فونديشن

رابعه انشاءات

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4th Year Civil - Structures

Foundation Design

(10)

Mid-term revision
Part (2).

Ain Shams University
Faculty of Engineering
December 2011
CES 451: **Foundation Engineering**

4th Year, Civil Engineering
Students of Structure Eng. Div
Time: 2.0 hours
Mid term Exam

Question	1	2	3	Total	**Name**:
Mark					**Section**:
Initials					**BN**:

The examination consists of **3** questions in **10** pages.
Make a reasonable assumption of any missing data.
All sketches should be neatly drawn and properly dimensioned

Question 1

a) Compare between the elastic modulus and coefficient of subgrade reaction, and discuss the relation between them.

b) Design a reinforced concrete isolated footing for a R. C. column 120 cm in diameter. The column is carrying a net working load 900 ton. The net bearing capacity of supporting soil is 9.0 t/m^2.

Data :

Materials: Concrete f_{cu} = 300 kg/cm^2 , Steel 40/60 f_y = 4000 kg/cm^2

Working stress: f_c = 100 kg/cm^2, f_s = 2200 kg/cm^2, q_c = 7 kg/cm^2, q_{cp} = 10 kg/cm^2,

local bond stress = 12 kg/cm^2

Ultimate stress: q_{cu} = 9 kg/cm^2, q_{cpu} = 14.5 kg/cm^2, q_{bu} = 18 kg/cm^2

$C1_{min.}$ = 3.0 , j = 0.74
C1 = 3.5 , j = 0.78
C1 = 4.0 , j = 0.80
C1 = 4.85 , j = 0.826

Area of different reinforcement steel bars:

Φ12: area = 1.13 cm^2, Φ16: area = 2.00 cm^2, Φ18: area = 2.84 cm^2
Φ20: area = 3.14 cm^2, Φ22: area = 3.80 cm^2, Φ25: area = 4.91 cm^2

- $d = C_1 \left(M_u / (f_{cu} \cdot b) \right)^{0.5}$
  $As = M_u / f_y \cdot d \cdot j$

c) For the two columns shown in Figure 1, suggest a suitable type of shallow foundation. Sketch the concrete dimensions and reinforcement details.
(Area of foundation must be drown with suitable scale 1: 50 or 1: 100). q_{all} = 30.0 t/m^2

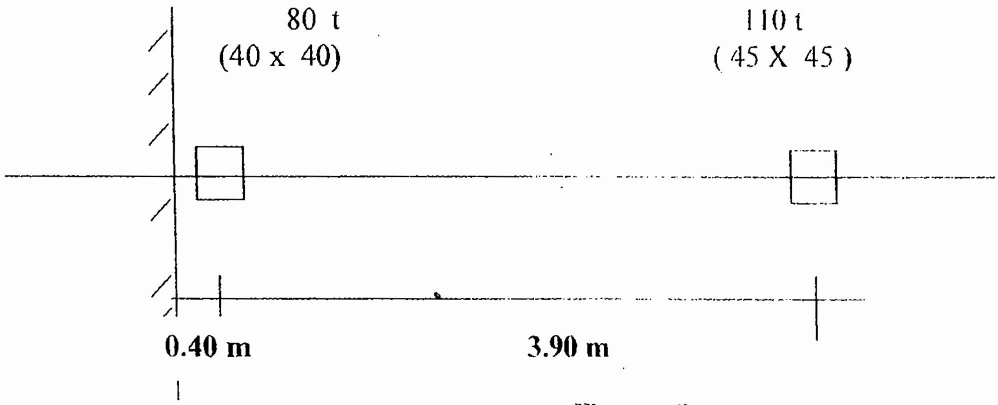


Figure (1)

Question 2

a) Evaluate the following statements (right or wrong) and comment on your evaluation (Any answer without comments is not accepted):

i. Driven piles are suitable piling technique in city centers beside historical buildings.
ii. In CFA piles, the concrete should have slump smaller than 20 cm.

iii. Bentonite slurry is suitable to stabilize the drilling hole during construction of large diameter bored piles in sandy soil.

iv. Pile load tests (static and/or dynamic) should be performed at least on 50% of working piles.

v. Pile skin friction is fully mobilized at small settlement.

b) Figure 2 shows the subsurface soil profile at a site and the geotechnical parameters of the soil layers in that site. A tower crane is to be constructed in this site. The foundation is a square footing 5m x 5m x 1.5m. The vertical load of the crane is 250 kN. The footing weight reaches 937.5 kN The crane can rotate in any direction around its vertical axe. The maximum weight to be transported by the crane is 100 kN. The maximum lifting distance is 30.0 m.
The crane footing is founded on 4.0 driven concrete piles with pile diameter 0.5 m.

i. Calculate the pile loads in case the crane is on x axis.

ii. Determine the pile length applying a factor of safety of 3.0.

For driven piles:
K_{HC} = 1.0
δ = ¾ φ
Nq = 75

$$Q_{ult} = P_b N_q \pi R^2 + \sum_{H=0}^{H=L} K_{HC} P_o (\tan\delta) 2\pi R \Delta H$$

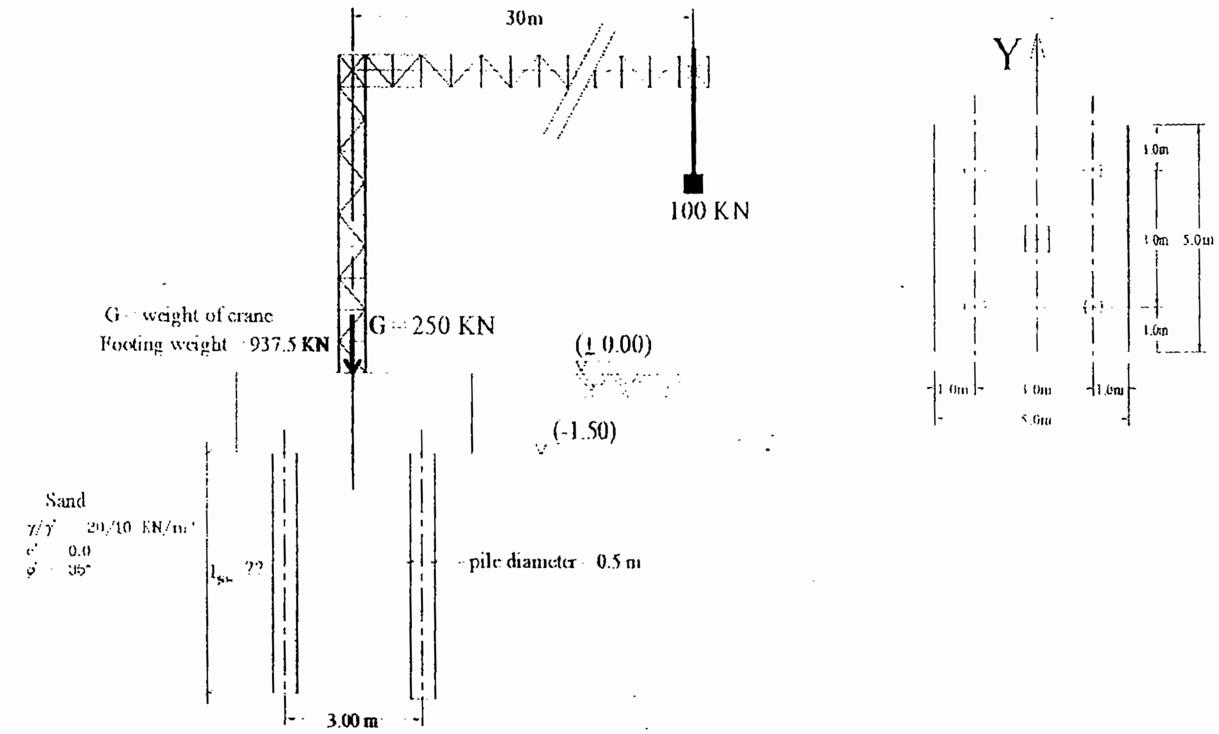


Figure (2)

Question 3

A reinforced concrete footing (9.0 m long X 1.20 m wide X 1.20 m thick) is carrying a masonary wall. Use ohde equation, to determine the required masonary wall load (kN/m') equivalent to uniform settlement 8 cm beneath the footing.

Input Data:

Modulus of elasticity of clay = 20 MN/m².

Modulus of elasticity of R. C. = 21000 kN/cm².

The footing should be divided into six elements.

C_0 = 1.60 $\qquad C_i = \dfrac{C_0}{[1 + 1.2(i)^{1.4}]}$

Ain Shams University	4th Year, Civil Engineering
Faculty of Engineering	Students of Structure Eng. Div.
November 2010	Time: **1.5** hours
CES 451: **Foundation Engineering**	Mid-term Exam

Question	1	2	3	4	Total	**Name:**	
Mark						**Section:**	
Initials						**BN:**	

The examination consists of **4** questions in **12** pages.
Make a reasonable assumption of any missing data.
All sketches should be neatly drawn and properly dimensioned.

Question 1

A square R.C. isolated footing is proposed to support a square column of a composite section (as shown in figure 1). The column carries an axial compression load of 2000 KN. The concrete dimensions of the column cross section are 0.4 x 0.4 m. The proposed dimensions of the R.C. footing are 2.5 x 2.5 m, and its thickness is 0.5 m as estimated from a preliminary design. It is required to check the safety of the proposed footing thickness **only for punching shear**. If the given footing thickness is unsafe, estimate the footing thickness that will be safe in punching shear (no more calculations or checks are required).

- Column dimensions: 0.4 x 0.4 m
- R.C. footing thickness: 0.5 m
- f_{cu} = 30 N/mm^2

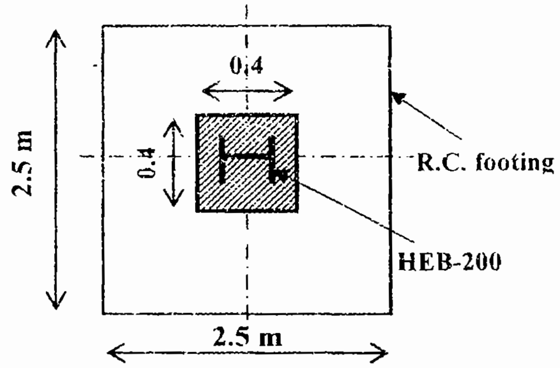


Figure (1)

Question 2

Two isolated square footings (F_1 and F_2) are founded on a thick layer of quite homogenous silty sand followed by a rock deposit (as shown in figure 2). The thickness of the silty sand layer is 13.0 m from the ground surface. The foundation depth of the two footings is 2.0 m. The average value of the compression modulus of the silty sand is 20 MPa. It is required to:

i) Calculate the average contact pressure below each footing.
ii) Calculate the average settlement below each footing (the compressible silty sand can be divided into two layers).
iii) Estimate a reasonable value for the coefficient of subgrade reaction below each footing.
iv) Estimate the differential settlement between the two footings.
v) If the allowable foundation settlement is 30 mm and the allowable differential settlement is 1:500, check on the satisfaction of both the settlement and the differential settlement of (F_1 and F_2) with respect to the given permissible limits.

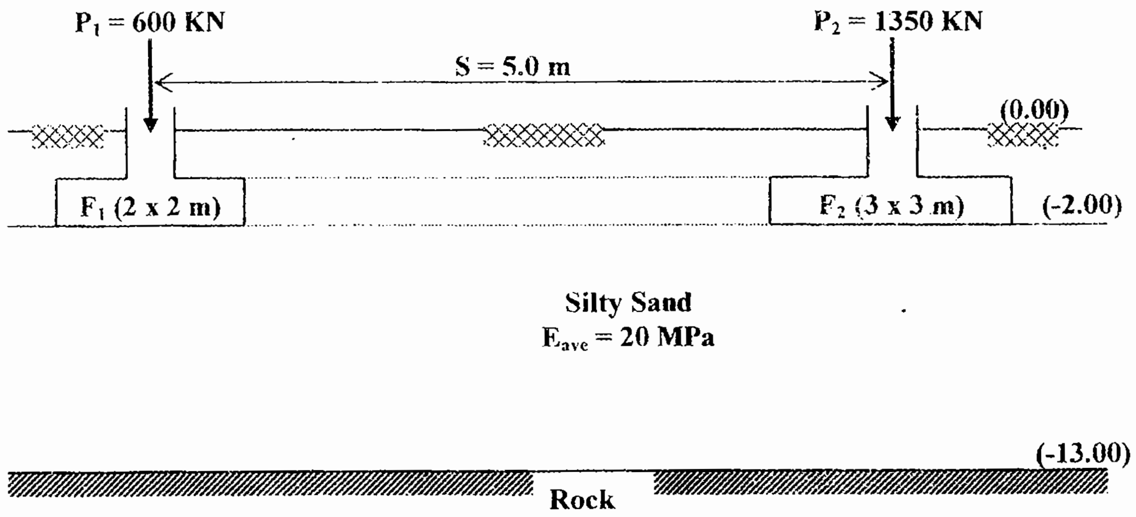


Figure (2)

Question 3

It is decided to design the R.C. combined footing shown in **Figure** 3 considering soil elasticity. The footing is 1.5 X 5.4 m and carries two columns 2.70 m center to center. Each column is subjected to: N=1000 kN, M=50 kN.m. The footing is 100 cm in thickness and can be divided into 6 elements.

The following is required:

i- Determine the contact stress under the footing using Winkler assumption (Ks_o= 2000 kN/m^3).

ii- Determine the contact stress under the footing assuming the soil is elastic, homogeneous, isotropic and semi-infinite. Use (C_o =1.33, C_1 =0.52, C_2=0.3, C_3 =0.2, C_4 =0.16, C_5 =0.12), Ec = 2000 kN/cm^2 and Es = 1000 kN/m^2.

iii- Compare between the two solutions and explain the difference.

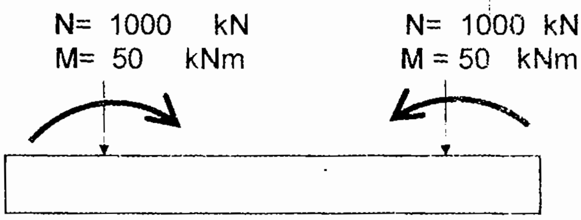


Figure 3

Question 4

a- Advice the most suitable pile for following conditions:
   1- Offshore platform with water depth of 20 m
   2- Foundation of an extension building of a hospital where the soil consists of 15 m sandy silt followed by very dense sand and the ground water table lies 2.0 below ground surface
   3- Foundation of a road bridge where the subsoil consists of dense sand and the ground water table lies just at ground surface

b- Comment on static pile load test using anchors or Osterberg cell as a reaction system.

c- Results of geotechnical investigation at a site showed that the soil profile (see figure 4) consists of a thick layer of medium to dense sand down to 15.0 m followed by rock formations. A column with working load (dead and live loads) of 5000 kN is to be founded on driven piles with pile diameter 0.5 m in the sand layer. The pile length is 10 m below foundation level. The foundation depth is just at the ground water table that lies 1.0 m below ground surface. Calculate the bearing capacity of the single pile under compression and under tension loads.

Soil Parameters

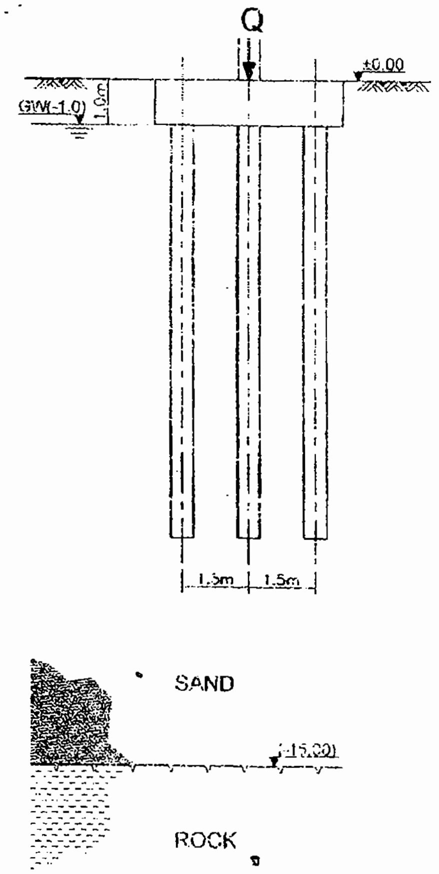
Soil parameter	Sand
E [MN/m²]	50
ν [-]	0.3
γ / γ′ [kN/m³]	20/10
c′ [kN/m²]	0.0
φ′ [°]	33

E Primary loading stiffness
ν Unloading/reloading Poisson's ratio
γ / γ' Total / Effective unit weight of soil
c' Cohesion
φ' Angle of internal friction

Pile diameter D = 0.5 m
Pile length L = 10 m
$E_{concrete}$ = 30000 MPa

For driven piles:
$K_{HC} = 1.0$
$K_{HT} = 0.7$
$\delta = \frac{3}{4} \varphi$
$N_q = 60$

$$Q_{ult} = P_b\, N_q\, \pi R^2 + \sum_{H=0}^{H=L} K_{HC}\, P_o\, (\tan\delta)\, 2\pi R\, \Delta H$$



section

Figure (4)

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Ain Shams University
Faculty of Engineering
Structural Eng. Department
4th Year Civil-PW Division
Foundation Engineering.
June 2011

جامعة عين شمس – كلية الهندسة
قسم الهندسة الإنشائية
رابعه مدني– طلبة شعبة الأشغال العامة
هندسة الأساسات.
يونيو 2011

General remarks:

- The exam consists of 5 questions in 4 pages
- Answer all questions
- Assume any missing data reasonably

Question 1

a) Illustrate each of the following using neat sketches:

i. The different types of shallow foundations
ii. The main functions of the plain concrete footing in the shallow foundations construction and design
iii. The suitable conditions for the use of raft foundation
iv. The main factors affecting the rigidity of shallow foundation

b) It is required to design a shallow foundation to support a circular column. The diameter of the circular column is 0.9 m, and it carries an axial compression load of 4500 KN. The suggested thickness of the plain concrete footing is 40 cm. The allowable net bearing capacity of the subsoil is 200 kPa. Draw details for the designed foundation in both plan and cross sectional elevation using scale 1:50.

