Bearing Capacity of Bored Pile Model Constructed in Gypseous Soil

Asst. Prof. Bushra Suhale Al-Busoda
Department of Civil Engineering
College of Engineering
University of Baghdad
Email: albusoda@yahoo.com

Asst. Lect. Asmaa Hasan Al-Rubaye
Department of Civil Engineering
College of Engineering
University of Baghdad
Email: asmaa5azan@gmail.com

ABSTRACT

Gypseous soils are distributed in many regions in the world including Iraq, which cover more than (31%) of the surface area of the country. Existence of these soils, always with high gypsum content, caused difficult problems to the buildings and strategic projects due to dissolution and leaching of the gypsum caused by the action of water flow through soil mass. For the study, the gypseous soil was brought from Bahr Al-Najaf, Al-Najaf Governorate which is located in the middle of Iraq. The model pile was embedded in gypseous soil with 42% gypsum content. Compression axial model pile load tests have been carried out for model pile embedded in gypseous soil at initial degree of saturation of (7%) before and after soil saturation. Several criteria have been used to calculate the bearing capacity of the model bored pile through the results of the pile load tests. It was found that Shen's method gave almost an acceptable result for all model pile load tests. Large draw down in bearing capacity was observed when model pile has been loaded after it was subjected to soaking for (24) hours because of loss of cementing action of gypsum by wetting.

Key words: gypseous soil, bored pile, bearing capacity, soaking, …..etc.

قوة التحمل لنموذج ركيزة الحفر شيدت في تربة الجبسية

أ.م.د. بشرى سهيل البوسدة
قسم هندسة المدنية
جامعة بغداد

م.م. أسماء حسن الربيعي
قسم الهندسة المدنية
جامعة بغداد

الخلاصة

تتوزع التربة الجبسية في العديد من المناطق في العالم بما في ذلك العراق ، والتي تغطي اكثر من 31% من مساحة البلاد. ان وجود هذه التربة بمحتوى جبس عالي ، يتسبب بمشاكل مختلفة للمباني و المشاريع الاستراتيجية نتيجة انحلال الجبس الناجم عن تسرب المياه من خلال كتلة التربة . التربة الجبسية التي تم اعتمادها في هذا البحث أحضرت من منطقة بحر النجف في محافظة النجف. نفذة ركيزة الحفر في تربة جبسية بمحتوى جبس يقارب ال 42 ٪ وقد أجريت اختبارات حمل الأنضغاط المحوري للركيزة المدفونة في تربة جبسية بدرجة من التشبع الأولي(7 ٪) قبل وبعد تشبع التربة. في هذه الدراسة تم استخدام عدة معايير مختلفة لتقييم قدرة تحمل ركيزة الحفر من خلال استخدام نتائج التي حصلت من فحص الركيزة. وقد وجد أن طريقة شن كادت أن تعطي نتيجة مقبولة لجميع اختبارات الحمل لنموذج الركيزة المستخدمة في هذا البحث. هبوط كبير تم ملاحظته في قابلية تحمل الركائز عند تحميلها بعد تعرضها الى الغمر بالماء لمدة 24 ساعة وذلك نتيجة لذوبان مادة الجبس الذي يعمل مادة رابطة بين حبيبات التربة.

الكلمات الرئيسية : تربة جبسية, ركيزة حفر, قابلية تحمل, غمر,.....

1. INTRODUCTION

Gypseous soils are classified as one of the problematic soils due to their complex and unpredictable behavior. They exist in many parts of the world, concentrated mainly in arid and semi-arid regions, ,**Al- Saoudi, et al., 2013**. In Iraq, it has been reported that many major projects suffered from several problems related to construction on or by gypseous soils such as cracks, tilting, collapse and leaching the soil, **Mahdi, 2004**. For examples, the damage cases and collapse occurred in the soil under the foundations of the houses in AL-Thawrra Hai, 1969, in Mosul City, **Al-Busoda**, **1999**.

It is a well-known fact that gypseous soils exhibit high bearing capacity and very low compressibility when they are dry. The collapsibility of gypseous soils results from the direct contact of water.

In civil engineering, it can be defined that a soil is a "gypseous soil" when it has gypsum content enough to change the properties of this soil, **Seleam, 2006**.

Deep foundations usually consist of piles, which are structural units installed by driving or by in-situ construction method. Foundation on collapsible soil suffers from sudden settlement, which may contribute to serious damage due to inundation.

The basis of the "soil mechanics approach" to calculating the carrying capacity of piles is that the total resistance of the pile to compression loads is the sum of two components, namely skin friction and end resistance. A pile in which the skin frictional component predominates is known as a *Friction Pile*; while a pile bearing on rock or some other hard incompressible material is known as an *End-bearing Pile*. With end-bearing piles, care must be exercised to ensure that the hard, dense layer is adequate to support the load, **Tomlinson, 2004**.

Ghazali, et al., 1990, presented a case history about the design of pile foundations in calcareous and coral formations and pile load tests in Jeddah area on the eastern coast of the Red Sea. This case study presents two design approaches: precast concrete driven piles, and bored and grouted piles. According to the pile load tests of these two proposed pile types, bored and grouted cast in place concrete piles were found to be the most suitable type for coral formation and carbonate sediments of the east coast of the Red Sea. The researchers concluded that the driven pile causes the soil grains to crush rather than displace factually. It also causes a breakage in the structure and cementation of the coral rock, which results in low skin friction. The observed allowable settlements for driven precast concrete piles were high and exceeded the values stated in the specification even before reaching the working load.

Nabil, 2001, studied the behavior of bored pile groups in cemented sands by a field testing program at a site in South Surra, Kuwait. The program consisted of axial load tests on single bored piles in tension and compression. Two groups of piles, each consisting of five piles were tested. The soil deposit at the site consists of medium dense, weakly cemented sands with strength parameters of cohesion of 20 kPa and internal friction angle of 35degree. Test results on single piles indicated that the axial load distribution along the piles in compression was nearly linear. Also the single piles in compression resisted 70% of the applied load at failure in side friction and 30% in base resistance.

