BEHAVIOR OF BARRETTE PILE IN PURE AND CEMENTED SAND USING OSTERBERG CELL

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ABSTRACT: The piles transfer the super structure loads to the soil by three different mechanisms, friction, end bearing, or both friction and end bearing. It is very important to determine the value of each force, separately. For this purpose Osterberg method, (O-cell), of loading was applied in a barrette pile installed in physical model. The O-cell is a device placed just above the pile base, or at a specific distance above the base, used to produce two equal and opposite loads. Different parameters such as cemented sand depth to barrette length (D/L) ratio, and relative density (Dr) were studied. Comparison between the measured results obtained with the O-Cell and the conventional tests using Egyptian code method, are presented. From this study, it can be found that both barrette shaft resistance and pile base capacity are affected by the studied parameters (D/L) ratio, and relative density (Dr). Also, it can be found that the barrette shaft resistance strongly affected by adding cement to sand soil.

KEYWORDS: piles, Settlement, Skin friction, End bearing.

1 INTRODUCTION

Deep foundations such as piles are used to transfer structural loads in situations where shallow foundations cannot provide the required bearing capacity, or where the settlement is a major concern [1]. Geotechnical engineers faced many challenges to provide more reliable and efficient foundation solutions to support large, heavy and more complicated structures. Good understanding of pile behavior is important for efficient design, analysis, construction and inspection of different types of foundations [2], [3]. Osterberg presented many studies focused on several aspects of the topics related to determination of shaft and base resistance of pile [4] to [8]. Different methods of construction were used, bored and driven piles. This study concerned with barrette square piles. The load settlement relationship for single pile is very complex. Many studies were developed over years for investigating the settlement behavior of a single pile [9] to [12]. The settlement is usually the limiting design criterion [13]. The behavior of an axially loaded pile is affected by several factors and, therefore, is usually restored to some established assumptions and/or empirical approaches. In particular, those with regards to soil-pile structure interaction and the distribution of soil resistance (skin friction) with depth [2], [3]. The methods available to predict the ultimate capacity load of a single pile are: (i) theory of bearing capacity; (ii) the pile load test; (iii) empirical methods based on dynamic driving formulae; and (iv) semi-empirical methods using in-situ penetration test results [2]. Still the most reliable method to verify the bearing capacity of a pile is by static load test [9].

This research was carried out to investigate the performance of vertically loaded single barrette pile installed in sand or cement sand mixture. The major objectives of this study were: (i) determination of barrette pile capacity obtained from different methods such as Osterberg Cell (O-Cell) method, and Conventional method, (ii) determination of individual parts of barrette load capacity, shaft and bearing capacity separately, (iii) studying the load-settlement behavior of a single barrette pile embedded in cemented sand with different D/L ratios, (iv) effect of cement-sand mixture on the behavior of barrette, and (v) studying the effect of relative density (D_r). Thereafter, many researchers were concentrated on prediction of piles behavior in sand soil using different techniques [14] to [19].

In this research, tests were carried out on a barrette pile (square 6.0x6.0 cm cross section and 60.0 cm length) to illustrate the load-displacement relationships of piles by the O-cell method. Three groups of tests are performed to study the parameters affected on the pile bearing capacity installed in sandy soil with different relative densities. Each test is conducted in accordance to the conventional and the O-cell procedures. The value of sand height/pile length (H/L) is kept constant at a ratio of 2.0, i.e., the thickness of the sand layer under the pile base was kept constant at 60.0 cm. In all tests, the surfaces of piles are roughened using sand paper to simulate the frictional force along the shaft. Three values of the relative density (D_r) for the used sand are 60 %, 70 %, and 86%. The effect of treated sand with cement (20% percentage of its weight) for a depth (D) measured from the surface has been studied.

2 EXPERIMENTAL MODEL

2.1 Tank model

The used model is a cubic steel tank with internal dimensions of 120 x 120 x 120 cm. Thickness of the tank walls is 0.4 cm. The tank edges and walls are stiffened with steel angle. The base of the tank is founded on plain concrete bed.

