UNAM

UNIVERSITY OF NAMIBIA

FACULTY	AGRICULTURE, ENGINEERING AND NATURAL SCIENCES
SCHOOL	ENGINEERING AND THE BUILT ENVIRONMENT
DEPARTMENT	CIVIL AND MINING ENGINEERING
SUBJECT	GEO-TECHNICAL ENGINEERING
SUBJECT CODE	TCVG3711
DATE	MAY 2023
DURATION	3 HOURS
MARKS	100

FIRST OPPORTUNITY EXAMINATION

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This question paper consists of **5** pages excluding this front page.
Additionally, **3** pages of charts and tables and **1** answer sheet (to be submitted) are provided.

Instructions

1. **Closed** book examination.
2. Read the questions carefully.
3. The paper contains 5 questions. **Attempt any FOUR (4) questions** for full marks.
4. Some relevant equations, tables and charts have been provided.
5. Answers should be brief and to-the-point and where necessary be supplemented with neat sketches.
6. Marks for each question are indicated.
7. Any missing or 'wrong' data may be assumed suitably giving proper justification.

QUESTION 1: SITE INVESTIGATION & DESIGN METHODS (25 MARKS)

a) State any ***five (5) phases*** involved in carrying out a detailed site investigation. ***(5 marks)***

b) Briefly describe the ***Standard Penetration Test (SPT)*** in-situ testing method as used in site investigation and give some advantages of this test. ***(6 marks)***

c) A footing 3 m by 3m is founded at a depth of 1.5 m in a sandy soil layer. The water table is located at a depth of 4.0 m from the ground surface. The unit weight of the soil above the water table is 18 kN/m^3 while that below the water table is 20 kN/m^3. The Dutch cone point resistances q_c against depth is given in the Table Q1 below.

Table Q1: q_c test results

Depth (m)	0-2.5	2.5-3.75	3.75-4.25	4.25-5.5-	5.5-7.0
q_c (MN/m^2)	5.5	9	13	11	15

i. Make a proper sketch of the foundation situation ***(2 marks)***
ii. Plot the depth of (m) versus q_c (MN/m^2) curve ***(4 marks)***
iii. Determine the immediate and final settlement after a period of 10 years using the Schmertmann method. ***(8 marks)***

QUESTION 2: BEARING CAPACITY & SHALLOW FOUNDATIONS (25 MARKS)

a) List the various types of shallow foundations. *(4 marks)*

b) List the factors that ought to be considered when selecting a foundation *(4 marks)*

c) A continuous footing founded at a depth of 0.6 m is designed to support a column as shown in ***Figure Q2***. The load on the column, including the column weight, is Q = 1000 kN. The foundation rests on a homogeneous silty sand. Subsurface exploration and laboratory testing found that the soil's effective cohesion is 25 kN/m^2 and the effective friction angle is 32°. The groundwater table is 1.5 m below the ground surface. The bulk unit weight above the groundwater table is 17.5 kN/m^3; the saturated unit weight below the groundwater table is 18.5 kN/m^3.

