CE 366 Foundation Engineering – I

2011-2012 Spring Semester

Homework 1

Due on: 05.04.2012

Question 1 (20%)

The figure below shows the plan dimensions of an existing factory building founded on the surface of a thick deposit of homogeneous clay. The foundation pressure from the building is 30 kN/m^2. Also shown is the line of an existing tunnel through the clay, the crown of the tunnel being at an average depth of 12 m below ground level.

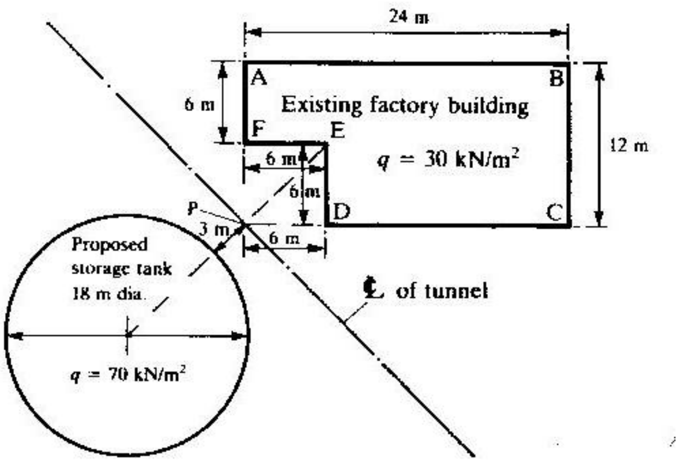


Figure 1.

It is proposed to construct a storage tank in the position shown, having an 18 m diameter flexible foundation which will transmit a pressure of 70 kN/m^2 to the surface of the clay. If this proposed construction is carried out, estimate:

a) The total vertical stress in the soil 12 m below point P and
b) The immediate surface settlement which will occur at P and the edge and center of the circular foundation.

The properties of the clay are ρ_s = 1.90 Mg/m^3, E = 5500 kN/m^2 and ν = 0.5.

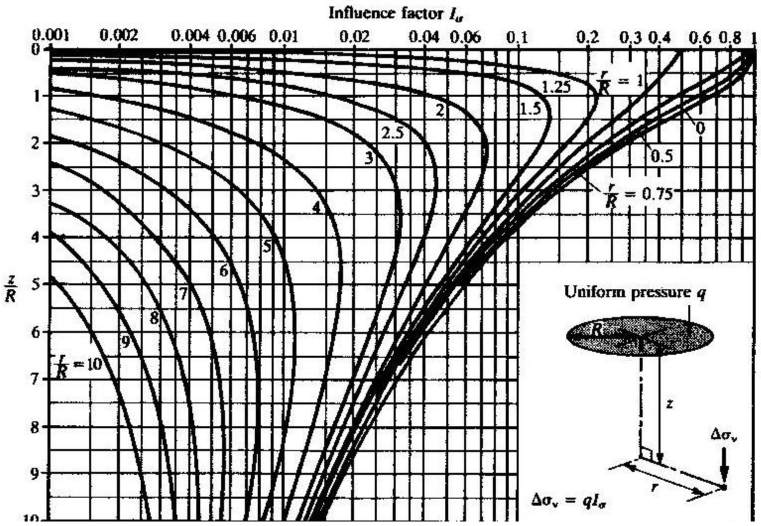


Figure 2. Values of influence factor I_σ for calculating increase in total vertical stress Δσv under a uniformly loaded circular area (After Foster and Ahlvin, 1954)

