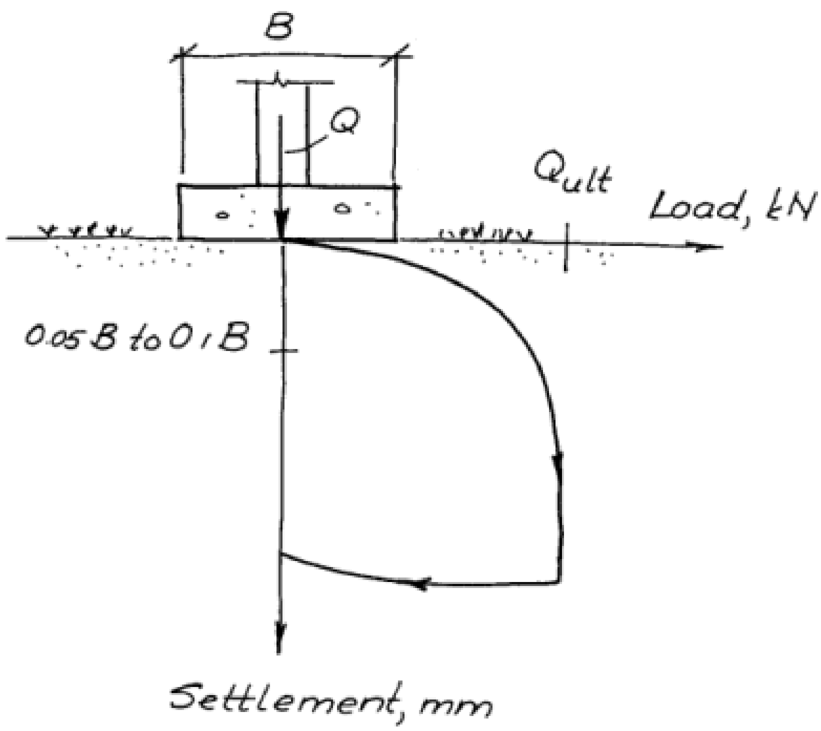
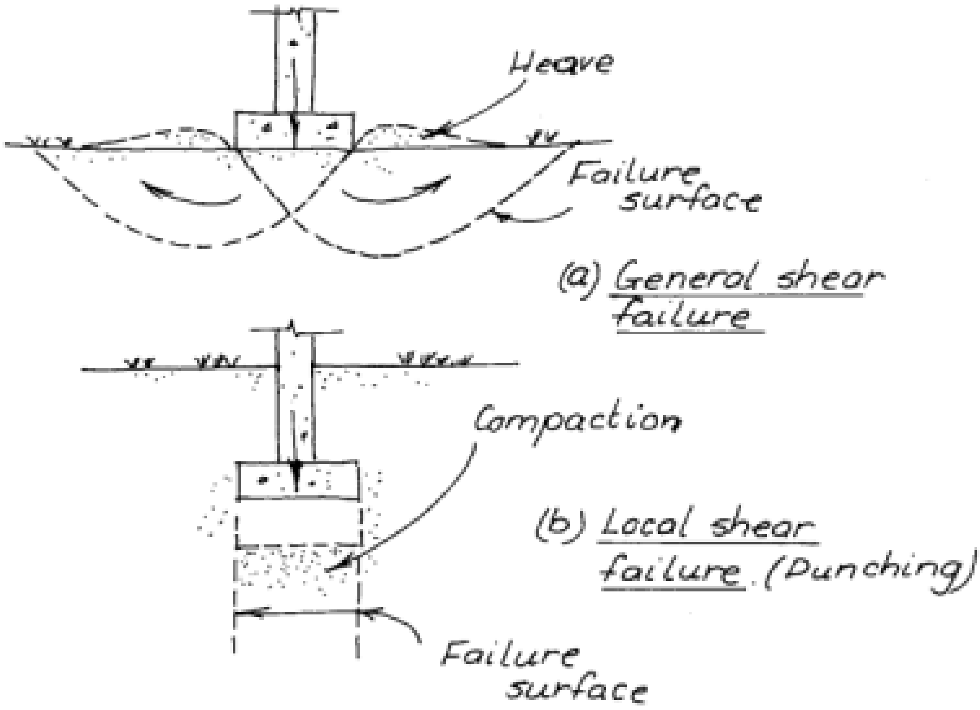
Bearing capacity of foundations