2.2 Tested barrette and O-cell model

In this study, the barrette pile used was squarely shaped pile. It has a cross section 6.0x6.0 cm and length of 60.0 cm. In these tests the barrette surface was roughened using sandpaper to increase the frictional force along the shaft. It was provided with a head and O-cell model. The Osterberg loading system consists of oil supply unit, conduit and cell. The oil supply unit contains reservoir, manual pump and pressure gauge of capacity 25 kPa. The O-cell is a small hydraulic jack consisting of a casing incorporated moving piston, designed to give two loads equal in magnitude and opposite in direction. The external width of the used cell is 5 cm. An external cubic unit has been added around O-cell to give square cross section shape of pile as shown in Figure 1. A stopper, (Rigid steel rod connected between pile head and base beam of frame), is used to cease the shaft motion to be able to complete the test up to failure in soil at pile base as shown in Figure 1. To calibrate the O-cell model, a special technique as shown in Figure 2 (a) was used. Also, in the case of conventional test method a calibrated proving ring was attached directly on the pile head to measure the equivalent applied load as illustrated in Figure 2 (b). At pressurizing oil, the O-cell exerts two equal and opposite forces. The pressure was exerted incrementally using hydraulic jack and the corresponding reading of the proving ring was recorded. For any value of soil pressure, the corresponding downward force exerted by the O-cell was equal to the summation of the force recorded by the proving ring and the own weight of the pile above the O-cell. Also, the upward force equal to the downward force because both the reaction and action forces should be the same. The downward and upward displacement of the pile was measured by using a mechanical dial gauge with accuracy 0.00254 cm. The upward shaft displacement was measured using dial gauge at the top surface of shaft, whereas, the base downward displacement was measured using another dial gauge connected with base by a steel rod passing through pile hole.

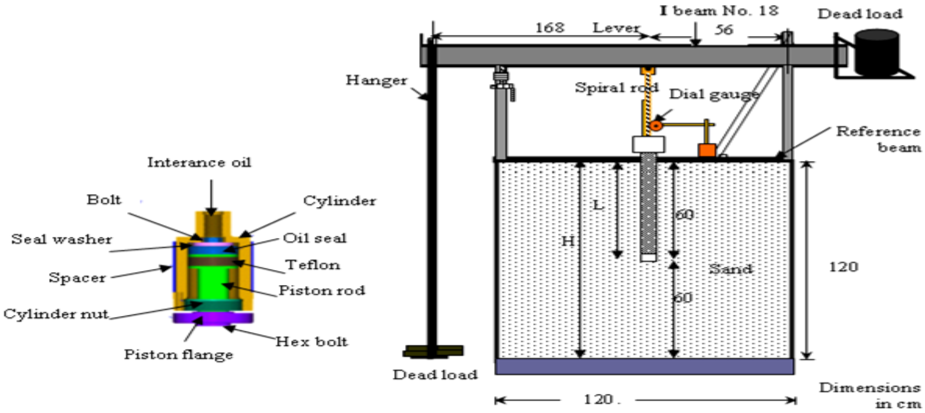
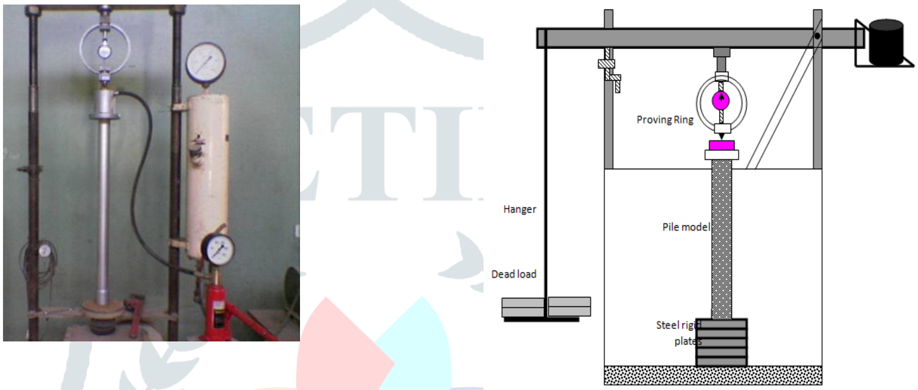


Figure 1. Sketch shows the experimental model used (After Husein et al.).



(a) Calibration of O-cell model (b) Calibration of conventional loading system

Figure 2. Calibration technique used in this study (After Towfeek).

2.3 Materials used for the testing

a) Sand soil

The tested soil used in this study was dry sand collected from a quarry near Assuit, Egypt. The main physical properties of used sand were gotten according to Egyptian Code of Soil Mechanics and Foundations [20]. Determination of compaction parameters were carried out according to ASTM specification [21]. The sand soil was washed on sieve with opening of 0.063 mm to make sure that it does not include any percentage of fine soil. The Grain size distribution curve is shown in Figure 3. It can be found that the used sand is medium to coarse, and may be classified as poorly graded sand (SP) according to Unified Soil Classification System (ASTM) [21].