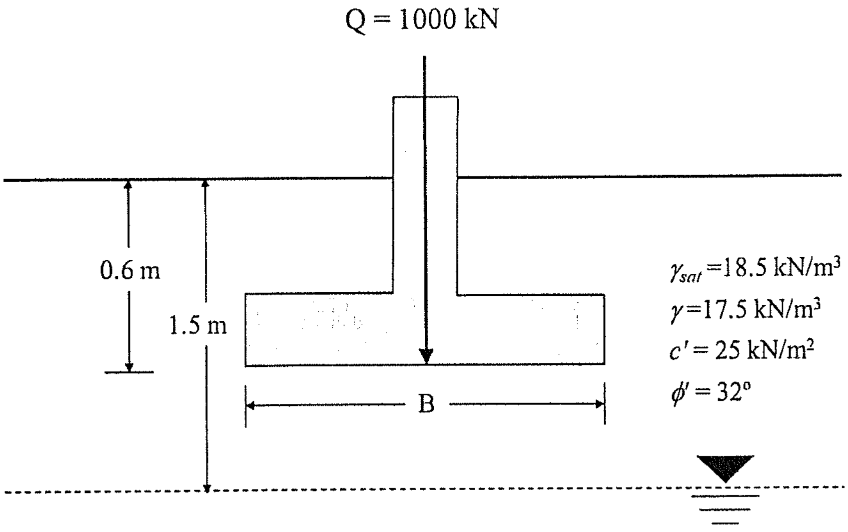


Figure Q2

i. Using ***Terzaghi's method*** and assuming a factor of safety of 3, estimate the dimension of footing (B) to satisfy the bearing capacity criteria. *(12 marks)*

ii. Estimate the ***ultimate*** and ***allowable*** bearing capacity of the footing. *(5 marks)*

QUESTION 3: DEEP FOUNDATIONS (25 MARKS)

a) Several 12 m long piles of diameter 400 mm were installed in sand. A standard penetration test was carried out at the installation site to determine the consistency of the sand and the values obtained are given in Table Q3.

Table Q3 Depth versus corrected STP values

Depth (m)	N_{cor}
0-2	12
2-6	18
6-16	21

Determine the allowable pile capacity if a factor of safety of 3 is required ***(5 marks)***

b) A storage facility is to be supported by a 4 by 4 bored reinforced concrete pile group extending 15 m into a stratified sand stratum, as shown in ***Figures Q3(a)*** and ***Q3(b).*** The individual piles are 0.5 m in diameter and are spaced 2.0 m centre-to-centre. The combined weight of the pile cap and fully loaded storage facility is 65 000 kN. The ground water table is at a depth of 4 m below the ground surface.

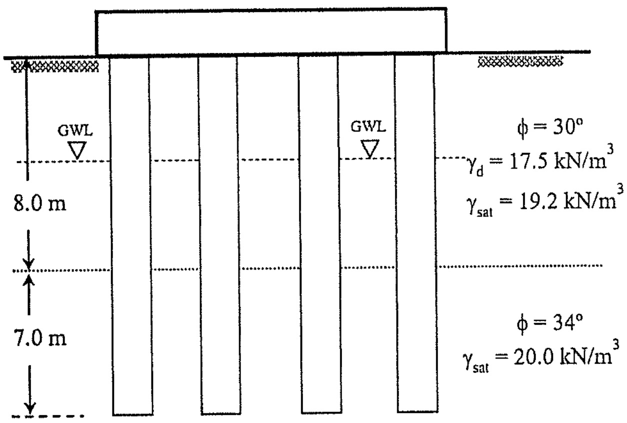


Figure Q3(a)

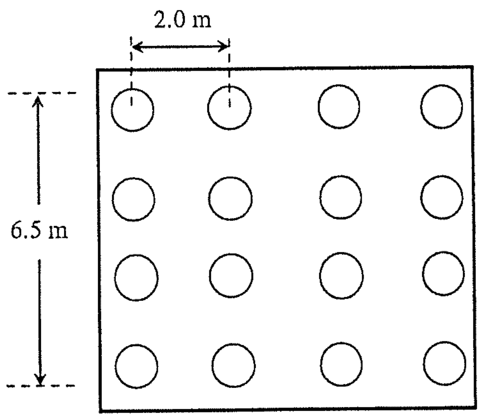


Figure Q3(b)

i. Estimate the ultimate load bearing capacity of ***one pile.*** ***(10 marks)***

ii. Considering a factor of safety of 3.0 with respect to bearing capacity failure, estimate the ***pile load capacity of the group.*** ***(8 marks)***

iii. Comment on whether the ***design is suitable*** with respect to bearing capacity. ***(2 marks)***