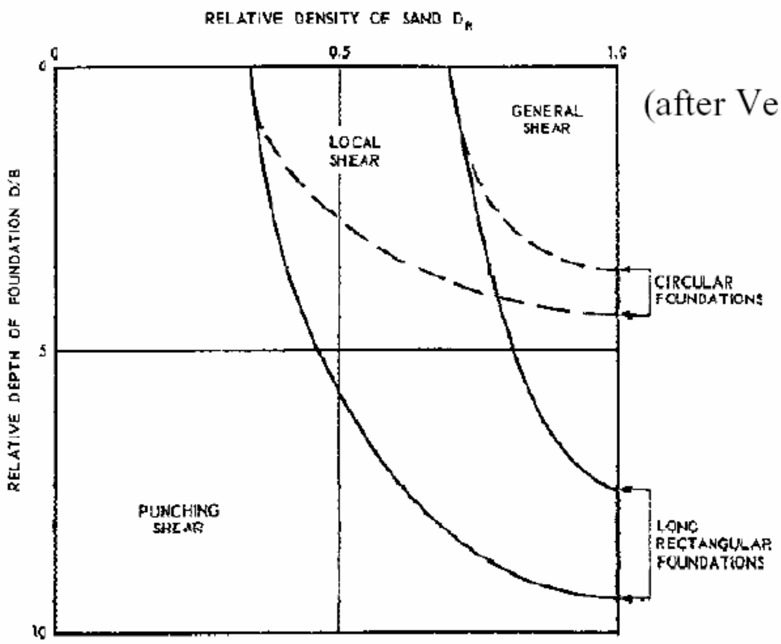
Bearing capacity of surface foundation



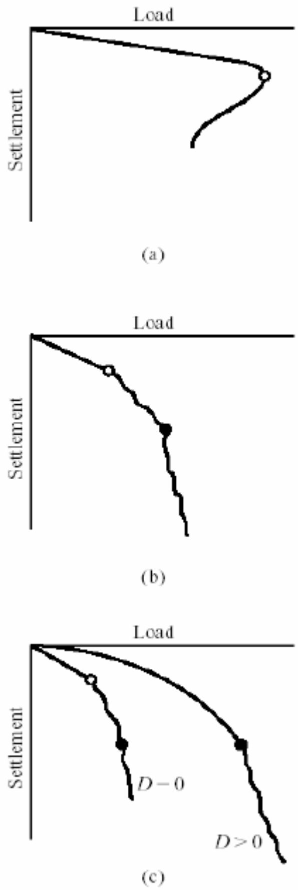
Failure mechanism of surface foundation



Soil Conditions and Bearing Capacity Failure



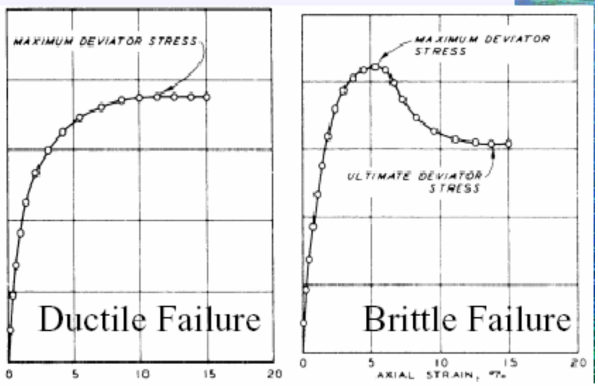
(after Vesić (1973))



Load Displacement Curves

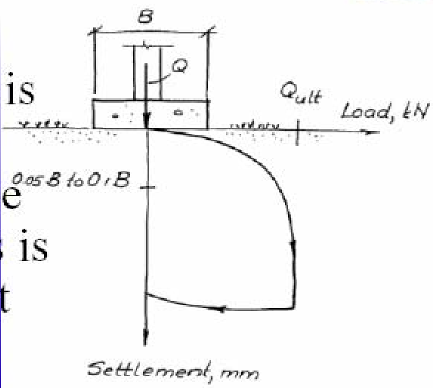
(after Vesić (1973))

a) General Shear Failure
b) Local Shear Failure
c) Punching Shear Failure

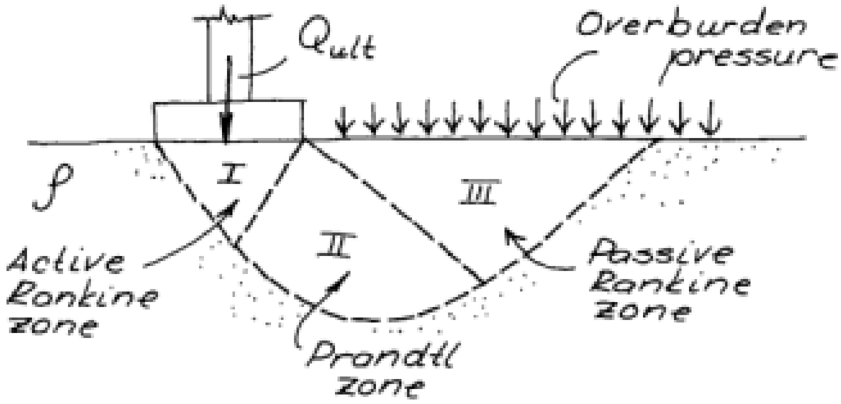


Comments on Shear Failure

- Usually only necessary to analyse general shear failure
- Local and punching shear failure can usually be anticipated by settlement analysis
- Failure in shallow foundations is generally settlement failure; bearing capacity failure must be analysed, but in practical terms is usually secondary to settlement analysis



Failure zones below surface foundation-Terzaghi's method



$$q_{ult} = q_c + q_q + q_\gamma$$

q_c: Cohesion
q_q: Overburden pressure
q_γ: Unit weight of soil

Assumptions for Terzaghi's Method

- Depth of foundation is less than or equal to its width
- No sliding occurs between foundation and soil (rough foundation)
- Soil beneath foundation is homogeneous semi-infinite mass
- Mohr-Coulomb model for soil
- General shear failure mode is the governing mode (but not the only mode)

Assumptions for Terzaghi's Method

- No soil consolidation occurs
- Foundation is very rigid relative to the soil
- Soil above bottom of foundation has no shear strength; is only a surcharge load against the overturning load
- Applied load is compressive and applied vertically to the centroid of the foundation
- No applied moments present

Terzaghi's bearing capacity theroy

$$q_u = cN_c S_c + \overline{q} N_q S_q + 0.5\gamma' B N_\gamma S_\gamma$$

Bearing Capacity Factors: N_c, N_q, $N_r = f(\phi)$

Shape Factor	S_c	S_q	S_r
Square	1.3	1	0.8
Continuous	1.0	1.0	1.0
Round	1.3	1	0.6

Terzaghi Equations and Factors

Loaded strip, width B

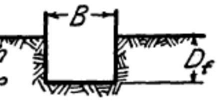
Total load per unit length of footing

General shear failure: $Q_d = B(cN_c + \gamma D_f N_q + \frac{1}{2}\gamma B N_\gamma)$

Local shear failure: $Q'_d = B(\frac{2}{3}cN'_c + \gamma D_f N'_q + \frac{1}{2}\gamma B N'_\gamma)$

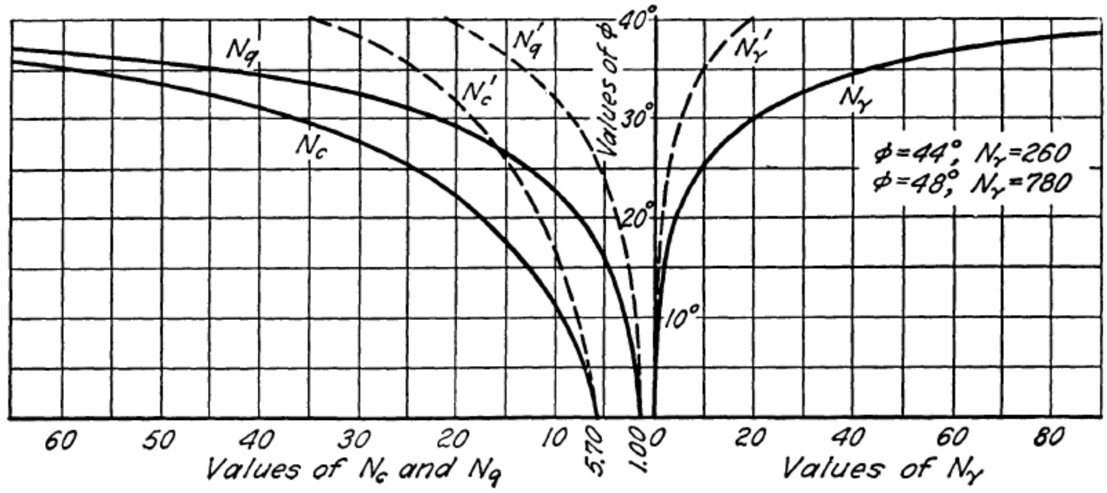
Square footing, width B

Total critical load: $Q_{d_s} = B^2(1.3cN_c + \gamma D_f N_q + 0.4\gamma B N_\gamma)$