The maximum and minimum dry density was determined being equal to 18.5 kN/m^3 and 15.2 kN/m^3, respectively. The uniformity coefficient (C_u), the coefficient of curvature (C_c), and mean grain size (D_{50}) are 2.89, 1.13, and 0.65 mm, respectively. The sand was prepared by placing it in the tank to specified height on layers each of 10 cm. Timber moulds were placed at different levels to determine the unit weight of the sand. To obtain any certain value of relative density, the sand was placed into a tank having a known volume by a specific designed weight. Three values of the relative density (D_r), 60 %, 70 %, and 86 % were used and each layer of sand was compacted using a rammer without water content for the corresponding relative density.

Triaxial compression test was used to determine the angle of internal friction (φ). Their values for different relative densities (D_r) of sand, 60%, 70%, and 86 % were 36º, 39º and 42º, respectively.

b) Cemented sand

The cement used in this study was collected from Assiut Cement Company. Cement Kiln Dust (CKD) was added to sand in amount equal to 20% of dry weight of used sand. The mixture was manually prepared till it became totally homogeneous, and was placed into the tank to a specific height in layers each of 10 cm thickness, and manually compacted using a rammer to decrease the percentage of air voids. To obtain any certain value of relative density, the cement – sand mixture is placed into a tank having a known volume by a specific designed weight and compacted manually with rammer. Three values of relative density (D_r), 60 %, 70 %, or 86 %, were taken into consideration. In the field, the procedure of adding cement to sand is carried out using injection or using an opening more than pile width and filled with cemented sand, then install the pile.

2.4 Preparation and Testing Groups

Tests were carried out on sand and its improvement using ordinary Portland cement. Some parameters have been considered in this study such as relative density (D_r), depth of cemented sand (D), and cemented sand depth/pile length (D/L ratio) as shown in Figure 4. Tests program were divided into three main groups. Group I concerned with the study on pure sand having three different relative densities 60%, 70% and 86%. Groups II and III concerned with the study on cement-sand mixture having three previous different relative densities and D/L ratio of 0.25 and 0.5, respectively. Tests program and the details of all groups are tabulated in Table 1.

Group	Test No.	D_r (%)	D/L	$Q_{us\text{-}O\text{-}cell}$ (kN) Cemented sand	$Q_{us\text{-}O\text{-}cell}$ (kN) Pure sand	ΔQ_s (kN)
II	4	60	0.25	3.0	0.7	2.3
	5	70	0.25	4.2	1.2	3.0
	6	86	0.25	6.0	1.5	4.5
III	7	60	0.5	3.6	0.7	2.9
	8	70	0.5	6.1	1.2	4.9
	9	86	0.5	9.8	1.5	8.3

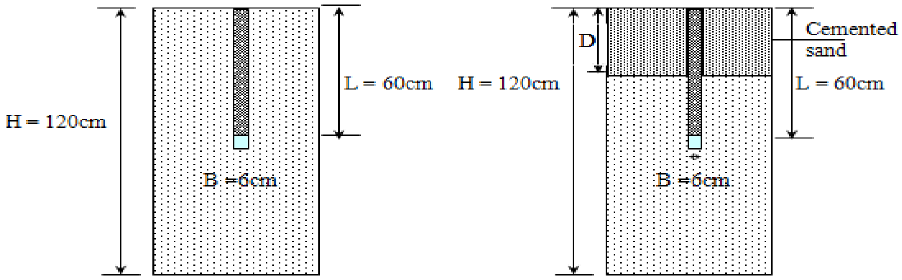


Figure 4. Sketch of barrette - soil model

3. TEST PROCEDURES

In the case of conventional test method, the total pile capacity including both shaft **(Q_s)** and base **(Q_b)** capacity was recorded for each increment. The test will be completed up to the ultimate capacity. These tests were performed according to Egyptian Code for Soil Mechanics and Foundations [20]. In pile testing using O-cell method, the shaft load acts upwards against the pile body. Also, the base load was increased at the early stage of loading, independently from the shaft load. For the tested pile using O-cell, the shaft load reached its ultimate value first, while the base loads remained still below their ultimate value. So, the test should be terminated. In order to be able to complete the test, the shaft displacement has to be ceased using the stopper. For each load increment, the downward displacement of the base and the upward displacement of the shaft were recorded as mentioned in item 2.2. The test will be completed up to a base displacement equal to 10% of the equivalent pile diameter [7]. Three groups of tests were performed for different relative density of the tested pure sand and cemented sand mixtures to study the parameters that affects on pile resistance as mentioned in Table 1.