,Abd Elsamee, 2012, had conducted three in-situ pile load tests on bored piles of 900 mm diameter and 50 m length. Soil profile indicates that the soil type from elevation 0.00 to -10.00 m is calcareous silty- sand with broken shells, from elevation -49.00 to -52.00 m is calcareous silty- sand, and from elevation -52.00 to -60.00 m is hard silty-clay with intervening calcareous silty-sand. The ultimate capacities of the piles are determined from the load test results using different criteria. These criteria were Tangent Graphical method, Hansen method, Chin's method, Ahmed and Pise (1997), and Decourt's extrapolation method. The results of different criteria show that the percentage of friction load carried by the shaft is approximately 85% to 90% and the percentage of load carried by the end bearing is 15% to 10%. Hansen (1963) method gives higher values of ultimate capacity carried by the pile than the other methods.

2. SOIL PROPERTIES

2.1 Physical Properties

These tests include specific gravity, atterberg limits, grain size distribution, relative density, and permeability tests. The details of these tests are illustrated in **Table 1**. and **Fig. 1** which show the grain size distribution curves.

2.2 Engineering Tests

Engineering tests were conducted on gypsums soil. The initial degree of saturation for soil sample was 7%. The engineering tests comprise collapse test, one-dimensional compression test, and direct shear test. The results of these tests are given in **Table 2**. and **Figs. 2**, **3**, and **4**, respectively.

3. DETAILS OF MODEL PILE

Aluminum solid pile was used as pile prototype. The pile surface was rough, in order to insure the interaction between soil and pile due to the friction on pile-soil interface, and the angle of interface friction for this testing pile was obtained from a series of shear box tests.
Pile shape is shown in **Plate 1** and its properties are illustrated in **Table 3**.

4. MODEL LOADING SETUPS

The model setups are listed below:

- Test box with (450*600*600) mm in size
- Loading jack
- Axial loading system
  1) S-type load cell (500 kg) capacity
  2) Wagezelle type load cell (1000 kg) capacity, (tip load cell)
  3) Two Load Cells Indicators
  4) Two dial gauges (0.01 mm)
  5) Two magnetic holders

- Two steel plates, at the center of one side of each plate there is a hollow semi-circle with radius of (21mm)

5. SOIL BED PREPARATION FOR FLOATING PILE, (F-PILE)

Gypseous soil was prepared at initial degree of saturation equal to 7%. The model box has been divided in to 9 layers. Weight of soil was calculated depending on volume of each layer and dry in-place unit weight of soil (12.5 kN/m^3). Soil was mixed thoroughly with the required amount of water by hands till completing the whole quantity. After preparing the specimen, it was put in the model box using static loads. After making some trials, it was found that 32 Kg was enough to ensure that soil sample would fill the expected volume of one layer. For distributing static loads uniformly on the surface of the soil, two steel plates were used, as shown in **Plate 2**. The dimensions of each plate were (582*296*2) mm and at the center of one side a hollow semi-circle with radius (21) mm slightly larger than the radius of the pile was made. The plates for one layer were put in X-direction and for the next layer in Y-direction to prevent making weak joint.

6. INSTALLATION OF MODEL PILES

For model pile which has been embedded in homogeneous gypseous soil, it was decided to determine the values (percentages) of mobilized skin friction and base resistance under compression pile load test. Therefore the floating model pile was used. To install the model floating pile, steel plate of (1mm) thickness and one hole (21mm) in diameter was placed at center of plate. The plate with a hole was welded to a cylindrical steel tube of (3cm) length which works as a casing for pile to keep the model pile vertically in the box and prevent horizontal movement, see **Plate 3**.

7. TEST PROCEDURE FOR MODEL LOADING TEST

In loading stages, to decide the amount of loads that will be exerted on the model piles, theoretical static equation is used. The working load of pile is calculated by dividing the predicted ultimate pile capacity by a factor of safety equal to (2.5). The procedure recommended by the American Standard ,**ASTM D,1143.** was followed during the model pile load test. Model pile was loaded to 250% of the working load with increments; each one was equal to 25% of working load.

The loading process was performed using manual hydraulic jack provided with load cell (S-type) to record the axial load exerted on the model pile and tip load cell for recording pile tip resistance, see **Plate 4**.

The following model tests were conducted for rough prototype pile:

1) Axial pile load test was carried out when the initial degree of saturation was 7%. **Fig. 5** shows pile load-settlement curve.
1. Pile model test was soaked for 24 hours before pile loading test, axial (compression) load was exerted on model pile after 24 hours from inundation, when the initial condition was (S= 7%), the shape of pile load-settlement curve is presented in **Fig. 6**.

The pile settlement was measured by dial gauge of (0.01) mm, while soil settlement was measured at a distance of (50 mm) from the side of pile by dial gauge (0.01) mm. For connecting the dial gauges on the model box, two magnetic holders were used. **Plate 5** shows the arrangements of dial gauges for soil and pile settlement readings.

8. CALCULATING THE RESISTANCE OF PILE TO COMPRESSIVE LOAD

Design of a pile foundation for axial load starts with an analysis of how the load is transferred to the soil, often thought limited to determining only the pile capacity, sometimes separating the capacity on components of shaft and toe resistances. The load-transfer analysis is often called static analysis or capacity analysis, **Fellenius, 2006.**

The ultimate bearing capacity for ($\boldsymbol{c}$) and ($\boldsymbol{\phi}$) soil can be determined by the static formula as follows:

$$Qu = Qb + Qs \tag{1}$$

$$Qu = A_P\left[cN_C + \sigma_{vb}\, N_q\right] + \sum A_S\,(c\alpha + K_S\sigma_v\, tan\,\delta) \tag{2}$$

Value of ($\boldsymbol{K}$) depends on several factors, for bored pile is equal to coefficient of lateral earth pressure at rest condition (K_o) and calculated from equation 3.

$$K_o = 1 - \sin\phi \tag{3}$$

The (α) value lies in the range of 0.3 to 0.6 for bored pile, **Malone, 1996**. The (α) value elected in above equations was (0.45).