Unit weight of earth $= \gamma$

Unit shear resistance, $S = c + \sigma \tan\phi$



Terzaghi Bearing Factors

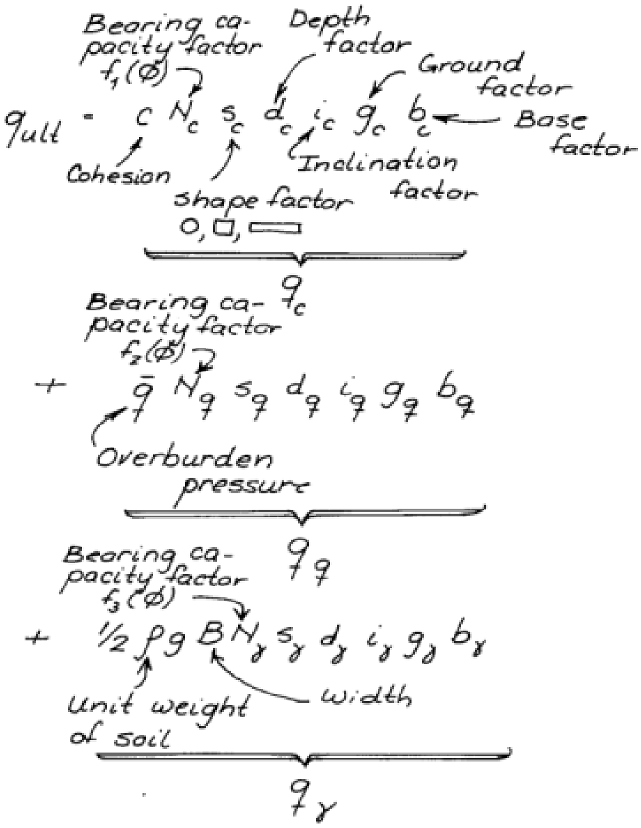
$$N_c = (N_q - 1)\cot\phi'$$

$$N_q = \frac{e^{\frac{270-\phi'}{180}\pi\tan\phi'}}{2\cos^2(45+\phi'/2)}$$

- Equations for N_c, N_q shown at left
- Values for N_γ originally derived from Cullman's graphical method; can be approximated by equations
- All strictly a function of ϕ

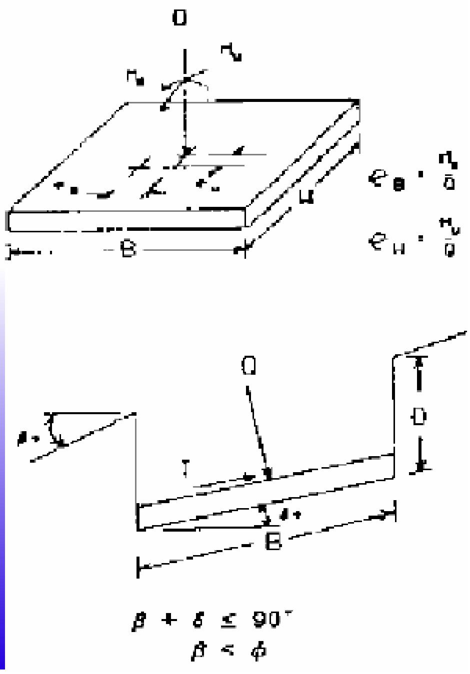
General (Vesic's) Bearing Capacity Equation

- Similar in basic format to Terzaghi's Method, but takes into account a large number of factors
- Some variations in the way it is implemented