Table 1. Group details and properties of used materials

Group	Test No.	Mixture	D/L ratio	D_r (%)	φ (Degree)	c (kN/m^2)
I	1	Pure sand	0	60	36^o	0
	2			70	39^o	0
	3			86	42^o	0
II	4	20% Cement	0.25	60	40^o	8
	5			70	41^o	14
	6			86	42.5^o	16
III	7	20% Cement	0.50	60	40^o	8
	8			70	41^o	14
	9			86	42.5^o	16

4. ANALYSIS OF RESULTS AND DISCUSSIONS

A number of laboratory tests including O-cell and conventional methods are used to determine the ultimate load (Qu) of single barrette pile for each method. For the results obtained from the O-cell tests, the ultimate load (Qu-O-cell) at settlement equal to 10% of pile width is the summation of the shaft load (Qus) and base load (Qub) at the same settlement. In this way, the pile was assumed to be rigid, that is, the bottom and the top move the same amount, and have the same deflection but different loads [2].

$$Q_{U\text{-}O\text{-}CELL} = Q_{US} + Q_{UB} \qquad (1)$$

4.1 Behavior of Barrette Pile in Pure Sand (Load-settlement relationships)

Figures 5 to 7 represent the relation between applied loads and corresponding settlements for each of skin friction (shaft load Qus) and base load (Qub), separately. These Figures show that the ultimate shin friction and ultimate base capacity reach to failure at displacements approximately equal to 3% and 10% of pile width, respectively as shown in Table 2. This means that the skin friction reaches to failure before end bearing, so that, the shaft is stopped with stopper so that the base-settlement behavior could be completed as shown in previous mentioned Figures.

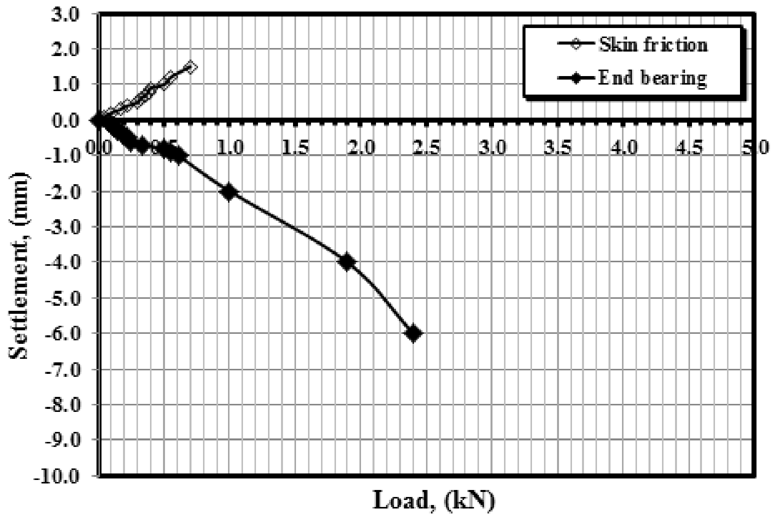


Figure 5. Load – Settlement relationship using O-cell method, case of pure sand, (D_r = 60%).

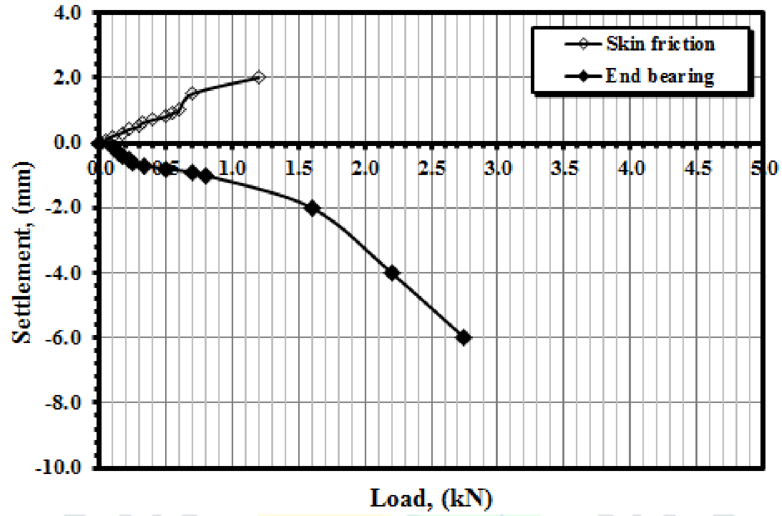


Figure 6. Load – Settlement relationship using O-cell method, case of pure sand, (D_r = 70%).