Design Data:

- f_{cu} = 30 N/mm^2 ; f_y = 360 N/mm^2
- Cross sectional area of reinforcing steel bars:

Steel bar diameter	Cross sectional area (mm^2)	Steel bar diameter	Cross sectional area (mm^2)
Φ10	78.5	Φ18	254.5
Φ12	113.1	Φ20	314.2
Φ16	201	Φ25	490.9

Question 2

Evaluate the following statements (right or wrong) and comment on your evaluation (***Any answer without comments is not accepted***):

a) Driven piles are not suitable piling technique in city centers beside historical buildings.
b) In CFA piles, the concrete should have slump larger than 20 cm.
c) Bentonite slurry is used to stabilize the drilling hole during construction of large diameter bored piles in sandy soil and has no negative effect on its shaft capacity.
d) Pile load tests (static and/or dynamic) should be performed at least on 50% of working piles.
e) Pile skin friction is fully mobilized at small settlement.
f) The settlement of pile group under vertical compression loads is smaller than the settlement of the same single pile under the same average load of the pile group
g) The settlement of pile group depends on the number of the piles.
h) In a pile group that is connected with a rigid pile cap and subjected to horizontal load, the front piles carry higher loads than the rear piles.

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Question 3

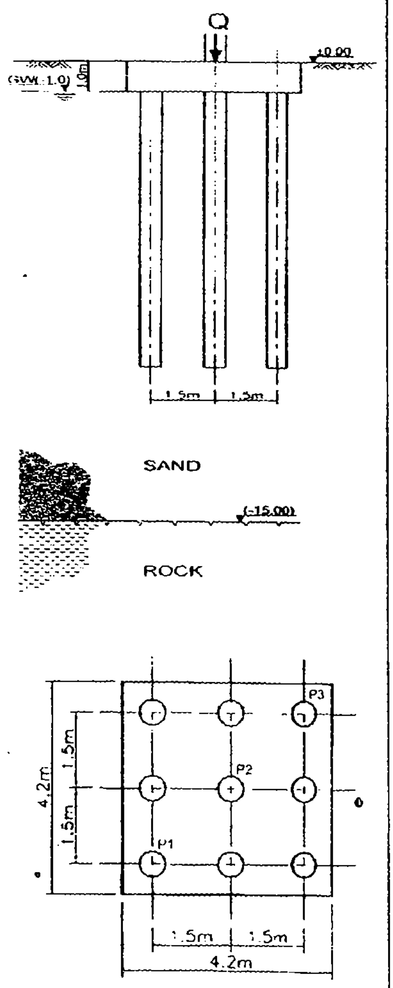
Results of geotechnical investigation at a site showed that the soil profile, as shown in Figure 2, consists of a thick layer of medium to dense sand down to 15.0 m followed by rock formations. A column with working load (dead and live loads) of 5000 kN is to be founded on driven piles with pile diameter 0.55 m in the sand layer. The pile length is 9 m. The foundation depth is just at the ground water table that lies 1.0 m below ground surface. Nine piles were arranged below the pile cap as shown in the Figure xx. The following is required:

a) Calculate the settlement of the pile group.

b) If the settlement of the single pile under working loads is 3 mm, calculate the pile group action.

c) If the applied working loads on the pile cap are as follows:
Q = 3200 kN
Mx = 2500 kNm
My = 1400 kNm
Determine the loads taken by piles No. P1, P2 and P3.

d) Determine the factor of safety of piles No. P1, P2 and P3 under the above mentioned loading condition. Comment on the results.



Soil Parameters

Soil parameter		Sand
E	[MN/m²]	40
v	[-]	0.3
γ / γ′	[kN/m³]	20/10
c′	[kN/m²]	0.0
φ′	[°]	33

E — Primary loading stiffness
v — Unloading/reloading Poisson's ratio
γ / γ' — Total / Effective unit weight of soil
c' — Cohesion
φ' — Angle of internal friction

Pile diameter D = 0.55 m
Pile length L = 9 m
$E_{concrete}$ = 30000 MPa

For driven piles:
$K_{HC} = 1.0$
$\delta = \frac{3}{4}\varphi$
$N_q = 60$

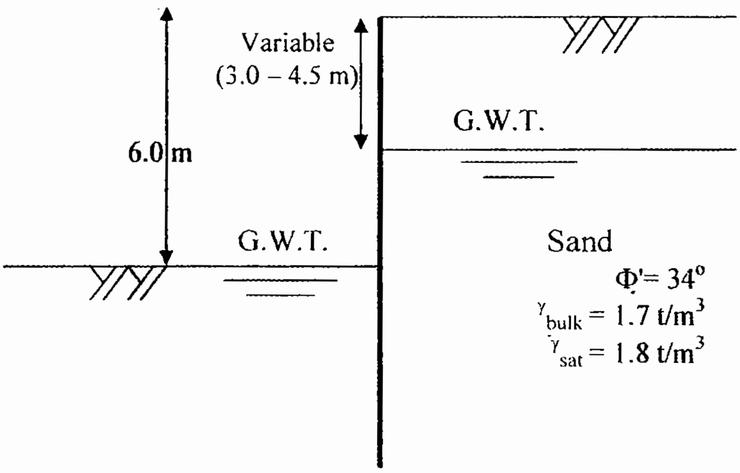
$$Q_{ult} = P_b\, N_q\, \pi R^2 + \sum_{H=0}^{H=L} K_{HC}\, P_o\, (\tan\delta)\, 2\pi R\, \Delta H$$

Question 4

a) Choose the suitable sign (√) or (x) for the shown statements and illustrate the reason for each one. (Use sketches if required): <u>If you do not illustrate the reason, the answer will not be accepted</u>:

1. The secant pile wall is used to support excavation and to prevent water leakage to inside the excavation area.
2. For the same conditions and dimensions, the safe depth of the fixed earth support wall is greater than that of the free earth support wall.
3. For the same conditions and dimensions, the acting earth pressure above the dredge line on the fixed earth support wall is the same as that acting above the dredge on the free earth support wall.

b) For the shown cantilever pile wall, determine the safe penetration depth.



Question 5

Choose the correct answer from the given varieties to set a suitable form for each of the following statements:

(1) Earth embankment can be used in ground improvement through the technique of......

(i) deep compaction	(ii) preloading
(iii) soil replacement	(iv) grouting

(2) The stability of the earth embankment side slopes is affected by the shear strength characteristics of........

(i) the embankment material only	(ii) the foundation soil only
(iii) both the embankment material and the foundation soil	(iv) non of the above

(3) By compacting a soil sample, the sample volume is decreased due to the decrease in the volume of voids by ejecting ....

(i) air	(ii) water
(iii) both air and water	(iv) solids

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(4) After compaction, the soil saturation degree........

(i) decreases
(ii) increases
(iii) sometimes decreases and sometimes increases
(iv) remains constant

(5) After compaction, the soil permeability........

(i) decreases
(ii) increases
(iii) sometimes decreases and sometimes increases
(iv) remains constant

(6) The maximum dry density of a compacted soil corresponds to.......

(i) a maximum void ratio
(ii) a minimum void ratio
(iii) a maximum water content
(iv) a minimum water content

(7) If a relative density of 80% is corresponding to a relative compaction of 95%, then for a required relative density of 85% the relative compaction will be........

(i) 95%
(ii) less than 95%
(iii) greater than 95%
(iv) properly less than 95% or greater than 95%

(8) By increasing the relative density of a granular soil, the internal friction angle of the soil......

(i) decreases
(ii) increases
(iii) sometimes decreases and sometimes increases
(iv) remains constant

(9) The earth embankment can be used as an earth dam, in such a case the embankment soil material shall be.......

(i) sand
(ii) gravel
(iii) mix of sand and gravel
(iv) clay

(10) For a railway earth embankment, the most suitable type of soil to be used in the embankment construction is.........

(i) sand
(ii) gravel
(iii) mixture of sand and gravel
(iv) clay

(11) If an earth embankment is to be constructed using coarse-grained granular soil, then the embankment soil shall be..........

(i) organic and well graded
(ii) inorganic and poorly graded
(iii) organic and poorly graded
(iv) inorganic and well graded

(12) If an earth embankment of coarse-grained granular soil is constructed on a deep deposit of sand, then the embankment settlement will be.....

(i) short-term settlement
(ii) long-term settlement
(iii) consolidation settlement
(iv) both short and long term settlement

Best Wishes

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Faculty of Engineering
Structural Eng. Department
4th Year Civil-PW Division
Foundation Engineering.
May 2010

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قسم الهندسة الإنشائية
رابعه مدني– طلبة شعبة الأشغال العامة
هندسة الأساسات.
مايو 2010

General remarks:

- The exam consists of 5 questions in 3 pages
- Answer all questions
- Assume any missing data reasonably

Question (1)

A) Design an isolated footing to carry a column load 2500 KN. The **column dimensions** are 0.90 x 0.40 m. Draw sectional elevation and plan with scale 1: 50. (f_{cu} = 25 N/mm^2, f_y = 360 N/mm^2). Thickness of P.C. is 30 cm, and q_{all} = 150 KN/m^2.

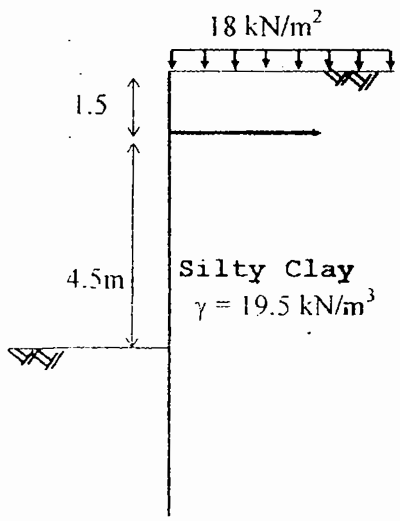
B) Choose the suitable sign (√) or (x) for the shown statements and **illustrate** the reason for each one. (Use sketches if required): If you do not illustrate the reason, the answer will not be accepted

1. Ground beams can resist the effect of differential settlement between footings.
2. The footing carrying vertical load and temporary moment has greater dimensions than that carrying vertical load only.
3. Steel stirrups are not used in the combined footing.
4. No need to check punching shear for strap beam footing.

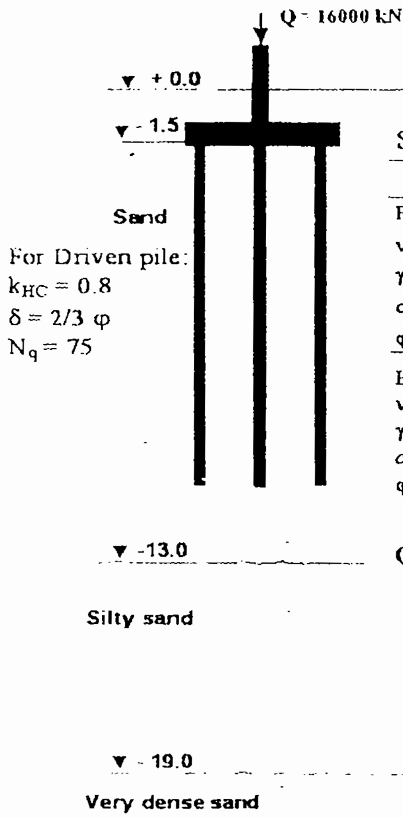
Question (2)

A) Compare between using grouted tie backs and deadman as supports for wall.

B) For the shown anchored free earth supported steel sheet pile wall, calculate the safe embedment depth and the force in the tie back if it is spaced 2.5 m horizontally
(C'=8 kN/m^2 , ϕ' = 22°).



Question (3)



Soil Parameters

Soil parameter	Sand	Silty Sand	Very dense sand
E [MN/m²]	60	20	100
ν [-]	0.3	0.3	0.3
γ / γ' [kN/m³]	18/8	19/10	20/11
c' [kN/m²]	0.0	5.0	0.0
φ' [°]	35	30	37.5

E Deformation modulus of soil (Young's Modulus)
ν Poisson's ratio
γ / γ' Total / Effective unit weight of soil
c' Cohesion
φ' Angle of internal friction

$$Q_{ult} = p_b\, N_q \pi\, R^2 + \sum_{H=0}^{H=D} K_{Hc} p_o \tan\,\delta.\, 2\pi\, R\, \Delta H$$

Figure: Soil profile and geotechnical parameters

Results of geotechnical investigation at a site showed that the soil profile (see attached figure) consists of a thick layer of sand down to 13 m followed by a layer of silty sand with depth of 6m. A very dense sand layer was found up to 19 m below ground surface. A column with working load (dead and live loads) of 16000 kN is to be founded on driven piles with pile diameter 0.6 m in the upper sand layer. The pile tip should be on – 11.5. It is required to:

1- Determine the allowable pile load considering a factor of safety (F.S. = 3.0) using the static equation.
2- Determine the required number of piles and draw a sketch showing the distribution of the piles beneath the pile cap
3- Calculate the settlement of the pile group assuming that the settlement is controlled only by the silty sand layer.
4- If the settlement of the single pile under working loads is 5 mm, calculate the pile group action

Question (4)

Evaluate the following statement (right or wrong) and comment on your evaluation ***(the answer without comments will not be accepted)***:

1. Driven piles are the most suitable piling technique in city centers beside historical buildings.
2. Bentonite slurry is used to stabilize the drilling hole during construction of large diameter bored piles in sandy soil.
3. Pile skin friction is fully mobilized at small settlement
4. The structural loads are carried completely by the piles of a piled raft foundation.
5. In a pile group under tension loads, the soil own weight between the piles can govern the pullout resistance of the pile group.

Question (5)

1. What are the main problems to be considered in the design of earth embankment?
2. Explain briefly the design criteria for earth embankment.
3. Using neat sketches, discuss the process of surface and deep compaction in soil improvement.
4. What is meant by preloading? And what are the different techniques used to accelerate it.

Ain Shams University
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Foundation Engineering.
May 2009

جامعة عين شمس – كلية الهندسة
قسم الهندسة الإنشائية
رابعة مدني – طلبة شعبة الأشغال العامة
هندسة الأساسات.
مايو ٢٠٠٩

General remarks:

- The exam consists of 4 questions in 3 pages
- Answer all questions
- Assume any missing data reasonably

Question 1

Design an isolated footing to carry a column load 300 t. The column dimensions are 1.0 x 0.3 m. Draw sectional elevation and plan with scale 1: 50.
(f_{cu} = 25 N/mm^2, f_y = 360 N/mm^2).
Thickness of P.C. is 25cm, and q_{all} = 150 kN/m^2.

Question 2

A) Describe the following using neat sketches whenever it is required:
1- The types of anchorage systems.
2- Analysis of braced excavations.

B) For the shown anchored free earth support tangent pile wall, determine the safe penetration depth and the maximum bending moment on the wall.