9. PREDICTION OF THE ULTIMATE PILE CAPACITY

It is difficult to define the failure load of pile when it has not been loaded to failure. There are a number of criteria used to determine the bearing capacity of piles from pile load test, the criteria used included:

1. *Tangent Graphical Method*: defines the failure as the load at the intersection of the initial straight portion of the curve and final straight portion of the curve.
2. *Terzaghi Method*: when the pile settlement is equal to 10% of pile diameter.
3. *Log load-Log settlement*: This method is used for long pile length with large-diameter by plotting a logarithmic relationship between the value of the (settlement / Diameter) and the load. The maximum load is determined by depending on the diameter of the pile, where the *ASTM*322 identifies the maximum value when (settlement / diameter) is 0.05, **Fattah,** and **Al-Shakarchi, 2009**.
4. *Chin-Kondner Extrapolation*: according to Chin's method the tests carried out with piles in field and in laboratory show that, load-settlement relation is hyperbolic. A plot is made between settlement divided by corresponding load and the settlement. After some initial

variation, the plotted values fall on a straight line. The inverse slope of this line gives the ultimate load, **Fattah** and **,Al-Shakarchi, 2009**.

$$\delta_1/P = m\delta_1 + c_2 \tag{4}$$

5. *Brinch Hansen Method (1963)*: the square root of each settlement value from pile load test data divided by corresponding load value is plotted against the settlement. **Fattah** and **Al-Shakarchi, 2009 and Dewaikar, 2012**.

Ultimate load is given as:

$$Qu = 1/2\sqrt{c_1 * c_2} \tag{5}$$

6. *Decourt's Extrapolation (1999)*: divided each load with its corresponding settlement and plot the resulting value against the applied load. A linear regression over the apparent line (often be the last points) determine the line. Decourt identified the ultimate load as intersection of this line with load axis, **Fattah,** and **Al-Shakarchi, 2009 and Dewaikar, 2012**.
7. *De Beer Method*: by plotting the load-settlement data in a double-logarithmic form. The intersection point of two straight lines on a log-log plot gives the magnitude of ultimate load, **Fattah and ,Al-Shakarchi, 2009**.
8. *Shen's Method (1980)*: load-settlement curve is drawn with settlement vs log load coordinates and a curve with linear tail is obtained. Starting point of linear tail is defined as the ultimate load, **Dewaikar, 2012**.

10. ULTIMATE BEARING CAPACITY TERMS FOR FLOATING PILE

Through the study, which was conducted on a floating pile embedded in gypseous soil, and also conclusions of former researchers as ,**Fattah et al., 2009** and **Abd Elsamee, 2012**. Shen's method was used for selecting the values of ultimate bearing capacity. It was seen that this method gave almost acceptable results for model pile load tests. **Table 5.** clarifies the skin friction and base resistance obtained from results of model bored pile load tests, which have been tested at initial degree of saturation at soaked and un-soaked states. It also shows the percent of reduction (**RD** %) in $\boldsymbol{Qu}$ due to soaking, where:

$$RD = \frac{Qu_{un-soaked} - Qu_{soaked}}{Qu_{un-soaked}} \times 100 \tag{6}$$

11. RESULTS FOR PHYSICAL TESTS

The particle size distribution tests conducted using dry and wet sieve analyses method. The data on soil reflects a significant difference between the dry and wet sieving by water, with respect to soil with gypsum content equal to (42%) the dry sieving showed only (6.4%) fines while the wet sieving resulted in (44%) fines. The ability of gypsum for dissolution leads to an erroneous determination of particle size distribution by wet sieving (using water). As shown in **Fig. 1** there is no difference observed between the curve of dry sieving and the curve of wet sieving of samples soaked in kerosene.

Hydrometer test was carried out by using water saturated with gypsum for avoiding dissolution of gypseous soil in water saturated with gypsum. The percentage of passing sieve No. 200 from wet sieving by kerosene is (9.3%), which is between (5-12) percent. The gypseous soil is classified as (SP-SM) according to the Unified Soil Classification System.

The specific gravity decreases for the soil with high gypsum content. The low specific gravity of gypseous soil is attributed to low specific gravity of gypsum, which is equal to (2.32).

Atterberg limits play an important role in classification of cohesive soils, which affect the magnitude of many properties such as compressibility and strength. Liquid limit results were obtained by cone pentrometer method. The results of tests are shown in **Table 1**.

From the results of field and minimum and maximum unit weights of gypseous soil, the relative density of gypseous soil is (35%), thus soil has a loose state.

The coefficient of permeability (k) was determined by the constant head method from three differents times. The coefficient of permeability was determined over a short period after the confirmation that the amount of water flow was constant. The results obtained of permeability test are shown in **Table 1**. According to the results obtained, the soil may be classified as "low permeability soil", as stated by ,**Lambe,** and **Whiteman, 1969**.

12. RESULTS FOR ENGINEERING TESTS

The severity of collapse problem has been classified according to the classification suggested by ,**Jennings** and **Knight, 1975**. It is found to be problem. The addition of water leads to break bonds between soil particles and results in settlement of soil sample.

For the one-dimensional compression test, the unloading portion of the curve showed a little rebound after the release of the load since the deformation was primarily due to rearrangement of the grains and softening of gypsum.

