RESEARCH ARTICLE

Effect of Pile Section Shape on Bearing Capacity under Dry and Saturated Conditions

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Huda W Abdulwadood, Bushra Suhale Albusoda

Department of Civil Engineering, University of Baghdad College of Engineering, Baghdad, Baghdad Governorate, Iraq

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Abstract

Background

Gypseous soil exhibits significant collapsibility when saturated due to the dissolution of gypsum bonds, resulting in substantial reductions in shear strength and settlement problems. Understanding the influence of pile morphology on shaft resistance under these conditions is essential for constructing foundations in collapsible soils. The load-settlement behavior of the pile foundation can be established through an empirical pile loading test after preparing the soil and installing the piles in the model.

Methods

A physical model measuring 37×80×80 cm was constructed to assess the performance of three aluminum floating piles (square, circular, and rectangular) with identical cross-sectional areas, embedded in loose gypseous soil containing 58% gypsum and exhibiting a relative density of 30%. Pile load experiments with a constant rate of penetration (1 mm/min) were conducted under both dry and saturated conditions. Twelve methods were employed to determine the ultimate bearing capacity, including Davisson, De Beer, Brinch Hansen's 80% and 90%, Chin-Kondner, Decourt, and ASTM D-1143.

Results

Soaking caused a significant decrease in capacity; the ultimate load dropped by approximately 45-55% for the square pile, 55-60% for the rectangular pile, and 60-65% for the circular pile, depending on the interpretation method used. The Chin-Kondner method is notable

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1. **Ibrahim M Mashhour**, Arab Academy for Science, Cairo, Egypt

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among interpretation methods, providing the most consistent and accurate estimates of ultimate capacity in both dry and saturated conditions, with the lowest variability across shapes (coefficient of variability < 10%).

Conclusions

The shape of piles significantly influences load transfer in gypseous soils, especially when saturated. Square piles offer greater reliability and are less prone to strength loss due to collapse. In collapsible gypseous soils with high gypsum content, using square sections and Chin-Kondner interpretation is recommended for more accurate pile foundation design. Davisson's method provided the most conservative estimate of pile capacity among the twelve methods, particularly when saturated.

Keywords
Ultimate capacity, load settlement data, gypseous soil samples, pile geometry, and graphical theoretical methods.

Corresponding author: Bushra Suhale Albusoda (dr.bushra_albusoda@coeng.uobaghdad.edu.iq)

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1. Introduction

Soil properties around the pile are crucial for assessing its geotechnical capacity, as this capacity comprises two main aspects: load transfer capacity, which directly relates to the interaction between the pile and the soil, and structural capacity, which depends on the pile's material properties. Under soaking conditions, the cementation bonds between soil particles break down, increasing the potential for collapse and reducing the large void ratio, leading to rapid settlement and significant deformation in collapsible soil structures.[1,2]

Collapsible soils are problematic soils that exhibit considerable strength when dry but lose strength significantly upon saturation, which can lead to settlement problems. Gypseous soil is especially prone to collapse, influenced by factors like loading, moisture, soil density, and immersion conditions.[3]

Pile foundations are the most common type of foundation used in geotechnical engineering because of their remarkable carrying capacity, low settlement, high flexibility, and structural stability.[4]

The physical and mechanical properties of gypseous soil, including specific gravity and solubility (2-2.5 g/l), are directly affected by high gypsum concentration, as gypseous soil is a type of collapsed soil.[5]

Samarra Tourist Hotel, Karbala High Water Tank, and the deterioration and collapse under the weight of many facilities in Mosul and Tikrit were among the most significant soil-collapsing issues in Iraq.[6]

Because a down-drag force developed around the pile shaft embedded in collapsible soil, the structures were damaged during saturation.[7] Determining the degree of gypseous soil severity based on the collapse potential value is essential for assessing the possible damage in the region.[8]

The pile is typically designed using theoretical equations provided by various codes. To verify the pile's load capacity, a pile load test must be conducted. The ultimate load capacity, also known as the load that causes rapid settlement due to a significant or moderate increase in applied load, is the sum of skin friction and end bearing resistance. According to ASTM D-3689(1995), ASTM D 3966-07, and ASTM D-1143, there are four main types of pile load tests: pull-out load, dynamic load, lateral load, and axial compression load. Four primary methods are used to apply axial compression loads in axial compression load tests.[9]

These techniques include the Slow Maintained Load Test (SMT), the Constant Rate of Penetration Test (CPR), and the Swedish Cyclic Test (SC). Any of these approaches has requirements and limits. The CRP method is recommended because, in some methods, a significant load is needed to reach the pile's plunging failure load.[10]

Various criteria have been suggested for determining the ultimate load capacity using graphical methods based on load-settlement curve results. Hansen (1963), Chin-Kondner (1970), Fuller and Hoy (1970), Mazurkiewicz (1972), Buller and Hoy (1977), De Beer and Wallays (1989), Corps of Engineers (1991), Decourt (1999), and others proposed these graphical techniques. In accordance with ASTM 1143, the analysis was conducted using various criteria to determine the capacity of the board pile in Baghdad soil based on the pile load test. Hansen (1963), the Chin-Kondner estimation, and the Log-Log techniques all provided high estimates of the pile's ultimate load capacity. Due to its simplicity, the Terzaghi method was used to predict the ultimate pile capacity. This method considers the load value corresponding to a settlement of about 10% of the pile diameter.[11]