QUESTION 4: SLOPE STABILITY ANALSYSIS (25 MARKS)

a) Briefly explain ***slope stability failure.*** *(1 mark)*

b) Mention any four (4) possible ***causes of slope failure.*** *(2 marks)*

c) Describe two (2) ***mitigation measures*** for repairing a slope that is close to failure. *(2 marks)*

d) An 8 m tall embankment has a slope of 2V:3H as shown in the ***Figure Q4***. The fill material has properties of $\gamma' = 17$ kN/m^3, $\phi' = 30°$ and $c' = 22$ kPa. It is assumed that the depth of the groundwater table is well below the slip surface in question. Using the ***Fellenius method*** of slices, analyse the stability of the slope for the specified slip circle by determining the ***factor of safety***. Use a total of 9 slices and ignore the formation of any tension cracks. (Use the *answer sheet* provided). *(20 marks)*

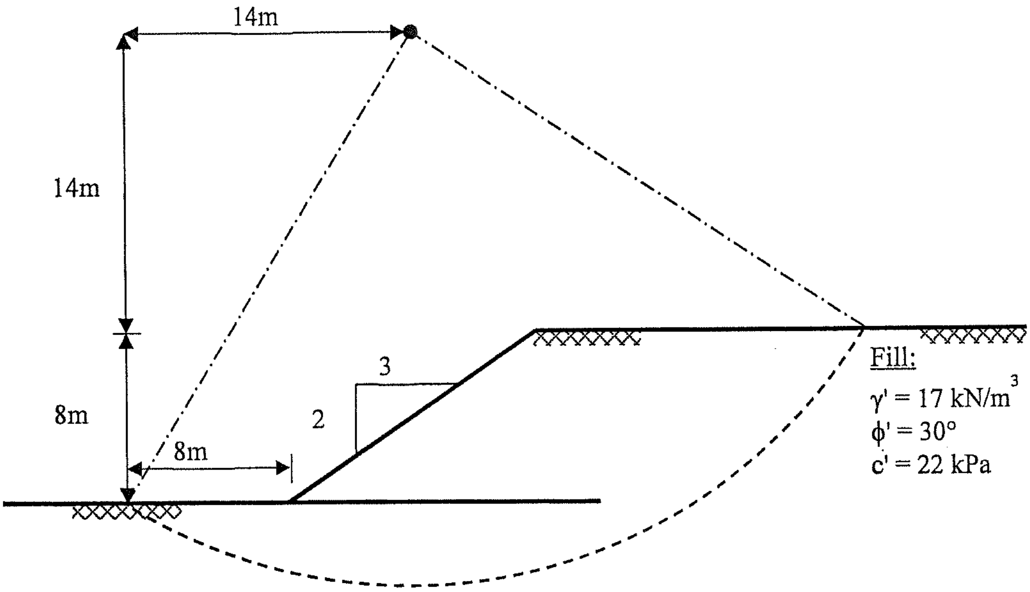


Figure Q4

QUESTION 5: LATERAL EARTH PRESSURES & RETAINING WALLS (25 MARKS)

The cross-section of a retaining wall is shown in **Figure Q5**. Determine the factors of safety with respect to (WRT) overturning, sliding and bearing capacity. Use Rankine's theory for your analysis as well as the Terzaghi bearing capacity theory for bearing capacity equations for simplicity. Take the unit weight of concrete as 24 kN/m^3.