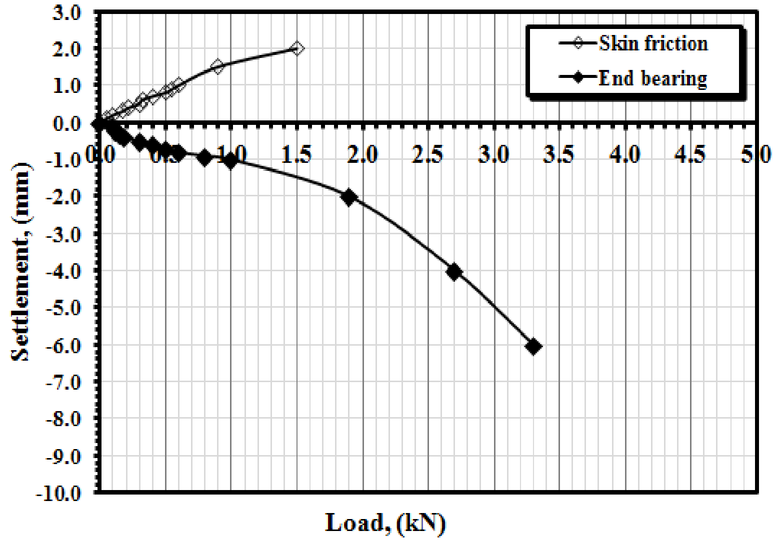


Figure 7. Load – Settlement relationship using O-cell method,case of pure sand, (D_r = 86%).

Table 2. Test results in the case of pure sand

Group	Test No.	Dr (%)	Q_{ub} (kN)	Q_{us} (kN)	Q_u O-cell (kN)	Q_u Conv. kN	$\frac{Q_{u\text{-}O\text{-}cell}}{Q_{u\text{-}Conv.}}$
I	1	60	2.4	0.7	3.1	3.55	0.87
	2	70	2.8	1.2	4.0	4.7	0.85
	3	86	3.3	1.5	4.8	4.91	0.98

Figure 8 shows the comparison between the ultimate pile load obtained by the conventional method of loading test ($Q_{u\text{-}Conv}$), and that by the O-cell method ($Q_{u\text{-}O\text{-}cell}$) for different cases of pure sand density expressed in relative density (D_r %).

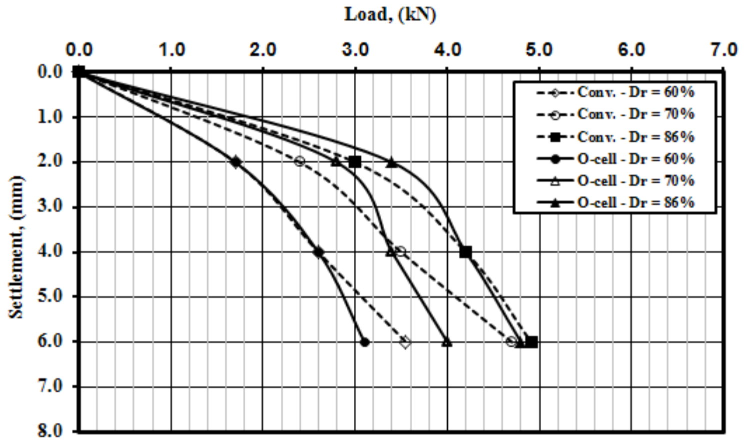


Figure 8. The load-settlement curves for the O-cell and Conv. tests, (case of pure sand).

Figure 8 shows that, the barrette loads are directly proportional to the relative density of sand for both methods of loading O-cell or conventional methods. However, the barrette load increases as the relative density increases. It can be seen that the results obtained from O-cell method (Qu-O-cell) are in agreement well with those obtained from conventional method (Qu-Conv). Also, it can be noticed that (Qu-O-cell) underestimates the ultimate pile load by a factor varies 0.9 to 1.0 as it can be seen in Figures 8 and 9.

