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EFFECT OF CEMENTATION ON THE CARRYING CAPACITY OF BARRETTE PILES

Ahamed Rushedy Towfeek [1]

[1] Lecturer, Civil Eng. Department, Al- Azhar University, Qena,. Egypt

ملخص البحث

تم تطوير إختبار قدرة تحمل الخوازيق سواء كانت خوازيق دق أو خوازيق تثقيب عن طريق العالم أوستربرج الذي وضع خلية أسفل الخازوق موصلة بجاك هيدروليكي وعداد قراءات لايجاد قدرة تحمل جسم الخازوق وقدرة قدمة الخازوق كلا علي حدة . في هذا البحث تم وضع الخلية أسفل الخازوق المربع في تربة رملية وتم قياس قدرة التحمل لجسم الخازوق والقدمة كلا علي حدة بمعلومية عوامل مختلفة مثل عرض وطول الخازوق والكثافة النسبية للتربة وتم مطابقتها بالكود المصري للهندسة الجيوتقنية والاساسات.

ABSTRACT

Conventional pile load tests are commonly used to predict the pile load capacity; recent development for evaluation of the capacity for the bored and drilled piles is the Osterberg cell or O-cell test. This test provides a simple, efficient and economical method of performing a static test on pile foundation. In this study, the Osterberg cell test is carried out on piles embedded in sandy soil. Different pile diameters are tested in sandy soil with different relative densities. For this purpose Osterberg method, (O-cell), 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. The parameters 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 estimated values using Egyptian code method are presented. From this study, it could be observed that, both barrette shaft resistance and pile base capacity are affected by the studied parameters (D/L) ratio, and relative density (Dr). Moreover, it is also observed that found that the barrette shaft resistance strongly affected by adding cement to sand soil.

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

1 INTRODUCTION

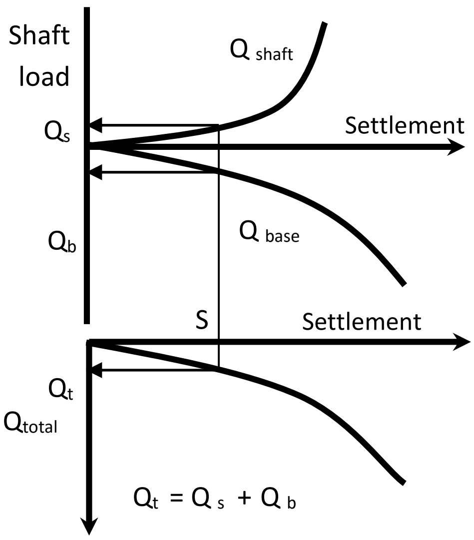
For soil-single pile system, the most reliable method to determine the bearing capacity of a pile is the pile loading test. However, in some certain circumstances the conventional pile loading test is not easily performed since its procedures require considerable time and cost for constructing anchor piles and loading frames (Abdel-Aziz, 1999). Moreover, there are many difficulties in using the conventional method in some cases such as the high capacity piles which require very large counterweights. These are some reasons for developing new method for performing static pile loading test. The new method was developed in Japan three decades ago. In 1984, Osterberg had developed a new procedure in the USA, since then the procedure which known as Osterberg load cell procedure is getting popular (Osterberg, 2001). The O-cell test method has steadily gained popularity and approximately 200 tests have been performed on bored piles in the USA and Southeast Asia in September 1996 (Osterberg, 1998). In 2001, O-cell was used for testing pile models in laboratory (Osterberg, 1998). This method allows measuring the pile shaft load and the base resistance separately by installing a hydraulic jack at/near the pile toe, which creates two equal forces, upward force on the shaft and downward force on the base (Osterberg, 2001). Federal Highway Administration (FHWA) found that the use of O-cell method had risen to about 65% of all bored pile testing (Baker, 1994). This method probably now exceeds to about 90% in the USA. (Schmertmann and Hayes, 1997). Following up this test, Osterberg worked with others to refine the cell design and promote its use.

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 (El-Naggar, 2003). Osterberg presented many studies focused on several aspects of the topics related to determination of shaft and base resistance of pile (Osterberg, 1998 and Baligh, 2005). 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 (Hussein, 2007).

This research was carried out to investigate the performance of vertically loaded single barrette pile installed in sand or cement sand. The major objectives of this study are: (i) determination of barrette pile capacity obtained from different methods such as Osterberg Cell (O-Cell) method, and Conventional method, (ii) determination of barrette, shaft and base capacities 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).