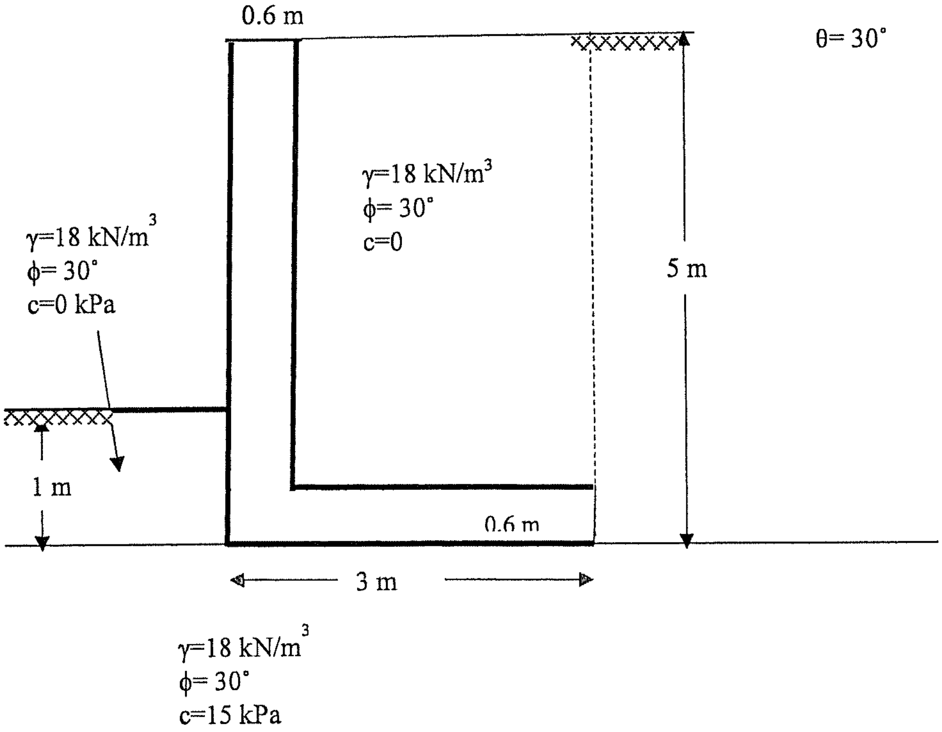


Figure Q5

Equations:

$$C_w = 0.5 + 0.5\left(\frac{D_w}{D_f + B}\right) \qquad I_c = \frac{1.71}{N^{1.4}}$$

Terzaghi's bearing capacity expression

$$q_{ult} = cN_c s_c + qN_q + 0.5B\gamma N_\gamma s_\gamma$$

$$q_{all} = \frac{q_{ult}}{FS} \qquad I_z^{max} = 0.5 + 0.1\sqrt{\frac{q_{net}}{\sigma_{vp}}}$$

Meyerhoff's bearing capacity expression

For vertical loads

$$q_{ult} = cN_c s_c d_c + qN_q s_q d_q + 0.5B\gamma N_\gamma s_\gamma d_\gamma$$

For inclined loads

$$q_{ult} = cN_c d_c i_c + qN_q d_q i_q + 0.5B\gamma N_\gamma d_\gamma i_\gamma$$

$$q_{all} = \frac{25}{B^{0.7} I_c} \qquad S = C_1 + C_2\, q_n \sum_0^{2B} \frac{I_z}{E}\Delta_z$$

Hansen's bearing capacity expression

$$q_{ult} = cN_c s_c d_c i_c g_c b_c + qN_q s_q d_q i_q g_q b_q + 0.5B\gamma N_\gamma s_\gamma d_\gamma i_\gamma g_\gamma b_\gamma$$

$$q_b = 9c_u \qquad C_1 = 1 - 0.5\frac{\sigma'_0}{q_n}$$

$$C_2 = 1 + 0.2\,log\,10t$$

For undrained conditions

$$q_{ult} = 5.14s_u(1 + s'_c + d'_c - i'_c - g'_c - b'_c) + q$$

$$q_s = \alpha c_u$$

Vesic's bearing capacity expression

$$q_{ult} = cN_c s_c d_c i_c g_c b_c + qN_q s_q d_q i_q g_q b_q + 0.5B\gamma N_\gamma s_\gamma d_\gamma i_\gamma g_\gamma b_\gamma$$

$$q_b = \sigma'_v N_q \qquad q_s = \sigma'_v k \cdot \tan\delta$$

$$q_{ult} = cN_c + qN_q + 0.5\gamma N_\gamma \qquad Q_{ult} = Q_s + Q_b \qquad Q_b = (N_c C_u + N_q \sigma_v)A_b$$