The ultimate pile load test for the pile placement in gypseous ground was examined through an experimental simulation. When comparing the load-settlement graph data with the theoretical calculations, several failure criteria were considered, and the most appropriate one was selected. Results obtained using Shen's Approach (1980) were suitable, but the procedures developed by Brinch Hansen in 1963, Decourt extrapolation, and Chin-Konder extrapolation yielded higher values.[12]

Each technique may accurately estimate the ultimate load if the tested load is high and close to the ultimate load limit, but at lower loads, the results tend to be overstated. Davisson and De Beer's techniques cannot be used for non-failed piles in this study; however, Chin, Mazurkiewicz, and Decourt's methods are suitable. As a result, it is challenging to propose a precise strategy for determining the final pile capacity.[13]

Nine techniques were used to evaluate the bearing capacity of driven piles at various locations in Iraq. The most effective methods are De Beer, ChinKonder, and Vander Veen. Although Vander Veen's method is time-consuming, these techniques yield the highest bearing capacity, which is linked to minimal pile settlement. Meanwhile, the Bulter, Hoy, and

Brinch Hansen's 90% techniques provided satisfactory capacity with limited settlement, while Fuller, Hoy, and Davison approaches produced acceptable results with sustainable settlement. The results indicated that the Terzaghi method (10% of pile diameter) was overestimated, and a sufficient criterion for this research is 4% of pile diameter.[14]

When calculating the ultimate load capacity using a mathematical formula or a computer program, several factors should be considered, including the specific pile type, the applied load, its dimensions, and the material used in its construction. A comparison of the results obtained through the computer program method was conducted using the Brinch-Hansen, Decourt, and Chin-Kondner approaches. Although the Decourt and Chin-Kondner procedures produced results roughly comparable to those of the Brinch-Hansen and software methods, the study suggested that none of these procedures should be used until a settlement failure occurs.[15]

The most accurate field-experiment data were obtained using Bazaar and Luciano Decourt's empirical analysis method. Test results were interpreted with the methods of Chin, Lastiasih, and Mazurkiewicz. Based on the conclusions from these empirical techniques and the interpretation of the field test's ultimate bearing capacity, pile load data were analyzed using the finite element approach. According to pile loading tests at failure, the study's findings indicated that the finite element methods by Lastiasih and Luciano Decourt are among the most precise for determining ultimate load capacity.[16]

Various alternative interpretation methods were employed to determine pile capacity based on results from pile load tests conducted in three separate areas in Nasiriyah, south of Iraq. Considering that Chin-Kondner's ultimate load for the 22 pile load tests is 22% higher than Hansen's ultimate load, these methods cannot be used to predict pile capacity. The approaches of DeBeer, Decourt, and Mazurkiewicz produced the closest average failure load, but Buttler-Hoy's method showed the smallest failure capacity.[17]

Although several research studies have explored the behavior of piles in gypseous and other collapsible soils, the combined influence of pile geometry (shape) and saturation, and its analysis using multiple graphical criteria for ultimate capacity, has not been comprehensively assessed. The research aims to examine the impact of pile geometry and saturation using multiple interpretation criteria that have not been fully explored. The three pile geometries (square, circular, and rectangular) were chosen to investigate how cross-sectional shape affects shaft resistance while maintaining a constant area, despite differing perimeter-to-area ratios. This structural analysis provides a systematic approach, while the physical model allows for direct observation of pile-soil interaction under controlled boundary conditions. Comparing dry and saturated conditions is essential because wet gypseous soil behaves differently mechanically. Gypsum bond dissolution and apparent cohesiveness influence pile performance in both environments, aiding in assessing pile geometry failure susceptibility and establishing safe design parameters. Twelve load-settlement interpretation methods were employed to improve scientific accuracy and minimize judgment bias.

2. Soil and pile properties

The floating bored piles (square 14 mm, circular 16 mm, and rectangular 20×10 mm) used in this study are hollow aluminum, 1.3 mm thick and 250 mm long.

Rigid-type friction piles were used in this study; therefore, hollow piles were selected to minimize the impact on the bases. The lateral roughness was standardized across the three pile types to eliminate it as a variable, allowing the study to focus on the effect of pile geometry on load-bearing capacity. Table 1 presents the geometric properties of the model piles and details of their cross-sectional areas. They are placed in the soil inside the experimental steel box.

The values indicate that the cross-sectional areas are nearly equal. The perimeter increases from circular to square and rectangular piles, which may affect the available shaft surface for skin friction mobilization. The perimeter-to-area ratio is a key dimensionless parameter that may directly influence pile behavior, but shear and loading mechanisms also play significant roles. Air-dried, collapsible, gypseous soil containing 58% gypsum, with a loose dry density of 11.4 kN/m^3,

Table 1. Geometric properties of model piles with equivalent cross-sectional area.

Pile shape	Dimensions (cm)	Area, A (cm^2)	Perimeter, P (cm)	P/A
Circular	1.6	2.01	5.03	2.5
Square	1.4*1.4	1.96	5.6	2.86
Rectangular	2 *1	2	6	3

was used. It was placed in a steel container measuring 37×80×80 cm with a 6 mm wall thickness to accurately simulate pile behavior on site and maintain boundary conditions.