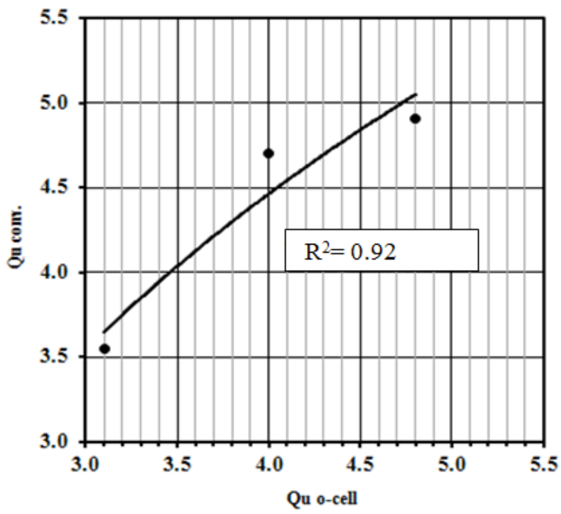


Figure 9. Comparison between O-cell technique and conventional method, (case of pure sand).

4.2 Study of the barrette behavior in cemented sand

The experimental results of the O-cell tests of the barrette pile embedded in cemented sand are presented. The ultimate shaft resistance of barrette pile is well defined. The results were illustrated in Figures 10 and 11, and were tabulated as shown in Table 3.

Table 3. Test results in the case of cement-sand mixture

Group	Test No.	D_r (%)	D/L	$Q_{us\text{-}O\text{-}cell}$ (kN) Cemented sand	$Q_{us\text{-}O\text{-}cell}$ (kN) Pure sand	ΔQ_s (kN)
II	4	60	0.25	3.0	0.7	2.3
	5	70	0.25	4.2	1.2	3.0
	6	86	0.25	6.0	1.5	4.5
III	7	60	0.5	3.6	0.7	2.9
	8	70	0.5	6.1	1.2	4.9
	9	86	0.5	9.8	1.5	8.3

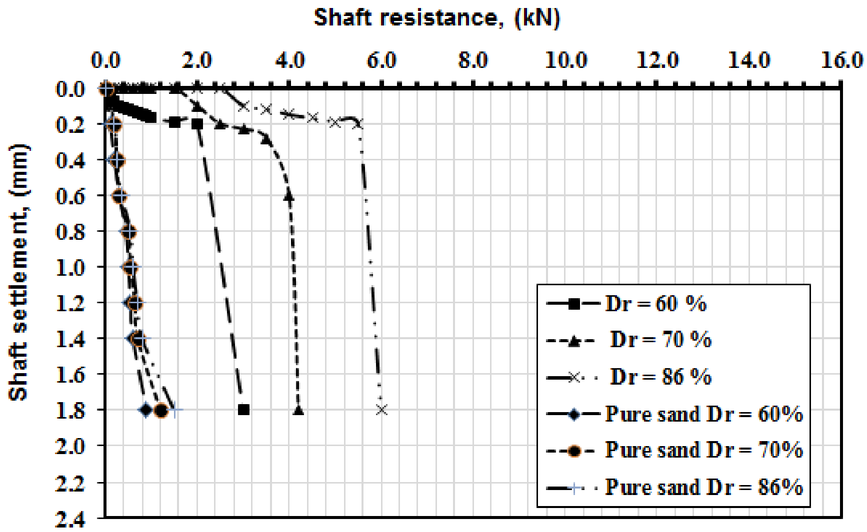


Figure 10. Shaft resistance of barrette in cemented sand (D/L = 0.25).