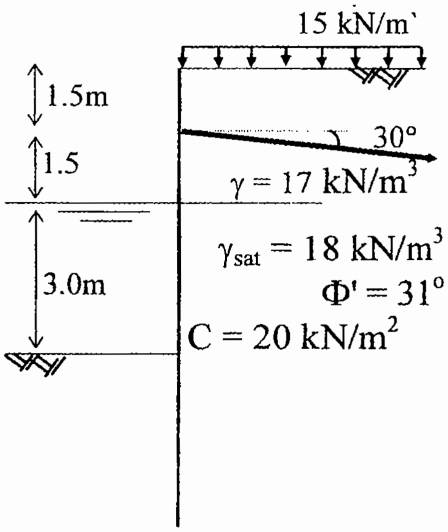

Figure (1)

Question 3

Describe the following using neat sketches whenever it is required:

a) The required checks for the analysis of earth embankments.
b) The possible ways to increase the safety of earth embankments.
c) The methods to improve the soil below the embankments.
d) The factors governing the choice of suitable soil type for the construction of an earth embankment

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Question 4

a) Explain briefly using nest sketches each of the following;

1. Classification of piles with respect to piling technology and soil-pile interaction.
2. How can the piling technology affect the pile capacity?
3. Special consideration must be followed when driving piles through cohesive soil.
4. Factors controlling the choice of pile installation procedure.
5. Effect of shallow soft clays on the capacity of piles subjected to tension loading.
6. Determination of the pile capacity using field testing procedures.

b) Figure (2) shows the subsurface soil profile and results of laboratory tests for a given site. Groups of bored piles (50cm in diameter and 10m long) were proposed for this site. These piles to be constructed after excavation of the site to a depth of 2.5m below ground surface which is considered the bottom level of the pile cap. The ground water table is at -2.5m below ground level. Calculate;

1. The maximum allowable load per pile.
2. Discuss the effect of increasing the pile length to 20m on the pile capacity.

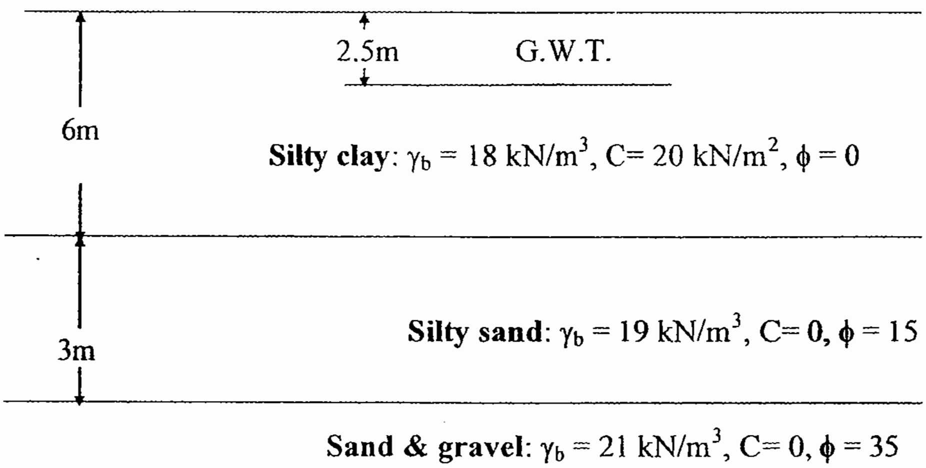

Figure (2)

c) A group of piles (5x6 piles) having a diameter of 0.45m and spaced at 1.35m are driven to a depth of 18m below the ground surface. The soil formation at the site is illustrated in Fig. (3). If the maximum allowable settlement of the group is 2.5cm. Determine the maximum allowable compression and tension capacity of the group (K_{HC}=1.0, K_{HT}=0.6).

Level	-2	-4	-6	-8	-10	-12	-14	-16	-18	-20	-22	-24	-26	-28	-30	-32
N_{30}	3	3	8	18	8	8	9	11	11	12	12	13	13	40	48	50

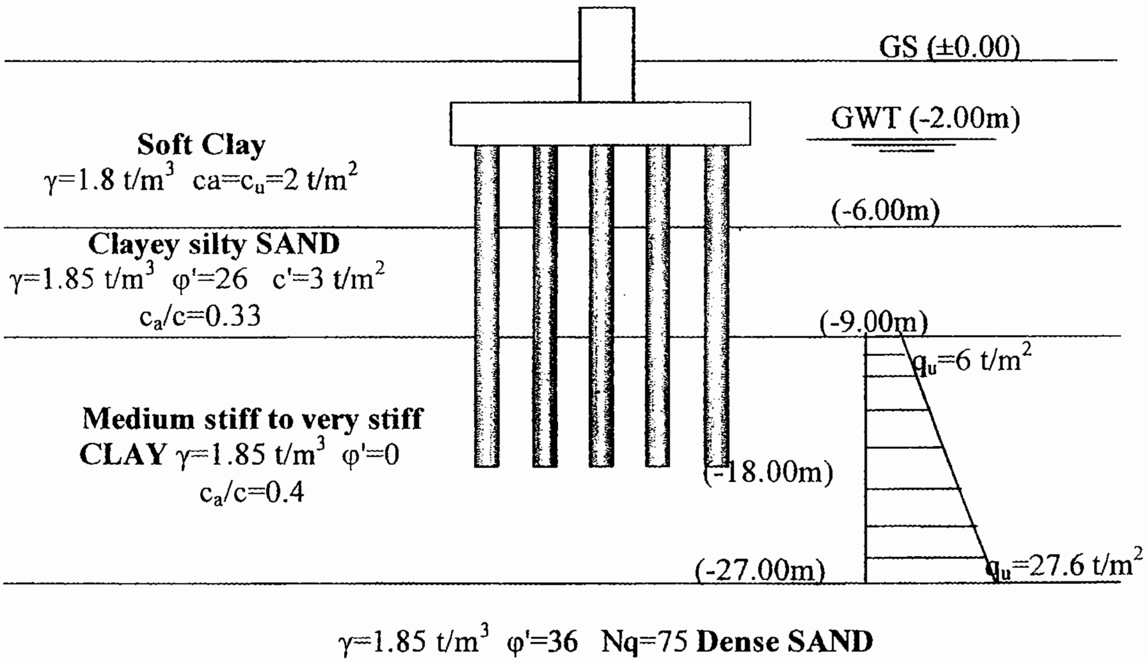

Figure (3)

Best Wishes

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- Example 1 (Midterm 2011 structure – question 2-a):-

i- √

- لا يسمح باستخدام الـ driven piles فى الأماكن السكنية أو بجوار المبانى الأثرية لأن عملية الدق تؤدى لحدوث اهتزازات للأرض قد تؤثر على سلامة المنشآت المجاورة.

ii- √

- فى حالة الـ CFA يجب أن يكون قوام الخرسانة عالى السيولة لتسهيل عملية إنزال حديد التسليح بعد صب الخرسانة.

iii- x

- يستخدم الـ bentonite slurry لسند جوانب الحفر فى حالة التربة الرملية ولكنه يقلل من الـ skin friction نظرا لتكون الـ Mud cake على جوانب الحفرة.

iv- x

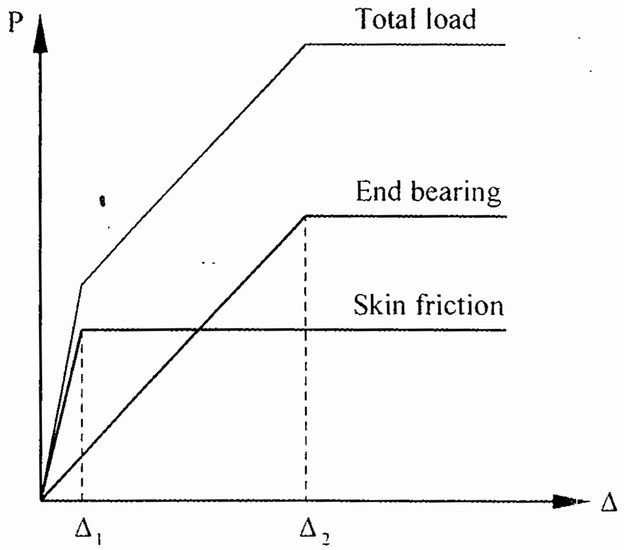
- يتم إجراء اختبار التحميل Pile load test بمعدل اختبار لكل 200 خازوق بالموقع ولا يقل عدد الاختبارات عن اختبار واحد.

v- √

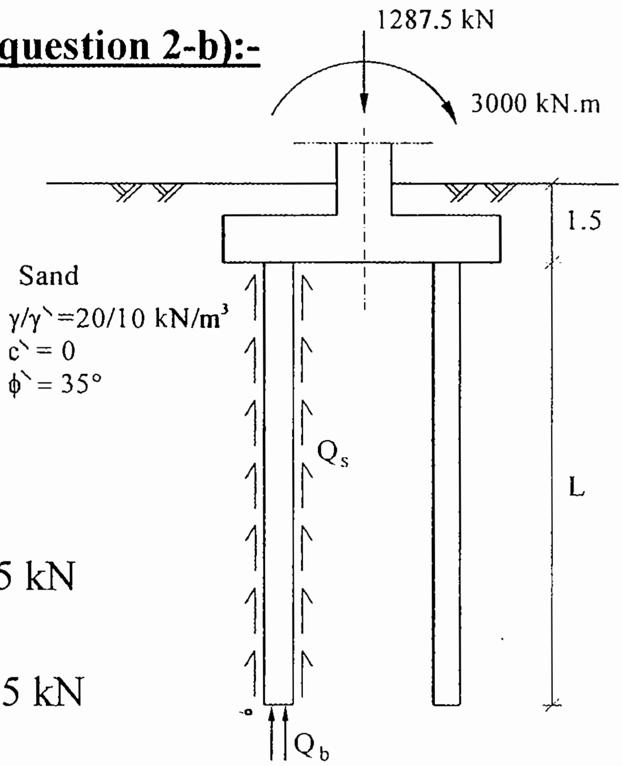
- The skin friction needs a small pile settlement to be fully mobilized as in case of large diameter bored piles:-

  - Δ_1 = 5-10 mm or 1% of pile diameter.

  - Δ_2 = 5% of pile diameter.



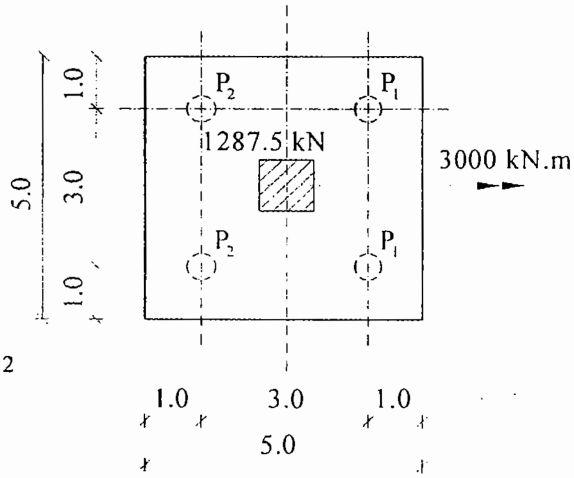
- Example 2 (Midterm 2011 structure – question 2-b):-



i- Pile loads:-

- $N = 250 + 100 + 937.5 = 1287.5$ kN
- $M_y = 100 \times 30 = 3000$ kN.m
- $\sum x^2 = 4 \times 1.5^2 = 9\ m^2$
- $Q_i = \dfrac{N}{n} + \dfrac{M_y}{\sum x^2} \cdot x_i$
- $Q_1 = \dfrac{1287.5}{4} + \dfrac{3000}{9} \times 1.5 = 821.875$ kN
- $Q_2 = \dfrac{1287.5}{4} - \dfrac{300}{9} \times 1.5 = -178.125$ kN

ii- Pile length:-



- For pile No. 1 (max. compression):-

- $Q_{ult} = Q_b + Q_s$
- $Q_b = q \cdot N_q \cdot (\dfrac{\pi \cdot d^2}{4})$
- $q = 1.5 \times 20 + L \times 20 = 15 + 20\ L \quad kN/m^2$

$\Rightarrow Q_b = (15 + 20\ L) \times 75 \times \left(\dfrac{\pi \times (0.5)^2}{4}\right)$

$\Rightarrow Q_b = 294.52\ L + 220.89$

- $Q_s = (K_{HC} \cdot \sigma_v \cdot \tan\ \delta)(\pi \cdot d \cdot \ell)$
- $\sigma_v = 1.5 \times 20 + \dfrac{L}{2} \times 20 = 15 + 10\ L$
- $\delta = \dfrac{3}{4} \times \phi = \dfrac{3}{4} \times 35 = 26.25^\circ$

$\Rightarrow Q_s = \left(1 \times (15 + 10\ L)\ \tan 26.25^\circ\right)(\pi \times 0.5 \times L)$

$\Rightarrow Q_s = 11.62\ L + 7.75\ L^2$

- $Q_{ult} = 294.52\ L + 220.89 + 11.62\ L + 7.75\ L^2$

$\Rightarrow Q_{ult} = 7.75\ L^2 + 306.14\ L + 220.89$

- $Q_{all} = \dfrac{Q_{ult}}{F.O.S.} = \dfrac{7.75\ L^2 + 306.14\ L + 220.89}{3}$

$\Rightarrow Q_{all} = 2.58\ L^2 + 102.05\ L + 73.63$

$2.58\ L^2 + 102.05\ L + 73.63 = 821.88$

$2.58\ L^2 + 102.05\ L - 748.25 = 0$

$\Rightarrow L_1 = 6.32\ m$ (1)

- Check on pile capacity as a structural element:-

$$Q_{all} = A_p \times f_{co} = \frac{\pi\ (500)^2}{4} \times 4.5 = 883.6\ kN \quad > 821.88\ kN \quad O.K.$$

- For pile No. 2 (max. tension):-

- $T_{ult} = Q_s = 11.62\ L + 7.75\ L^2$
- $Q_s = (K_{HT} \cdot \sigma_v \cdot \tan\delta)(\pi \cdot d \cdot \ell)$
- assume $K_{HT} = 0.7$

$\Rightarrow Q_s = \left(0.7 \times (15 + 10\ L)\ \tan 26.25^\circ\right)(\pi \times 0.5 \times L)$

$\Rightarrow Q_s = 8.13\ L + 5.42\ L^2$

- $T_{all} = \dfrac{T_{ult}}{F.O.S.} + o.w.$

$\Rightarrow T_{all} = \dfrac{8.13\ L + 5.42\ L^2}{3} + 25 \times \left(\dfrac{\pi \cdot (0.5)^2}{4}\right) \cdot L$

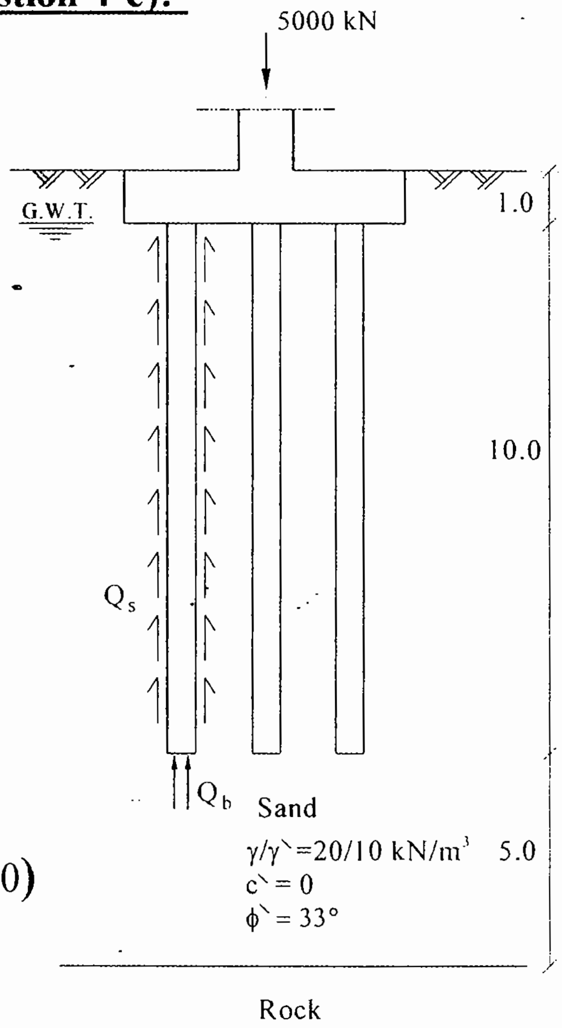
$\Rightarrow T_{all} = 1.81\ L^2 + 7.62\ L = 178.125$

$\Rightarrow L_2 = 8.04\ m$ (2)

- From (1) and (2)