As shown in Figure 1, sandpaper was used to roughen the pile shafts to generate friction along the embedded length of the piles in gypseous soil.[18] Based on the soil sample's physical characteristics (a mixture of fine to medium-sized particles with a high gypsum concentration, which imparted some cohesiveness), medium-grit sandpaper (80-120 grit) was selected.[19]

The floating bored piles were installed using a steel frame that maintains their vertical position, with an embedded length of 200 mm. The surface roughness of each pile was treated with medium-grit sandpaper to simulate pile shaft friction. Table 2 lists the soil characteristics.

Note that the 250 mm pile length reflects a realistic L/D ratio for a small laboratory model of a rigid pile. This minimizes the influence of test box boundaries and aligns with laboratory measurements of gypseous soil. It has all the features needed to simulate a high-gypsum friction pile. Due to the loose, dry soil, a relative density of 30% effectively mimics natural gypseous soil in certain areas and clearly demonstrates soil settlement from load and saturation. A highly compressible soil with 58% gypsum enables the observation of saturation effects.

Analyzing full-scale pile behavior under specific field conditions requires a detailed model, which is often more costly and time-consuming. The practicality of using a scaled-down model, despite its limitations, must be acknowledged, including stress distributions and pile movements, which can be affected by the soil container's boundaries and by the friction between the container wall and soil particles. The ratio of the pile diameter to mean grain size (D50) should be greater than 35 for vertical loading.[20]

Figure 1. Shows the aluminum pile models with different geometries and a steel laboratory box container.

Table 2. Characteristics of the soil used in this study.

Soil	Properties	Values
Gypseous Soil Sample	Soil Classification (USCS)	SP
	Gypsum Content	58
	Dry Unit Weight (kN/m^3)	11.4
	Relative Density %	30
	Cohesion	8
	Angle of Internal Friction (°)	38

$$\frac{\text{pile diameter (or equivalent)}}{D_{50}} = \frac{16\ \text{mm}}{0.3\ \text{mm}} = 53 > 35 \text{ It is o.k.}$$

The distance below the pile tip to ensure it is a friction pile should be about 8d, which is 8(16) = 128 mm. However, the actual distance was approximately 400 mm, and the distance between piles exceeded 7d to ensure a single isolated pile and prevent group effects.

To reduce the internal scale effect between the pile and the tested soil[21]:

$$\frac{\text{pile diameter}}{D_{10}} \geq 50$$

$$\frac{16}{0.07} = 288 \geq 50$$

3. Pile load test

The Constant Rates of Penetration Testing Method, as defined in ASTM D-1143, was employed in this study by gradually increasing the pressure load to push the pile through a collapsible gypseous soil sample at a steady rate of 1mm per minute. Various criteria can be used to interpret the test's load-settling curve. The soil model was designed to represent three different pile geometries installed in a dry, loose gypseous soil sample.

The rain technique was employed to achieve a relative density of 30%, with a consistent drop height of 25 cm to ensure uniform particle deposition. The resulting dry density of 11.4 kN/m^3 was confirmed through three density measurements of the container after deposition. Six layers of gypsum soil were placed in the steel box model, each 10 cm thick, as shown in Figure 2.

Figure 3 shows that a mechanical jack can be used to apply axial compression force to the pile after soil preparation and pile installation. The load cell, shaped like an 'S,' recorded the load transmitted to the pile, which differs from the ultimate load. Ensure that the weight is transmitted as a central pressure over the pile head; each pile has an aluminum plate cover measuring 10 cm × 10 cm × 2 cm. The load cell was calibrated with known weights, while the LVDTs were calibrated using a micrometer. The recommended static loading rate of 1 mm/min is advised for slowly applied loads in collapsible soils to minimize sudden collapse surges and prevent pore pressure buildup during saturation. Both the LVDT and the load cell are connected to the data logger, which records the LVDT measurements of the pile's settlement. The soil must be saturated for a full day to ensure complete saturation. A tank measuring 45×45×45 cm was constructed and positioned beside the laboratory model box. Water is pumped from the tank to three openings at the base of the model, allowing the soil layers to become saturated from below over 24 hours. The rise of water through the surface layers was observed through a side glass window integrated into the laboratory model. When the readings stabilized and water flooded the upper soil layers, it indicated full saturation.

Figure 2. Represents the raining technique.