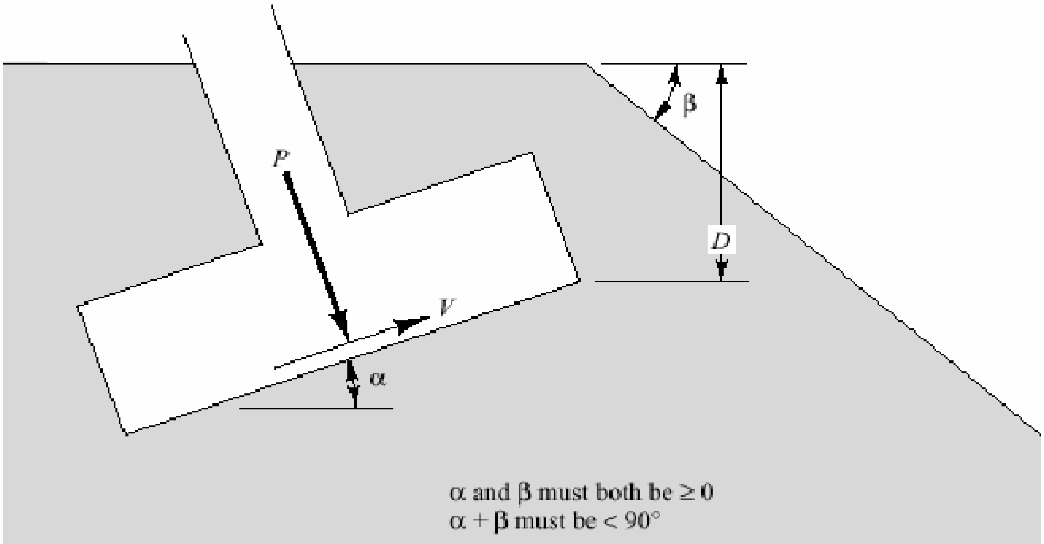


Factors in Vesić Method

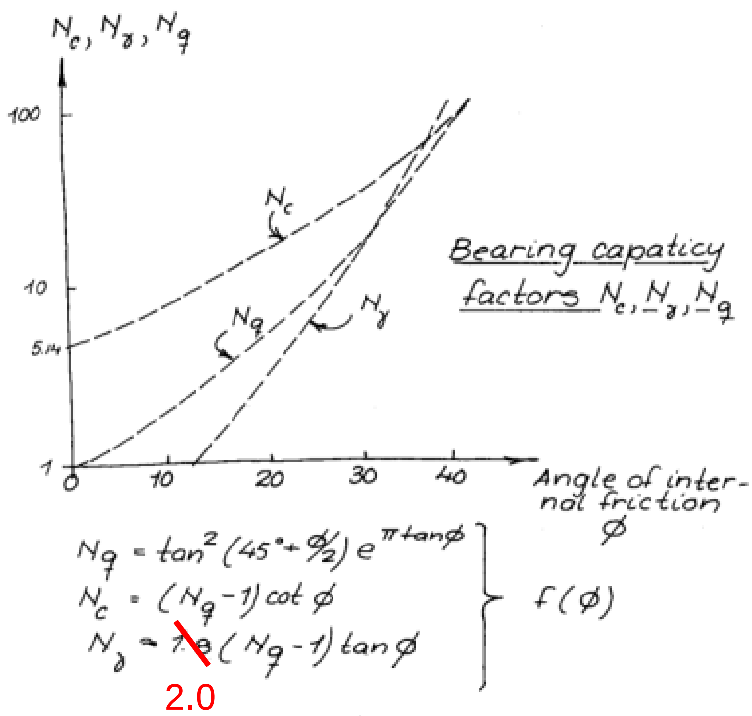
- Bearing Capacity Factor (N)
- Shape Factor (s)
- Depth Factor (d)
- Inclination Factor (i)
- Ground Factor (g)
- Base Factor (b)



Notations for Vesić's Method



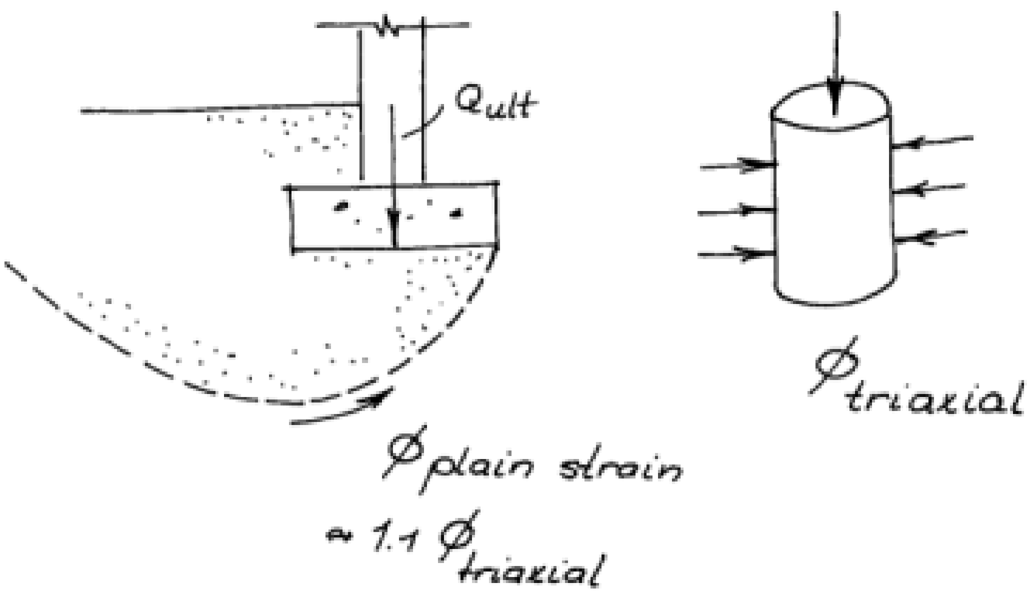
Vesic's Bearing capacity factors



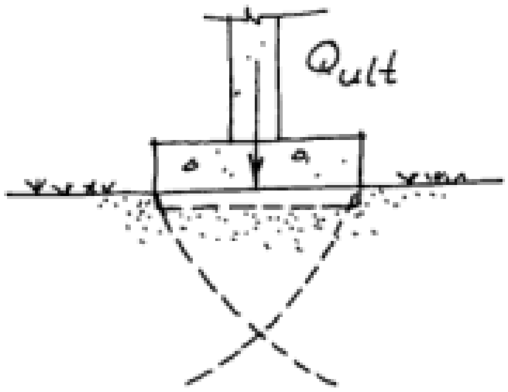
Selection of Strength Parameters

- Always use saturated strength
- For plain strain condition
  - ϕ can be increased by 10%
- Drained or undrained strength
  - If positive excess water pressure is generated during loading, use undrained strength, otherwise use drained strength

Plain strain friction angle



Punching failure



$$c' = \tfrac{2}{3}\,c$$

$$\tan\phi' = \tfrac{2}{3}\tan\phi$$

Loose sand
Loose silt

Effective stress analysis of foundation on sand

Sand. Effective stress analysis (ϕ-analysis)

$c = 0, \quad \phi' \approx \phi_d$ ← From drained triaxial or direct shear tests

$$\phi_{plain\ strain} \approx 1.1\,\phi_{triaxial}$$

Vertical load
Horizontal surface

$$q_{ult} = \sout{c N_c s_c d_c i_c g_c b_c} \qquad c = 0$$

$$+\ \bar{q}\, N_q\, s_q\, d_q\, i_q\, g_q\, b_q$$

- $s_q = 1 + \frac{B}{L}\tan\phi$
- $d_q = 1.0$ (if shear strength is neglected)
- $i_q = 1.0$, $g_q = 1.0$, $b_q = 1.0$

$$+\ 0.5\, N_\gamma\, \rho g\, s_\gamma\, d_\gamma\, i_\gamma\, g_\gamma\, b_\gamma$$

- $s_\gamma = (1 - 0.4\,B/L)$
- $d_\gamma = 1.0$, $i_\gamma = 1.0$, $g_\gamma = 1.0$, $b_\gamma = 1.0$