For the direct shear test, in soaked state the reduction in value of cohesion is due to loss of cementing action of gypsum by wetting. Similar results were found by ,**Al-Dulaimi, 2004** and ,**Hussein, 2012**. while the angle of internal friction is less influenced by the soaking process.

13. RESULTS FOR PILE LOAD TEST

In soaked state, before pile load test, the soil was subjected to soaking from top surface. From the results of the dial gauge readings of pile and soil settlements it is found that the soil settlement is more than the pile settlement. **Fig. 7** shows the variation of pile settlement and soil settlement within 24 hours of soaking. When pile was loaded at soaked state, large draw down in bearing capacity was observed and trend of behavior is similar to that of local shear failure. This behaviour may be attributed to the breaking of bonds due to soaking. The soil exhibited a loss in strength parameters because of loss of cementing action of gypsum by wetting.

The values of the ultimate bearing capacity which are obtained from pile load-settlement curves according to different criteria, and the theoretical calculations are summarized in **Table 4**. From the results obtained, it was found that some criteria like Chin-Konder extrapolation, Brinch Hansen 1963, and Decourt give high estimation of the bearing capacity for model pile load tests. It is thought that these methods are not suitable for bored pile of large diameter, the same result was observed by ,**Fattah** and **Al-Shakarchi, 2009,** for bored pile constructed in Baghdad city, and **,Abd Elsamee, 2012**, for pile load tests on bored piles constructed in soil contained calcareous silty- sand**.** Log load-Log settlement, Terzaghi, and Tangent Graphical Method were given lower value than the other criteria for evaluation of the bearing capacity of floating piles in soaked condition.

14. CONCLUSIONS

Based on the experimental results of the experimental work, the following conclusions may be obtained:

1) From the different criteria that were used for evaluation of the ultimate bearing capacity, Log load-Log settlement, , and Tangent Graphical Method were given lower value than the other criteria, while Chin-Konder extrapolation method, Brinch Hansen (1963), and Decourt extrapolation gave high estimation of the bearing capacity in model pile load tests. Shen's method gave almost the acceptable results for model pile load tests.
2) Large draw down in bearing capacity was observed when floating pile was loaded after it was subjected to soaking for (24 hours). The percent of reduction (**RD**, %) in Q_u due to soaking was 45%.
3) When the model box was soaked with water, the gypseous soil was affected and collapsed; the final settlement of gypseous soil (11.02, mm) was more than the final settlement of pile (9.18, mm).

REFERENCES

- Al-Aqaby, M.D., 2004. *Effect of Kerosen on Propertiese of a Gypseous Soil,* M.Sc. Thesis, Civil Engineering Department, University of Baghdad.

- Al-Busoda, B.S.Z., 1999, *Studies on the Behavior of Gypseous Soil and its Treatment during Loading,* M.Sc. Thesis, Civil Engineering Department, University of Baghdad.

- Al-Dulaimi, N.S., 2004, *Characteristics of Gypseous Soils Treated with Calicum Chloride Solution,* M.Sc. Thesis, Civil Engineering Department, University of Baghdad.

- Al-Saoudi, N.K.S., Al-Khafaji, A.N., Al-Mosawi, M.J., 2013, *Challenging Problems of Gypseous Soils in Iraq*, Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering, Paris.

- ASTM D1143-81, 1994, *Standard Test Method for Piles under Static Axial Compressive Load.*
- ASTM D1556-07, 2007, *Standard Test Method for Density and Unit Weight of Soil in Place by the Sand-Cone Method.*

- ASTM D2216-98, 1999, *Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass.*

- ASTM D2434-68, 2000, *Standard Test Method for Permeability of Granular Soils (Constant Head).*

- ASTM D2435-00, 1996, *Standard Test Method for One-Dimensional Consolidation Properties of Soils.*

- ASTM D2487-00, 2000, *Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System).*

- ASTM D3080, 1989, *Standard Test Method for Direct Shear Test of Soils under Consolidated Drained Conditions.*

- ASTM D422-02, 2000, *Test Method for Particle-Size Analysis of Soils.*

- ASTM D422-63, 1998, *Standard Test Method for Particle-Size Analysis of Soils.*

- ASTM D4254-00, 2000, *Standard Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density.*

- ASTM D5333–92, 1993, *Standard Test Method for Measurement of Collapse Potential of Soils.*

- ASTM D854-00, 2000, *Specific Gravity of Soil Solids by Water Pycnometer.*

- British Standard Institution, 1975, *Methods of Testing Soil for Civil Engineering Purposes*, B. S. 1377.
- Dewaikar, D.M., 2012, *Analysis of Pile Load Tests Data*, Asian Journal.

- Abd Elsamee, W.N., 2012, *Evaluation of the Ultimate Capacity of Friction Piles*, Engineering Sciences, Vol.4, No.11, PP.778-789.

- Fattah, M.Y., Al-Shakarchi, Y.J., 2009, *A Comparision Between Diferent Criteria in Evaluating the Bearing Capacity of a Bored Pile in Baghdad City*, The 6th Engineering Conference,Civil Engineering, University of Baghdad, Vol.1.

- Fellenius, B.H., 2006, *Basics of Foundation Design*, Electronic Edition.

- Ghazali, F.M., Baghdadi, Z.A., and Mansur, O.A., 1990, *A Comparative Study of Pile Foundations in Coral Formations and Calcareous Sediments*, Engineering Sciences, Vol.2, No.1, PP.3-17.

- Hussein, R.S., 2012, *Bearing Capacity of Shallow Footing on Compacted Dune Sand Over Reinforced Gypseous Soil*, M.Sc. Thesis, Civil Engineering Department, University of Baghdad.