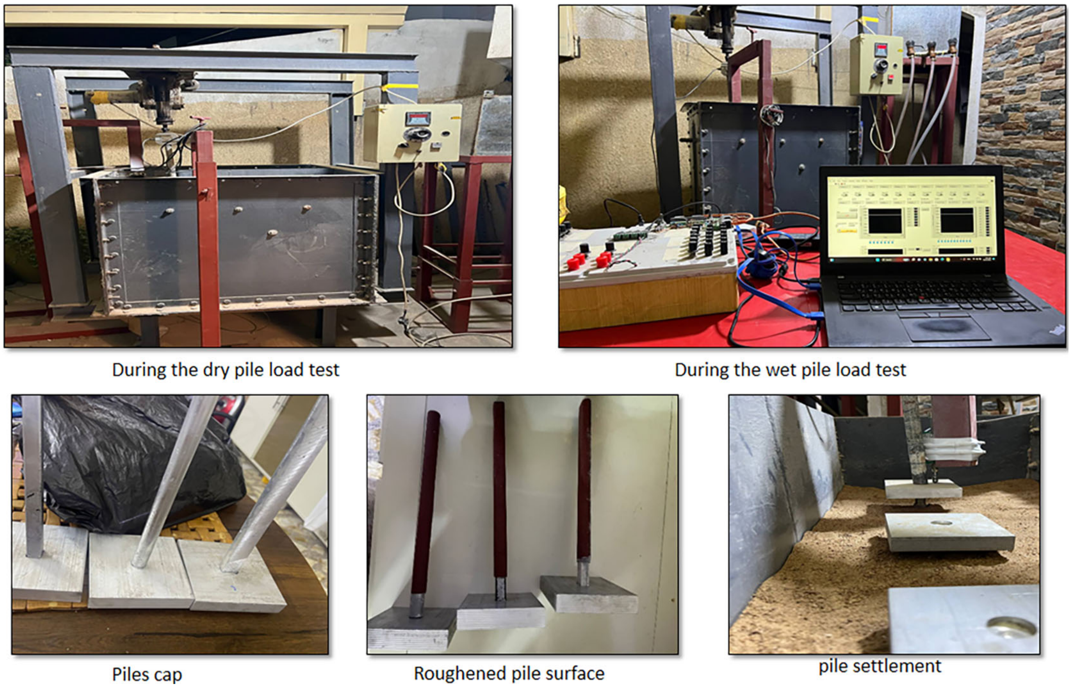

Figure 3. Illustrates the preparation of the piles and the components for the laboratory test.

4. Pile load settlement test results

A load-settlement curve shows the results of the pile load test for both saturated and unsaturated samples. This study considers three pile shapes: square, round, and rectangular, with equivalent cross-sectional areas. In loose, dry soil with a relative density of 30%, the piles were installed as bored piles. Figure 4 illustrates a simulation of a floating pile on gypseous soil under unsaturated conditions, and Figure 5 presents a soaked test.

Figures 4 and 5 display the measured load-settlement response of the three pile shapes under dry and saturated gypseous soil conditions, respectively. The curves show an initially stiff, nearly linear reaction, followed by gradual nonlinearity and progressive degradation in stiffness. These plots serve as the basis for the 12 graphical and semi-empirical interpretation methods used in this study.

The ultimate load capacity of the piles under the specified conditions has been determined from the provided load-settlement curves. As discussed in the next section (part 5), many factors have been taken into account to complete this review.

5. Failure criteria

Several criteria were used to evaluate the results of the pile-loading experiment for each pile geometry, with a dry unit weight of 11.4 kN/m^3 and a loose relative density of 30%, under both wet and non-soaked conditions. The following conditions were applied:

5.1 The Davisson approach

Davisson (1972) proposed using Equation (1) to determine the failure load, which corresponds to the pile's elastic movement.[22]

$$Q_{ult} = 0.15 + \frac{D}{120} \tag{1}$$

Where D: the pile diameter in inches.

5.2 Terzaghi approach

Based on the curve from the pile load test, the pile's load capacity equals the load causing settlement, which is 10% of the pile diameter.[23]

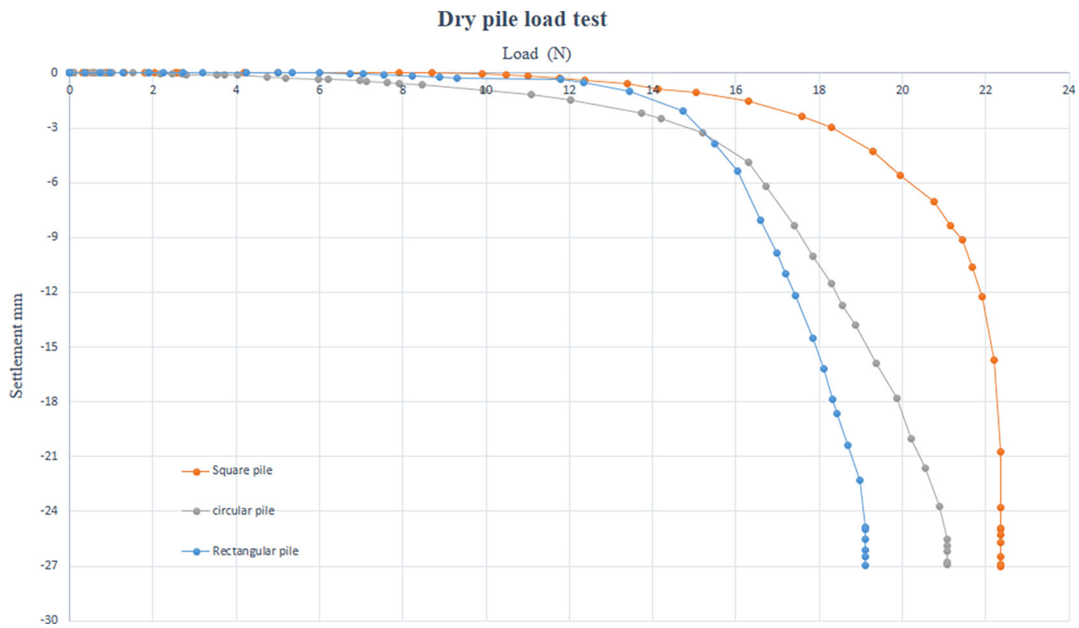

Figure 4. **Dry load-settlement curves for floating piles (circular, rectangular, and square) with 25 cm length embedded in loose gypseous soil with y dry = 11.4 kN/m3.**