Bearing capacity of footing in sand

Sand

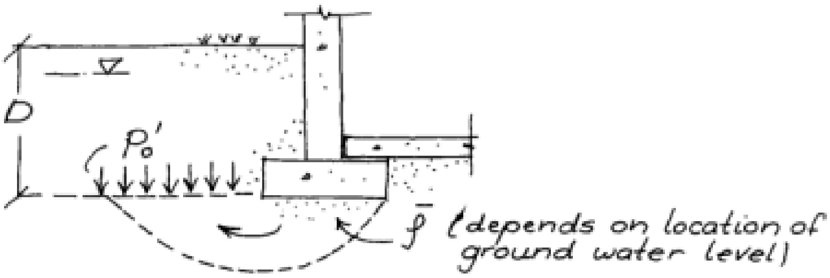
$$q_{ult} = \underbrace{D\bar{\rho}g}_{p_o'} N_q (1 + B/L \tan\phi)$$

p_o' ← Effective overburden pressure

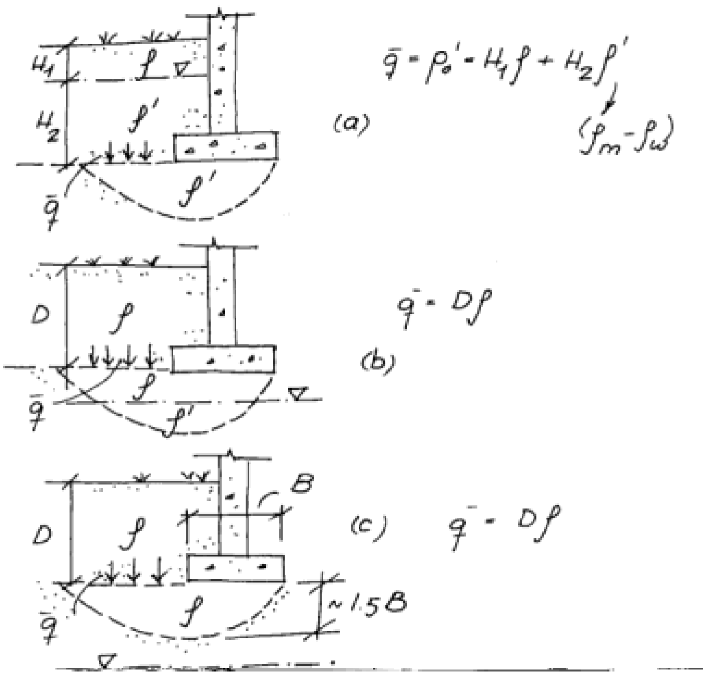
$$+ 0.5\, B N_\gamma \bar{\rho} g (1 - 0.4\, B/L)$$

D=0

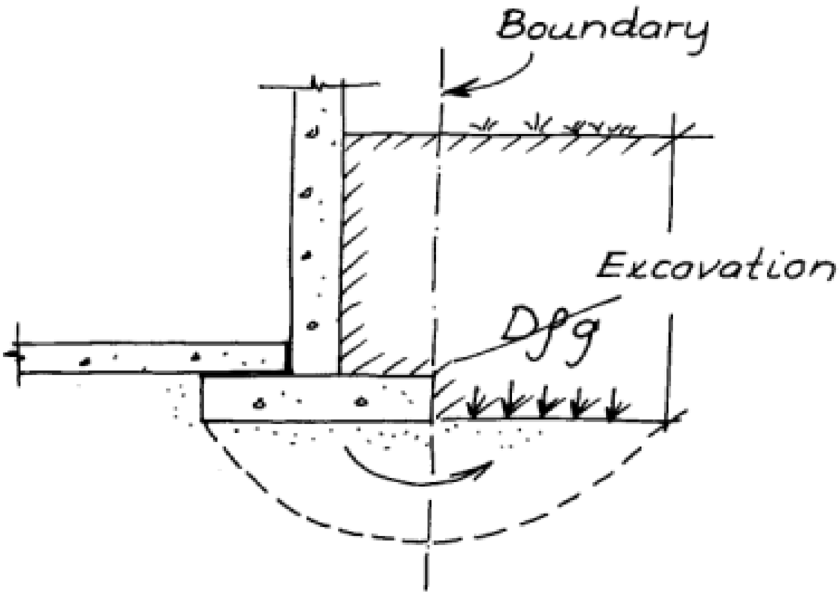
$$q_{ult} = 0.5\, B N_\gamma \bar{\rho} g (1 - 0.4\, B/L)$$



Bearing capacity of footing in sand (layered soil)

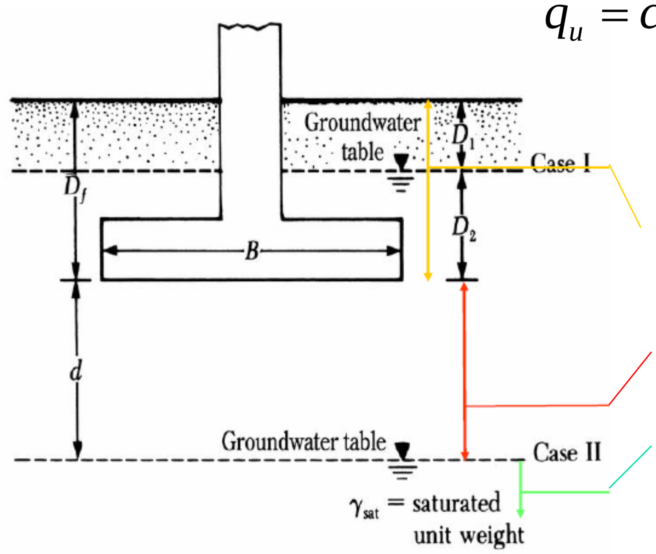


Footing in excavation



Groundwater Table

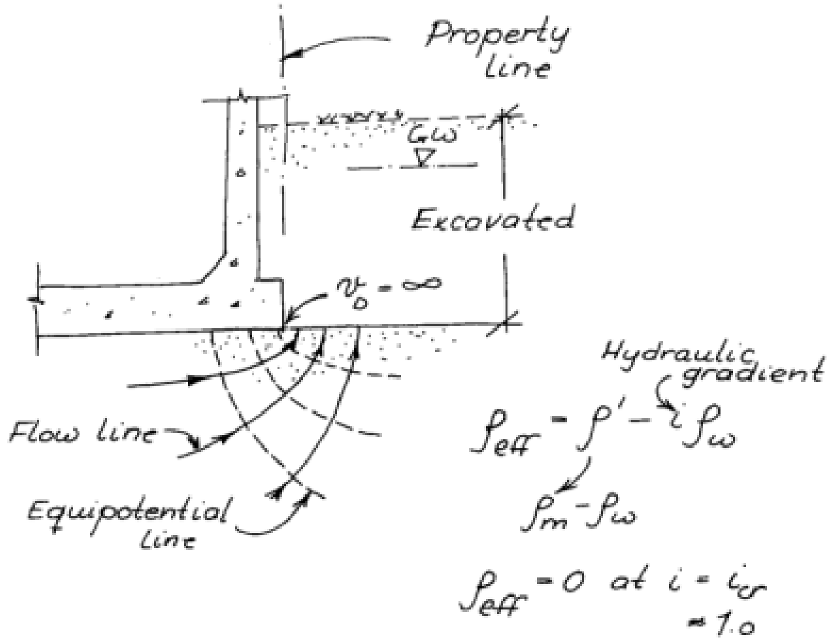
$$q_u = cN_cS_c + \bar{q}N_qS_q + 0.5\gamma_{eq}'BN_\gamma S_\gamma$$