$\Rightarrow L_{Pile} = L_{max} = 8.04\ m$

- Example 3 (Midterm 2010 structure – question 4-c):-



- Pile capacity in compression:-

$$- Q_{ult} = Q_b + Q_s$$

$$- Q_b = q \cdot N_q \cdot (\frac{\pi \cdot d^2}{4})$$

$$- q = 1\times 20 + 10\times 10 = 120 \text{ kN/m}^2$$

$$\Rightarrow Q_b = 120\times 60\times \left(\frac{\pi\times(0.5)^2}{4}\right)$$

$$\Rightarrow Q_b = 1413.7 \text{ kN}$$

$$- Q_s = (K_{HC}\cdot\sigma_v\cdot\tan\delta)(\pi\cdot d\cdot L)$$

$$- \sigma_v = 1\times 20 + 5\times 10 = 70 \text{ kN/m}^2$$

$$- \delta = \frac{3}{4}\times\phi = \frac{3}{4}\times 33 = 24.75^\circ$$

$$\Rightarrow Q_s = \left(1\times 70\times\tan 24.75^\circ\right)(\pi\times 0.5\times 10)$$

$$\Rightarrow Q_s = 506.9 \text{ kN}$$

$$- Q_{ult} = 1413.7 + 506.9 = 1920.6 \text{ kN}$$

$$- Q_{all} = \frac{Q_{ult}}{F.O.S.} = \frac{1920.6}{3} = 640.2 \text{ kN}$$

- Check on pile capacity as a structural element:-

$$Q_{all} = A_p\times f_{co} = \frac{\pi\,(500)^2}{4}\times 4.5 = 883.6 \text{ kN} \quad > 640.2 \text{ kN O.K.}$$

- Pile capacity in tension:-

$$- T_{ult} = Q_s$$

$$- Q_s = (K_{HT}\cdot\sigma_v\cdot\tan\delta)(\pi\cdot d\cdot L)$$

$$\Rightarrow Q_s = \left(0.7\times 70\times\tan 24.75^\circ\right)(\pi\times 0.5\times 10) = 254.8 \text{ kN}$$

$$- T_{all} = \frac{T_{ult}}{F.O.S.} + o.w. = \frac{254.8}{3} + 25\times(\frac{\pi\cdot(0.5)^2}{4})\times 10 = 134 \text{ kN}$$

- Example 4 (June 2011 civil – question 2):-

a- √

- لا يسمح باستخدام الـ driven piles فى الأماكن السكنية أو بجوار المبانى الأثرية لأن عملية الدق تؤدى لحدوث اهتزازات للأرض قد تؤثر على سلامة المنشآت المجاورة.

b- √

- فى حالة الـ CFA يجب أن يكون قوام الخرسانة عالى السيولة لتسهيل عملية إنزال حديد التسليح بعد صب الخرسانة.

c- x

- يستخدم الـ bentonite slurry لسند جوانب الحفر فى حالة التربة الرملية ولكنه يقلل من الـ skin friction نظرا لتكون الـ Mud cake على جوانب الحفرة.

d- x

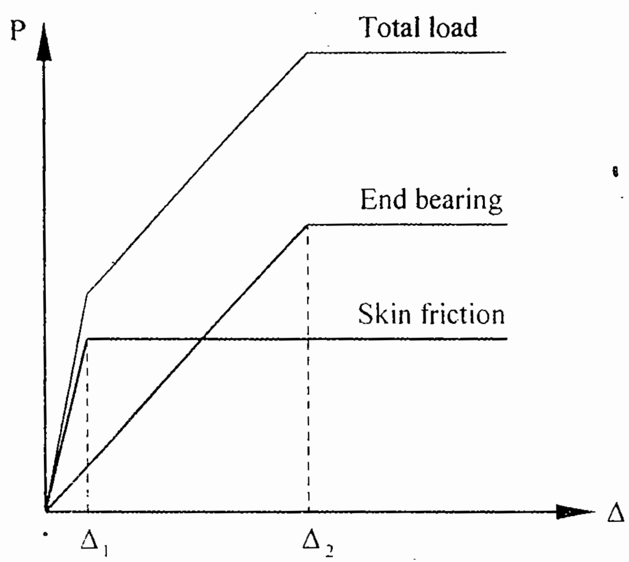
- يتم إجراء اختبار التحميل Pile load test بمعدل اختبار لكل 200 خازوق بالموقع ولا يقل عدد الاختبارات عن اختبار واحد.

e- √

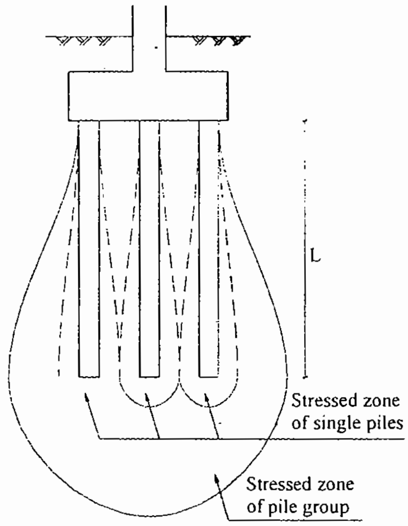
- The skin friction needs a small pile settlement to be fully mobilized as in case of large diameter bored piles:-

- Δ_1 = 5-10 mm or 1% of pile diameter.

- Δ_2 = 5% of pile diameter.

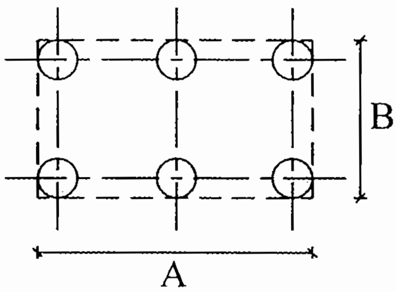


f- x



- هبوط مجموعة الخوازيق دائما أكبر من هبوط الخازوق الواحد لأن مجموعة الخوازيق لها منطقة تأثير أكبر من الخازوق الواحد.

g- x

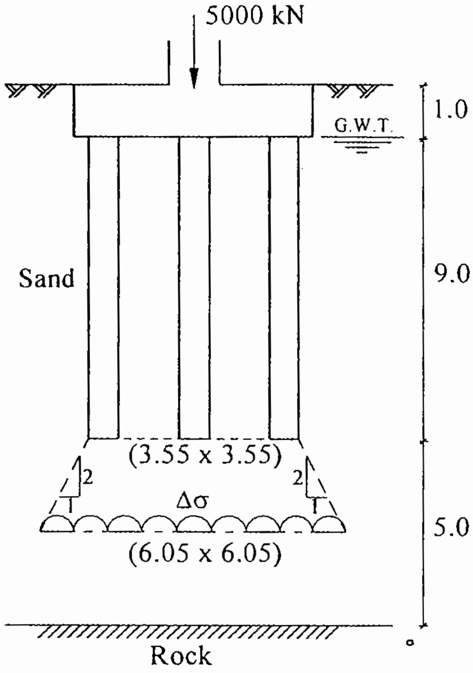


- هبوط مجموعة الخوازيق يعتمد على أبعاد المجموعة وليس على عدد الخوازيق.

h- x

- فى حالة مجموعة الخوازيق المعرضة لأحمال أفقية تتوزع الاحمال الافقية على الخوازيق بحيث تتحمل الخوازيق فى الصفوف الخلفية حمل أفقى أكبر من الخوازيق فى الصفوف الأمامية كما تتحمل الخوازيق الواقعة على الأطراف حمل أكبر من الخوازيق الداخلية.

- Example 5 (June 2011 civil – question 3):-



a- Settlement of pile group:-

$$- \Delta\sigma = \frac{5000}{6.05^2} = 136.6 \text{ kN/m}^2$$

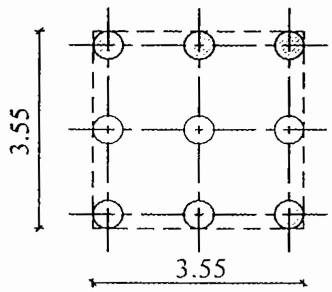
$$- S_g = \frac{1}{E} \cdot \Delta\sigma \cdot H$$

$$\Rightarrow S_g = \frac{1}{40 \times 10^3} \times 136.6 \times 500 = 1.71 \text{ cm}$$

b- Group action:-

$$- G_a = \frac{S_g}{S_o} = \frac{1.71}{0.3} = 5.7$$

c- Loads taken by piles:-

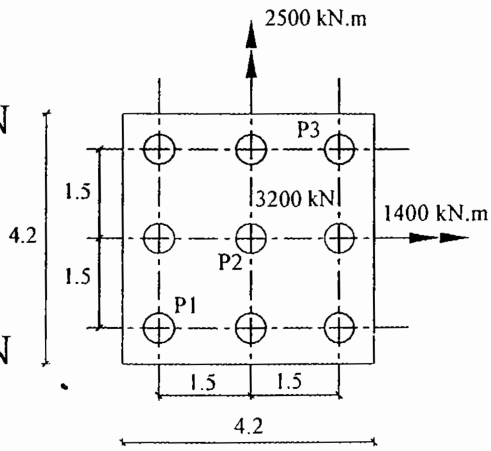


$$- Q_i = \frac{V}{n} + \frac{M_y}{\sum x^2} \times x_i + \frac{M_x}{\sum y^2} \times y_i$$

- Where:-

$$- \sum x^2 = \sum y^2 = 6 \times 1.5^2 = 13.5 \text{ m}^2$$

$$\Rightarrow Q_i = \frac{3200}{9} + \frac{1400}{13.5} \times x_i + \frac{2500}{13.5} \times y_i$$



$$- Q_1 = \frac{3200}{9} - \frac{1400}{13.5} \times 1.5 - \frac{2500}{13.5} \times 1.5 = -77.8 \text{ kN}$$

$$- Q_2 = \frac{3200}{9} = 355.6 \text{ kN}$$

$$- Q_3 = \frac{3200}{9} + \frac{1400}{13.5} \times 1.5 + \frac{2500}{13.5} \times 1.5 = 788.9 \text{ kN}$$

- Loads capacity of single pile:-

1- For driven pile under compression:-

$$- Q_{ult} = Q_b + Q_s$$

$$- Q_s = (K_{HC} \cdot \sigma_v \ \tan\delta)\ (\pi \cdot d \cdot \ell)$$

$$- \sigma_v = 1 \times 20 + 4.5 \times 10 = 65 \text{ kN/m}^2$$

$$- \delta = \frac{3}{4} \times \phi = \frac{3}{4} \times 33 = 24.75^\circ$$

$$\Rightarrow Q_s = (1 \times 65 \ \tan 24.75^\circ)\ (\pi \times 0.55 \times 9) = 466 \text{ kN}$$

$$Q_b = q \cdot N_q \cdot (\frac{\pi . d^2}{4})$$

$$- q = 1 \times 20 + 9 \times 10 = 110 \text{ kN/m}^2$$

$$\Rightarrow Q_b = 110 \times 60 \times (\frac{\pi \times (0.55)^2}{4}) = 1568 \text{ kN}$$

$$\Rightarrow Q_{ult} = 466 + 1568 = 2034 \text{ kN}$$

2- For driven pile under tension:-

$$- T_{ult} = Q_s = 466 \text{ kN}$$

- Check on pile capacity as a structural element:-

$$Q_{all} = A_p \times f_{co} = \frac{\pi \ (550)^2}{4} \times 4.5 = 1069 \text{ kN}$$

$$\Rightarrow Q_{ult} = 1069 \times 3 = 3207 \text{ kN} \quad > 2034 \text{ kN}$$

d- Factor of safety for each pile:-

1- For pile P1:-

$$- \text{o.w.} = 25 \times \frac{\pi \ (0.55)^2}{4} \times 9 = 53.5 \text{ kN}$$

$$\Rightarrow \text{F.O.S.} = \frac{T_{ult} + \text{o.w.}}{T_{act}} = \frac{466 + 53.5}{77.8} = 6.7 > 3 \Rightarrow \text{ Safe}$$

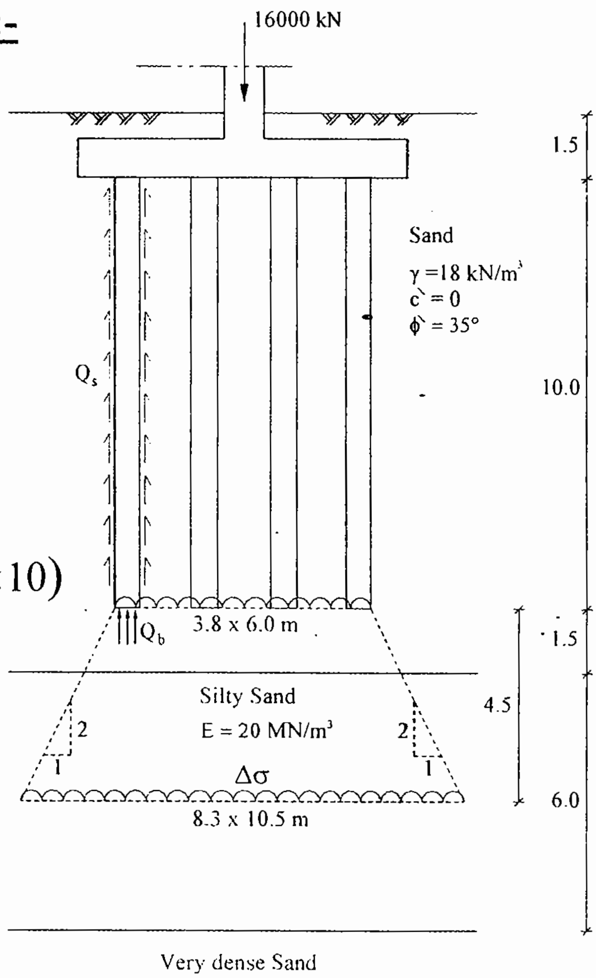
2- For pile P2:-

$$- \text{F.O.S.} = \frac{Q_{ult}}{Q_{act}} = \frac{2034}{355.6} = 5.72 > 3 \Rightarrow \text{ Safe}$$

3- For pile P3:-

$$- \text{F.O.S.} = \frac{Q_{ult}}{Q_{act}} = \frac{2034}{788.9} = 2.58 < 3 \Rightarrow \text{ Unsafe}$$

- Example 6 (May 2010 civil – question 3):-



1- Capacity of single pile:-

- $Q_{ult} = Q_b + Q_s$
- $Q_s = (K_{HC} \cdot \sigma_v \tan \delta)(\pi \cdot d \cdot \ell)$
- $K_{HC} = 0.8$ (given)
- $\sigma_v = 6.5 \times 18 = 117 \text{ kN/m}^2$
- $\delta = \frac{2}{3} \times \phi = \frac{2}{3} \times 35 = 23.33^\circ$

$\Rightarrow Q_s = (0.8 \times 117 \times \tan 23.33^\circ)(\pi \times 0.6 \times 10)$

$\Rightarrow Q_s = 760.9 \text{ kN}$

- $Q_b = q \cdot N_q \cdot (\frac{\pi \cdot d^2}{4})$
- $q = 11.5 \times 18 = 207 \text{ kN/m}^2$
- $N_q = 75$ (given)

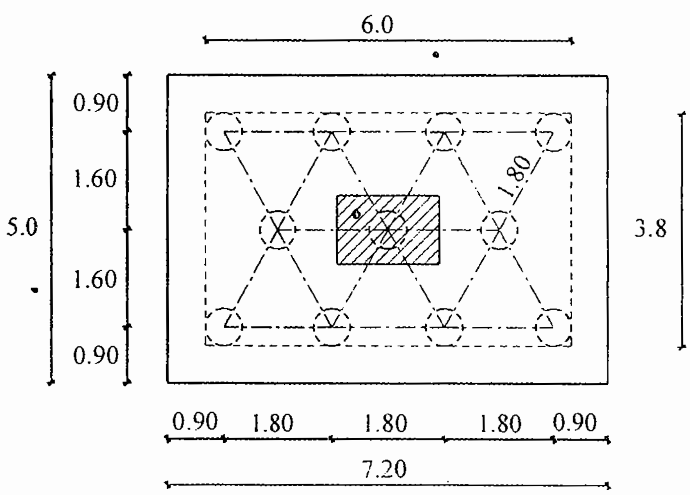
$\Rightarrow Q_b = 207 \times 75 \times (\frac{\pi \times (0.6)^2}{4}) = 4389.6 \text{ kN}$

$\therefore Q_{ult} = 760.9 + 4389.6 = 5150.5 \text{ kN}$

- $Q_{all} = \frac{Q_{ult}}{F.O.S.} = \frac{5150.5}{3} = 1716.8 \text{ kN}$

2- For column load of 16000kN:-

- $n = \frac{1.15 \times P_{col}}{Q_{all}} = \frac{1.15 \times 16000}{1716.8} = 10.7$ take n = 11 piles



