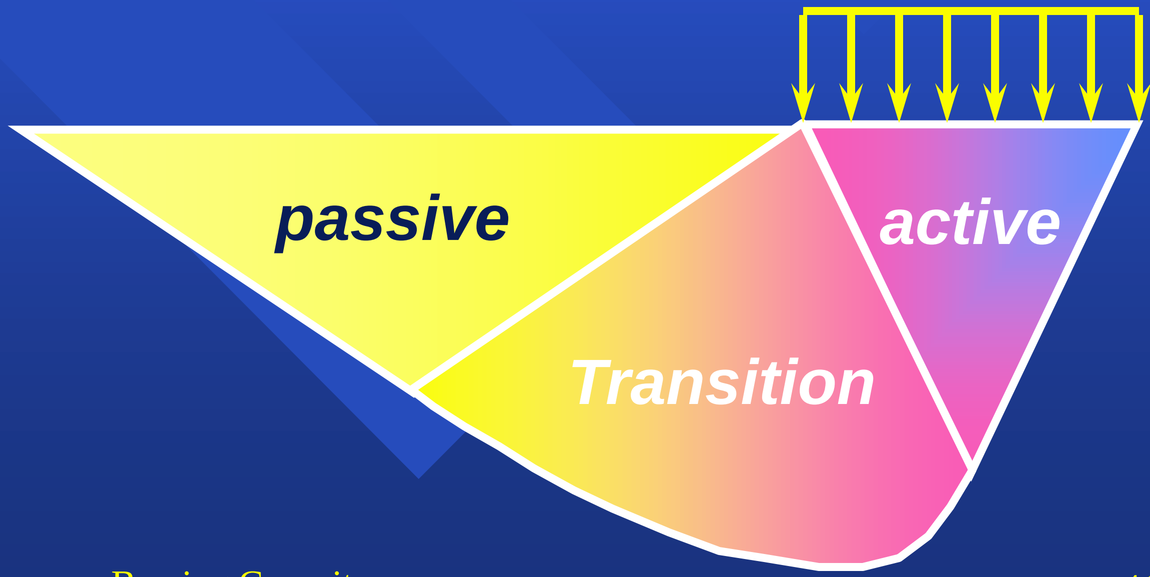
# Terzaghi B/C Assumptions

**Three zones do exist:**

1- Active zone, just below the foundation.

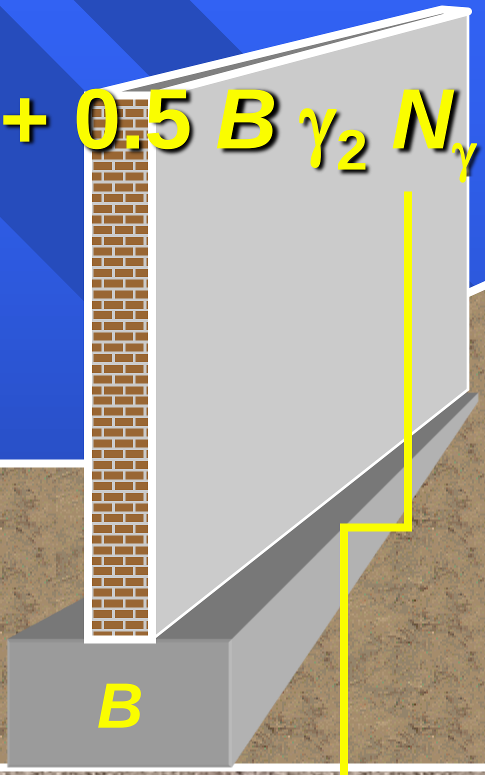
2- Transition zone, between the active and passive zones.

3- Passive zone, near the ground surface, just beside the foundation.