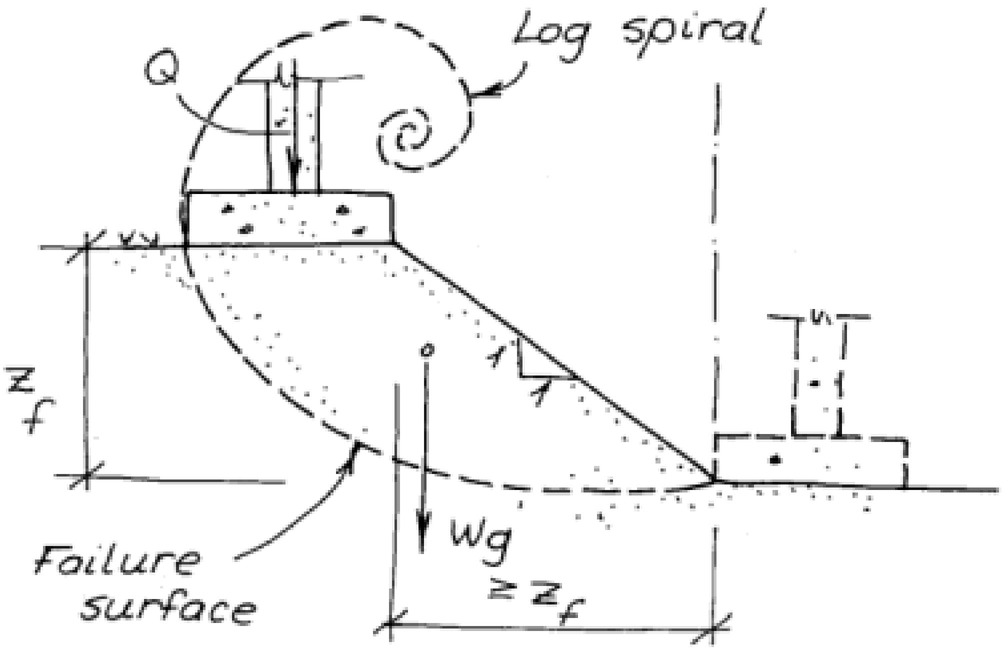
$D_w < D_f$	$\gamma'_{eq} = \gamma' = \gamma_{sat} - \gamma_w$
$D_f < D_w < D_f + B$	$\gamma'_{eq} = \gamma' + \left(\frac{D_w - D_f}{B}\right)(\gamma - \gamma')$
$D_w > D_f + B$	$\gamma'_{eq} = \gamma$

Use worst case D_w

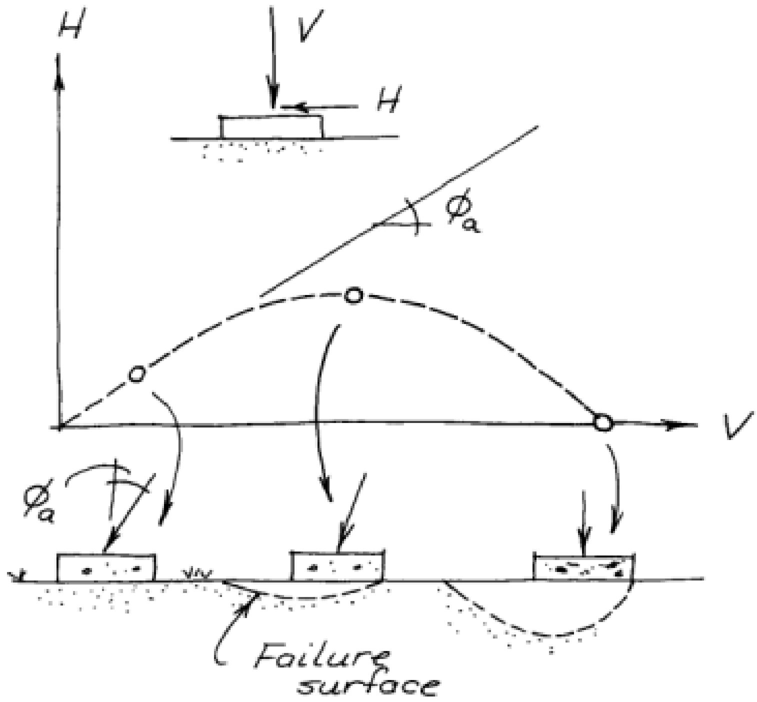
Effect of hydraulic gradient on bearing capacity



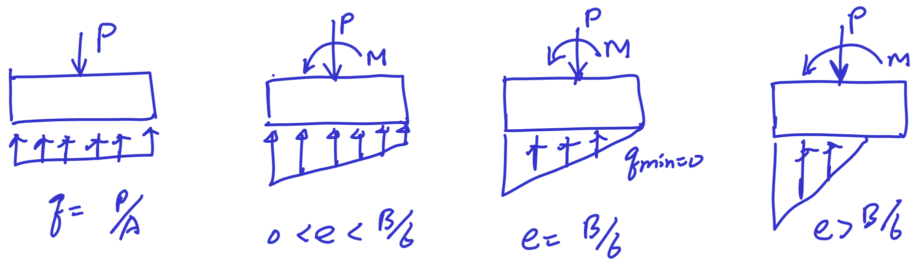
Effect of adjacent footing in slope



Effect of horizontal load on bearing capacity



Effect of eccentric load on bearing capacity



Tension in concrete

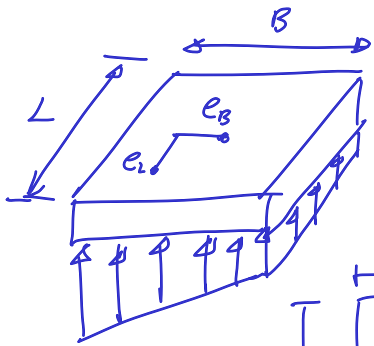
$$q_{\substack{max\\min}} = \frac{P}{A}\left(1 \pm \frac{6e}{B}\right)$$