$$q_{ult} = 1.3cN_c + qN_q + 0.4\gamma N_\gamma \qquad q_s = \alpha c_u + \sigma'_v k \cdot \tan\delta \qquad Q_b = q_b A_b \qquad Q_s = q_s A_s$$

$$q_{ult} = 1.3cN_c + qN_q + 0.3\gamma N_\gamma$$

$$\text{Efficiency of the pile group} = \frac{Pile\ group\ capacity}{n \times Single\ pile\ capacity}$$

$$F = \frac{1}{\Sigma W \sin\alpha}\sum\left[\{c'b + (W - ub)\tan\phi'\}\frac{\sec\alpha}{1 + (\tan\alpha\tan\phi'/F)}\right] \qquad Q_{all} = \frac{Q_{ult}}{FS} \qquad z_c = \frac{2c'}{\gamma}\tan\left(45^\circ + \frac{\phi'}{2}\right)$$

$$F = \frac{\sum_{i=1}^{n}[c'_i \Delta l_i + (W_i \cos\alpha_i - U_i)\tan\varphi'_i]}{\sum_{i=1}^{n} W_i \sin\alpha_i} \qquad z_c = \frac{2c_u}{\gamma}$$

$$K_p = \frac{1 + \sin\phi}{1 - \sin\phi} = \tan^2(45 + \phi/2)$$

$$K_a = \frac{1 - \sin\phi}{1 + \sin\phi} = \tan^2(45 - \phi/2)$$

$$F_{sliding} = \frac{P_P + \sum\{W_i\}.\tan\delta + B \cdot c_a}{P_A}$$

$$FS_s = \frac{c_u}{\gamma H N_s} \qquad FS = \frac{c_u \cdot R^2 \cdot \theta)}{W \cdot l}$$

$$F_{overturning} = \frac{P_P\, h/3 + \sum\{W_i x_i\}}{P_A\, H/3}$$

$$[\sigma_h']_{active} = K_a \sigma_v' - 2c\sqrt{K_a}$$

$$q_{max} = \frac{4Q}{3L(B - 2e)} \qquad K_0 = 1 - \sin\phi'$$

$$[\sigma_h']_{passive} = K_p \sigma_v' + 2c\sqrt{K_p}$$

For rectangular footings reduce dimension as follows:

$$q_{max} = \frac{P}{B \times L}\left(1 + \frac{6e}{B}\right) \qquad L' = L - 2e_y \ ; \ e_y = \frac{M_x}{P}$$

$$q_{min} = \frac{P}{B \times L}\left(1 - \frac{6e}{B}\right) \qquad B' = B - 2e_x \ ; \ e_x = \frac{M_y}{P}$$

$$K_a = \frac{\cos\beta - \sqrt{(\cos^2\beta - \cos^2\phi')}}{\cos\beta + \sqrt{(\cos^2\beta - \cos^2\phi')}}$$

$$K_p = \frac{\cos\beta + \sqrt{(\cos^2\beta - \cos^2\phi')}}{\cos\beta - \sqrt{(\cos^2\beta - \cos^2\phi')}}$$

Tables & Charts:

Bearing Capacity Factors

ϕ	Terzaghi's (1943) Expression N_c	N_q	N_γ	Hansen, Meyerhoff, and Vesic's Expressions N_c	N_q	Hansen (1970) N_γ	Meyerhoff (1951, 1963) N_γ	Vesic (1973, 1975) N_γ
0	5.7	1.0	0.0	5.14	1.0	0.0	0.0	0.0
5	7.3	1.6	0.5	6.49	1.6	0.1	0.1	0.4
10	9.6	2.7	1.2	8.34	2.5	0.4	0.4	1.2
15	12.9	4.4	2.5	11.0	3.9	1.2	1.1	2.6
20	17.7	7.4	5.0	14.8	6.4	2.9	2.9	5.4
25	25.1	12.7	9.7	20.1	10.7	6.8	6.8	12.5
30	37.2	22.5	19.7	30.1	18.4	15.1	15.7	22.4
35	57.8	41.4	42.4	46.4	33.5	34.4	37.6	48.1
40	95.7	81.3	100	75.3	64.1	79.4	93.6	109.3
45	172	173	298	134	135	201	262.3	271.3