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 relationship of piles by the O-cell method. Three groups of tests were performed to study the parameters affect the bearing capacity of piles 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 tip 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. The sand was prepared with three values of relative density (D_r) 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 also been studied.

From the O-cell obtained test results, the total load (Q_t) is summation of the shaft load (Q_s) and base load (Q_b) at the same displacement as shown in Fig. (1).



$$Q_t = Q_s + Q_b \quad (1)$$

Fig. (1) Typical results from O-cell test

2. EXPERIMENTAL MODEL

2.1 Tank model

The internal dimensions of the cubic steel tank are 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 pad.

2.2 Tested Barrette and O-cell model

In this study, the barrette pile used was square in shaped pile. It has a cross section of 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 2. 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 2.

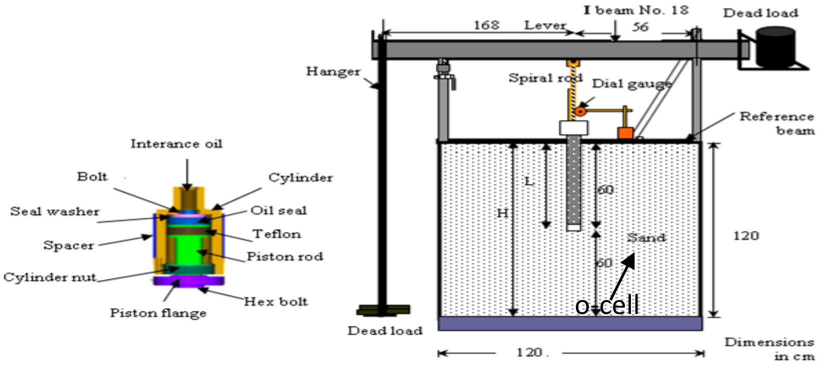


Fig. (2) The used experimental model (After Husein et al, 2006).

2.3 Materials used for the testing

a) Sand

The tested soil used in this study was dry sand obtained a quarry near Assuit, Egypt. The main physical properties of used sand were gotten according to Egyptian Code of Soil Mechanics and Foundations (Egyptian Code, 2001). Determination of compaction parameters were carried out according to ASTM specification (ASTM, 1994).

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.

Shear box 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) Cement-sand composition

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 until 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.

2.4 Testing Program and 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.

Table (1). Tests program and the details of all groups

Group	Test No.	D_r (%)	D/L	$Q_{us\text{-}O\text{-}cell}$ (kN) Cement 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

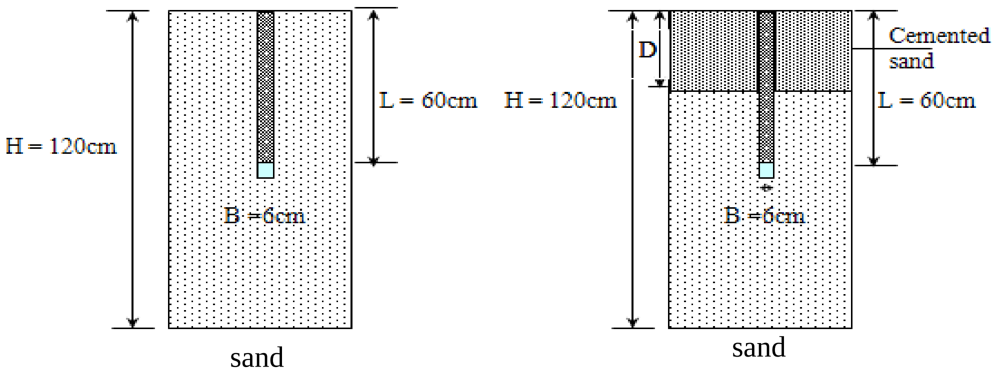


Fig. (4). Sketch of barrette - soil model

3. Experimental Work

In the case of conventional pile load test method, the ultimate pile capacity of 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 (Egyptian Code, 2001). 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. The test will be completed up to a base displacement equal to 10% of the equivalent pile diameter (Egyptian Code, 2001). Three groups of tests were performed for different relative density of the tested pure sand and cemented sand mixtures to study the parameters those affect the pile resistance as listed in Table 2.