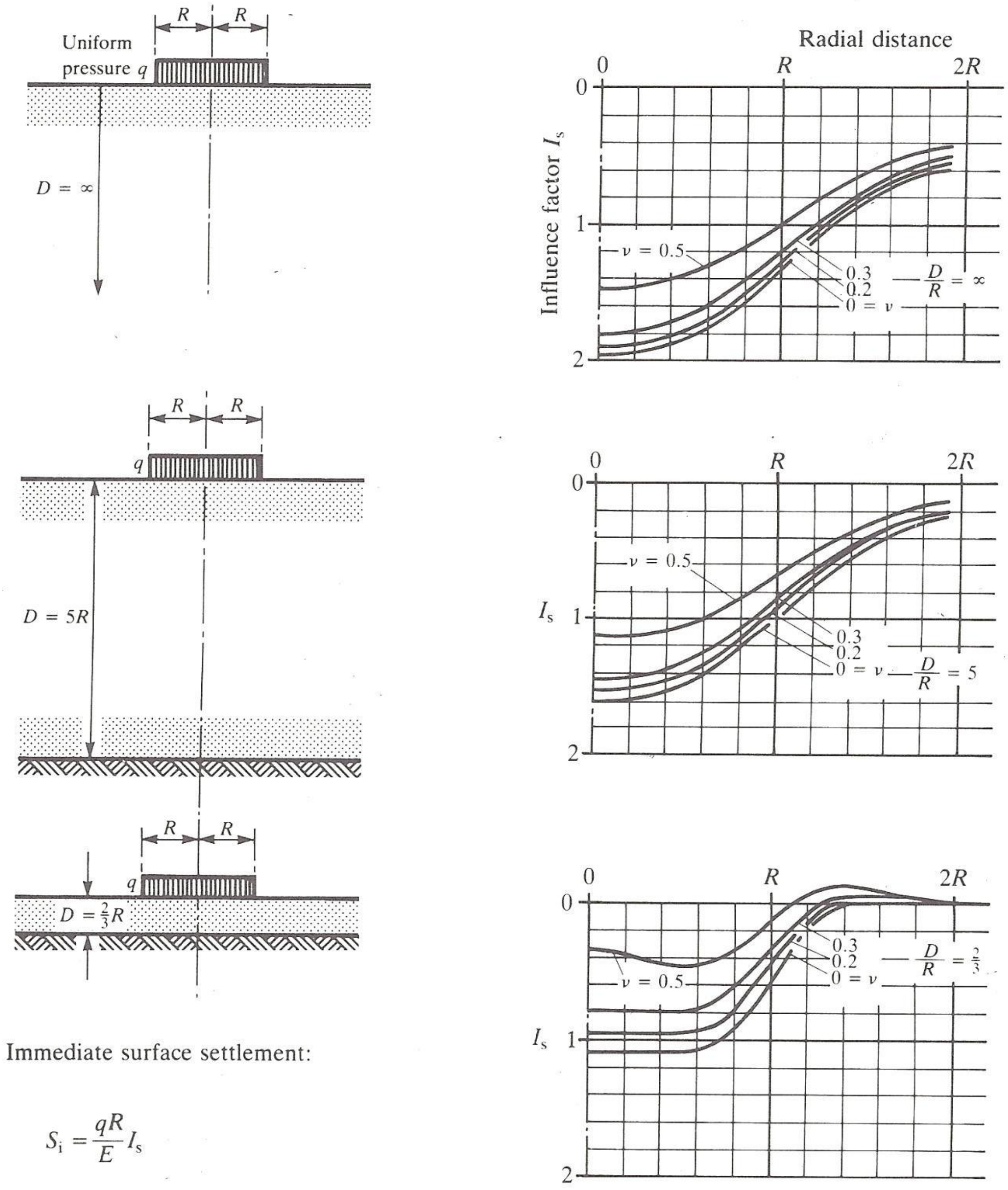


Figure 3. Values of influence factor I_s for calculating the immediate surface settlement S_i under a uniformly loaded flexible circular area (After Terzaghi, 1943)

SOLUTION:

a) The total vertical stress in the soil 12 m below P will be given by:

σ_v = total overburden pressure + increase in stress due to the existing building + increase in stress due to the proposed storage tank

Total overburden pressure $\sigma_{v0} = 1.90 \times 9.81 \times 12 = \underline{223.67 \text{ kN/m}^2}$

The increase in stress due to the existing building is obtained using the Fadum chart shown in Figure 1.6 in Lecture Notes. From the principle of superposition, the increase in total vertical stress under point P is given by:

$\Delta\sigma_v = \Delta\sigma_{v,ABCP} - \Delta\sigma_{v,FEDP}$
$\Delta\sigma_v = q(I_\sigma)_{ABCP} - q(I_\sigma)_{FEDP}$

With reference to Figure 1:

Area	B(m)	L(m)	z(m)	m=B/z	n=L/z	I_σ
ABCP	12	24	12	1	2	0.198
FEDP	6	6	12	0.5	0.5	0.083

Thus $\Delta\sigma_v = 30\text{x}0.198 - 30\text{x}0.083 = \underline{3.45 \text{ kN/ m}^2}$

The increase in stress due to the storage tank may be calculated using an influence factor obtained from Figure 2, or using the Newmark chart in Figure 1.7 in Lecture Notes.