- Jennings, J. E., and Knight, K., 1975, *A Guide to Construction on or with Materials Exhibiting Additional Settlement Due to 'Collapse' of Grain Structure, Proceedings,* Sixth Regional Conference for Africa on Soil Mechanics and foundation Engineering Johannesburg, South Africa, PP.99-105.

- Lambe, T.w., and Whiteman, R. V., 1969, *Soils Mechanics, John Wiley and Sons Inc.,* New York.

- Mahdi, B.O., 2004, *Some Engineering Aspects of Gypseous Soils,* Ph.D. Thesis, Civil Engineering Department, University of Baghdad.

- Malone, A.W., 1996, *Foundation Design and Construction, Geotechnical Engineering Office, Civil Engineering and Development Department,* the Government of the Hong Kong, Geo Publication No.1, Via the Internet.

- Nabil, F.I., 2001, *Axial Load Tests on Bored Piles and Groups in Cemented Sands,* Journal of Geotechnical and Geoenvironmental Engineering, Vol. 127, No. 9, PP. 766-773.

- Seleam, S.N., 2006, *Evaluation of Collapsibility of Gypseous Soils in Iraq*, Journal of Engineering, Vol. 13, No. 3, PP. 712-726.

- Tomlinson, M.J., 2004*, Pile Design and Construction Practice,* Fourth Edition.

- Varghese, P.C., 2009, *Foundation Engineering,* Sixth Edition.

NOMENCLATURE

A_P= cross-sectional area of pile, m^2
A_S = surface area of pile shaft, m
c = soil cohesion, kPa
C_1 = slope of the best fitting straight line, dimensionless
C_2 = y-intercept of straight line for best fittnig
Cc = compression index, dimensionless
CP = collapse potential, %
Cr = rebound index, dimensionless
Dr = relative density of soil, %
Gs = specific gravity, dimensionless
K = coefficient of permeability, cm/sec
K_o = coefficient of earth pressure at rest condition, dimensionless
K_S = coefficient of earth pressure, dimensionless
L = length of pile penetrating settling soil, m
L/D pile = length-to-diameter ratio, dimensionless
L.L = liquid limit, %
m = slope of straight line, dimensionless
N_C , N_q = bearing capacity factors, dimensionless
P = load, kN

P.I = plasticity index, %
P.L = plastic limit, %
Qb = end-bearing resistance, Kg
Qs = skin friction resistance, Kg
Qu = ultimate bearing capacity, Kg
RD = percent reduction in ultimate bearing capacity, %
S = degree of saturation, %
α = adhesion factor, dimensionless
γ_d = in-place dry unit weight, kN/m^3
γ_{dmax} = maximum value of dry unit weight, kN/m^3
γ_{dmin} = minimum value of dry unit weight, kN/m^3
δ = interface friction angle, deg.
δ_1 = pile settlement, mm
σ_v = effective overburden pressure, kPa
σ_{vb} = effective overburden pressure for base soil, kPa
ϕ = internal friction angle, deg.

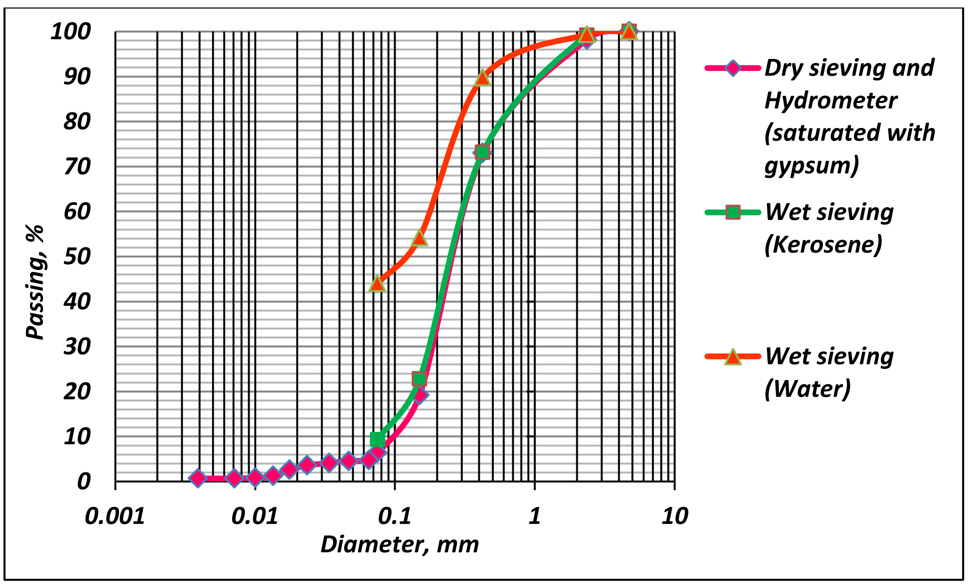

Figure 1. Grain size distribution curves of gypseous soil.

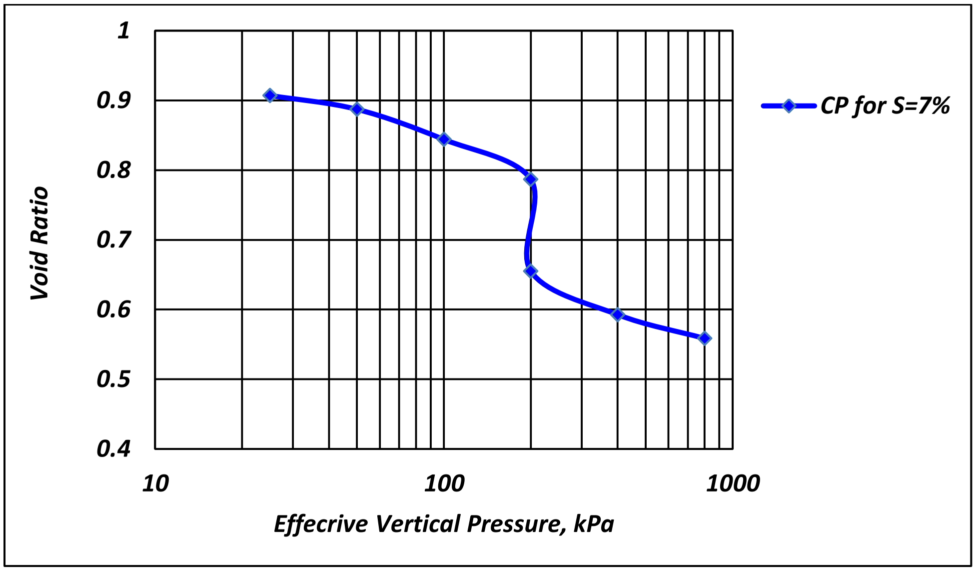

Figure 2. Result of single collapse test for gypseous soil.