Pile type	δ
Steel piles	20°
Timber piles	$3/4\ \varphi$
Concrete piles	$3/4\ \varphi$

Shape Factors:

Meyerhoff (1951,1963):

$s_c = 1.0 + 0.2K_p\frac{B}{L}$, $\quad K_p = tan^2\left(45 + \frac{\phi}{2}\right)$

$s_q = s_\gamma = 1.0 + 0.1K_p\frac{B}{L}$, (for $\phi > 10°$)

$s_q = s_\gamma = 1$, (for $\phi = 0°$)

Hansen (1970):

$s'_c = 0.2\frac{B}{L}$, (for $\phi = 0°$)

$s_c = 1.0 + \frac{N_q}{N_c}\cdot\frac{B}{L}$

$s_q = 1.0 + \frac{B}{L}\cdot sin\phi$

$s_\gamma = 1.0 - 0.4\frac{B}{L}$

Vesic (1973,1975):

$s_c = 1.0 + \frac{N_q}{N_c}\cdot\frac{B}{L}$

$s_q = 1.0 + \frac{B}{L}\cdot sin\phi$

$s_\gamma = 1.0 - 0.4\frac{B}{L}$

Depth Factors:

Meyerhoff (1951,1963):

$d_c = 1.0 + 0.2\sqrt{K_p}\frac{D}{B}$, $\quad K_p = tan^2\left(45 + \frac{\phi}{2}\right)$

$d_q = d_\gamma = 1.0 + 0.1\sqrt{K_p}\frac{D}{B}$, (for $\phi > 10°$)

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

Hansen (1970):

$d'_c = 0.4k$, (for $\phi = 0°$)

$d_c = 1.0 + 0.4k$

$d_q = 1.0 + 2tan\phi(1 - sin\phi)^2k$

$For\ \frac{D}{B} \le 1:\ k = \left(\frac{D}{B}\right) \quad For\ \frac{D}{B} > 1:\ k(radians) = tan^{-1}\left(\frac{D}{B}\right)$

$d_\gamma = 1.0$

Vesic (1973,1975):

$d'_c = 0.4k$, (for $\phi = 0°$)

$d_c = 1.0 + 0.4k$

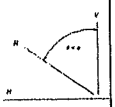
$d_q = 1.0 + 2tan\phi(1 - sin\phi)^2k$

$For\ \frac{D}{B} \le 1:\ k = \left(\frac{D}{B}\right) \quad For\ \frac{D}{B} > 1:\ k(radians) = tan^{-1}\left(\frac{D}{B}\right)$

$d_\gamma = 1.0$

Inclination Factors:

Meyerhoff (1951,1963):

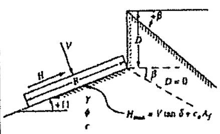


$i_c = i_q = \left(1 - \frac{\theta}{90°}\right)^2$

$i_\gamma = \left(1 - \frac{\theta°}{\phi°}\right)^2$, (for $\phi > 0°$)

$i_\gamma = 0$, (for $\theta > 0, \phi = 0°$)

Hansen (1970):



$i'_c = 0.5 - 0.5\sqrt{1 - \frac{H}{A_f c_a}}$, (for $\phi = 0°$)

$i_c = i_q - \frac{1 - i_q}{N_q - 1}$

$i_q = \left[1 - \frac{0.5H}{V + A_f c_a cot\phi}\right]^{\alpha_1}$, $(2 \le \alpha_1 \le 5)$

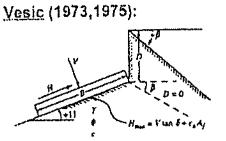
$i_\gamma = \left[1 - \frac{\left(0.7 - \frac{\theta°}{450°}\right)H}{V + A_f c_a cot\phi}\right]^{\alpha_2}$, $(2 \le \alpha_2 \le 5)$