# Terzaghi Bearing Equation for Strip Footing

$$q_{u\,net} = c\,N_c + \gamma_1\,D\,(N_q - 1) + 0.5\,B\,\gamma_2\,N_\gamma$$




**Overburden**

$\gamma_1 D$

**Failure Zone (depth ≈ 2B)**

**Generalized soil strength : c, $\phi$ (drainage as applicable)**

**Soil unit weight : $\gamma_2$ (total or effective as applicable)**

# Terzaghi Bearing Equation

$q_{ult} =$

$q_{ult} = c\,N_c$ Cohesion Term

$q_{ult} = c\,N_c + \gamma_1\,D\,N_q$ Above F.L.

$q_{ult} = c\,N_c + \gamma_1\,D\,N_q + 0.5B\,\gamma_2\,N_\gamma$

Below F.L.

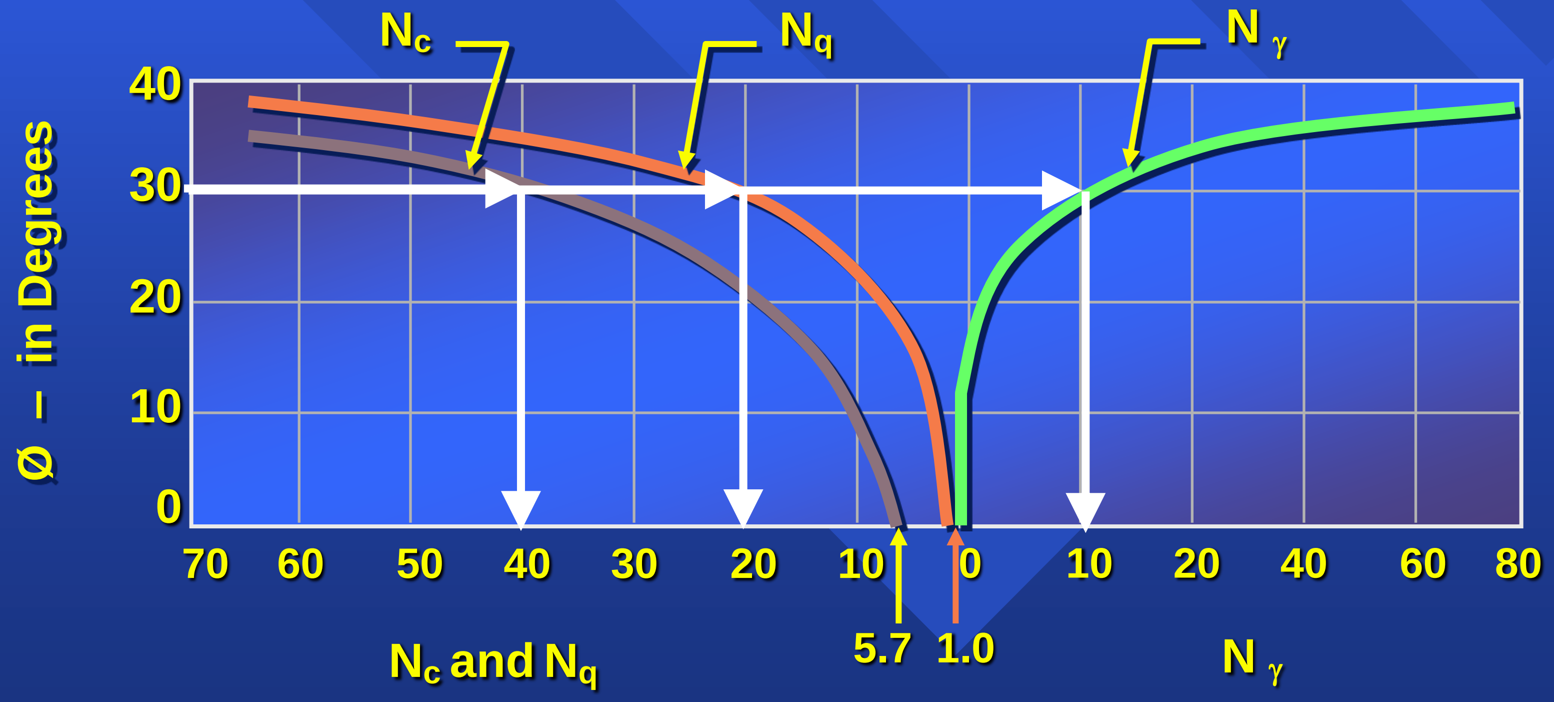
# Terzaghi Bearing Equation

***$N_c$, $N_q$, $N_\gamma$ are Terzaghi B/C Coefficients, f($\phi$)***

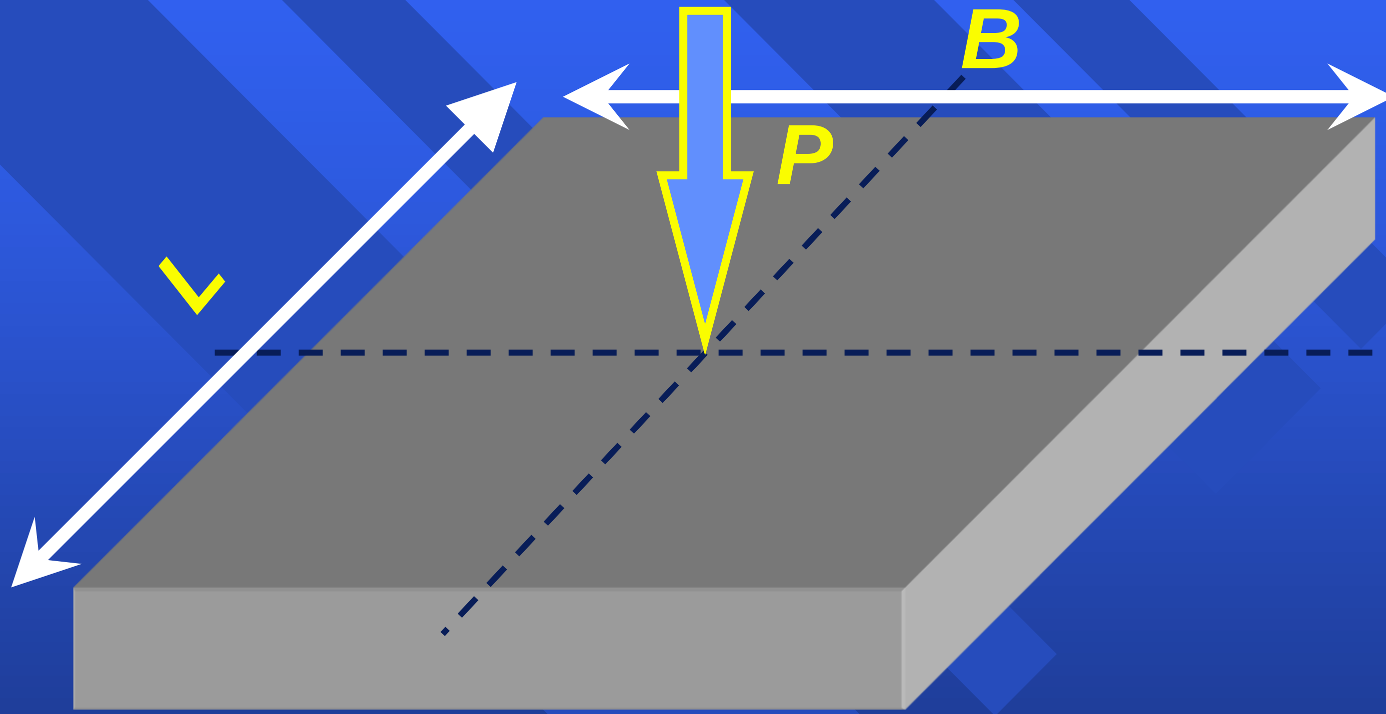
***C, $\phi$ are the soil shear strength parameters***