Table (2). 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°	0
	2			70	39°	0
	3			86	42°	0
II	4	20% Cement	0.25	60	40°	8
	5			70	41°	14
	6			86	42.5°	16
III	7	20% Cement	0.50	60	40°	8
	8			70	41°	14
	9			86	42.5°	16

4. ANALYSIS OF RESULTS AND DISCUSSION

A number of laboratory tests including O-cell and conventional methods were used to determine the ultimate load (Qu) of single barrette pile. 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. The pile was assumed to be rigid, so the bottom and the top movements are of the same amount, and have the same deflection but different loads (Osterberg, 1998).

$$\mathbf{Q_{U\text{-}O\text{-}CELL} = Q_{US} + Q_{UB}} \qquad \mathbf{(2)}$$

4.1 Behavior of Barrette Pile in Pure Sand

Figs. 5 to 7 represent the relationship between applied loads and corresponding settlements for both skin friction (shaft load Qus) and base load (Qub). 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 Figs. 5 , 6 and 7 and Table 3.

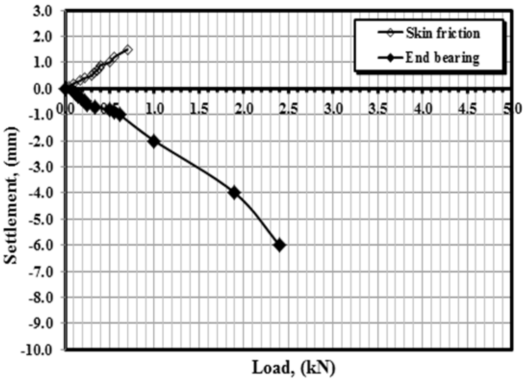


Fig. (5). Load – Settlement relationship using

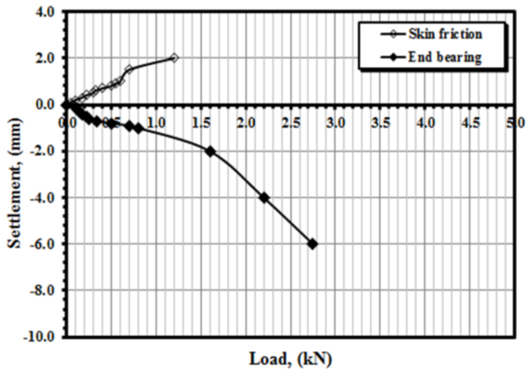


Figure (6). Load – Settlement relationship using O-cell method, of pure sand, (D_r = 70%).

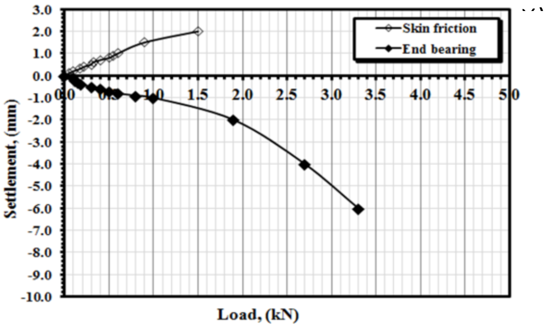


Fig (7). Load – Settlement relationship using O-cell method, case of pure sand, (D_r = 86%).

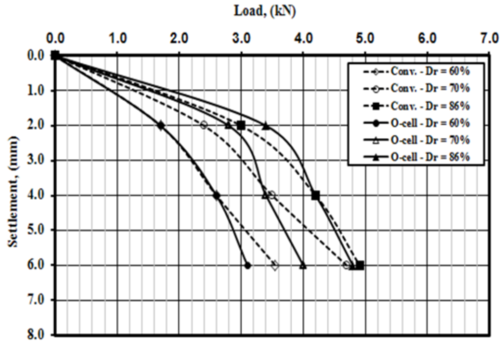


Fig. (8). The load-settlement curves for the O-cell and Conv. tests, (case of pure sand).

Table (3). Test results in the case of pure sand

Group	Test No.	Dr (%)	Q_{ub} (kN)	Q_{us} (kN)	$Q_{u\ O\text{-}cell}$ (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 9 shows, the barrette loads to be 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). Moreover, it can also 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 Figure 9.

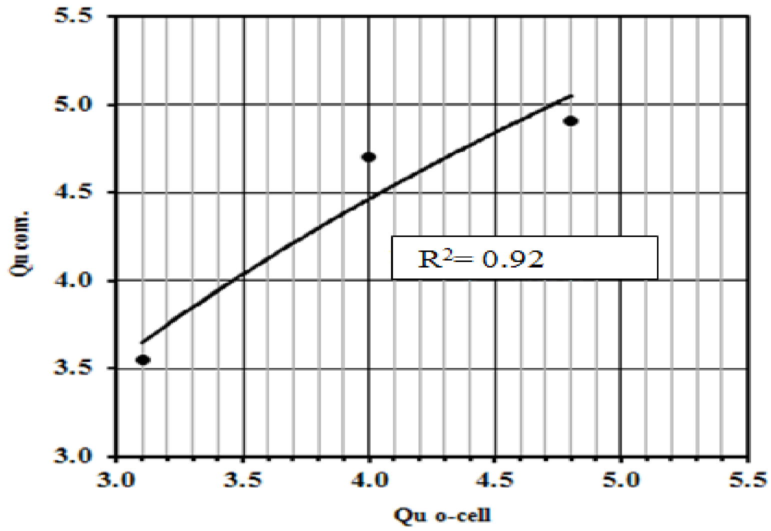


Fig. (9). Comparison between O-cell technique and conventional method, (case of pure sand).