With reference to Figure 2, the radial distance to P is r = 12 m, radius R = 9 m and the depth z = 12m. Therefore z/R = 4/3, r/R = 4/3 and $I_\sigma = 0.18$.

$\Delta\sigma_v = 70 \times 0.18 = \underline{12.60 \text{ kN/m}^2}$

For the Newmark chart, a plan showing the circular foundation and point P is drawn to a scale such that the line AB in Figure 1.7 in Lecture Notes represents the depth z=12m. This plan is then superimposed on Figure 1.7 in Lecture Notes with point P positioned over the origin of the chart. The number of influence areas enclosed by the loaded area is assessed as n=35.4. Thus,

$\Delta\sigma_v = q\, I_n = 70 \times 0.005 \times 35.4 = \underline{12.39 \text{ kN/m}^2}$

Thus, the total vertical stress in the soil 12 m below point P is given by

$\sigma_v = 223.67 + 3.45 + 12.60 = \underline{239.72 \text{ kN/m}^2}$

b) We assume that any settlements due to the existing structures will already have occurred and hence the immediate settlements will result only from the additional load imposed by the tank. The surface settlements can be estimated from equation below:

$$S_i = \frac{qR}{E} I_s$$

where herein q = 70 kN/m^2 , R = 9 m, E = 5500 kN/m^2 and I_s is obtained from Figure 3.

Assuming the clay layer to be infinitely thick we have D/R = ∞, and given that μ = 0.5 we obtain influence factors and immediate settlements as follows:

At the centre of the foundation, radial distance = 0, I_s = 1.5 and

$$S_i = \frac{70x9x1.5}{5500} = 0.172m = 172mm$$

At the edge of the foundation, radial distance = R, I_s = 1.0 and

$$S_i = \frac{70x9x1.0}{5500} = 0.115m = 115mm$$

At point P, radial distance = 4/3, I_s = 0.75 and

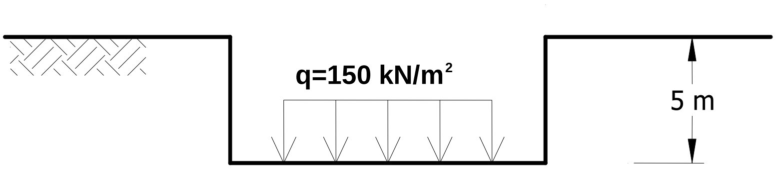
$$S_i = \frac{70x9x0.75}{5500} = 0.086m = 86mm$$

Question 2.a (10%)

Estimate the net foundation pressure after the application of a gross foundation pressure of 150 kPa at a foundation depth of 5 meters. Unit weight of the soil can be taken as 18 kN/m^3.

$$q_{net} = q_{gross} - \gamma D$$

$$= 150-(5x18)=60 \text{ kPa}$$



Question 2.b (10%)

At 6 m depth, a silty sand layer was encountered and a Standard Penetration Test (SPT) was performed. For the first, second and third 15 cm increments, the blowcounts were reported as 7,8,8 blows, respectively. Safety hammer of an energy ratio of 55 % was used during the test. The borehole diameter was measured as 110 mm and the SPT sampler used was a standard sampler with constant inside diameter (no room for liners). The length of the rod from the bottom of the safety hammer to the sampler at 6 m depth was measured as 8.2 m. Estimate the overburden and procedure corrected SPT blowcounts ($N_{1,60}$) for 30 cm penetration of the sampler (water table depth is at 2 m and the unit weights of soil above and below water tables can be assumed as 18 and 19 kN/m^3, respectively)

SOLUTION:

N= 8+8=16 blows/ 30 cm Silty Sand Correction: N=15+0.5(16-15) = 15.5 blows = 16 blows

$$C_N = \sqrt{\frac{100}{\sigma'_v}} = \sqrt{\frac{100}{(2x18)+(4x(19-10))}} = 1.18 \quad C_E = \frac{55}{60} = 0.92 \quad C_B = 1.0 \quad C_R = 0.95$$

$$C_S = 1.0$$

$$N_{1,60} = N.C_N.C_E.C_B.C_R.C_S = 16x1.18x0.92x1.0x0.95x1.0 = 16.5 \quad blows/30cm = 17 \quad blows/30cm$$

Question 3 (20%)

A building will be constructed on a clay deposit. The building will rest on a mat foundation at 2m depth and has 10m*10m dimensions in plan. The clay deposit is 12m deep and overlies a rock layer. The groundwater level is at 2m depth. The coefficient of volume compressibility of clay layer is $0.85*10^{-4}$ m^2/kN. An approximate average influence factor for vertical displacement (immediate settlement) I_s under foundation area can be taken as 1.20. Poisson's ratio of clay (ν) is 0.5. Skempton-Bjerrum correction factor μ can be taken as 0.65. The undrained modulus of clay is 60 MN/m^2. Take Υ_w = 10 kN/m^3. If $q_{all,net}$ = 104 kN/m^2, calculate the settlement under the center of the building.

HINT:

$$s_i = \frac{qB}{E}(1 - \vartheta^2)I_s$$

$s_{oed} = m_v * \Delta\sigma^I * H$; for overconsolidated clays $s_c = \mu * s_{oed}$

$\Delta\sigma^I = 4 * q_n * I_\sigma$ and $I_\sigma = 0.175$ (corner)

SOLUTION:

$$s_i = \frac{qB}{E}(1 - \vartheta^2)I_s$$

$$s_i = \frac{104x10}{60000}\ 1 - 0.5^2\ x1.2 = 0.0156m = 1.56\ cm$$

$\Delta\sigma^I = 4xq_nxI_\sigma = 4x104x0.175 = 72.8$ kPa

$s_{oed} = m_v x\Delta\sigma^I xH = 0.85x10^{-4}x72.8x10 = 0.06188$ m

$s_c = \mu x s_{oed} = 0.65 \text{ x } 0.06188 = 0.0402 = 4.02$ cm

$s_t = s_i + s_c = 1.56 + 4.02 = 5.58$ cm

Question 4 (20%)