# Bearing Capacity Factors

$$q_{ult} = c\,N_c + \gamma_1\,D\,N_q + 0.5\,B\,\gamma_2\,N_\gamma$$



# Terzaghi Bearing Equation



# Foundation Shape Factors

$$q_{ult} = c.N_c \lambda_c + \gamma_1 D N_q \lambda_q + 0.5B \gamma_2 N_\gamma \lambda_\gamma$$

## For Rectangular or Square Footing

$\lambda_c = 1.0 + 0.30 B/L$

$\lambda_q = 1.0$

$\lambda_\gamma = 1.0 - 0.30 B/L$

Egyptian Code of Practice

## For Circular Footing

$\lambda_c = 1.30$

$\lambda_q = 1.00$

$\lambda_\gamma = 0.70$

Egyptian Code of Practice

# Terzaghi's Equation for Different Foundation Shapes

## Continuous (Strip) Footing:

$$q_u = c\,N_c + \gamma_1\,D\,N_q + 0.5\,B\,\gamma_2\,N_\gamma$$

$$q_{u\text{-}net} = c\,N_c + \gamma_1\,D\,(N_q - 1) + 0.5\,B\,\gamma_2\,N_\gamma$$

## Square Footing:

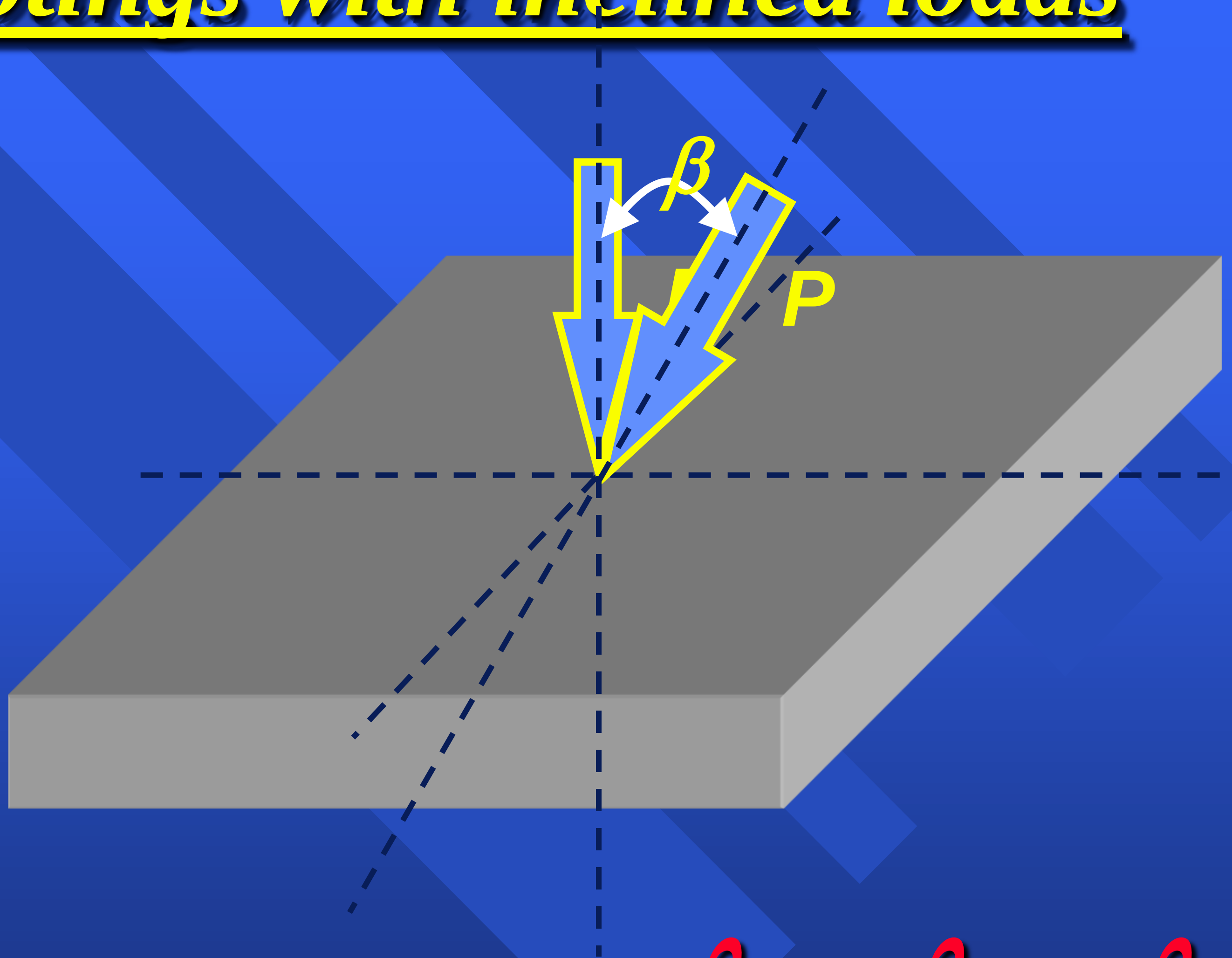
$$q_{u\text{-}net} = 1.3\,c\,N_c + \gamma_1\,D\,(N_q - 1) + 0.35\,B\,\gamma_2\,N_\gamma$$