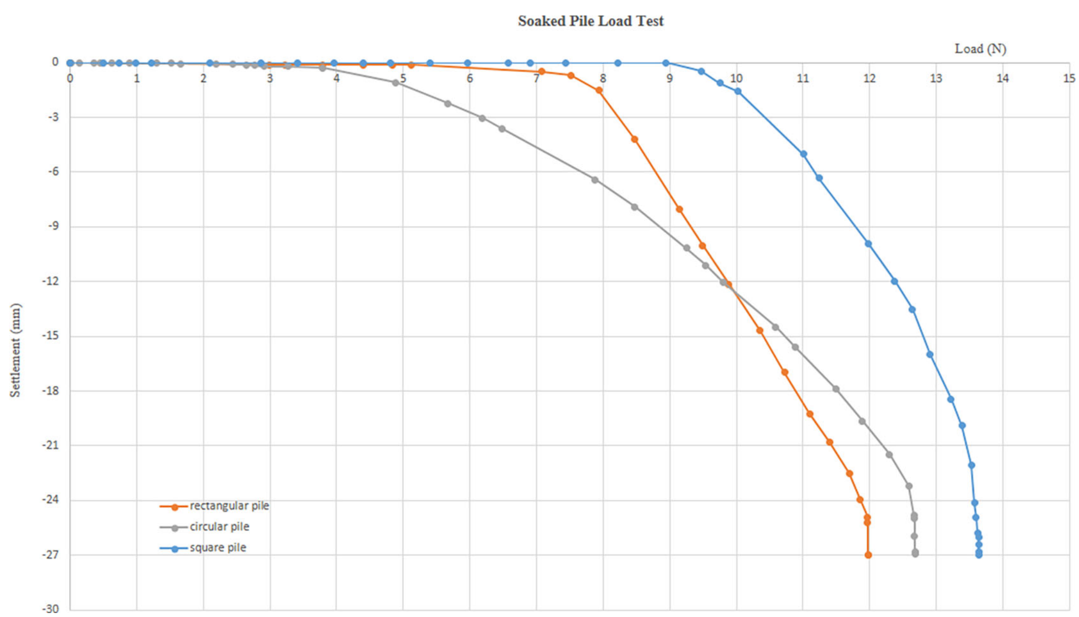

Figure 5. **Soaked pile load test curves for floating piles (circular, rectangular, and square) with 25 cm length embedded in loose gypseous soil with y dry = 11.4 kN/m3.**

5.3 ASTM D-1143 method

The ultimate load is the load resulting from the pile continuing to penetrate, which is at least 15% of the pile's average diameter or width.[24]

5.4 The yield load method of De Beer

De Beer was the first to introduce this method in 1968. A double-logarithmic diagram is used to depict load-movement data. The failure load is defined as the point at which the logarithmic lines for load and settlement intersect.[25]

5.5 The Brinch Hansen's 80% approach

According to Hansen (1963), pile capacity is defined as the load that causes the pile head to settle four times, or 80% of the load. The experimental data are plotted as S/Q versus S, where S is the pile settlement, and Q is the applied load. The data in the near-liner range of this plot are fitted by Equations (2)[26]:

$$C_1 + C_2 = \frac{S}{Q} \tag{2}$$

Where C_1 and C_2 are obtained from the intercept and slope of the best-fit line.

5.6 The Chin-Kondner approach

This method was introduced by Chin-Kondner in 1970 to estimate a pile's ultimate capacity. Equation (3), where C_1 is the slope of the straight line, can be used to determine the ultimate load by plotting the settlement-versus-load curve and dividing by the corresponding settlement.[27]

$$Q_{ult} = \frac{1}{C_1} \tag{3}$$

Where C_1: Straight line's slope.

5.7 The Decourt Extrapolation approach

This method was introduced by Decorut (1999). It involved plotting a curve of applied load versus corresponding settlement at each load. The intersection of the regression line with the load axis was used to determine the Decorut load.[21]

5.8 The Brinch Hansen's 90% approach

Drawing the load settlement graph and identifying the load (Q ult) and settlement (δ) that result in double the amount of pile head settlement observed at 90% of Q ult, this is known as the failing load.[9]

5.9 The Shen's approach

The log load was plotted against the settlement to establish the pile's ultimate capacity load. By using this procedure, the ultimate load was represented by a straight line.[28]

5.10 The Fuller and Hoy's approach

The intersection of the load axis and the tangent to the load-settlement curve, with a slope of 0.05 inch per ton, was used to determine the ultimate load capacity.[29]

5.11 The Butler and Hoy's approach

This method resembles Fuller and Hoy's technique, which determined the ultimate load by identifying the point where the tangent to the loading-settlement curve with a slope of 0.05 inch per ton intersects the curve's initial straight segment.[30]

5.12 The Mazurkiewicz's approach

This method, introduced by Mazurkiewicz in 1972, assumes that the load-settlement curve is parabolic. Horizontal lines are drawn at the points where vertical lines from the settlement axis intersect the curve. The ultimate load is located at the point where a line, drawn at a 45-degree angle, meets these horizontal lines and crosses the load axis.[13]

Final load capacities for all pile geometries tested in the soil sample during the dry- and saturated-pile load tests are detailed in Tables 3 and 4, respectively.

A statistical analysis of the ultimate capacities obtained from twelve interpretation methods for each pile shape under both dry and saturated conditions was performed as illustrated in Table 5. This analysis used the ultimate load capacity values from Tables 3 and 4, based on,[31] and was carried out using Equations 4, 5, and 6, as shown in Table 5.

Table 3. Ultimate pile capacity (N) for dry loose gypseous soil for circular, square, and rectangular piles with a length of 25 cm.