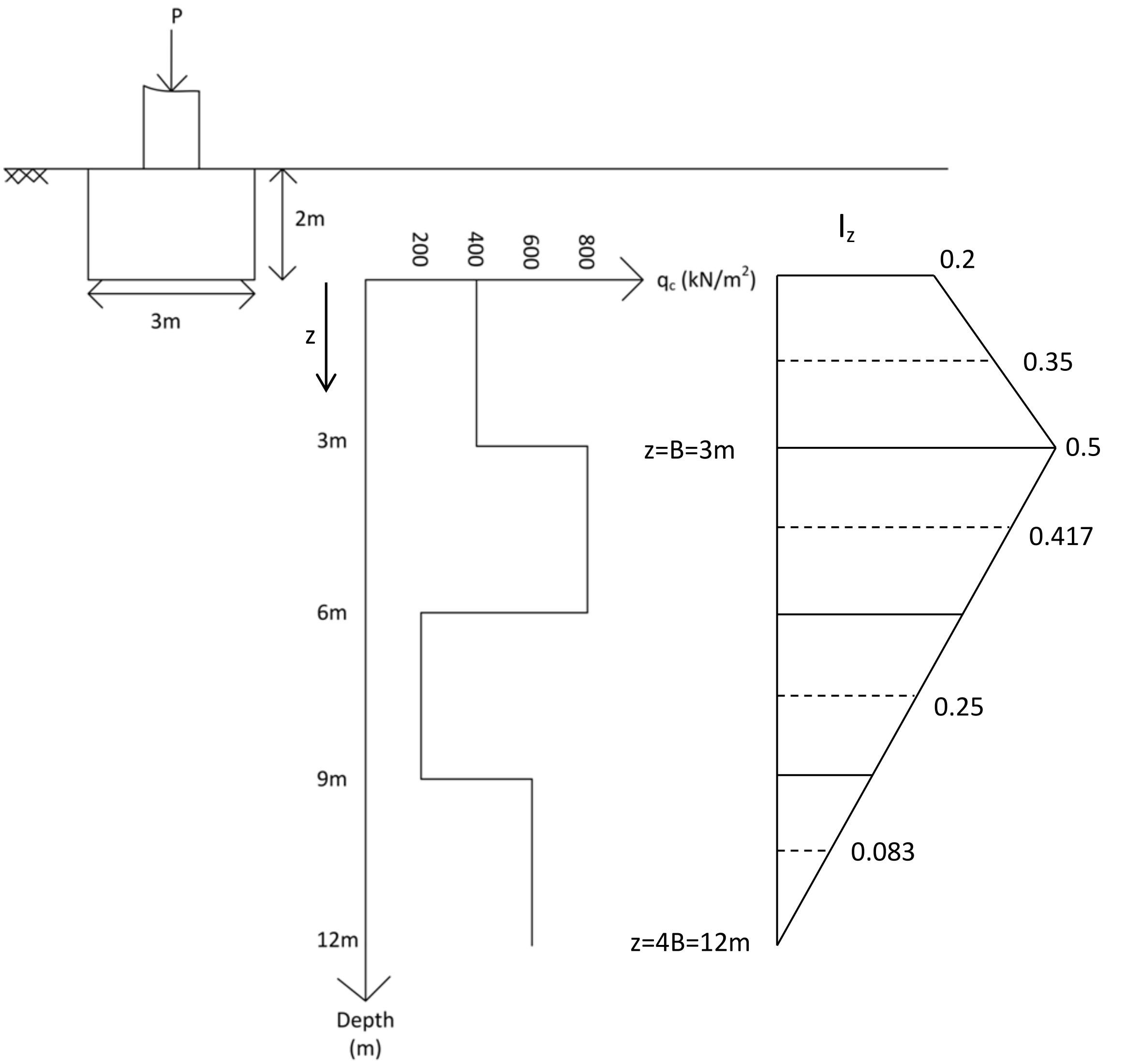
Footing of a wall is 3 m wide and is constructed at a depth of 2 m. Relevant data for the cone penetration resistance of the underlying soil is provided in the figure below. Calculate the line load (P) in units of kN/m that the footing can support for an allowable settlement of 5 cm, using Schmertmann's strain distribution method.

$I_z = 0.2$ at $z = 0$ Assume: $E_s = 2q_c$

$I_z = 0.5$ at $z = B$ $c_1 = 0.9$ (depth factor)

$I_z = 0.0$ at $z = 4B$ $c_2 = 1.4$ (creep factor)

SOLUTION:



Layer	Δz Layer Thickness, m	z Depth from foundation level , m	I_z Influence factor	q_c Cone Penetration Resistance, kPa	$E_s = 2q_c$ Elastic Modulus, kPa	C_1 (given) Depth Factor	C_2 (given) Creep Factor	$S = C_1 C_2 q_{net} I_z / E_s \Delta z$ Settlement, m
1	3	1.5	0.35	400	800	0.9	1.4	$1.65 \times 10^{-3}\ q_{net}$
2	3	4.5	0.417	800	1600	0.9	1.4	$0.99 \times 10^{-3}\ q_{net}$
3	3	7.5	0.25	200	400	0.9	1.4	$2.36 \times 10^{-3}\ q_{net}$
4	3	10.5	0.083	600	1200	0.9	1.4	$0.26 \times 10^{-3}\ q_{net}$
							Σ	**$5.26 \times 10^{-3}\ q_{net}$**

Desired Settlement = 5cm = 0.05m=$5.26 \times 10^{-3}\ q_{net}$

q_{net} = 9.5 kPa

$q_{net} = Q/B - \gamma D = 9.5$ kPa   Assume $\gamma = 19\ kN/m^3$

9.5 = Q / 3 – 2x19

Q= 142.5 kN/m

Question 5 (20%)

a) A rectangular footing having 1.8 × 2.6 m plan dimensions rests on normally consolidated clay, foundation depth being 2.0 m below ground surface. Water table is at 2 m depth. The clay has the following short term (undrained) and long term (drained) shear strength parameters:

Undrained, c_u = 50 kPa $\phi_u = 0^o$, *Drained*, c' = 5 kPa , $\phi' = 25^o$
Dry unit weight = 19 kN/m^3 , *Saturated unit weight* = 20 kN/m^3

Calculate (i) **short-term** and (ii) **long-term,** net safe bearing capacity using F.S.=3.0. (Assume that the water level does not change in short term and in long term cases.) Considering that the net safe bearing capacity is the allowable pressure we can apply on to the soil, comment in one sentence, which value we should use in our design.