3- Settlement of pile group:-

$$- S_g = \frac{1}{E} \cdot \Delta\sigma \cdot H$$

- Where:-

- $E = 20\ MN/m^2 = 20 \times 10^3\ kN/m^2$

$$- \Delta\sigma = \frac{16000}{8.3 \times 10.5} = 183.6\ kN/m^2$$

$$\Rightarrow S_g = \frac{1}{20000} \times 183.6 \times 6 = 0.055\ m = 5.5\ cm$$

4- Group action:-

$$- G_a = \frac{S_g}{S_o} = \frac{5.5}{0.5} = 11$$

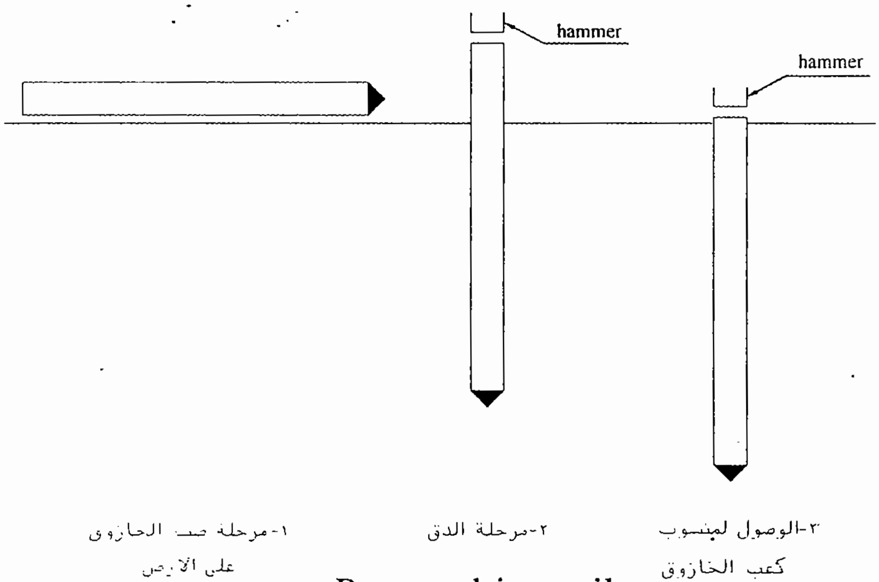
- Example 7 (May 2009 civil – question 4-a):-

1- Classification of piles:-

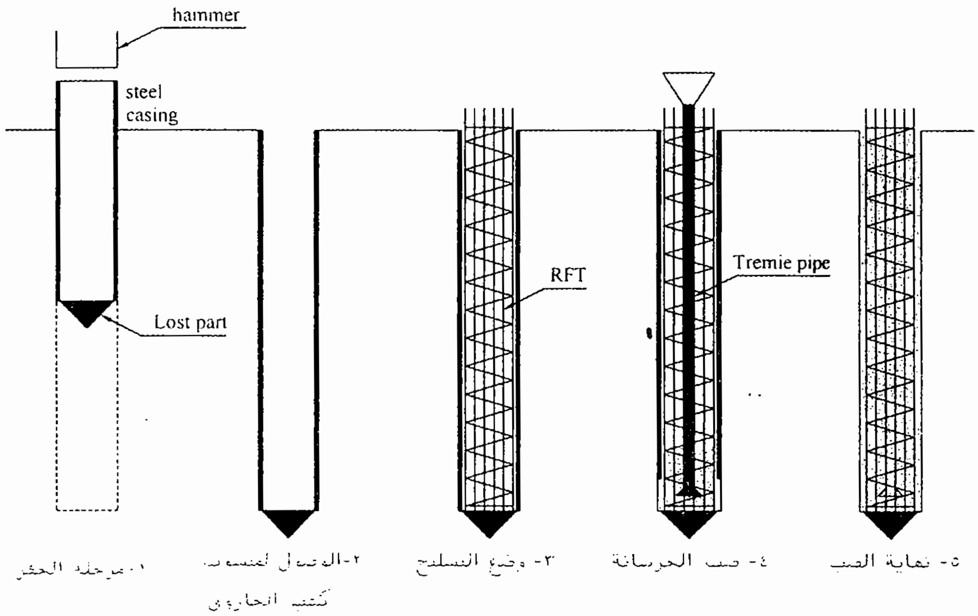
a- According to piling technology:-

1- Driven piles:- خوازيق الدق

- يتم تنفيذها عن طريق دق الخازوق فى التربة **(displacement piles)** وتكونْ ذات قطاع دائرى أو مربع ويمكن أن تكون من الخشب أو الحديد أو الخرسانة المسلحة وفى حالة الخوازيق الخرسانية يمكن صبها خارج الحفرة **Precast R.C. pile** أو يتم صبها داخل الحفرة **Cast in place R.C. piles**.



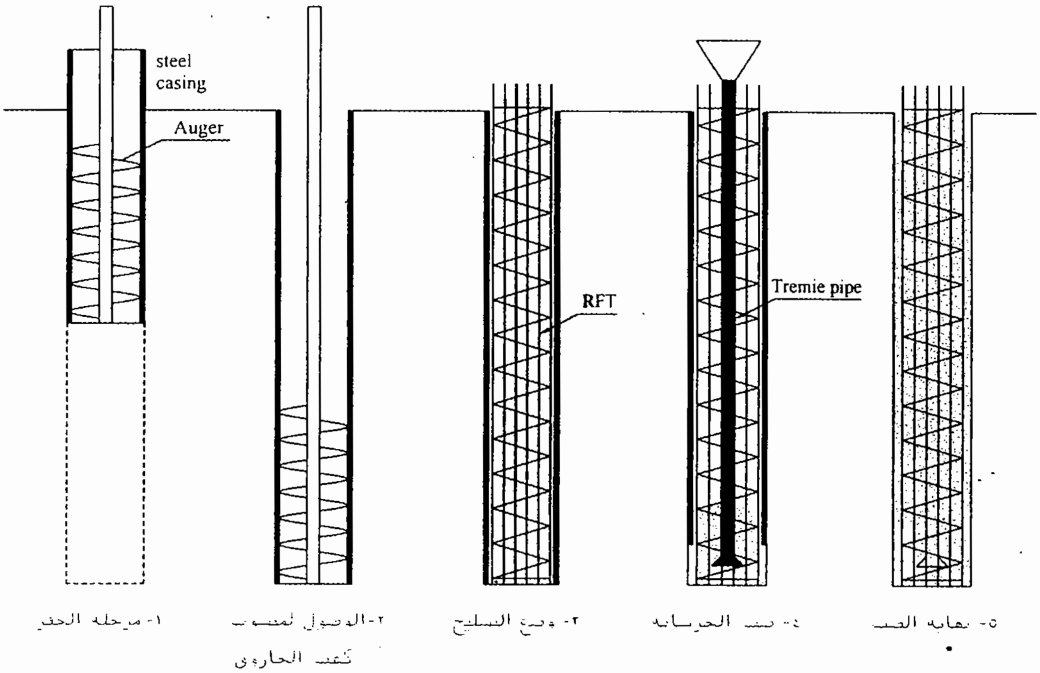
Precast driven pile



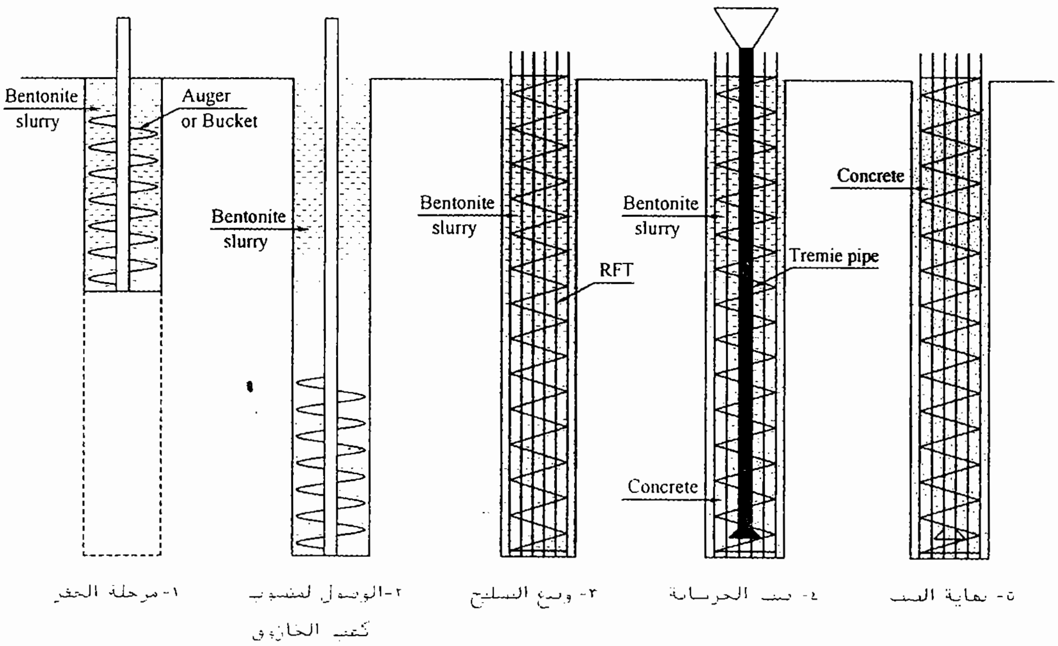
Cast in place driven pile

2- Bored piles:- خوازيق الحفر

- يتم تنفيذها عن طريق عمل حفرة فى التربة ثم يتم صب الخازوق فى مكان الحفرة **(replacement piles)** وتكون ذات قطاع دائرى من الخرسانة المسلحة ويتم سند جوانب الحفر إما عن طريق ماسورة **with temporary casing** أو بدون ماسورة وذلك عن طريق استخدام الـ **Bentonite slurry**.



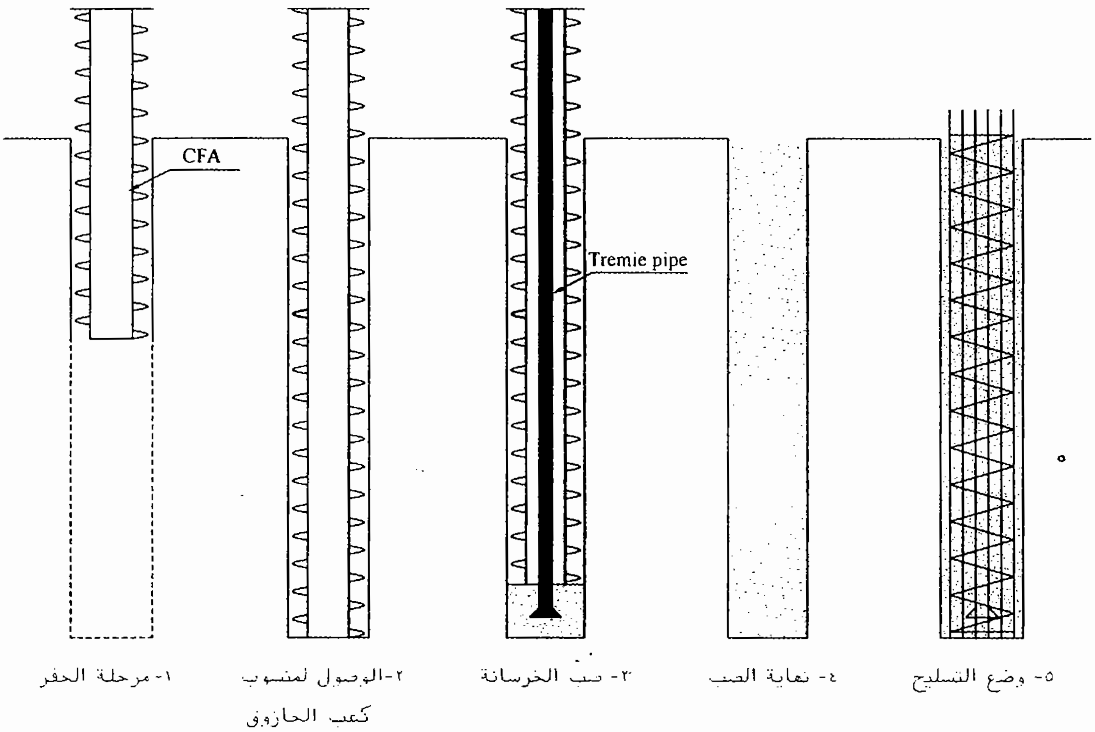
Bored pile with temporarycasing



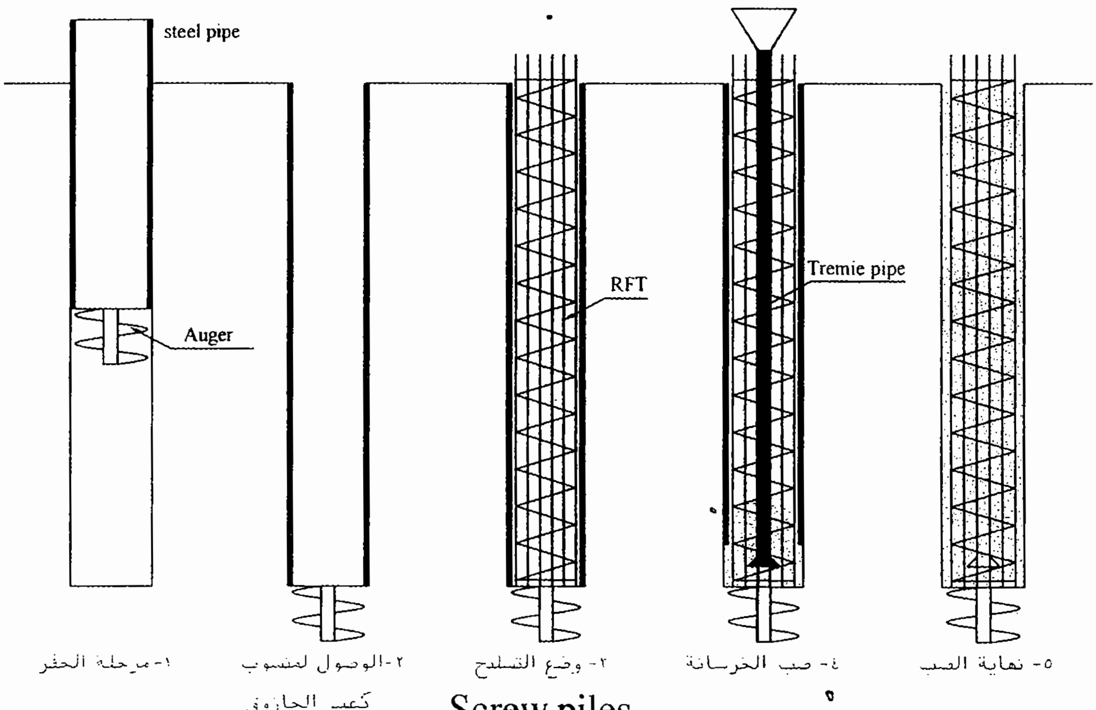
Bored pile with bentonite slurry

3- Screw piles &Continuous Flight Auger CFA piles:-

- وهو نوع متوسط بين خوازيق الدق وخوازيق الحفر حيث يشمل حفر جزء (displacement) ودق جزء (replacement) من التربة.



CFA Piles



Screw piles

b- According to soil-pile interaction

1- End bearing piles.

2- Friction Piles.

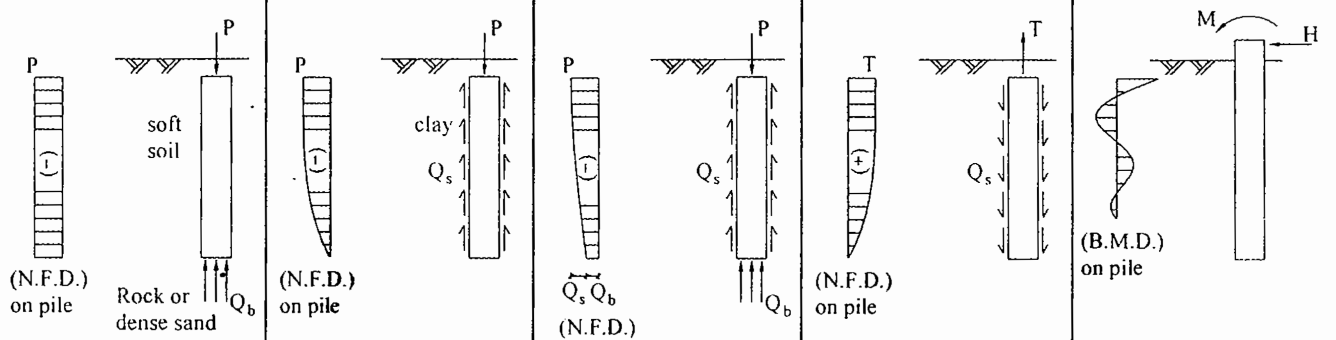
3- End bearing – friction piles.

4- Tension piles.

5- Piles resisting Horizontal force and B.M.

