Modification of Bearing Capacity Factors

1. Influence of foundation shapes

- **Empirical formula (De Beer, 1967)**

$$\Rightarrow q_o = cN_c\xi_c + q_sN_q\xi_q + \frac{1}{2}\gamma BN_\gamma\xi_\gamma$$

ξ_c , ξ_q , ξ_γ : shape factors (empirical)

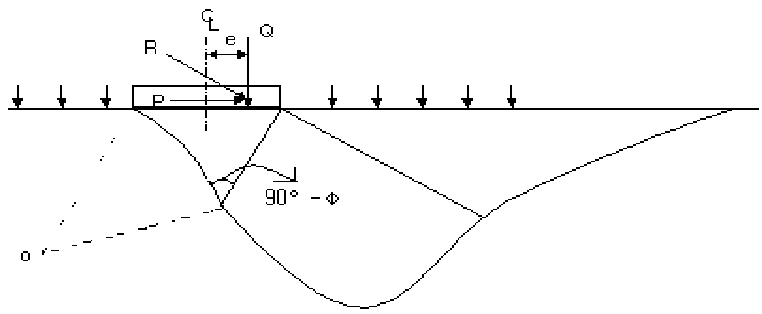
for strip footing :

$$\xi_c = \xi_q = \xi_\gamma = 1$$

for rectangular footing :

$$\xi_c = 1 + \frac{B}{L}\cdot\frac{N_q}{N_c},\ \ \xi_q = 1 + \frac{B}{L}\tan\Phi,\ \ \xi_\gamma = 1 - 0.4\frac{B}{L}$$

2. Influence of inclination and eccentricity of the load (Brinch Hanson)



- **Check** :

① Sliding due to inclination

→ sliding occurs if $P > P_{\max} = Ac_a + Q\tan\delta$

② Uplift due to eccentricity 90°-Φ

→ if e>B/4, cause uplift. for safety, e≤B/6

③ Bearing capacity for effective bearing area

$$\left(\begin{array}{c} \text{effective width} :\ B' = B - 2e_B \\ \text{effective length} :\ L' = L - 2e_L \\ \text{effective area} :\ A' = B' \times L' \end{array}\right)$$

TABLE 1
Ultimate Friction Factors and Adhesion for Dissimilar Materials

Interface Materials	Friction factor, tan δ	Friction angle, δ degrees
Mass concrete on the following foundation materials:		
Clean sound rock..................................	0.70	35
Clean gravel, gravel-sand mixtures, coarse sand...	0.55 to 0.60	29 to 31
Clean fine to medium sand, silty medium to coarse sand, silty or clayey gravel....................	0.45 to 0.55	24 to 29
Clean fine sand, silty or clayey fine to medium sand..	0.35 to 0.45	19 to 24
Fine sandy silt, nonplastic silt..................	0.30 to 0.35	17 to 19
Very stiff and hard residual or preconsolidated clay..	0.40 to 0.50	22 to 26
Medium stiff and stiff clay and silty clay........	0.30 to 0.35	17 to 19
(Masonry on foundation materials has same friction factors.)		
Steel sheet piles against the following soils:		
Clean gravel, gravel-sand mixtures, well-graded rock fill with spalls..........................	0.40	22
Clean sand, silty sand-gravel mixture, single size hard rock fill..................................	0.30	17
Silty sand, gravel or sand mixed with silt or clay	0.25	14
Fine sandy silt, nonplastic silt..................	0.20	11
Formed concrete or concrete sheet piling against the following soils:		
Clean gravel, gravel-sand mixture, well-graded rock fill with spalls..........................	0.40 to 0.50	22 to 26
Clean sand, silty sand-gravel mixture, single size hard rock fill..................................	0.30 to 0.40	17 to 22
Silty sand, gravel or sand mixed with silt or clay	0.30	17
Fine sandy silt, nonplastic silt..................	0.25	14
Various structural materials:		
Masonry on masonry, igneous and metamorphic rocks:		
Dressed soft rock on dressed soft rock..........	0.70	35
Dressed hard rock on dressed soft rock..........	0.65	33
Dressed hard rock on dressed hard rock..........	0.55	29
Masonry on wood (cross grain)....................	0.50	26
Steel on steel at sheet pile interlocks..........	0.30	17