## Circular Footing:

$$q_{u\text{-}net} = 1.3\,c\,N_c + \gamma_1\,D\,(N_q - 1) + 0.35\,B\,\gamma_2\,N_\gamma$$

$N_c$, $N_q$, $N_\gamma$ = B.C. Factors

# Footings with inclined loads




## *Inclined Load Factors* $\lambda_{ci}, \lambda_{qi}, \lambda_{gi}$

# Inclined Loads

$$\lambda_{ci} = \lambda_{qi} = (1.0 - \beta / 90)^2$$

$$\lambda_{\gamma i} = (1.0 - \beta / \phi)^2$$

***Correction Factors, $\lambda_{ci}$, $\lambda_{qi}$, and $\lambda_{\gamma i}$ are empirically determined from experiments***

# Inclined Load Factors

$$q_{ult} = c\,N_c\,\lambda_c\,\lambda_{ci} + \gamma_1\,D\,N_q\,\lambda_q\,\lambda_{qi} + 0.5B\,\gamma_2\,N_\gamma\,\lambda_\gamma\,\lambda_{\gamma i}$$

## Inclined Load Factors:

$$\lambda_{ci} = \lambda_{qi} = (1.0 - \beta/90)^2$$

$$\lambda_{\gamma i} = (1.0 - \beta/\phi)^2$$