4- According to statical system

1- End bearing pile	2- Friction pile	3- End bearing - friction	4- Tension	5- Hl. force and B.M.
كل الحمل ينتقل عن طريق الإرتكاز	كل الحمل ينتقل عن طريق الإحتكاك	الحالة العامة حيث ينتقل الحمل عن طريق الإحتكاك والإرتكاز	فى حالة الخوازيق المعرضة لأحمال شد ينتقل الحمل إلى التربة عن طريق الأحتكاك الجانبى فقط	
- $P \cong Q_b$ - For $Q_b > 0.85$ P	- $P \cong Q_s$ - For $Q_s > 0.85$ P	- $P = Q_s + Q_b$	- $T \cong Q_s$	



2- Effect of piling technology in pile capacity:-

- تتأثر قدرة تحمل الخازوق بطريقة التنفيذ لأن مقاومة التربة تختلف على حسب مقدار الـ **soil displacement** حيث توجد ثلاثة حالات:-

1- For large displacement piles:-

- وهى فى حالة خوازيق الدق الخرسانية أو الخشبية حيث يؤدى دق الخازوق داخل التربة إلى حدوث إزاحة لها مما يؤدى لتكثيف التربة حول جسم الخازوق وزيادة التماسك بين جسم الخازوق والتربة مما يؤدى إلى حدوث زيادة كبيرة فى مقاومة التربة.

2- For small displacement piles:-

- وهى فى حالة خوازيق الدق المعدنية ذات السمك القليل حيث لا تحدث إزاحة كبيرة للتربة وبالتالى لا يحدث تغير فى مقاومة التربة.

3- For replacement piles:-

- وهى فى حالة خوازيق الحفر حيث يتم ازلة التربة ثم وضع الخازوق مما يؤدى إلى حدوث نقص كبير فى مقاومة التربة.

3- Special considerations when driving piles in cohesive soil:-

- عند تنفيذ خوازيق الدق driven piles فى التربة المتماسكة cohesive soil يجب مراعاة ما يلى:-

١- تؤدى عملية الدق إلى زيادة ضغط المياه الجوفية pore water pressure مما قد يؤثر على المبانى المجاورة أو الخوازيق وهامات الخوازيق Pile caps التى تم تنفيذها لذلك يفضل عمل آبار لتخفيف الضغط pressure relief wells وذلك للتقليل من ضغط المياه.

٢- نظراً لأن معظم الحمل ينتقل عن طريق الاحتكاك skin friction فى حالة التربة المتماسكة فإنه يجب مراعاة أن يكون السطح الجانبى للخوازيق سطح خشن لزيادة الاحتكاك.

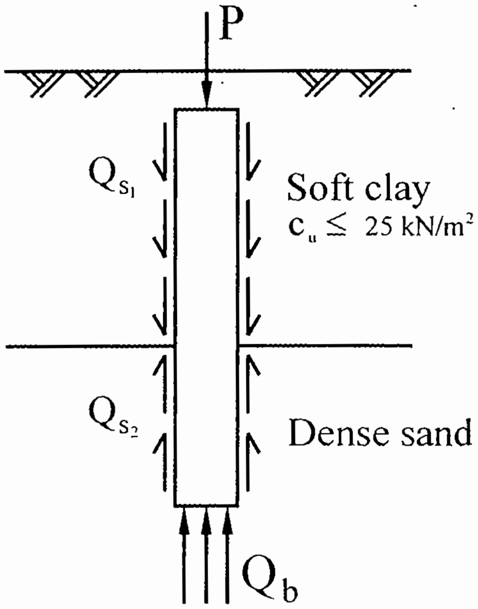
4- Factors controlling the choice of pile installation procedure:-

1- Structure loads.

2- Soil and ground water conditions.

3- Site constraints.

5- Effect of shallow soft clays on the capacity of piles subjected to tension loading:-



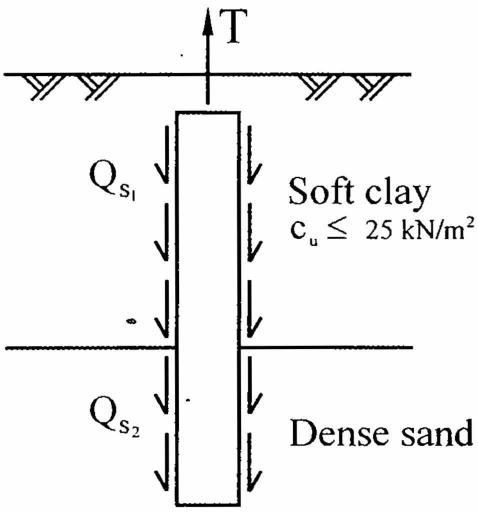
- إذا كان الخازوق يخترق طبقة سطحية ضعيفة جداً مثل soft or very soft clay ويرتكز على طبقة قوية مثل rock or very dense sand فإنه عندما تتعرض طبقة الـ soft clay لأحمال خارجية بخلاف حمل الخازوق يؤدى هذا الحمل إلى حدوث هبوط كبير فى هذه الطبقة مما يؤدى إلى تحرك حبيبات التربة لأسفل وبالتالى فإن الإحتكاك Q_s الناتج عن هذه الطبقة يصبح اتجاهه لأسفل أى أنه يصبح حمل إضافى على الخازوق وليس مقاومة تمنع حركة الخازوق لأسفل ويسمى الإحتكاك الناتج عن هذه الطبقة Negative skin friction.

- نتيجة لذلك يتم حساب قدرة تحمل الخازوق كما يلى:-

$$Q_{ult} = Q_b + Q_{s_2} - Q_{s_1}$$

- and

$$Q_{all} = \frac{Q_b + Q_{s_2}}{F.O.S.} - Q_{s_1}$$



– فى حالة الخازوق المعرض لقوة شد tension pile نلاحظ أن حدوث الـ Negative skin friction يزيد من مقاومة الشد للخازوق ولكن لا نأخذه فى الإعتبار لأن هذا more critical حيث يتم حساب قدرة تحمل الخازوق فى الشد كما يلى:–

$$T_{ult} = Q_{s_2}$$

- and

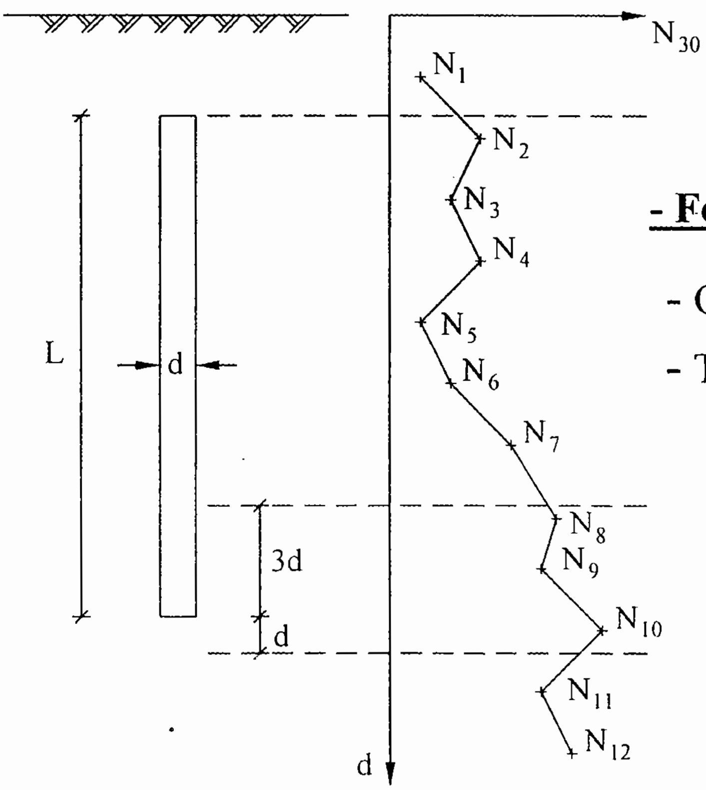
$$T_{all} = \frac{T_{ult}}{F.O.S.} + o.w.$$

6- Determination of the pile capacity using field testing procedures:-

– يتم تحديد قدرة تحمل التربة لإختراق الخازوق لها وذلك باستخدام نتائج التجارب الحقلية (مثل SPT, CPT, pressure meter test) وتعتبر هذه الطريقة أدق من المعادلات التى تعتمد على خواص التربة التى يتم تعيينها باستخدام اختبارات معملية.

-Pile capacity using Standard Penetration Test (SPT):-

– يتم تعيين حمل تشغيل الخازوق من العلاقة:–



- For driven pile:-

- $Q_{all} = 90\, N\, (\pi R^2) + \bar{N}\, (2\pi R L)$ (kN)
- $T_{all} = \bar{N}\, (2\pi R L) + o.w.$ (kN)

- Where:-

- Q_{all} = Allowable compression load per pile with a factor of safety 2.5 for end bearing resistance and 3.0 for friction resistance.

- T_{all} = Allowable tension load per pile with a factor of safety 3.0 for friction resistance.

- N = Average value of N_{30} in the distance affecting the end bearing resistance of the pile which is extended at distance 3d above pile tip and d below the pile tip.

$$\Rightarrow N = \frac{N_8 + N_9 + N_{10}}{3}$$

- $\overline{N}$ = Average value of N_{30} in the distance affecting the friction resistance of the pile which is extended along the pile shaft.

$$\Rightarrow \overline{N} = \frac{N_2 + N_3 + N_4 + N_5 + N_6 + N_7 + N_8 + N_9 + N_{10}}{9}$$

- o.w. = Own weight of pile.

- ملاحظات هامة:-

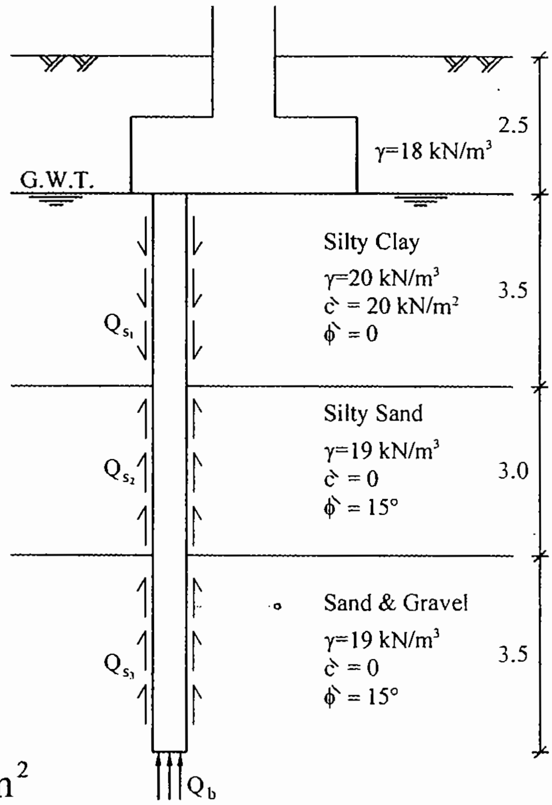
١- فى حالة الـ bored pile تتراوح قيم حمل تشغيل الخازوق Q_{all} بين 50% إلى 100% من قيم حمل تشغيل الخازوق المحسوبة من المعادلة السابقة.

٢- يمكن تعيين حمل تشغيل الخازوق بواسطة نتائج تجربة الـ SPT بطريقة غير مباشرة حيث نعين $N, \overline{N}$ كما سبق تماماً ثم تستنتج من جداول خاصة قيمة زاوية الإحتكاك φ_s للتربة حول الخازوق وكذلك قيمة زاوية الإحتكاك φ_b للتربة أسفل الخازوق حيث:-

From table:-

- at $N_{30} = N \quad \Rightarrow \quad \phi = \phi_b$
- at $N_{30} = \overline{N} \quad \Rightarrow \quad \phi = \phi_s$

- Example 8 (May 2009 civil – question 4-b):-



- For the silty clay layer $c_u < 25$ kPa

$\Rightarrow$ Negative skin friction will take place

$$Q_{ult} = Q_b + Q_{s_2} + Q_{s_3} - Q_{s_1}$$

- For silty clay layer:-

$$Q_{s_1} = c_a\ (\pi \cdot d \cdot \ell)$$

- $c_a = \alpha \times c = 0.35 \times 20 = 7\ kN/m^2$

$\Rightarrow Q_{s_1} = 7\ (\pi \times 0.5 \times 3.5) = 38.5\ kN$

- For Silty sand layer:-

- $Q_{s_2} = (K_{HC} \cdot \sigma_v\ \tan \delta)\ (\pi \cdot d \cdot \ell)$

- $\sigma_v = 2.5 \times 18 + 3.5 \times 10 + \frac{3}{2} \times 9 = 93.5\ kN/m^2$

- $\delta = \frac{3}{4} \times \phi = \frac{3}{4} \times 15 = 11.25^\circ$

$\Rightarrow Q_{s_2} = (93.5 \tan 11.25^\circ)\ (\pi \times 0.5 \times 3) = 87.6\ kN$

- For sand & gravel layer:-

$$Q_{s_3} = (K_{HC} \cdot \sigma_v\ \tan \delta)\ (\pi \cdot d \cdot \ell)$$

- $\sigma_v = 2.5 \times 18 + 3.5 \times 10 + 3 \times 9 + \frac{3.5}{2} \times 11 = 126.25\ kN/m^2$

- $\delta = \frac{3}{4} \times \phi = \frac{3}{4} \times 35 = 26.25^\circ$

$\Rightarrow Q_{s_3} = (126.25 \tan 26.25^\circ)\ (\pi \times 0.5 \times 3.5) = 342.3\ kN$

$$Q_b = q \cdot N_q \cdot (\frac{\pi \cdot d^2}{4})$$

- $q = 2.5 \times 18 + 3.5 \times 10 + 3 \times 9 + 3.5 \times 11 = 145.5\ kN/m^2$

- $\varphi' = 35 - 3 = 32^\circ \Rightarrow N_q = 48$

- $\varphi' = 35 - 3 = 32^\circ \Rightarrow N_q = 48$

$$\Rightarrow Q_b = 145.5 \times 48 \times \left(\frac{\pi \times (0.5)^2}{4}\right) = 1371.3 \text{ kN}$$

$$\therefore Q_{ult} = 1371.3 + 87.6 + 342.3 - 38.5 = 1762.7 \text{ kN}$$

$$- Q_{all} = \frac{Q_b + Q_{s_2} + Q_{s_3}}{F.O.S.} - Q_{s_1} = \frac{1371.3 + 87.6 + 342.3}{3} - 38.5$$

$$\boxed{\Rightarrow Q_{all} = 561.9 \text{ kN}}$$

- <u>Check on pile capacity as a structural element:-</u>

$$Q_{all} = A_p \times f_{co} = \frac{\pi\ (500)^2}{4} \times 4.5 = 883.6 \text{ kN} \quad > 561 \text{ kN O.K.}$$

- <u>If the pile length was increased to 20 m</u>

$$- Q_{s_3} = (K_{HC} \cdot \sigma_v \tan \delta)\ (\pi \cdot d \cdot \ell)$$

$$- \sigma_v = 2.5 \times 18 + 3.5 \times 10 + 3 \times 9 + \frac{13.5}{2} \times 11 = 181.25 \text{ kN/m}^2$$

$$- \delta = \frac{3}{4} \times \phi = \frac{3}{4} \times 35 = 26.25^\circ$$

$$\Rightarrow Q_{s_3} = (181.25 \tan 26.25^\circ)\ (\pi \times 0.5 \times 13.5) = 1895.4 \text{ kN}$$

$$- Q_b = q\, N_q \cdot \left(\frac{\pi \cdot d^2}{4}\right)$$

$$- q = 2.5 \times 18 + 3.5 \times 10 + 3 \times 9 + 13.5 \times 11 = 255.5 \text{ kN/m}^2$$

$$\Rightarrow Q_b = 255.5 \times 48 \times \left(\frac{\pi \times (0.5)^2}{4}\right) = 2403.3 \text{ kN}$$

$$\therefore Q_{ult} = 2403.3 + 87.6 + 1895.4 - 38.5 = 4347.8 \text{ kN}$$

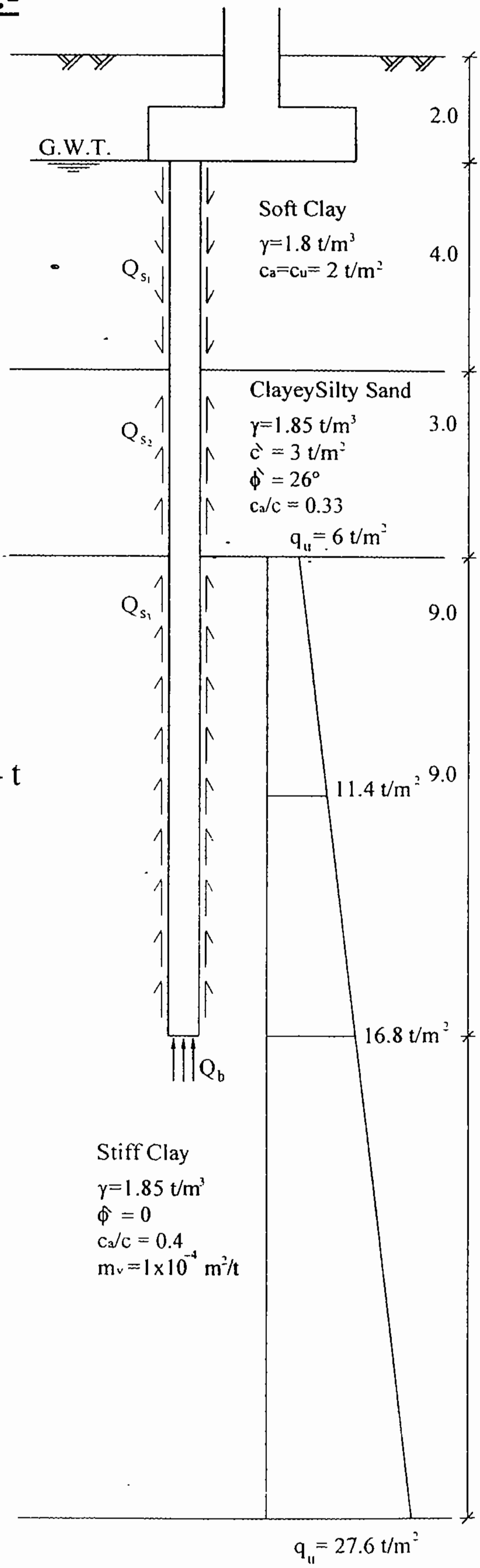
$$- Q_{all} = \frac{Q_b + Q_{s_2} + Q_{s_3}}{F.O.S.} - Q_{s_1} = \frac{2403.3 + 87.6 + 1895.4}{3} - 38.5$$

$$\Rightarrow Q_{all} = 1423.6 \text{ kN} > 883.6 \text{ kN}$$

$$\Rightarrow Q_{all} = 883.6 \text{ kN}$$

- Increasing the pile length to 20 m isn't economic because the pile capacity as a structural element will be governing in design.