Interface Materials (Cohesion)	Adhesion C_a (psf)
Very soft cohesive soil (0 - 250 psf)	0 - 250
Soft cohesive soil (250 - 500 psf)	250 - 500
Medium stiff cohesive soil (500 - 1000 psf)	500 - 750
Stiff cohesive soil (1000 - 2000 psf)	750 - 950
Very stiff cohesive soil (2000 - 4000 psf)	950 - 1,300

- **Bearing capacity equation for the general case of eccentric & inclined loading**

$\rightarrow Q_o = q_o \times B' \times L'$

$$q_o = cN_c\xi_c\xi_{ci} + q_s N_q \xi_q \xi_{qi} + \frac{1}{2}\gamma B N_\gamma \xi_\gamma \xi_{\gamma i}$$

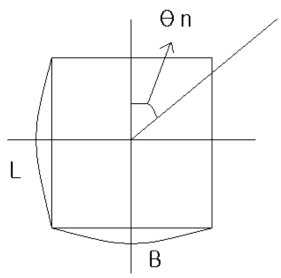
ξ_{ci} , ξ_{qi} , $\xi_{\gamma i}$: inclination factor

where

$$\xi_{qi} = [1 - \frac{P}{Q + B'L'c\cot\phi}]^m$$

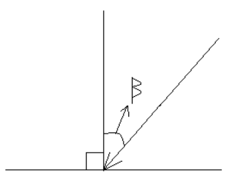
$$\xi_{\gamma i} = [1 - \frac{P}{Q + B'L'c\cot\phi}]^{m+1}$$

$$\xi_{ci} = \xi_{qi} - \frac{1-\xi_{qi}}{N_c \tan\phi}, \text{ if } \phi = 0, \quad \xi_{ci} = 1 - \frac{mp}{B'L'cN_c}$$



$$m_B = \frac{2 + \frac{B}{L}}{1 + \frac{B}{L}} \quad , \quad m_L = \frac{2 + \frac{L}{B}}{1 + \frac{L}{B}}$$

$$m_n = m_L \cos^2\Theta_n + m_B \sin^2\Theta_n$$



- **Hanna & Meyerhof (1981)**

$$F_{\gamma i} = (1 - \frac{\beta}{\Phi})^2$$

$$F_{ci} = F_{qi} = (1 - \frac{\beta}{90})^2$$

3.Influence of embedment depth of foundation

TABLE 4.2 MEYERHOF FOOTING DEPTH AND LOAD INCLINATION BEARING CAPACITY MODIFIERS[a].

$$q_0 = N_c s_c i_c d_c c + N_q s_q i_q d_q q + \frac{\gamma B}{2} N_\gamma s_\gamma i_\gamma d_\gamma$$

For $D < B$:

$$d_c = 1 + 0.2\sqrt{N_\phi}\frac{D}{B}$$

$$d_q = d_\gamma = 1 \qquad (\phi = 0°)$$

$$d_q = d_\gamma = 1 + 0.1\sqrt{N_\phi}\frac{D}{B} \qquad (\phi > 10°)$$

$$i_c = i_q = (1 - \alpha/90°)^2$$

$$i_\gamma = (1 - \alpha/\phi)^2$$

$$N_\phi = \tan^2(\tfrac{1}{4}\pi + \tfrac{1}{2}\phi)$$

[a] Meyerhof (1963).

TABLE 4.3 BRINCH HANSEN FOOTING DEPTH AND LOAD INCLINATION BEARING CAPACITY MODIFIERS[a].

$$q_0 = N_c s_c i_c d_c c + N_q s_q i_q d_q q + \frac{\gamma B}{2} N_\gamma s_\gamma i_\gamma d_\gamma$$