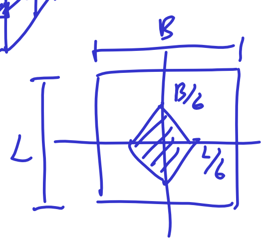
Always design $e \le B/6$

2 Direction - Eccentricity

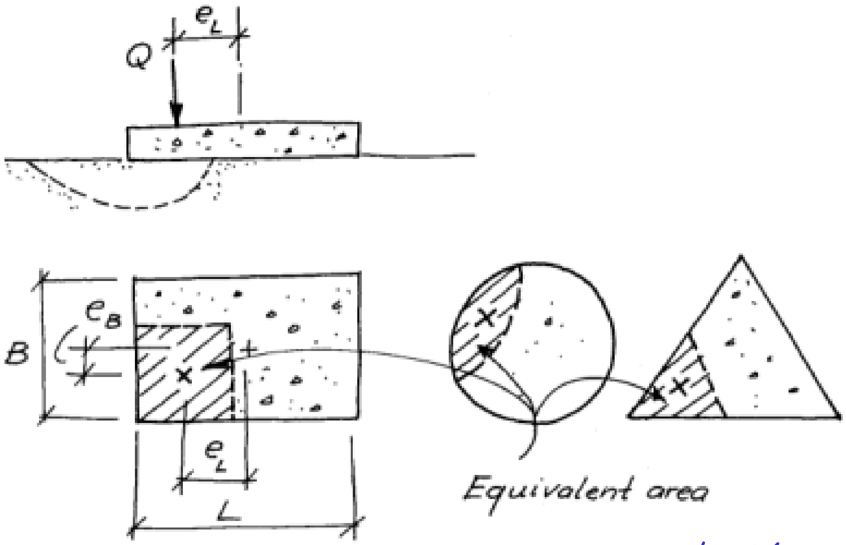
$$q' = \frac{P}{A}\left(1 \pm \frac{6e_B}{B} \pm \frac{6e_L}{L}\right)$$

$$\boxed{\frac{6e_B}{B} + \frac{6e_L}{L} \le 1.0}$$





Equivalent area of surface footing



$B' = B - 2e_B$
$L' = L - 2e_L$

- Use A' to calculate q_u' and $q_{allowable}'$ in B.C. Equations
- Design by $q_{equiv.} = P/A' \leq q_{allow.}'$

Total stress analysis of foundation in clay

Clay. Total stress analysis
($\phi = 0$-analysis, c-analysis)

c_u from field vane tests, undrained triaxial tests, unconfined compression tests

Horizontal surface
Vertical load

$$q_{ult} = c N_c s_c d_c i_c g_c b_c$$

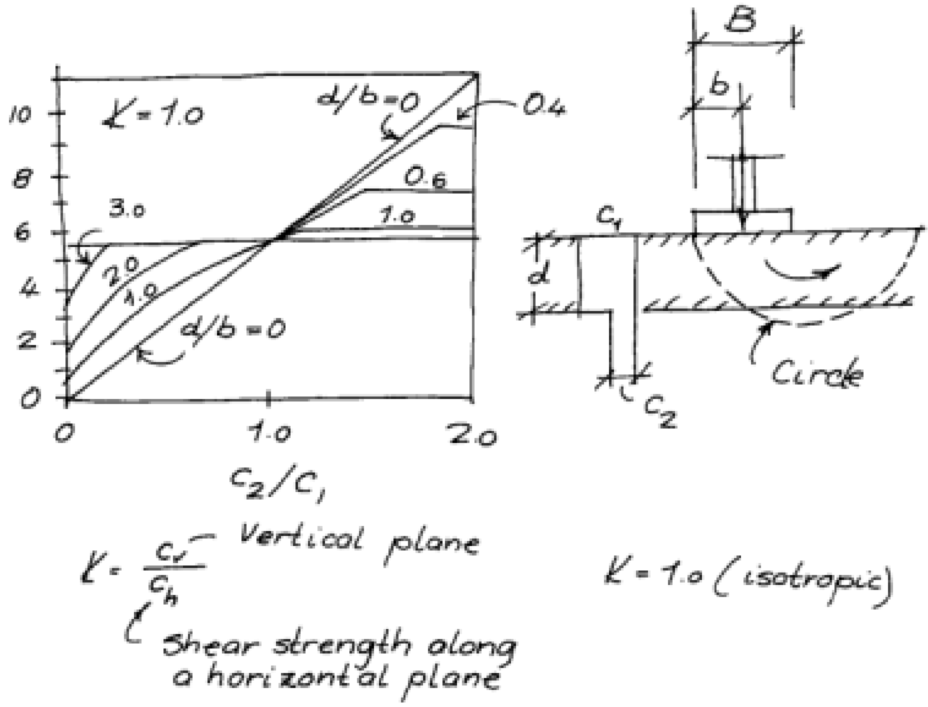
($N_c = 5.14$; $s_c = (1 + 0.2 B/L)$; $d_c = (1 + 0.4 D/B)$; $i_c = 1.0$; $g_c = 1.0$; $b_c = 1.0$)

$$+ \bar{q} N_q s_q d_q i_q b_q \qquad N_q = 1.0 \ (\phi = 0)$$

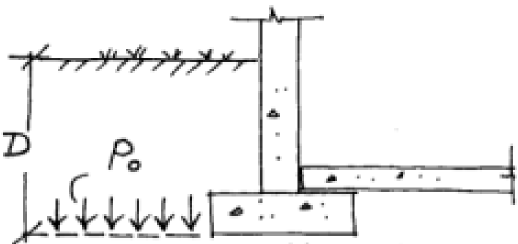
($\bar{q} = D\rho g$; $N_q = 1.0$; $s_q \sim 1.0$; $d_q \sim 1.0$; $i_q = 1.0$; $b_q = 1.0$)

$$+ \tfrac{1}{2} N_\gamma \rho g s_\gamma d_\gamma i_\gamma b_\gamma \qquad N_\gamma = 0 \ (\phi = 0)$$

Effect of soil layer on bearing capacity of footing in clay



Effect of overburden pressure on bearing capacity in clay



N_c (5.14)