$A_f = Effective\ Area\ (B' \times L')$

$c_a = Base\ Adhesion\ (0.6 - 1.0c)$

Inclination Factors:

Vesic (1973,1975):



$i'_c = 1.0 - \frac{m \cdot H}{A_f c_a N_c}$, (for $\phi = 0°$)

$i_c = i_q - \frac{1 - i_q}{N_q - 1}$

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

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

When H is parallel to B:

$\therefore m = m_B = \frac{2 + \frac{B}{L}}{1 + \frac{B}{L}}$

When H is parallel to L:

$\therefore m = m_L = \frac{2 + \frac{L}{B}}{1 + \frac{L}{B}}$

When H has components parallel to both B & L:

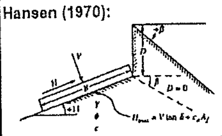
$\therefore m^2 = m_B^2 + m_L^2$

$A_f = B' \times L'\ (Effective\ Area)$

$c_a = Base\ Adhesion\ (0.6 - 1.0c)$

Ground Factors:

Hansen (1970):

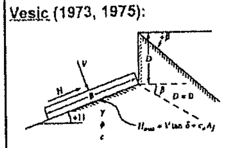


$g'_c = \frac{\beta°}{147°}$ (for $\phi = 0°$)

$g_c = 1.0 - \frac{\beta°}{147°}$

$g_q = g_\gamma = (1 - 0.5\ tan\beta)^5$

Vesic (1973, 1975):



$g'_c = \frac{\beta}{5.14}$ (for $\phi = 0°$)

$g_c = i_q - \frac{1 - i_q}{5.14\ tan\phi}$

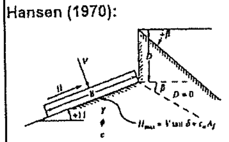
$g_q = g_\gamma = (1 - tan\beta)^2$

Source: Bowles (2002)

NOTE: $\beta°$ is measured clockwise from the horizontal

Base Factors:

Hansen (1970):



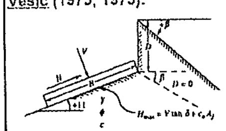
$b'_c = \frac{\eta°}{147°}$ (for $\phi = 0°$)

$b_c = 1.0 - \frac{\eta°}{147°}$

$b_q = e^{(-0.0349\eta° tan\phi)}$

$b_\gamma = e^{(-0.0471\eta° tan\phi)}$

Vesic (1973, 1975):



$b'_c = g'_c = \frac{\beta°}{5.14}$ (for $\phi = 0°$)

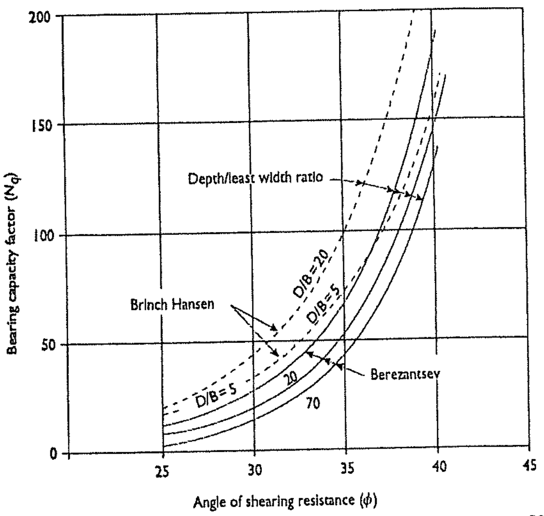
$b_c = 1.0 - \frac{2\eta°}{5.14\ tan\phi}$

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

Source: Bowles (2002)

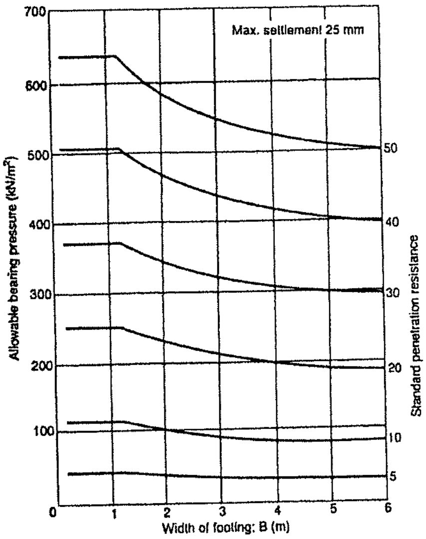
NOTE: $\eta°$ is measured anti-clockwise from the horizontal.