For $D < B$:

$$d_c = 1 + 0.4\frac{D}{B} \qquad (\phi = 0°)$$

$$d_c = d_q - \frac{1 - d_q}{N_c \tan\phi} \qquad (\phi > 0°)$$

$$d_q = 1 + 2\tan\phi\,(1 - \sin\phi)^2\frac{D}{B}$$

$$d_\gamma = 1$$

$$i_c = 1 - \frac{mH}{Ac(\pi + 2)} \qquad (\phi = 0°)$$

$$i_c = i_q - \frac{1 - i_q}{N_c \tan\phi} \qquad (\phi > 0°)$$

$$i_q = \left[1 - \frac{H}{V + Ac\cot\phi}\right]^m$$

$$i_\gamma = \left[1 - \frac{H}{V + Ac\cot\phi}\right]^{m+1}$$

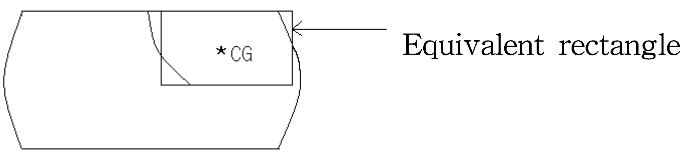
$$m = m_L\cos^2\theta_n + m_B\sin^2\theta_n$$

$$m_B = \frac{2 + B/L}{1 + B/L} \qquad m_L = \frac{2 + L/B}{1 + L/B}$$

θ_n is the projected direction of load in the plane of the footing, measured from the side of length L

[a] As modified by Vesić (1975).

4. Effective portion of foundation under eccentric loading (Brinch Hanson)



Rules : ① The load passes thru the CG of the effective portion

② Use an equivalent rectangular shape

5. Influence of soil compressibility & footing scale

- **Compressibility**

  Terzaghi : $c^* = \frac{2}{3}c$, $\tan\phi^* = \frac{2}{3}tan\phi$

- **Relative compressibility increase with footing size due to**

  i) Mohr envelop curvature

  ii) progressive rupture

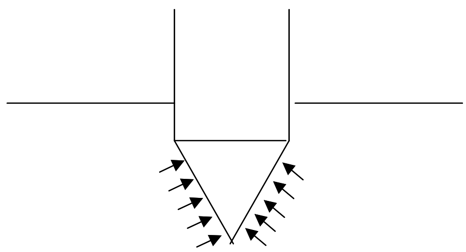
  iii) presence of weak zone

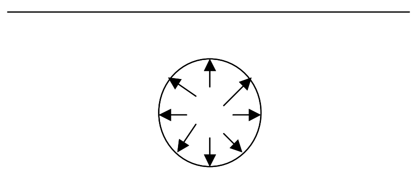
Homework #5 : What is progressive rupture ? Submit an answer report (5-6 pages)

Refs : ICSMFE 6th(1965) Montreal, Vol Ⅱ. pp 13-17

ICSMFE 7th(1969) Mexico, Vol Ⅲ, pp 270-272

- **Tentative solution assuming that ultimate normal pressure on the sides of compressed zone is equal to the pressure needed to expand a cavity in the same soil**





- **Calculate the rigidity index**

  $I_r = \frac{G}{c + q\tan\phi}$, $G = \frac{E}{2(1+\nu)}$ q : average overburden pressure

  ⇒ compare with I_{cr}

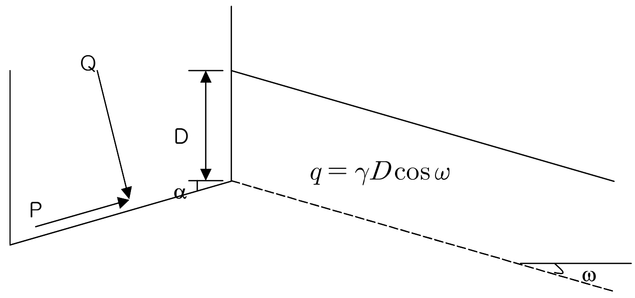
$$I_{cr} = \frac{1}{2}\exp[(3.30 - 0.45\frac{B}{L})\cot(45° - \frac{\phi}{2})]$$

  if $I_{cr} > I$, use compressibility factor

$$\xi_{qc} = \exp\left[\left((-4.4 + 0.6\frac{B}{L})\tan\phi\right) + \frac{(3.07\sin\phi)(\log 2I_r)}{1+\sin\phi}\right]$$

$$\xi_{cc} = \xi_{qc} - \frac{\xi_{qc}}{N_c\tan\phi}, \text{ if } \phi = 0, \ \xi_{cc} = 0.32 + 0.12\frac{B}{L} + 0.60\log I_r, \ \xi_{rc} = \xi_{qc}$$