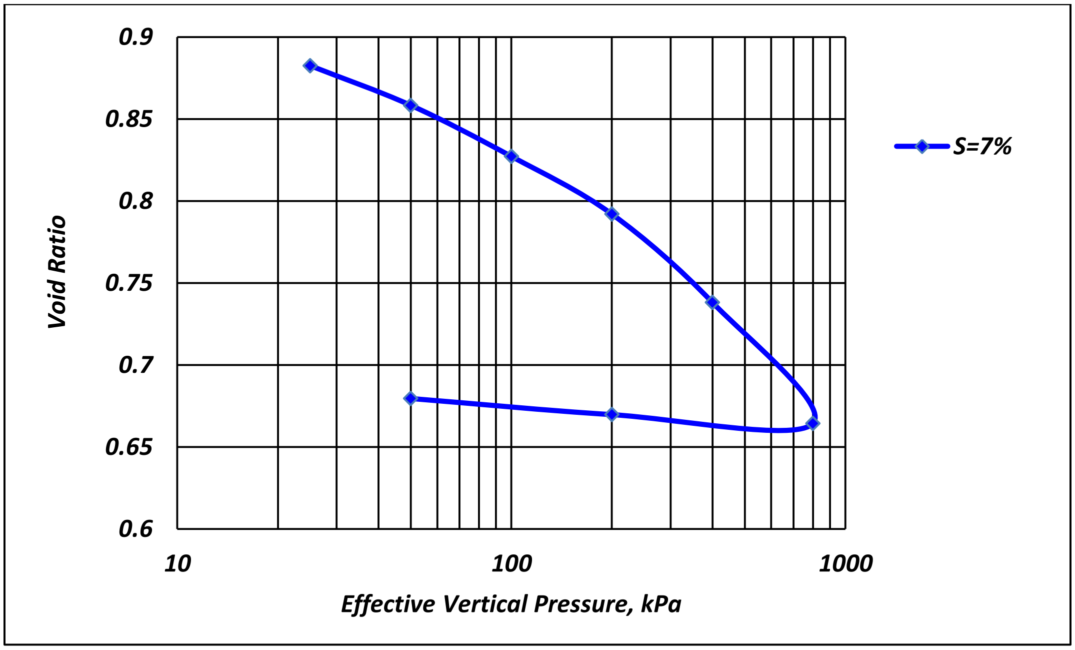

Figure 3. One-dimensional compression curves for gypseous soil.

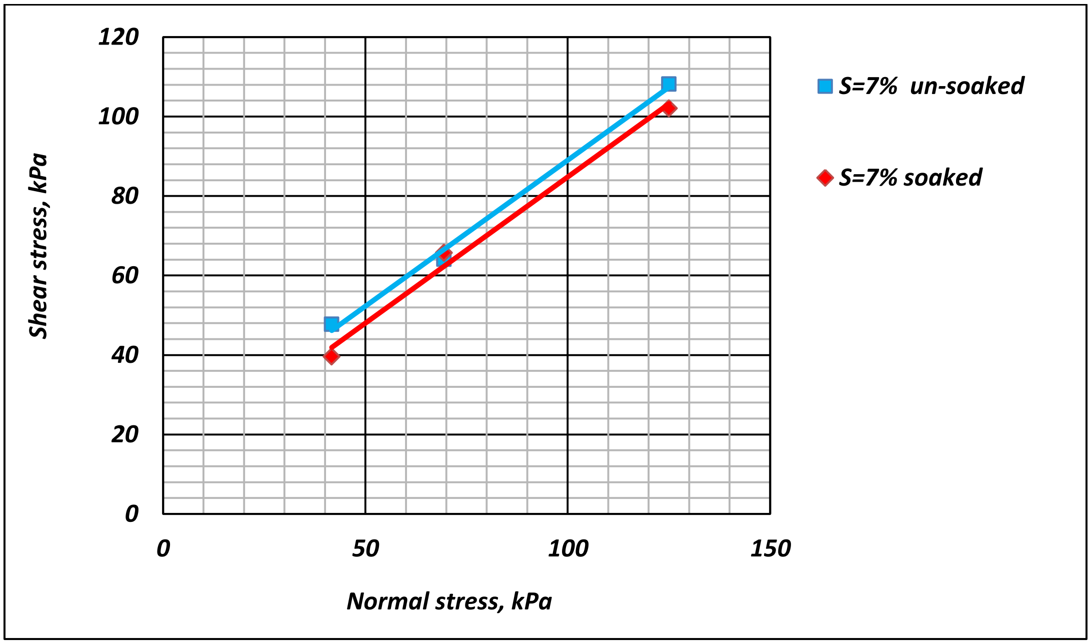

Figure 4. Shear stress –normal stress relationship for gypseous soil at 7% degree of saturation for soaked and un-soaked states.