- Example 9 (May 2009 civil – question 4-c):-



1- Group capacity from single pile capacity:-

- For the silty clay layer $c_u < 25$ kPa

$\Rightarrow$ Negative skin friction will take place

- $Q_{ult} = Q_b + Q_{s_2} + Q_{s_3} - Q_{s_1}$
- $Q_{s_1} = c_a\ (\pi \cdot d \cdot \ell)$

$\Rightarrow Q_{s_1} = 2\ (\pi \times 0.45 \times 4) = 11.3$ t

- $Q_{s_2} = (K_{HC} \cdot \sigma_v \cdot \tan\delta + c_a)(\pi \cdot d \cdot \ell)$
- $\sigma_v = 2\times1.8 + 4\times0.8 + \frac{3}{2}\times0.85 = 8.1$ t/m^2
- $\delta = \frac{3}{4}\times\phi = \frac{3}{4}\times36 = 19.5^\circ$
- $c_a = 0.33\times3 = 0.11$ t/m^2

$\Rightarrow Q_{s_2} = (8.1\tan19.5^\circ + 0.11)(\pi\times0.45\times3) = 16.4$ t

- $Q_{s_3} = c_a\ (\pi \cdot d \cdot \ell)$
- $c = \frac{q_u}{2} = \frac{14.4}{2} = 7.2$ t/m^2
- $c_a = \alpha.c = 0.4\times7.2 = 2.88$ t/m^2

$\Rightarrow Q_{s_3} = 2.88\ (\pi\times0.45\times9) = 36.6$ t

- $Q_b = c\,N_c \cdot (\frac{\pi \cdot d^2}{4})$

$\Rightarrow Q_b = \frac{16.8}{2}\times9\times(\frac{\pi\times(0.45)^2}{4}) = 12$ t

$\therefore Q_{ult} = 12 + 36.6 + 16.4 - 11.3 = 53.7$ t

- $Q_{all} = \frac{Q_b + Q_{s_2} + Q_{s_3}}{F.O.S.} - Q_{s_1} = \frac{12+36.6+16.4}{3} - 11.3$

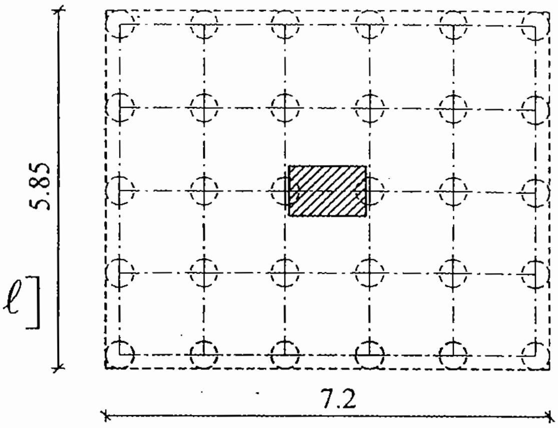
$\Rightarrow Q_{all} = 10.4$ t

$\Rightarrow Q_{ult_g} = n\times Q_{all} = 30\times10.4 = 312$ t

- Check on pile capacity as a structural element:-

$$Q_{all} = A_p \times f_{co} = \frac{\pi\ (450)^2}{4} \times 4.5 = 715.7 \text{ kN} > 104 \text{ kN O.K.}$$

2- Group capacity as a pier:-



- $Q_{ult_g} = Q_b + Q_{s_2} + Q_{s_3} - Q_{s_1}$
- $Q_{s_1} = c_a \cdot [2 \cdot (A+B) \cdot \ell]$

$\Rightarrow Q_{s_1} = 2 \times [2 \times 4 \times (7.2+5.85)] = 208.8 \text{ t}$

- $Q_{s_2} = (K_{HC} \cdot \sigma_v \cdot \tan\delta + c_a) \cdot [2 \cdot (A+B) \cdot \ell]$
- $\sigma_v = 2 \times 1.8 + 4 \times 0.8 + \frac{3}{2} \times 0.85 = 8.1 \text{ t/m}^2$
- $\delta = \frac{3}{4} \times \phi = \frac{3}{4} \times 36 = 19.5^\circ$

$\Rightarrow Q_{s_2} = (8.1 \tan 19.5^\circ + 0.33 \times 3)[2 \times 3 \times (7.2+5.85)] = 302.1 \text{ t}$

- $Q_{s_3} = c_a \cdot [2 \cdot (A+B) \cdot \ell]$
- $c = \frac{q_u}{2} = \frac{14.4}{2} = 7.2 \text{ t/m}^2$
- $c_a = \alpha \cdot c = 0.4 \times 7.2 = 2.88 \text{ t/m}^2$

$\Rightarrow Q_{s_3} = 2.88 \times [2 \times 9 \times (7.2+5.85)] = 676.5 \text{ t}$

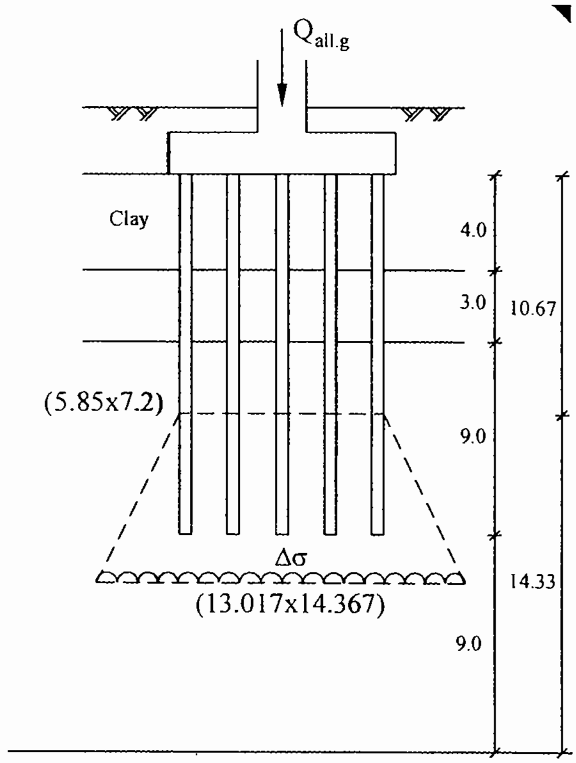
- $Q_b = c\, N_c \cdot (A \times B)$

$\Rightarrow Q_b = \frac{16.8}{2} \times 9 \times (7.2 \times 5.85) = 3184.3 \text{ t}$

$\therefore Q_{ult} = 3184.3 + 676.5 + 302.1 - 208.8 = 3954.1 \text{ t}$

- $Q_{ult_g} = \frac{Q_b + Q_{s_2} + Q_{s_3}}{F.O.S.} - Q_{s_1} = \frac{3184.3+676.5+302.1}{3} - 208.8 = 1178.8 \text{ t}$

3- Group capacity from settlement:-

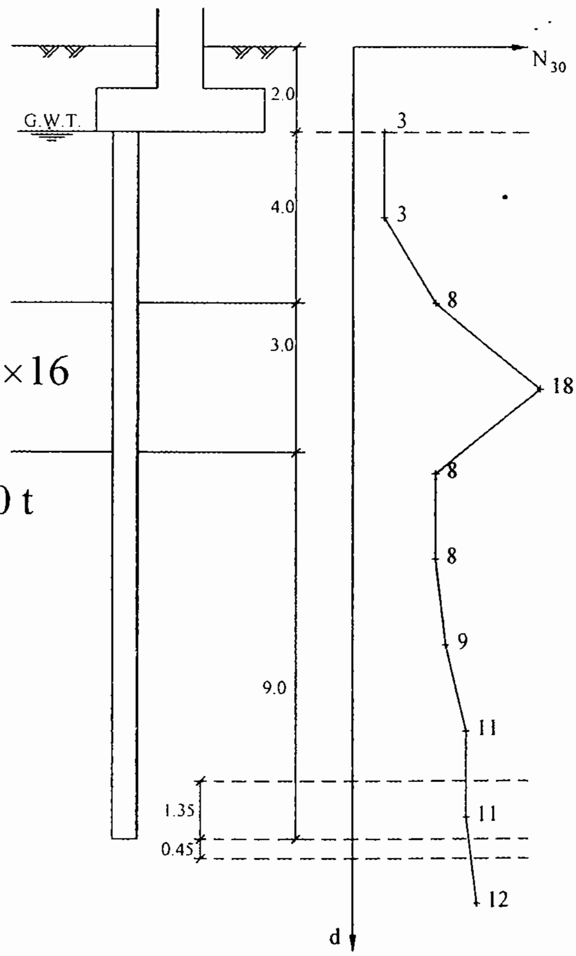


- $S_g = m_v \cdot \Delta\sigma \cdot H$

$$\Rightarrow 0.025 = 1\times10^{-4} \times \frac{Q_{ult.g}}{13.017\times14.367}\times 14.33$$

$\Rightarrow Q_{all.g} = 3262.7$ t

4- Group capacity from SPT results:-



- $Q_{all} = 90\, N\, (\pi\, R^2) + \bar{N}\, (2\, \pi\, R\, L)$
- Where:-
- $N = 11$
- $\bar{N} = \dfrac{3+3+8+18+8+8+9+11+11+12}{9} = 9.1$
- $Q_{all} = 90\times11\times\pi\times(0.225)^2 + 9.1\times2\times\pi\times0.225\times16$

$\Rightarrow Q_{all} = 363.3$ t

$\Rightarrow Q_{all_g} = n\times Q_{all} = 30\times363.3 = 10899\ kN = 1090$ t

From 1, 2,3 and 4

$\Rightarrow Q_{all_g} = 312$ t & $G_e = 1.0$

- Example 10:-

- A column is subjected to the following loads:-

  - N = 2500 kN
  - M_x = 250 kN.m
  - M_y = 300 kN.m

- It's required to

  1- Determine the numbers of piles required to support this column if the allowable capacity of a 50cm diameter and 12m long bored pile is 450 kN.

  2- Calculate the actual load acting on each pile.

  3- Draw a plan of the pile cap showing the pile arrangement.

- Solution:-

- Number of piles:-

$$- e_x = \frac{M_y}{N} = \frac{300}{2500} = 0.12 \text{ m}$$

$$- e_y = \frac{M_x}{N} = \frac{250}{2500} = 0.10 \text{ m}$$

$$\text{No. of piles} = \frac{1.15 \times P_{col}}{Q_{all}} \times (1+e_x)\cdot(1+e_y)$$

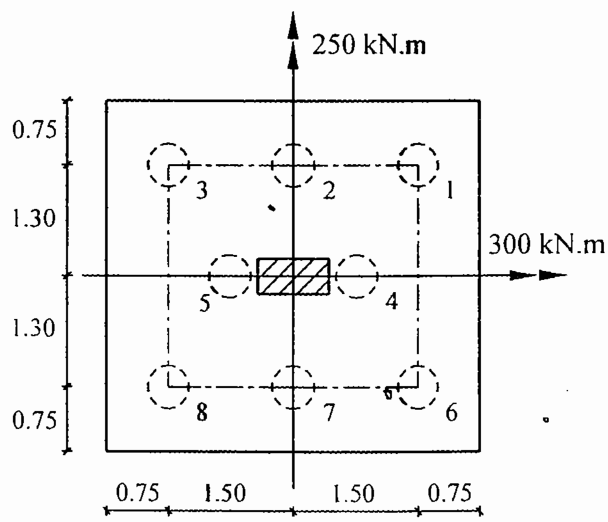
$$= \frac{1.15 \times 2500}{450} \times (1+0.12)\cdot(1+0.1) = 7.9 \Rightarrow \text{take } n = 8 \text{ piles}$$

- Arrangement of piles:-

- Try $S = S_{min} = 3 \times 0.5 = 1.5$ m

$\Rightarrow \sum x^2 = 4 \times 1.5^2 + 2 \times 0.75^2 = 10.125 \text{ m}^2$

$\Rightarrow \sum y^2 = 6 \times 1.3^2 = 10.14 \text{ m}^2$



- Check force in critical piles:-

- critical pile in compression is pile No. 1 where:-

$$Q_{max} = \frac{1.15 \times N}{n} = \frac{M_y}{\sum x^2} \cdot x_1 + \frac{M_x}{\sum y^2} \times y_1$$

$$\Rightarrow Q_{max} = \frac{1.15 \times 2500}{8} + \frac{300}{10.125} \times 1.5 + \frac{250}{10.14} \times 1.3$$

$$\Rightarrow Q_{max} = 435.9 \text{ kN} < Q_{all} = 450 \text{ kN} \Rightarrow \text{ safe}$$

- critical pile in tension is pile No. 8 where:-

$$Q_{min} = \frac{1.15 \times N}{n} - \frac{M_y}{\sum x^2} \cdot x_8 - \frac{M_x}{\sum y^2} \cdot y_8$$

$$\Rightarrow Q_{min} = \frac{1.15 \times 2500}{8} - \frac{300}{10.125} \times 1.5 - \frac{250}{10.14} \times 1.3$$

$$\Rightarrow Q_{min} = 282.9 \text{ kN} < \text{Zero} \Rightarrow \text{ safe}$$

- Actual force in each pile:-

$$Q_i = \frac{1.15 \times N}{n} + \frac{M_y}{\sum x^2} \times x_i + \frac{M_x}{\sum y^2} \times y_i$$

$$\Rightarrow Q_i = \frac{1.15 \times 2500}{8} + \frac{300}{10.125} \times x_i + \frac{300}{10.14} \times y_i$$

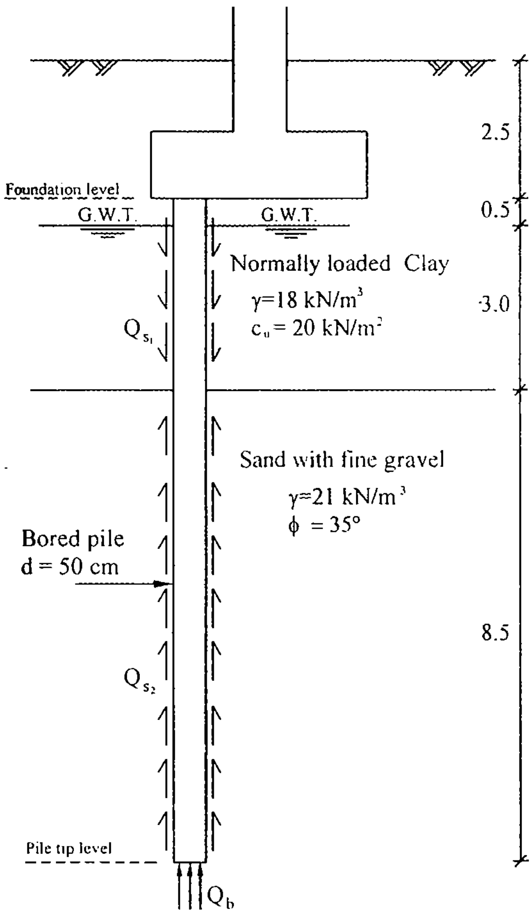
Pile No.	X (m)	Y (m)	Q_{act} (kN)
1	1.5	1.3	435.9
2	0	1.3	391.4
3	-1.5	1.3	347
4	0.75	0	381.6
5	-0.75	0	337.2
6	1.5	-1.3	371.8
7	0	-1.3	327.3
8	-1.5	-1.3	252.9