6. Influence of base tilt & ground surface slope



α, ω : in degree

① Base tilt

$$\xi_{qt} = \xi_{\gamma t} = (1 - \alpha \tan\phi)^2$$

$$\xi_{ct} = \xi_{qt} - \frac{1-\xi_{qt}}{N_c \tan\phi}, \text{ if } \phi = 0, \ \xi_{ct} = \frac{1-2\alpha}{\pi+2}$$

② Ground surface slope

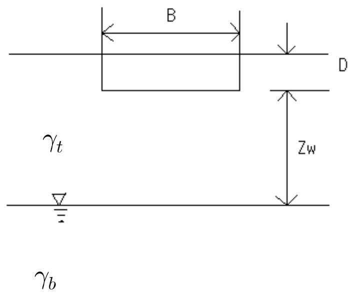
$$\xi_{qg} = \xi_{\gamma g} = (1 - \tan\omega)^2$$

$$\xi_{cg} = \xi_{qg} - \frac{1-\xi_{qg}}{N_c \tan\phi},$$

if $\phi = 0$, $\xi_{cg} = \frac{1-2\alpha}{\pi+2}$, $N_\gamma = -2\sin\omega$, $\xi_{qg} = \cos\omega$, $\xi_{\gamma g} = 1$

※ if $\omega > \frac{\phi}{2}$, slope stability analysis needed

7. Influence of ground water table



$$\gamma = \gamma_b + (z_w/B)(\gamma_t - \gamma_b)$$

* In overall, modification factors are shown in Table 4.4 / 4.5

TABLE 4.4 MEYERHOF AND BRINCH HANSEN FOOTING SHAPE BEARING CAPACITY MODIFIERS.

$$q_0 = N_c s_c i_c d_c c + N_q s_q i_q d_q q + \frac{\gamma B}{2} N_\gamma s_\gamma i_\gamma d_\gamma$$

Meyerhof (Meyerhof, 1963)

$$s_c = 1 + 0.2N_\phi \frac{B}{L}$$

$$s_q = s_\gamma = 1.0 \qquad (\phi = 0°)$$

$$s_q = s_\gamma = 1 + 0.1N_\phi \frac{B}{L} \qquad (\phi > 10°)$$

$$N_\phi = \tan^2(\tfrac{1}{4}\pi + \tfrac{1}{2}\phi)$$

Brinch Hansen (After Vesić, 1975)

$$s_c = 1 + \frac{B}{L}\frac{N_q}{N_c}$$

$$s_q = 1 + \frac{B}{L}\tan\phi$$

$$s_\gamma = 1 - 0.4\frac{B}{L}$$

For circular footing use $B/L = 1$.

TABLE 4.5 BRINCH HANSEN FOOTING AND GROUND INCLINATION BEARING CAPACITY MODIFIERS*.

$$q_0 = N_c s_c d_c g_c b_c c + N_q s_q d_q g_q b_q q + \frac{\gamma B}{2} N_\gamma s_\gamma d_\gamma g_\gamma b_\gamma$$

Footing Inclination Factors

$$b_q = b_\gamma = (1 - \alpha\tan\phi)^2$$

$$b_c = 1 - \frac{2\alpha}{\pi + 2} \qquad (\phi = 0°,\ \alpha \text{ in radians})$$

$$b_c = b_q - \frac{1 - b_q}{N_c\tan\phi} \qquad (\phi > 0°)$$

Ground Inclination Factors

$$g_q = g_\gamma = (1 - \tan\omega)^2 \qquad (\phi > 0°)$$

$$g_c = 1 - \frac{2\omega}{\pi + 2} \qquad (\phi = 0°,\ \omega \text{ in radians})$$

$$g_c = g_q - \frac{1 - g_q}{N_c\tan\phi} \qquad (\phi > 0°)$$

Restrictions: $\alpha < 45°$, $\omega < 45°$, $\omega < \phi$.
For ground inclination use $N_\gamma = -2\sin\omega$.

*As modified by Vesić (1975).