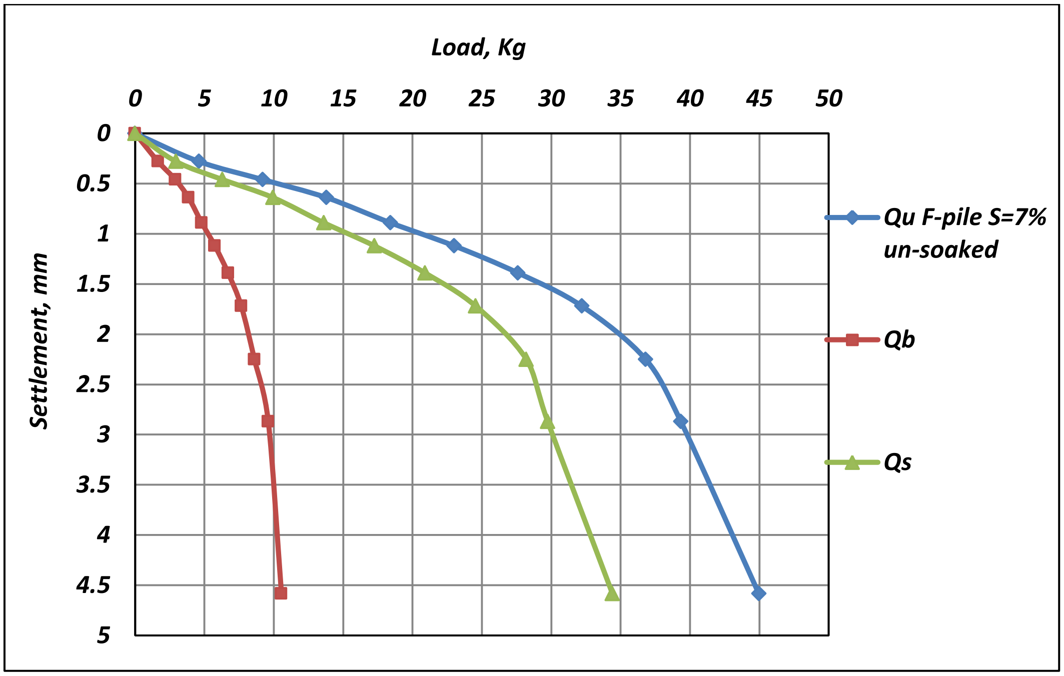

Figure 5. Load-settlement curves for floating pile with 7% degree of saturation in un-soaked state.

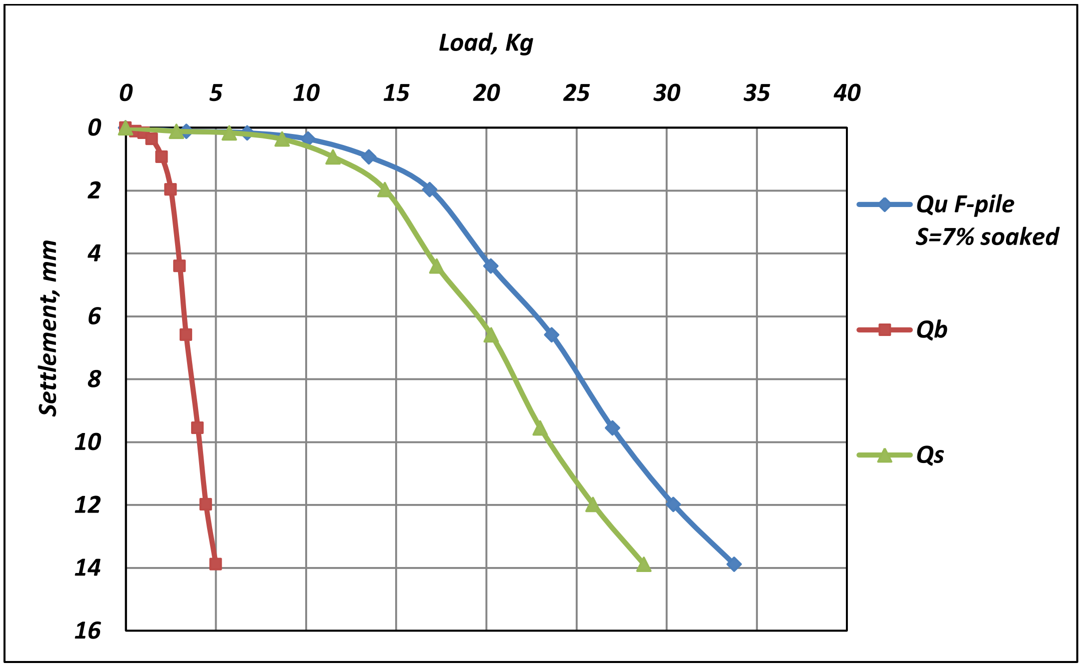

Figure 6. Load-settlement curves for floating pile with 7% degree of saturation in soaked state.