# Bearing Capacity of Clay, $\phi = 0$

$$q_{ult} = c\,N_c + \gamma_1\,D\,N_q + 0.50\,B\,\gamma_2\,N_\gamma$$

**For Clay:**

$N_c = 5.70$, $N_q = 1.0$, $N_\gamma = 0.0$

$$q_{ult} = 5.70\,c_u + \gamma_1\,D$$

$$q_{ult\,net} = 5.70\,c_u$$

$$q_{all\,net} = 1.90\,c_u$$

$$c_u = q_u/2$$

$q_u$ Unconfined compressive strength

# Bearing Capacity of Sand, $c_u = 0$

$$q_{ult} = c\,N_c + \gamma_1\,D\,N_q + 0.50\,B\,\gamma_2\,N_\gamma$$

***For Sand:***

***$N_c$, $N_q$, $N_\gamma$ are determined from curve, and $c_u = 0$, then:***

$$q_{ult} = \gamma_1\,D\,N_q + 0.50\,B\,\gamma_2\,N_\gamma$$

# Gross and Net Bearing Capacity

$$q_{all} = \frac{q_{ult}}{F.S.}$$ **Gross allowable bearing capacity**

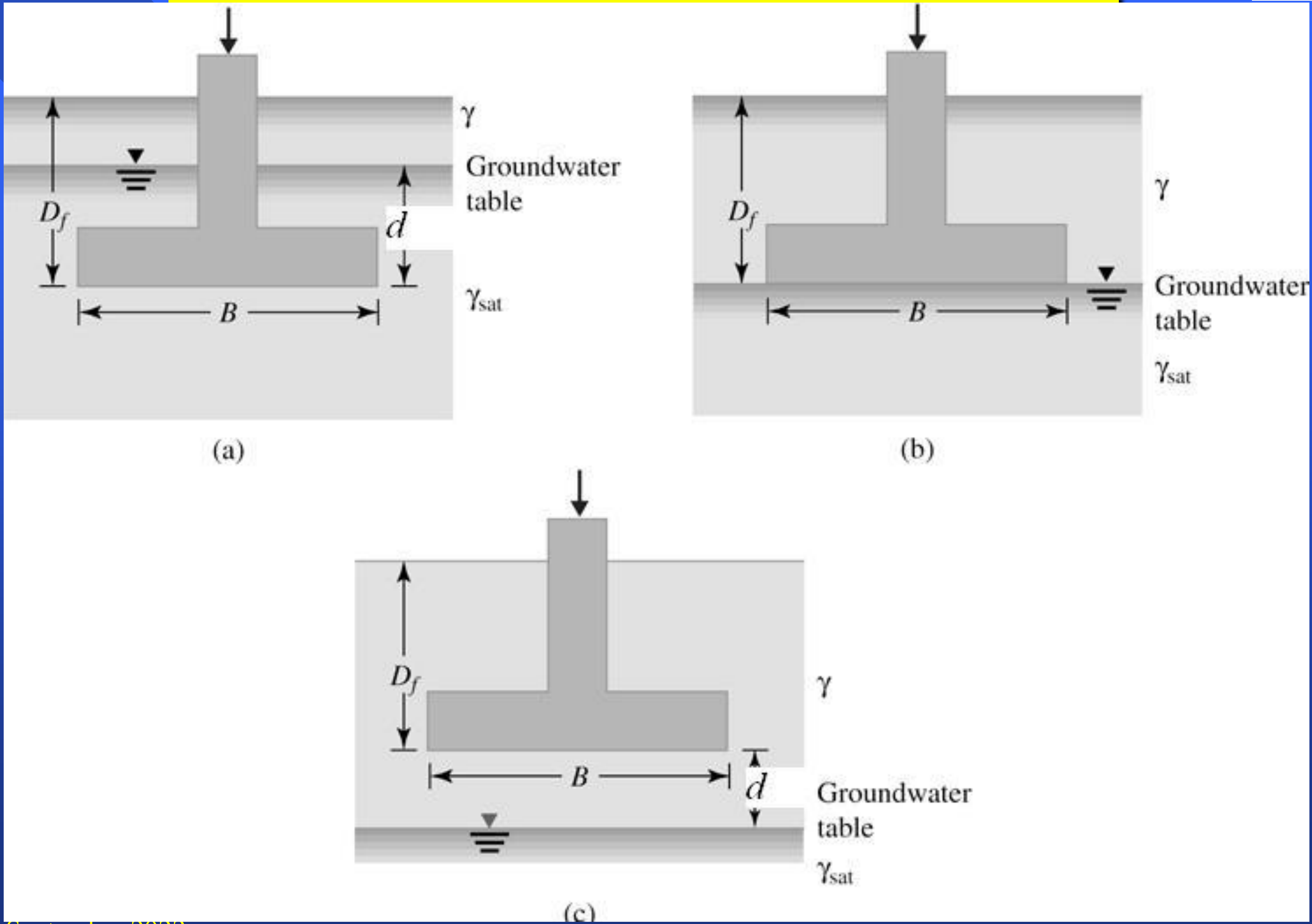
$$q_{ult} = q_{ult\ net} + \gamma_1 D$$ **Gross ultimate B/C**