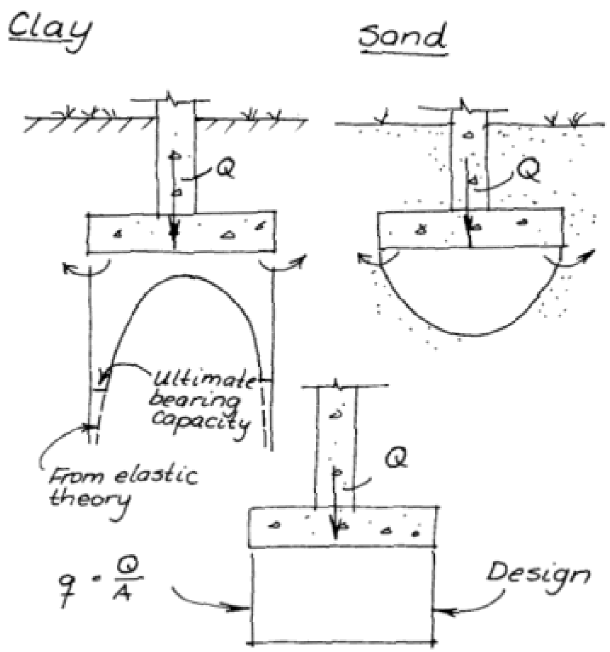
$$q_{ult} = 5 c_u (1 + 0.2\, B/L)(1 + 0.4\, D/B) + D\rho g$$

$D\rho g$ = P_o Total overburden pressure

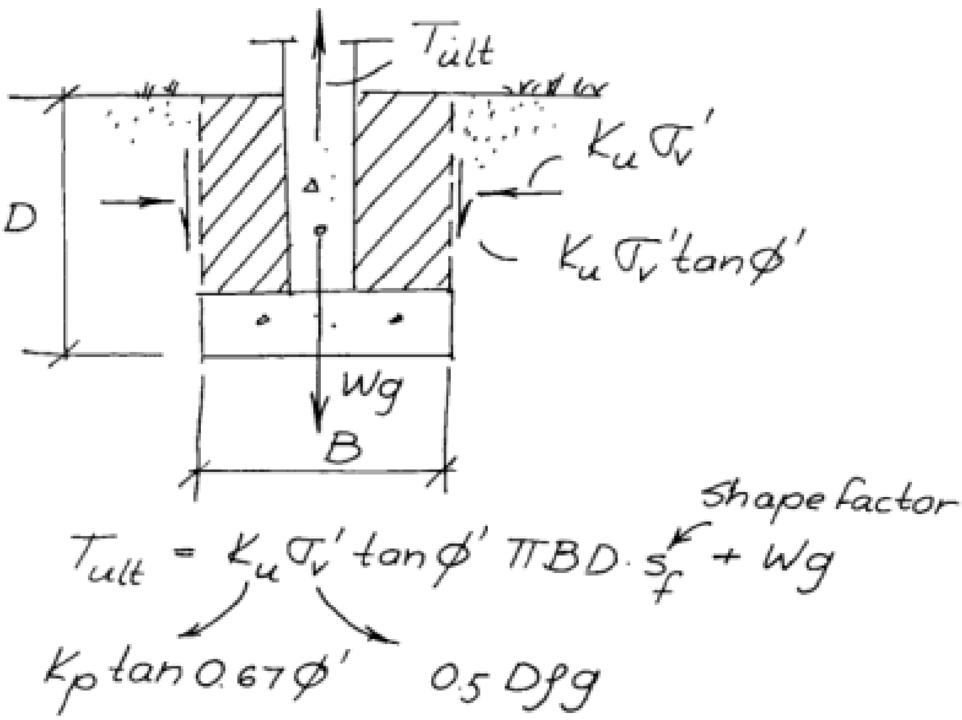
$$q_{allow} = \frac{q_{ult}}{F_s} = 1.7\, c_u (1 + 0.2\, B/L)(1 + 0.4\, D/B) + D\rho g \quad (D/B \leq 1.0)$$

F_s = 3.0

Pressure distribution below footing in clay and sand

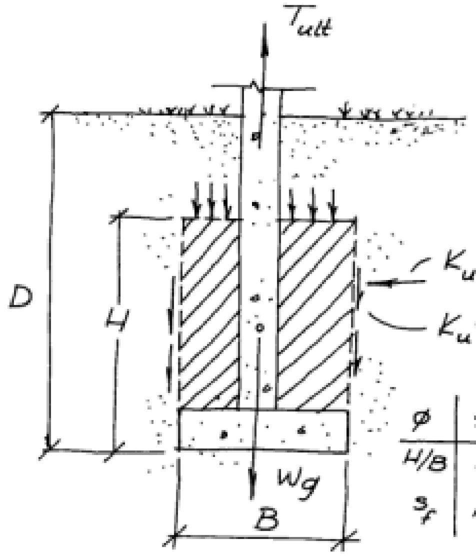


Pull out resistance of shallow footing



Pull out resistance of footing at depth

Pull out resistance deep.



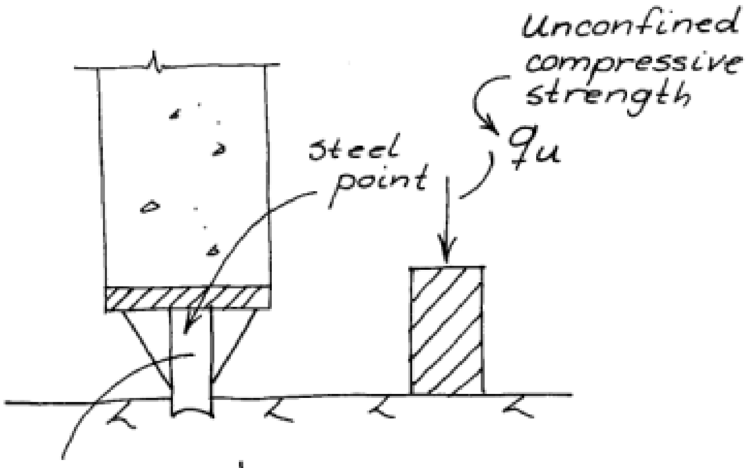
ϕ	20°	25°	30°	35°	40°	45°
H/B	2.5	3	4	5	7	9
s_f	1.12	1.30	1.60	2.25	3.45	5.50

$$T_{ult} = K_u \sigma_v' \tan\phi \cdot \pi B H s_f + Wg$$

K_u → $K_p \tan 0.67\phi$; σ_v' → $(D - H/2)\rho g$; s_f → shape factor

Bearing capacity on rock

Rock



$$q_{ult} = 5 \text{ à } 6\ q_u$$

$$q_{allow} = 0.2 \text{ à } 0.3\ q_u$$