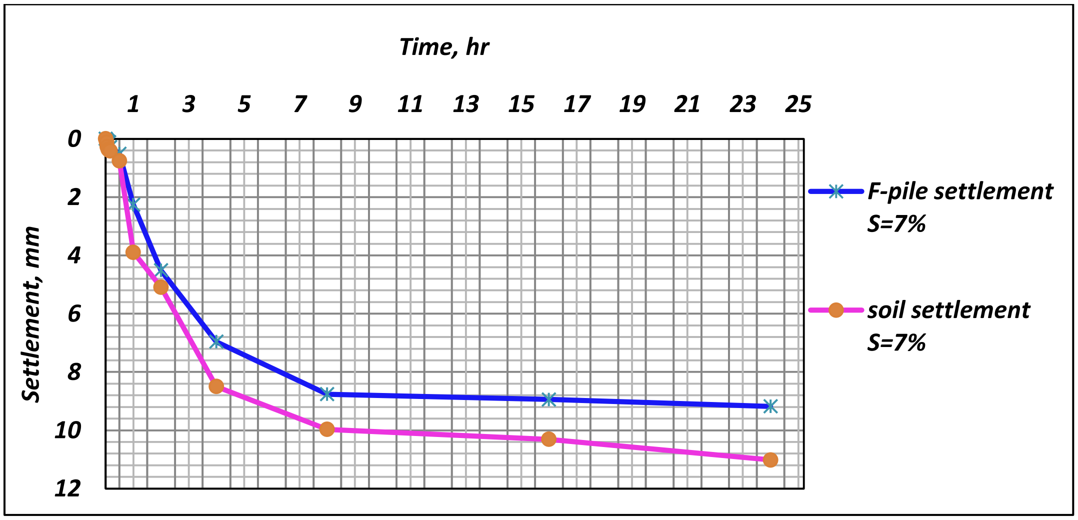

Figure 7. Variation of pile and soil settlements during soaking before loading the floating pile.

Plate 1. Shape of pile model test.

Plate 2. Static Loads for placing gypseous soil.

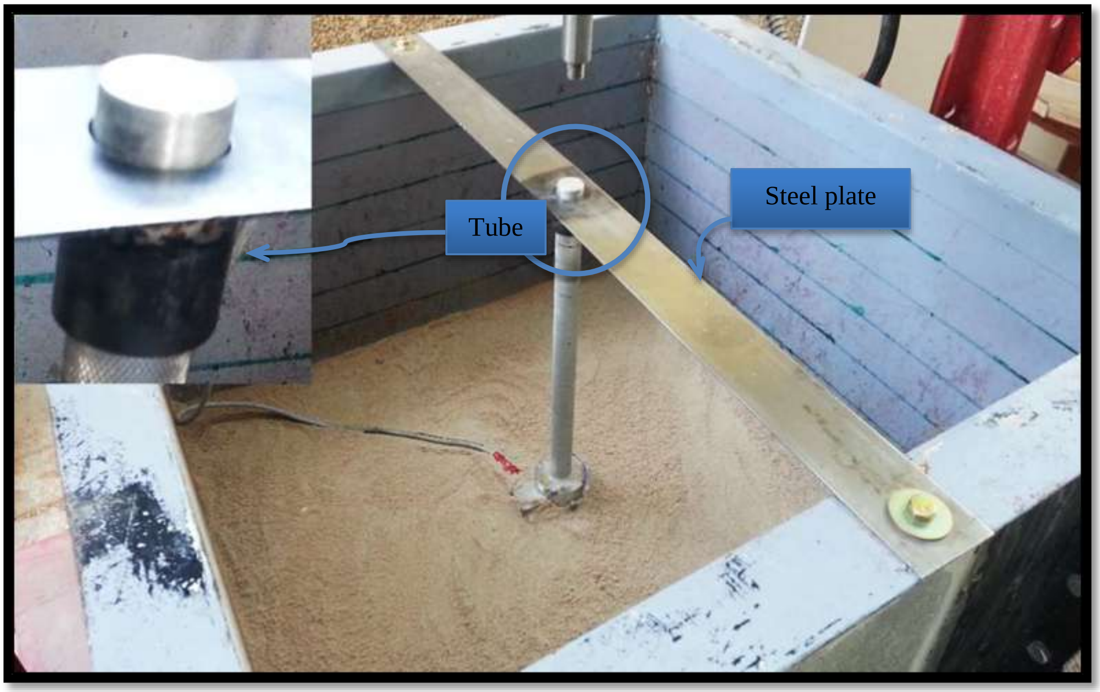

Plate 3. Steel plate fixed the model pile vertically in the box and prevented horizontal movement.

Plate 4. Load cells and their indicators.

Plate 5. Arrangements of dial gauges for soil and pile settlements readings.

Table 1. Results of physical tests for gypseous soil.

Properties		Value
Specific gravity, (*Gs*)		2.48
Atterberg's limits	Liquid limit (*L.L*)%	33
	Plastic limit (*P.L*)%	N.P
	Plasticity index (*P.I*)%	---
Minimum dry density, (γ_{min}) kN/m³		11.50
Maximum dry density, (γ_{max}) kN/m³		14.88
Dry field density, (γ_d) kN/m³		12.50
Relative density, (*Dr*) %		35
Permeability, (*K*) cm/sec		$2.11*10^{-4}$

Table 2. Results of engineering tests.

Properties		**value**
Collapse potential, CP%		7
Cc		0.166
Cr		0.0125
un-soaked	C, kPa	15.5
	ϕ, deg.	36
soaked	C, kPa	11
	ϕ, deg.	36

Table 3. Properties of pile model.

Properties	**Value**
Weight of pile	280 gm
Density of pile	2.78 gm/cm^3
Length of pile (L)	30 cm
Diameter of pile (D)	2 cm
L/D ratio	15

Table 4. Summary of ultimate capacity (kg) for bored floating piles constructed in gypseous soil at soaked and un-soaked states.

Predicted pile load capaciy (Kg)	CP =7% S = 7%	
	Unsoaked	Soaked
Theoretical (static method)	45.5	31.6
Tangent graphical method	33	15
Terzaghi method	36	17
Log load-log settlement	20	15
Chin-kondner extrapolation	60.97	38.3
Brinch hansen method (1963)	54.6	33.2
Decourt's extrapolation	58	26
De beer method	36.8	20.25
Shen's Method (1980)	36.8	20.25

Table 5. Skin friction and base resistance values for floating bored piles.

Un-soaked State					Soaked State					RD%
Qu, Kg	*Qb, Kg*	*Qs, Kg*	*Qs, %*	*Qb, %*	*Qu, Kg*	*Qb, Kg*	*Qs, Kg*	*Qs, %*	*Qb, %*	
36.8	8.6	28.2	77	23	20.25	3	17.25	85	15	45