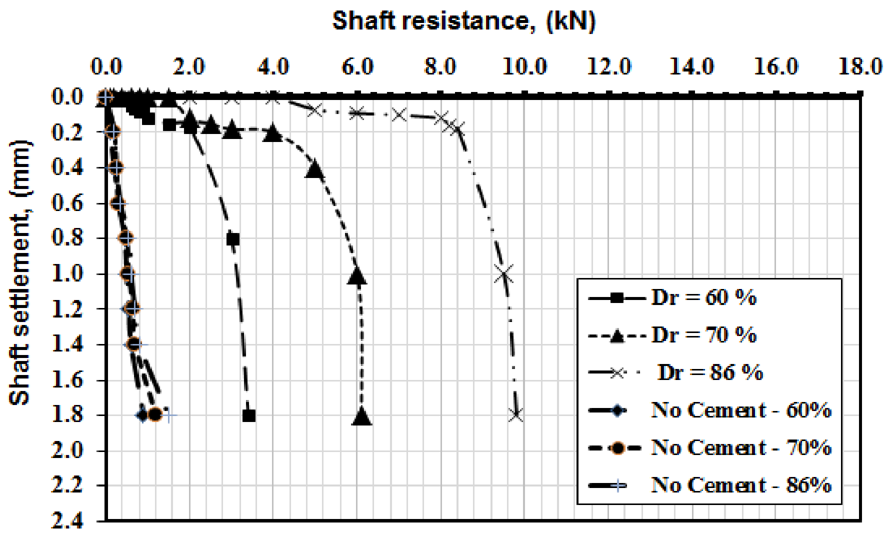


Figure 11. Shaft resistance of barrette in cemented sand (D/L = 0.50).

From these Figures, it can be found that the shaft resistance ($Q_{us\text{-}O\text{-}cell}$) in the case of cemented sand is always higher than that obtained in the case of pure sand. This may be attributed to two reasons. i) Pure sand is cohesionless soil, and the pile transfers most loads by end bearing. ii) With the addition of cement the sand gains cohesion, as shown in Table 1. So, this mixture behaves as a (c-ϕ) soil and makes barrette pile transfers more load by friction as compared to the pure sand cases. So, increasing in pile shaft resistance (ΔQ_s) shown in Table 3 due to increasing in adhesion between pile shaft and surrounding cemented sand. Figure 12 shows the effect of relative density (D_r) on shaft resistance in the case of cement-sand mixtures as compared to the pure sand cases. It can be noticed that by increasing relative density of mixture leads to increasing in shaft resistance. Also, the rate of increasing in shaft resistance is more than that in the case of pure sand.

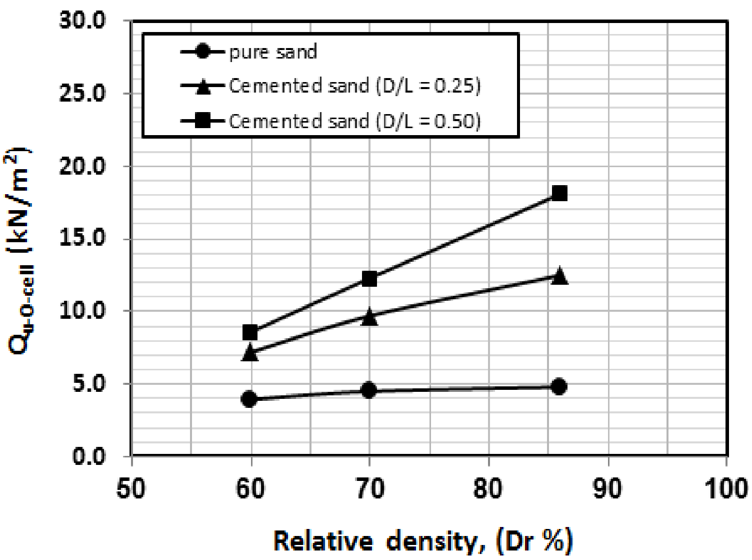


Figure 12. Shaft resistance of barrette versus relative density.

5 CONCLUSIONS

The present study is concerned with the investigation of shaft and base resistance of a single barrette pile using Osterberg cell. In the O-cell tests, the ultimate resistances for pile shaft (Q_{us}) and pile base (Q_{ub}) were measured, separately. The results obtained from O-cell tests were compared with those obtained from conventional method and equation of Egyptian code for soil mechanics and foundations. A pure sand soil and cement-sand mixture with different relative densities were studied. From this study the following conclusions can be summarized:

1. For barrette piles embedded in pure sand, both the ultimate resistance for barrette shaft and ultimate capacity for barrette base are affected with the relative density.
2. The shaft resistance reaches to failure before base resistance.
3. Adding cement to sand makes the mixture to have some cohesion (c) and behaves as a (c-ϕ) soil.
4. The shaft resistance of barrette piles embedded in cement-sand mixture is higher than that embedded in pure sand.
5. To increase the shaft resistance (positive skin friction) to a certain depth of piles constructed in sand soil, cement can be added using injection technique to gain sand some cohesion.

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