$$q_{all} = \frac{q_{ult\ net}}{F.S.} + \gamma_1 D$$ **Gross allowable B/C**

$$q_{all\ net} = \frac{q_{ult\ net}}{F.S.}$$ **Net allowable B/C**

$\gamma_1 D$ **is the overburden pressure**

# Effect of Water Table on B/C



# Effect of Water Table on B/C

$$q_{ult} = c\,N_c + \gamma_1 D\,N_q + 0.5B\,\gamma_2\,N_\gamma$$

**Case (a):**

$\gamma_1 D = \gamma_b (D_f - d) + \gamma_{sub}\,d,$

$\gamma_2 = \gamma_{sub}$

**Case (b):**

$\gamma_1 D = \gamma_b D_f,$

$\gamma_2 = \gamma_{sub}$

**Case (c):**

$\gamma_1 D = \gamma_b D_f,$

If , $d \le B$, then $\gamma_2 = \gamma_{sub}$

If , $d > B$, then $\gamma_2 = \gamma_b$

$\gamma_b$ = Bulk unit weight

$\gamma_{sub}$ = Submerged Unit weight,

$\gamma_{sub} = \gamma_{sat} - \gamma_{water}$

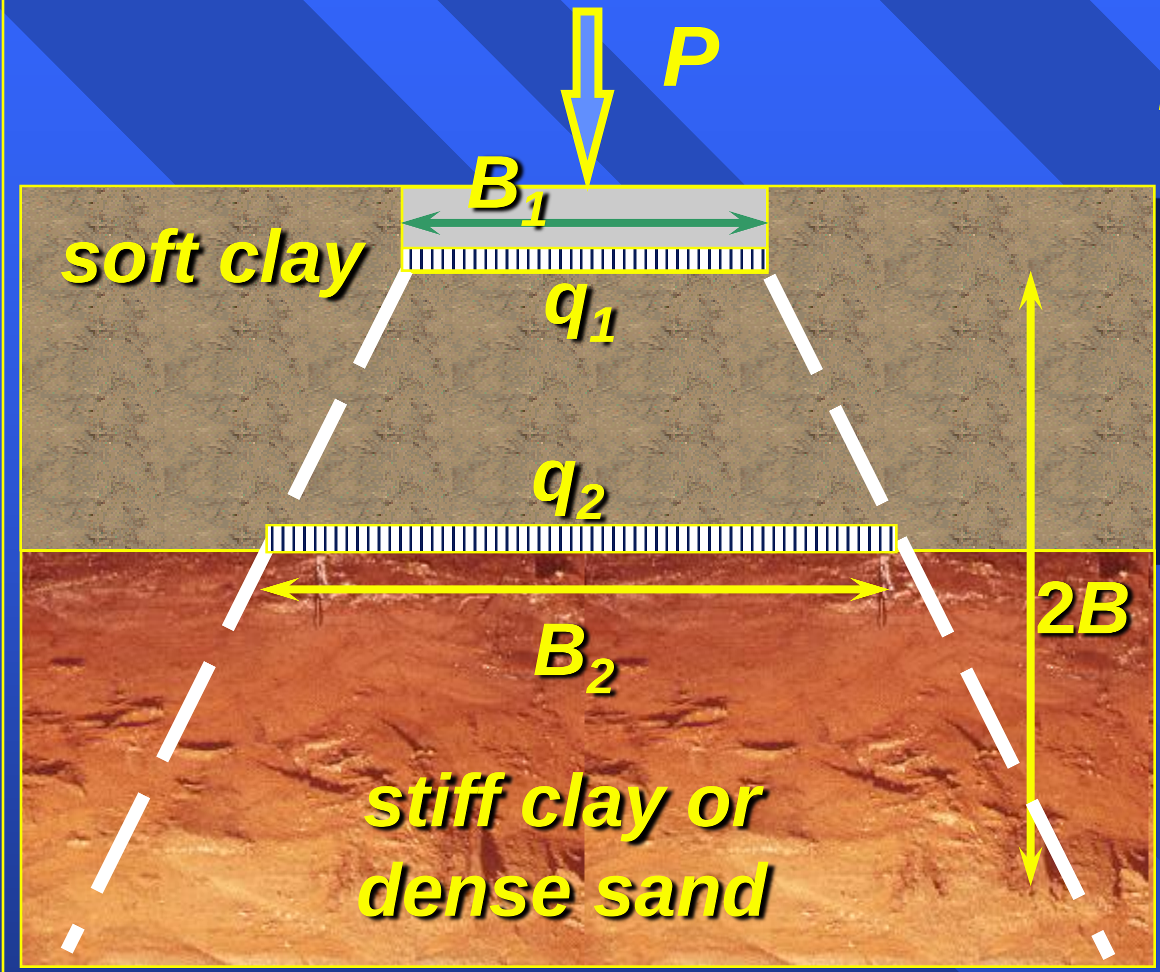
# ***Settlement Analysis***

***Allowable bearing capacity, as calculated from the settlement analysis, usually controls the soil bearing capacity, especially in clay and silt.***

***The maximum allowable settlement is set first, then the stress (bearing pressure) that will induce that settlement will be the allowable bearing capacity.***

***For stratified soils, 2:1 stress distribution is used to determine the stresses at the top of each layer.***

# Bearing Capacity in Stratified Deposits




$$P = q_1\, A_1 = q_1\, B_1\, L_1$$

$$P = q_2\, A_2 = q_2\, B_2\, L_2$$

$q_1$ is the allowable bearing capacity for layer 1

$q_2$ is the allowable bearing capacity for layer 2, and so on