4.2 Behavior of Barrette Cemented Sand

The experimental results of the O-cell tests of the barrette pile embedded in cemented sand are presented. In figures 10 and 11 and the results are summarized in table 4 , the ultimate shaft resistance of barrette pile is well defined.

Table (4). 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

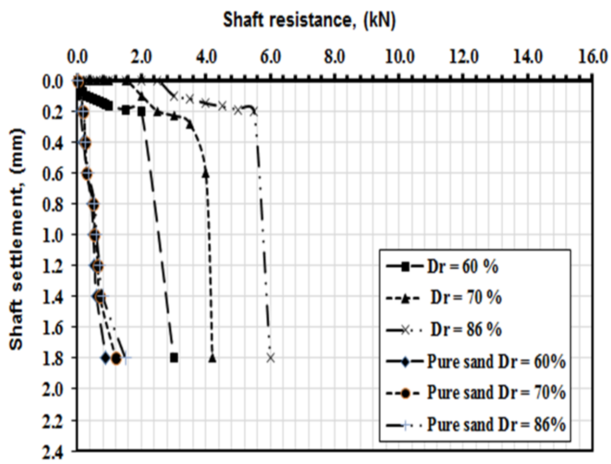


Fig. (10). Shaft resistance of barrette in cemented sand (D/L = 0.25).

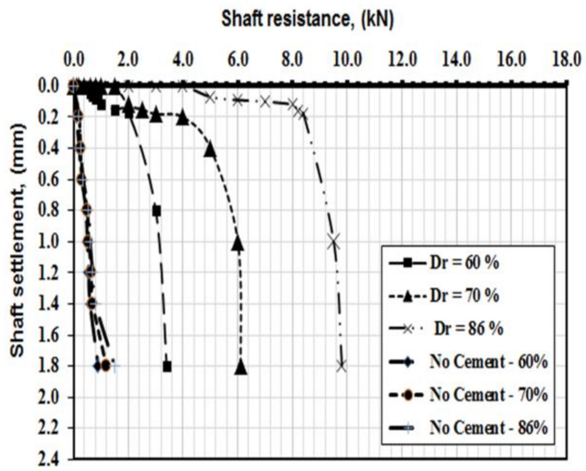


Fig.(11). Shaft resistance of barrette in cemented sand (D/L = 0.50).

From these Figures, it can be observed 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 4 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, increasing relative density of mixture leads to increasing in shaft resistance.The rate of increasing in shaft resistance is more than that in the case of pure sand.

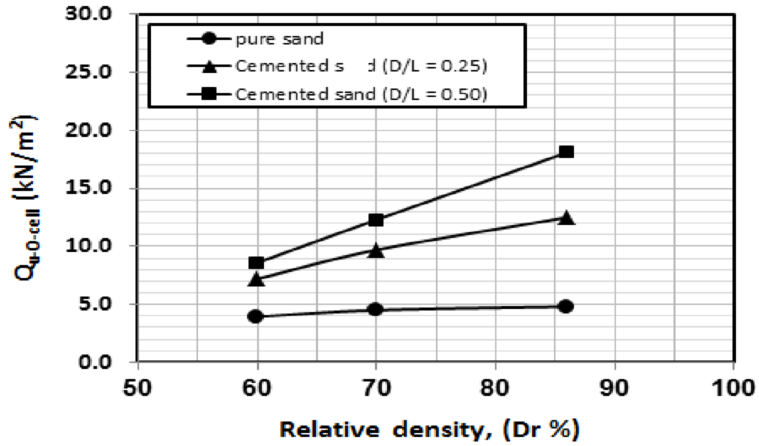


Fig. (12). Shaft resistance of barrette versus relative density.

5 CONCLUSIONS

The following main conclusions are drawn from the presented test results

1. For barrette piles embedded in pure sand, both the ultimate shaft resistance and ultimate base capacity are affected with the relative density.

2. The shaft resistance reaches to failure before base resistance.

3. The shaft resistance of barrette piles embedded in cement-sand mixture is higher than that embedded in pure sand.

4. 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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