- Example 11:-

- Figure (2) shows the subsurface soil profile at a site, and the geotechnical parameters of the soil layers in that site. Groups of bored piles (50cm in diameter and 12m long) were proposed to support the columns foundations (pile caps) in this site. The foundation depth of such pile caps is 2.5m below the ground surface.
  a) Calculate the allowable pile compression load, applying a factor of safety of 3.0
  b) Determine the required number of piles if the column load is 9000 kN.
  c) Draw the pile cap with arrangement of the estimated number of piles beneath it.
  d) Calculate the pile group settlement, assuming that the settlement of single pile, under its working load, is 1% of its diameter.
  e) Recalculate the required number of piles if the column loads are as follows:

Vertical normal load $Q_v = 9000$ kN
Moments $M_x = 2000$ kN.m and
$M_y = 1000$ kN.m

- Solution:-



- For the N.L. clay layer $c_u < 25$ kPa

$\Rightarrow$ Negative skin friction will take place

$$\Rightarrow Q_{ult} = Q_b + Q_{S2} - Q_{S1}$$

- For N.L. clay layer:-

$Q_{S1} = c_a\,(\pi.d.\ell)$

- Where:-

- $c_a = \alpha \times c = 0.35 \times 20 = 7$ kN/m²

$\Rightarrow Q_{S1} = 7\,(\pi \times 0.5 \times 3.5) = 38.5$ kN

- For Sand layer:-

$Q_{S2} = (K_{HC}.\sigma_o \tan\delta)\,(\pi.d.\ell)$

- Where:-

- $K_{HC} = 1.0$

- $\sigma_o = 3\times 18 + 3\times 8 + 4.25\times 11 = 124.75$ kN/m²

- $\delta = \frac{3}{4}\times\phi = \frac{3}{4}\times 35 = 26.25^\circ$

$\Rightarrow Q_{S2} = (124.75 \tan 26.25^\circ)\,(\pi\times 0.5\times 8.5) = 821.4$ kN

$$Q_b = q\, N_q\, .(\frac{\pi.d^2}{4})$$

- Where:-

- $q = 3\times18 + 3\times8 + 8.5\times11 = 171.5\ kN/m^2$

- $\varphi^{\backslash} = 35 - 3 = 32^o \Rightarrow N_q = 48$

$$\Rightarrow Q_b = 171.5\times 48 \times(\frac{\pi\times(0.5)^2}{4}) = 1616.3\ kN$$

$$\therefore\ Q_{ult} = 1616.3 + 821.4 - 38.5 = 2399.2\ kN$$

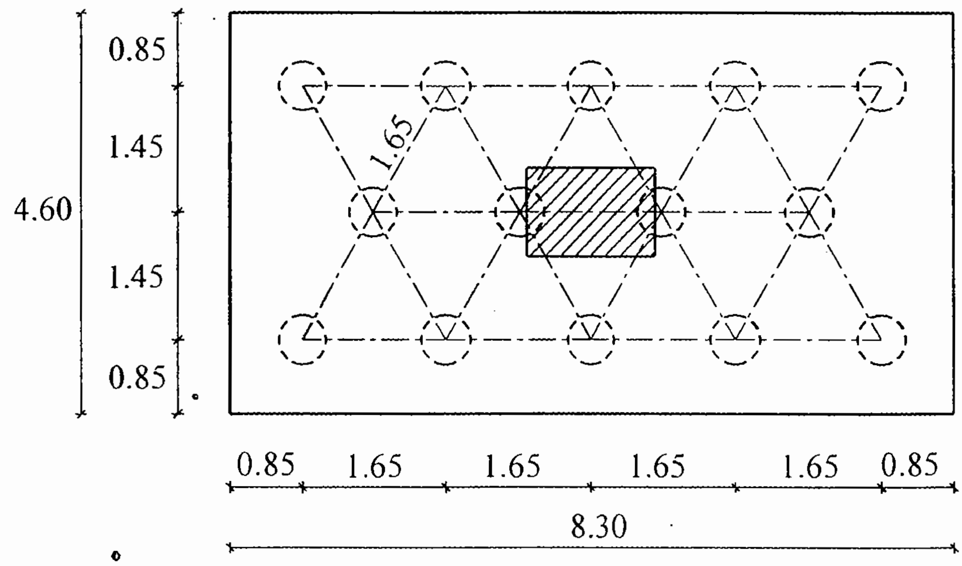
$$- Q_{all} = \frac{Q_b + Q_{s2}}{F.O.S.} - Q_{s1} = \frac{1616.3 + 821.4}{3} - 38.5 \Rightarrow \boxed{Q_{all} = 774\ kN}$$

<u>- Check on pile capacity as a structural element:-</u>

$$Q_{all} = A_p \times f_{co} = \frac{\pi\ (500)^2}{4} \times 4.5 = 883.6\ kN\ > 774\ kN\ \ O.K.$$

<u>- For column load of 9000kN:-</u>

$$- n = \frac{1.15\times P_{col}}{Q_{all}} = \frac{1.15\times9000}{774} = 13.4 \quad \text{take } n = 14 \text{ piles}$$



- Group settlement:-

$$S_g = S_o \times \sqrt{\frac{B}{d}}$$

Where:-

$S_o = 0.01 \times 55 = 0.55$ cm

$B = 1.45 \times 2 + 0.55 = 3.45$ m

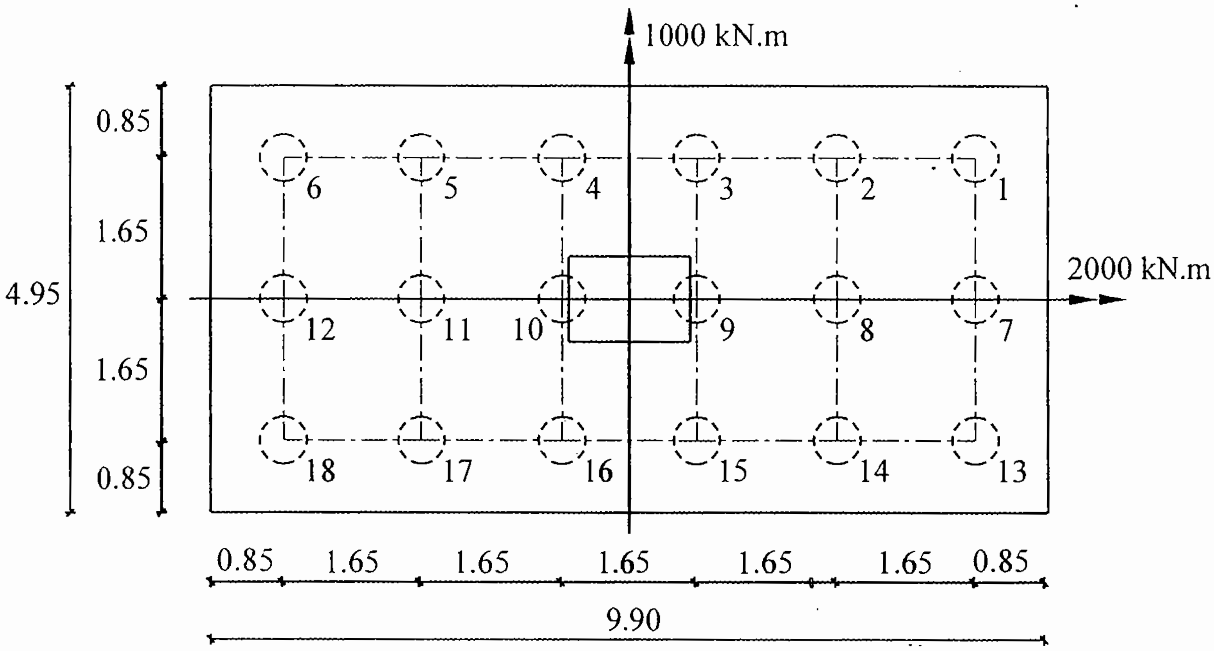
$$\Rightarrow \quad S_g = 0.55 \times \sqrt{\frac{3.45}{0.55}} = 1.38 \text{ cm}$$

- For pile cap under normal force and B.M.:-

$$- e_x = \frac{M_y}{N} = \frac{1000}{9000} = 0.11 \text{ m} \quad \& \quad - e_y = \frac{M_x}{N} = \frac{2000}{9000} = 0.22 \text{ m}$$

$$n = \frac{1.15 \times P_{col}}{Q_{all}} \times (1+e_x)(1+e_y) = \frac{1.15 \times 9000}{774} \times (1+0.11)(1+0.22) = 18.1$$

$\Rightarrow$ take $n = 18$ piles



$$\Rightarrow \sum x^2 = 6 \times (0.85^2 + 2.5^2 + 4.15^2) = 145.17 \text{ m}^2$$

$$\Rightarrow \sum y^2 = 12 \times 1.65^2 = 32.67 \text{ m}^2$$

- Check force in critical piles:-

- critical pile in compression is pile No. 1 where:-

$$Q_{max} = \frac{1.15 \times N}{n} + \frac{M_y}{\sum x^2} \times x_1 + \frac{M_x}{\sum y^2} \times y_1$$

$$\Rightarrow Q_{max} = \frac{1.15 \times 9000}{18} + \frac{2000}{145.17} \times 4.15 + \frac{1000}{32.67} \times 1.65$$

$$\Rightarrow Q_{max} = 682.7 \text{ kN} < Q_{all} = 774 \text{ kN} \Rightarrow \text{safe}$$

- critical pile in tension is pile No. 18 where:-

$$Q_{min} = \frac{1.15 \times N}{n} - \frac{M_y}{\sum x^2} \times x_{18} - \frac{M_x}{\sum y^2} \times y_{18}$$

$$\Rightarrow Q_{min} = \frac{1.15 \times 9000}{18} - \frac{2000}{145.17} \times 4.15 - \frac{1000}{32.67} \times 1.65$$

$$\Rightarrow Q_{min} = 467.3 \text{ kN} < \text{Zero} \Rightarrow \text{safe}$$

- Example 12:-

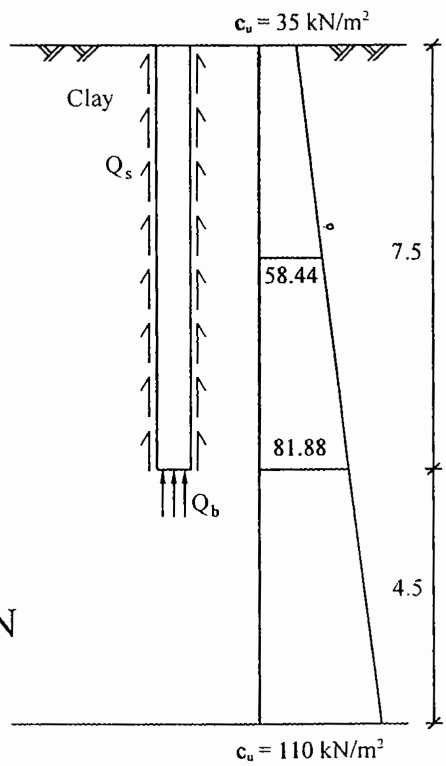
- A group of 25 precast concrete piles is driven to a depth of 7.5m in a silty clay deposit 12m thick. The piles are square in cross section (25x25cm) and spaced 1.0m center to center. The unconfined compressive strength of clay layer varies with depth from 70 kN/m^2 at the foundation level (0.00) to 220 kN/m^2 at the end of the clay layer (-12.0).

1- Determine the allowable compression load on the pile group, if the safety factor is 2.5 and the allowable group settlement is 25mm. Assume m_v=0.5 cm^2/kN.

2- Determine the value of the pile group efficiency.

3- Determine the single pile capacity under tension force.

- Solution:-



1- Group capacity from single pile capacity:-

$$Q_{ult} = Q_b + Q_s$$

$$= c.N_c.(d^2) + c_a.(4.d.L)$$

$$= 81.88 \times 9 \times 0.25^2 + 0.75 \times 58.44 \times 4 \times 0.25 \times 7.5$$

$$\Rightarrow Q_{ult} = 374.8 \text{ kN}$$

$$\Rightarrow Q_{all} = \frac{Q_{ult}}{F.O.S.} = \frac{374.8}{2.5} = 148.9 \text{ kN}$$

- From chart S/d = 4 $\Rightarrow G_e$=0.85

$$\Rightarrow Q_{all.g} = G_e \times n \times Q_{all} = 0.85 \times 25 \times 148.9 = 3164.1 \text{ kN}$$

2- Group capacity as a pier:-

$$- Q_{ult.g} = Q_b + Q_s$$

$$= c.N_c.A_b + c_a.A_s$$

$$- Q_b = c \cdot N_c \cdot A_b$$

$$= 81.88 \times 9 \times 4.25^2 = 13310.6 \text{ kN}$$

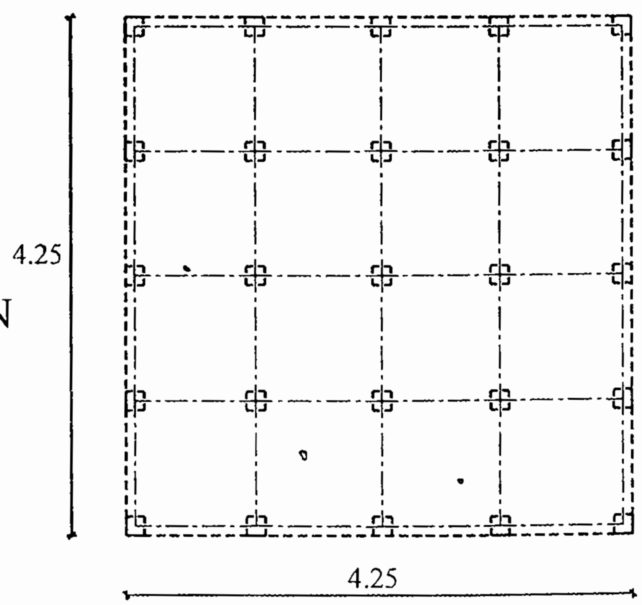
$$- Q_b = c_a \cdot A_s$$

$$= 58.44 \times 4 \times 4.25 \times 7.5 = 7451.1 \text{ kN}$$

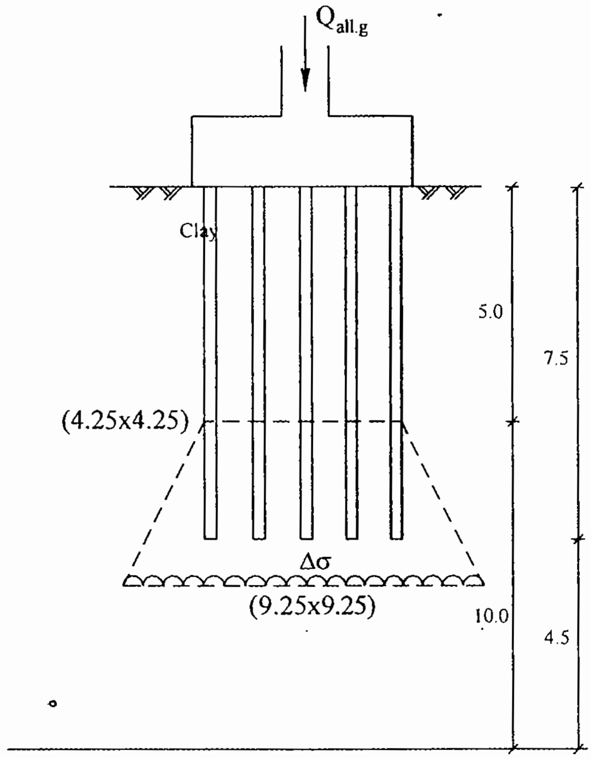
$$\Rightarrow Q_{ult.g} = 20761.7 \text{ kN}$$

$$\Rightarrow Q_{all.g} = \frac{Q_{ult}}{F.O.S.}$$

$$= \frac{20761.7}{2.5} = 8304.7 \text{ kN}$$



3- Group capacity from settlement:-



$$S_g = m_v \cdot \Delta\sigma \cdot H$$

$$\Rightarrow 0.025 = 0.5\times10^{-4} \times \frac{Q_{ult.g}}{9.25\times9.25}\times10$$

$$\Rightarrow Q_{ult.g} = 4278.1 \text{ kN}$$

From 1, 2 and 3

$$\Rightarrow Q_{all.g} = 3164.1 \text{ kN}$$

$$\& \; G_e = \frac{3164.1}{25\times148.9} = 0.85$$

1- Single pile capacity in tension:-

$$T_{ult} = Q_s = c_a.(4.d.L) = 0.75\times58.44\times4\times0.25\times7.5$$

$$\Rightarrow T_{ult} = 328.7 \text{ kN}$$

$$\Rightarrow T_{all} = \frac{T_{ult}}{F.O.S.} + w = \frac{328.7}{2.5} + 0.25^2\times7.5\times25 = 143.2 \text{ kN}$$