Method	Square pile	Circular pile	Rectangular pile
Davisson approach	21.0	14.9	15.0
Terzaghi approach	17.0	12.5	14.3
ASTM D-1143	17.3	14.3	14.0
De Beer method	15.0	14.5	22.0
Brinch Hansen's 80%	25.0	20.9	21.5
Chin-Kondner approach	22.7	21.5	19.3
Decourt extrapolation	21.0	19.0	17.8
Brinch Hansen's 90%	21.0	21.2	19.2
Shen's method	19.0	15.0	22.0
Fuller and Hoy's method	22.5	18.0	16.2
Butler and Hoy's method	22.0	17.7	15.9
Mazurkiewicz's method	22.5	21.5	19.3

Table 4. Ultimate bearing capacity (N) for saturated loose gypseous soil for circular, square, and rectangular piles with a length of 25 cm.

Method	Square pile	Circular pile	Rectangular pile
Davisson approach	13.3	9.3	8.1
Terzaghi approach	10.0	5.2	8.0
ASTM D-1143	10.2	5.9	8.0
De Beer method	10.0	5.0	7.0
Brinch Hansen's 80%	14.0	12.0	12.5
Chin-Kondner approach	13.6	12.8	12.0
Decourt extrapolation	13.5	10.9	11.0
Brinch Hansen's 90%	13.6	12.6	10.0
Shen's method	10.3	8.0	9.0
Fuller and Hoy's method	12.8	8.7	8.5
Butler and Hoy's method	12.4	8.3	8.0
Mazurkiewicz's method	13.5	13.0	11.6

Table 5. Statistical summary of interpreted ultimate capacities.

Condition	Pile shape	Mean capacities (N)	SD (N)	COV%
Dry	Square	20.5	2.88	14
Dry	Circular	17.6	3.26	18.5
Dry	Rectangular	18.0	2.95	16.3
Saturated	Square	12.3	1.63	13.3
Saturated	Circular	9.3	2.96	31.8
Saturated	Rectangular	9.5	1.87	19.7

$$\bar{x} = \frac{\sum_{i=1}^{n} X_i}{n} \tag{4}$$

Where:

x̄: mean ultimate load N.

x_i = individual measured ultimate load value.

n = total data points.

$$SD = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}} \tag{5}$$

Where:

SD: standard deviation.

COV: coefficient of variation.

$$\mathrm{COV} = \frac{SD}{\bar{x}} * 100\% \tag{6}$$

The values in Table 5 show that the square pile has the highest average ultimate capacity under both dry (20.5 N) and saturated (12.3 N) conditions, with relatively low COV values (14% and 13%). In comparison, the circular pile demonstrates greater variability, especially after saturation (COV = 31.8%), indicating a more scattered interpretation of capacity due to its increased vulnerability to gypsum dissolution and loss of interface friction. The rectangular pile exhibits moderate performance regarding both average capacity and variability. These trends confirm that the square pile is not only stronger on average but also more consistent across the twelve interpretation methods.

The perimeter-to-area ratio (P/A) is a key factor influencing the behavior of different pile geometries. However, shear and loading mechanisms also play a significant role. The results indicated that square and rectangular piles exhibit greater bearing capacity in dry soil compared to circular piles. This can be linked to the P/A ratio, which is higher for square and rectangular piles than for circular ones. In a saturated state, the square pile demonstrated greater bearing capacity than both the rectangular and circular piles by a larger margin. This difference is due to the loading mechanism associated with the various pile shapes. Contact loss is most severe for the pile with a high P/A ratio (rectangular pile) because the long, flat surfaces tend to lose contact with the soil more than other shapes. The square shape offers better load-bearing capacity due to the arching effect at the corners.

6. Conclusions

The geometry of the pile clearly affects its bearing behavior and the load transfer to the surrounding layer. This effect becomes more pronounced under different soil-moisture conditions. This study uses various failure criteria methods under both dry and saturated conditions to determine the pile's bearing capacity:

1- The results from the axial compression load test on modeled piles placed in loose gypseous soil under both dry and soaked conditions show that the shape of the pile significantly influences the ultimate bearing capacity and load-settlement response.

2- Although the cross-sectional area is the same for all tested piles (circular, square, and rectangular), the square pile exhibited the highest ultimate bearing capacity across all interpretation methods in both the dry and soaked states. This finding supports observations by,[32,33] who noted that shaft resistance is strongly influenced by pile shape and surface characteristics, especially in short piles, where side friction primarily controls load transfer.

3- Considering the length of the model piles (25 cm), shaft resistance seems to be the primary factor in determining pile behavior. This explains the significant influence of cross-sectional shape observed in dry conditions.

4- The pile load test under saturated conditions revealed a significant decrease in ultimate bearing capacity compared to the dry state, attributed to gypsum dissolution and a corresponding drop in apparent cohesion. This reduces skin friction by breaking cementation bonds, thereby lowering bearing capacity.

5- The reduction in bearing capacity due to saturation was more significant for the circular pile, whereas the square pile performed relatively better. This illustrates the impact of pile geometry on shaft resistance.

6- Shear and loading mechanisms significantly influence behavior, so the results show that square and rectangular piles have greater dry-soil bearing capacity than circular piles. The ratio of perimeter to area is higher for square and rectangular piles than for circular ones, which explains this trend. In the saturated state, the square pile exhibited a higher bearing capacity than the other shapes. Different pile shapes have distinct loading mechanisms. Because of their long, flat surfaces, rectangular piles with high P/A ratios lose soil contact, making arching and corner stress concentration more prominent, allowing square shapes to bear more load.