The allowable bearing capacity as determined from either the shear strength parameters or the settlement analysis.

# Settlement Analysis

Total Settlement =

Immediate Settlement +

Primary Consolidation Settlement +

Secondary Consolidation Settlement

## In Sand:

Total Settlement ≈ Immediate settlement

## In Silts, Stiff and Medium Clays:

Total Settlement ≈ Immediate Settlement +

Primary Consolidation Settlement

# Settlement Analysis

## In Soft Clays, Silts and Organic Soils:

***Total Settlement = Immediate Settlement + Primary Consolidation Settlement + Secondary Consolidation Settlement***

# Example

***A footing 1.8 m x 2.5 m is located at a depth of 1.5 m below the ground surface, in an over-consolidated clay layer. The groundwater level is 2 m below the ground surface. The unconfined compressive strength of that clay is 120 kPa, $\gamma_{bulk}$ = 18 kN/m$^3$, and $\gamma_{sat}$ = 20 kN/m$^3$. Determine the net allowable bearing capacity, assuming a factor of safety of 3.***

# Solution

$$q_{ult} = c\, N_c\, \lambda_c + \gamma_1\, D\, N_q\, \lambda_q + 0.5B\, \gamma_2\, N_\gamma\, \lambda_\gamma$$

For Clay: $N_c = 5.7$, $N_q = 1.0$, $N_\gamma = 0.0$

## For Rectangular Footing:

$\lambda_c = 1.0 + 0.30\ B/L = 1.0 + 0.30 \times 1.8/2.5 = 1.22$

$\lambda_q = 1.0$

$$q_{ult\ net} = c\, N_c\, \lambda_c + \gamma_1\, D\, (N_q - 1)\, \lambda_q$$

$q_u = 120$ kPa, $c_u = 60$ kPa

$$q_{ult\ net} = 60 \times 5.7 \times 1.22 = 417.20$$

$$q_{all\ net} = \frac{q_{ult\ net}}{F.S.} = \frac{417.2}{3} = 139.08\ kN/m^2$$

$$q_{all\ net} = 13.91\ t/m^2 = 1.39\ kg/cm^2$$