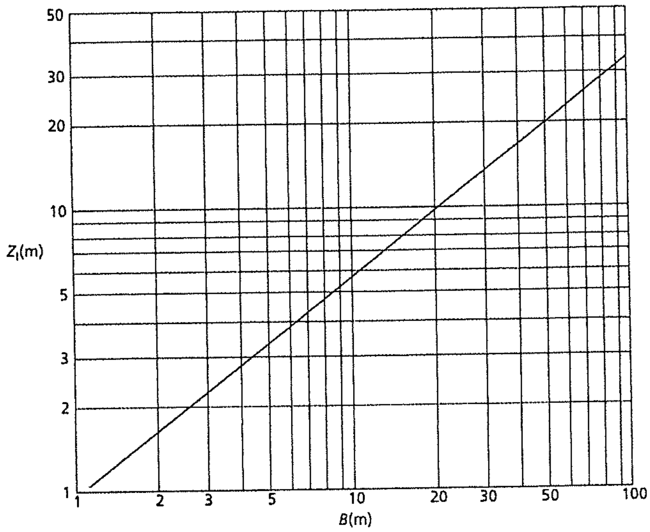
Equations, Charts and Tables

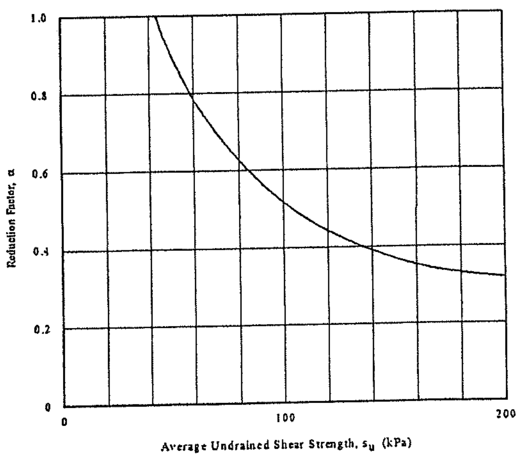


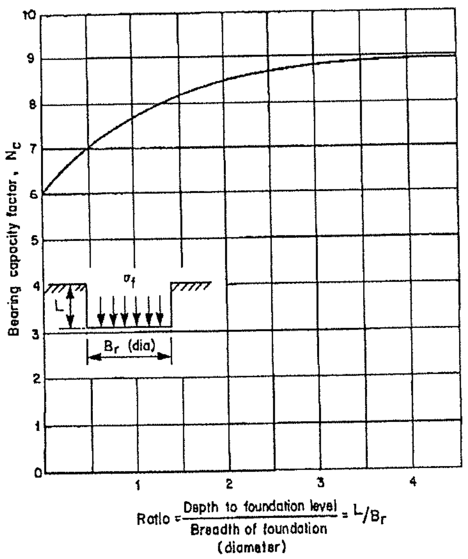
Installation method	K
Large displacement	1.0 – 2.0
Small displacement	0.75 - 1.25
Bored & cast in situ piles	0.7 – 1.0
Jetted piles	0.5 - 0.7

Pile/soil interface	δ
Smooth steel/sand	0.5φ - 0.7φ
Rough steel/sand	0.7φ - 0.9φ
Precast concrete/sand	0.8φ - 1.0φ
Cast-in-place concrete/sand	1.0φ
Timber/sand	0.8φ - 0.9φ









Student Name:______________________________ **Student Number:**______________