7- The most effective method for estimating ultimate pile capacity under both dry and saturated conditions is the Chin-Kondner method, which closely aligns with load-settlement behavior in floating piles and gypseous soils.

8- The Davisson method provided the most conservative estimate of pile capacity among the twelve interpretation methods, especially in saturated conditions. This aligns with its displacement and is particularly relevant for gypseous collapsible soils, where gradual bond degradation causes significant settlements before failure. In these soils, serviceability factors often influence design, making displacement-based criteria, such as Davisson's, more suitable than purely strength-based definitions.

9- The ASTM D-1143, Decourt, and De Beer methods yield moderate results and are less accurate than the Chin Kondner method.

10- The Terzaghi and Brinch Hansen methods (80% and 90%) assume clear shear failure, which does not reflect the gradual behavior or collapse in gypseous soil. Fuller and Hoy, as well as Butler and Hoy, are unsuitable for unstable or collapse-prone loading and subsidence behavior.

11- The dissolution of gypsum, which previously acted as a cementing agent, the breakdown of interparticle bonds, and sudden settlement under relatively small load increments due to increased compressibility were observed. The results of this study align with Al-Mukhtar et al. (1996), who reported substantial strength loss in gypseous soils after wetting, as well as with,[5,33] which noted dissolution and collapse characteristics observed in this study.

Data availability

Zenodo repository: Effect of Pile Section Shape on Bearing Capacity under Dry and Saturated Conditions. https://doi.org/10.5281/zenodo.18274515[34]

The repository contains the following underlying data:

- Excel sheets display raw load-settlement data for circular, square, and rectangular piles under dry and saturated soil conditions. This data was collected by the data logger during the tests.

The repository also contains the following extended data:

- The selected and processed data to demonstrate the load-settlement curve behavior. These data include:

Supplementary Table 1: The pile loads in Newton and the settlement values in millimeters recorded by the data logger for the circular pile in dry conditions.

Supplementary Table 2: The pile loads in Newton and the settlement values in millimeters recorded by the data logger for the square pile in dry conditions.

Supplementary Table 3: The pile loads in Newton and the settlement values in millimeters recorded by the data logger for the rectangular pile in dry conditions.

Supplementary Table 4: The pile loads in Newton and the settlement values in millimeters recorded by the data logger for the circular pile in saturated conditions.

Supplementary Table 5: The pile loads in Newton and the settlement values in millimeters recorded by the data logger for the square pile in saturated conditions.

Supplementary Table 6: The pile loads in Newton and the settlement values in millimeters recorded by the data logger for the rectangular pile in dry conditions.