Hint:

$q_f = 0.4\, \gamma\, B\, N_\gamma + 1.2\, c\, N_c + \gamma\, D\, N_q$ (for square footing)

$q_f = c_u\, (N_c)_{Skempton} + \gamma\, D$

$q_{nf} = q_f - \gamma\, D$

$(q_n)_{safe} = q_{nf}$ / F.S.

$$(N_c)_{rectangle} = (N_c)_{square} x \;\; 0.84 + 0.16 \frac{B}{L}$$

SOLUTION:

(i) Short term:

$q_f = c_u\, (N_c) + \gamma\, D$

$q_{nf} = q_f - \gamma\,\mathrm{D} = c_u . (N_c)$

Skempton N_c from Figure 4.6 in page 73 of Lecture Notes;

$\frac{D}{B} = \frac{2}{1.8} = 1.11 \rightarrow (N_c)_{square} = 7.8$

$$(N_c)_{rectangle} = (N_c)_{square} x \;\; 0.84 + 0.16 \frac{B}{L}$$

$$(N_c)_{rectangle} = 7.8 \ \ 0.84 + 0.16\frac{1.8}{2.6} \ = 7.8x0.95 = 7.41$$

$$q_{nf} = 50x7.41 = 371\ kPa$$

$$q_{netsafe} = \frac{q_{nf}}{F.S.} = \frac{371}{3} = 124\ kPa$$

(ii) <u>Long term:</u>

$q_f = \ 0.4\ \ \gamma.B.N_\gamma + \ 1.2\ \ c.N_c + \gamma.D.N_q$ (for square footing)

$$q_{nf} = q_f - \gamma D = \ 0.4\ \ \gamma.B.N_\gamma + \ 1.2\ \ c.N_c + \gamma.D.(N_q - 1)$$

$$q_{nf} = \ 0.4\ \times\ 20 - 10\ \times\ 1.8\ \times 8\ Hansen\ +\ 1.2\ \times 5 \times 20 + 19 \times 2 \times\ 11 - 1\ = 558\ kPa$$

$$q_{netsafe} = \frac{q_{nf}}{F.S.} = \frac{558}{3} = 186\ kPa$$

Conclusion: Short term is more critical case, and $q_{all} = 124\ kPa$ must be used in design.

b) Answer the questions below. (Note that students are required the understand the reasoning behind the answers.)

b1) If the same foundation as in part (a), would be constructed on a soil with drained friction angle of 35 degrees, instead of 25 degrees (cohesion is the same c' = 5 kPa), keeping all other parameters constant, the ultimate bearing capacity, q_f , would be ....higher.......................................

lower / higher / would not change.

b2) Keeping all other parameters constant as in part (a), the larger the B, the larger will be its drained ultimate bearing capacity. .....True...............

True or False

b3) When a foundation is constructed on a clay, short term ultimate bearing capacity will be more than the long term ultimate bearing capacity. .....False.............

True or False

b4) Ultimate bearing capacity of a foundation constructed on a clay soil, will be governed by the undrained shear strength, c_u of the clay, not the friction angle. .....True................

True or False

b5) N_c values in the two ultimate bearing capacity, q_f, equations given above have the same values ......False.............

True or False

b6) If the net ultimate bearing capacity (q_{nf}) is less than the net foundation pressure (q_{net}) the building is going to apply, then the building will have a bearing capacity failure. .....True...............

True or False

b7) Consider the bearing capacity of a cylindrical shaped reinforced concrete pile in clay. We can consider the pile similar to a circular foundation with large D_f/B ratio (depth of foundation >> width of foundation). The ultimate bearing capacity of a pile in clay can be calculated by $N_c \times c_u$. What is N_c number we should use in this case. N_c = ..9...