References

1. Abd-Alhameed HJ, Albusoda BS: **Impact of eccentricity and depth-to-breadth ratio on the behavior of skirt foundation rested on dry gypseous soil.** *Journal of the Mechanical Behavior of Materials, Materials.* 2022; **31**(1): 546–553.
Publisher Full Text
2. Hassan SM, Albusoda BS: **Mitigation of collapse characteristics of gypseous soils by activated carbon, sodium metasilicate, and cement dust: An experimental study.** *J. Mech. Behav. Mater.* 2022; **31**(1): 631–638.
Publisher Full Text
3. Abdulwadood HW, Albusoda BS: **The Collapsible Soil Definition and Mitigation Strategies: A Review Study.** *J. Eng.* 2024; **30**(11): 142–163.
Publisher Full Text
4. Abdulwadood HW, Albusoda BS: **Negative skin friction evaluation and mitigation: A review study.** *AIP Conference Proceedings.* AIP Publishing LLC.; 2024 Nov 19; Vol. **3219**(1): p. 020015.
Publisher Full Text
5. Al-Taie AJ, Albusoda BS, Alabdullah SFI, *et al.*: **An experimental study on leaching in gypseous soil subjected to triaxial loading.** *Geotech. Geol. Eng.* 2019; **37**: 3681–3693.
Publisher Full Text
6. Mahdi HA, Jihad AG: **Performance of under-reamed piles in collapsible soil.** *E3S Web of Conferences.* 2021; **318**: 01015.
Publisher Full Text
7. Noman BJ, Abd-Awn SH, Abbas HO: **Effect of pile spacing on group efficiency in gypseous soil.** *Civil Engineering Journal.* 2019; **5**(2): 373–389.
Publisher Full Text
8. AlDamluji OA-FS, Albusoda BS, Ali: **Performance evaluation of a model pile in gypseous soil.** 2020.
Reference Source
9. Prakash S, Sharma HD: *Pile Foundations in Engineering Practice.* John Wiley & Sons; 1991.
10. Whitaker T: **Note on the constant rate of penetration test for the determination of the ultimate bearing capacity of a pile.** *Proc. Inst. Civ. Eng.* 1963; **26**(1): 119–124.
Publisher Full Text
11. Mohsen AH, Albusoda BS: **Evaluation of the Bearing Capacity of the Board Pile in Collapsible Soil using A Laboratory Model.** *E3S Web of Conferences.* EDP Sciences; 2023; Vol. **427**: p. 01018.
Publisher Full Text
12. Al-Busoda BS, Al-Rubaye AH: **Bearing capacity of bored pile model constructed in gypseous soil.** *J. Eng.* 2015; **21**(3): 109–128.
Publisher Full Text
13. Birid KC: **Evaluation of ultimate pile compression capacity from static pile load test results.** *Advances in Analysis and Design of Deep Foundations.* Springer; 2018; pp. 1–10.
Publisher Full Text
14. Hussein HH: **Assessment of load capacity of piles and conclusion of a new criterion using static load tests.** *IOP Conference Series: Journal of Physics.* 2021; **1973**(1): 012205.
Publisher Full Text
15. Yousif AA, Ali EH: **Determination of piles bearing capacity using empirical methods and AllPile 6 software: Case studies in Port Sudan and Khartoum cities.** *International Journal of Material and Mathematical Sciences.* 2021; **3**(5): 113–121.
16. Lastiasih Y, Sari PT: **Comparison of ultimate bearing capacity based on empirical method, interpretation of loading pile test and finite element.** *IOP Conference Series: Materials Science and Engineering.* 2020; **930**: 012036.
Publisher Full Text
17. Abdel R, Shakir RR: **Evaluation of static pile load test results of ultimate bearing capacity by interpreting methods.** *IOP Conf. Ser. Earth Environ. Sci.* 2022; **961**(1): 012013.
Publisher Full Text
18. Sadrekarimi A, Gouhari MB, Roohimehr A: **Surface roughness effects on the shaft resistance of piles in dry sand.** *The Electronic Journal of Geotechnical Engineering.* 2009; **14**: 1–11.
Publisher Full Text
19. Subair AH, Al-Jorany AN: **Experimental and numerical analysis of axially loaded slender piles implementing a hypoplastic model.** *IOP Conference Series: Materials Science and Engineering.* 2021; **1067**: 012069.
Publisher Full Text
20. Beijer Lundberg A, Dijkstra J, Van Tol AF: **On the modelling of piles in sand inthe small geotechnical centrifuge.** *Proceedings of Eurofuge 2012.* Delft, The Netherlands: Delft University of Technology and Deltares; 2012, April 23–24.
21. Vipulanandan C, Wong D, Ochoa M, *et al.*: **Modelling of displacement piles in sand using a pressure chamber.** *Foundation Engineering: Current Principles and Practices.* American Society of Civil Engineers (ASCE); 1989; pp. 526–541.
22. Davisson MT: **High-capacity piles.** *Proceedings of Lecture Series on Innovations in Foundation Construction.* ASCE; 1972.
23. Fellenius BH: **The analysis of results from routine pile load tests.** *Ground Eng.* 1980; **13**(6): 19–31.
24. ASTM D. 1143-81: *Standard Test Method for Piles Under Static Axial Compressive Load.* West Conshohocken, Pa: American Society for Testing and Material.
25. De Beer EE: **Proefondervindelijke bijdrage tot de studie van het grensdraagvermogen van zand onder funderingen op staal; Bepaling von der vormfactor sb.** *Annales des Travaux Publics de Belgique.* 1967; **68**(6): 481–506.
26. Brinch Hansen J: **Discussion of hyperbolic stress-strain response: Cohesive soil.** *ASCE Journal of Soil Mechanics and Foundations Division.* 1963; **89**(4): 241–249.
27. Kondner RL: **Hyperbolic stress-strain response: cohesive soils.** *Journal of the Soil Mechanics and Foundations Division.* 1963 Feb; **89**(1):

115–143.
Publisher Full Text

28. Mishra A, Sawant VA, Deshmukh VB: **Prediction of pile capacity of socketed piles using different approaches.** *Geotech. Geol. Eng.* 2019; **37**(6): 5219–5230.
Publisher Full Text

29. Al-Kinani AM, Ahmed MD: **Comparison of single and group bored piles settlement based on field test and theoretical methods.** *J. Eng.* 2020; **26**(2): 144–158.

30. Olgun M, Yenginar Y, Hanati A: **Interpreting load–settlement curves of pile foundations by graphical methods.** *Eurasian Journal of Civil Engineering and Architecture.* 2017; **1**(2): 1–10.

31. Montgomery DC, Runger GC: *Applied Statistics and Probability for Engineers.* John Wiley & Sons; 6th ed. 2014.

32. Das BM: *Principles of Foundation Engineering.* Cengage Learning; 7th ed. 2010.

33. Tomlinson M: *Foundation Design and Construction.* Prentice Hall; 7th ed.2001.

34. Wogod H: Effect of Pile Section Shape on Bearing Capacity under Dry and Saturated Conditions. [Data set]. *Zenodo.* 2026.
Publisher Full Text

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✓ **Ibrahim M Mashhour**
Arab Academy for Science, Cairo, Egypt

The authors present a comprehensive experimental study and a sufficient and informative comparative analytical study. The topic is highly relevant for geotechnical engineering practice, especially in collapsible soil regions.
The experimental setup details were provided, and results were clearly presented and conclusions were logically explained.
The paper is recommended for indexing.
Two relevant references are suggested to be added below.

References

1. Hanna A, Mashhour I, Nguyen N: Drag Load on End-Bearing Piles in Partially Saturated Collapsible Soil. *Geotechnical and Geological Engineering*. 2022; **40** (7): 3431-3442 Publisher Full Text
2. I, Mashhour: Experimental Study on Negative Skin Friction on Piles In Collapsible Soils Due to Inundation.
https://www.researchgate.net/publication/316512616_Experimental_Study_on_Negative_Skin_Friction_on_Piles_in_Coll
.

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?

Yes

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Soil Mechanics, Unsaturated soil mechanics, geotechnical engineering, Piles in Collapsible soils, slope stability.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.