Journal of Engineering Sciences, Assiut University, Vol. 35, No. 4 pp.853-867, July 2007

INVESTIGATION OF SHAFT AND BASE RESISTANCE OF A SINGLE BORED PILE USING OSTERBERG CELL

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(Received April 21, 2007 Accepted June 10, 2007)

Evaluation of pile capacity in soil is an engineering problem of soil-structure interaction. Soil-pile interaction plays an important role in the analysis and design of pile foundations. Geotechnical engineers have recognized this role and many studies have focused on several aspects of the topics related to determination of pile resistance. There are different methods available to predict the ultimate load of a single bored pile, such as theory of bearing capacity of the soil foundation, based on pile load test, semi-empirical methods using in-situ test results, and empirical formulae were suggested by different codes of practice. Still the most reliable method to determine the bearing capacity of a pile is by static load test.

This study investigates some of the important problems related to soil-pile interaction. Specific problems examined here include: identify of skin friction and end bearing resistance of pile separately, comparison between the measured results obtained from experimental methods presented by Osterberg cell, (O-cell), or conventional tests and these obtained from equations of Egyptian code for soil mechanics and foundations to evaluate and verify the applicability of different methods. The experimental results were used to study the effect of the different parameters such as pile diameter, D, pile length to pile diameter ratio (L/D), and relative density (D_r) on the pile shaft and pile base resistances of bored piles. Also, in this research, the coefficients of lateral soil pressure (K_H) and bearing capacity factor (N_q) have been studied. From this study, It can be found that both pile shaft and pile base resistances have affected by the parameters D, L/D, and D_r.

KEYWORDS: *BORED PILES, LOADS, SETTLEMENT, SKIN FRICTION, END BEARING, SOIL-PILE INTERACTION.*

1. INTRODUCTION

Pile foundations are used to support structural loads in situations where shallow foundations cannot provide the required bearing capacity, or where the settlement is a major concern; El-Naggar [1]. Soil-pile interaction plays an important role in the analysis and design of foundations and piles. Geotechnical engineers have recognized this role. Osterberg presented many studies focused on several aspects of the topics related to determination of shaft and base resistance of pile; Osterberg [2]- [6]. Geotechnical engineers face 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. Different methods of construction have been used, bored and driven piles. This study concerns with bored piles. The load settlement relationship for single pile is very complex. Many procedures have been developed over years for estimating the settlement behavior of a single pile as El Garhy *et al.* [7], Baligh *et al.* [8] and Tomlinson [9]. The settlement is usually the limiting design criterion; Russo *et al.* [10]. The analysis and design of the load bearing capacity and settlement of an axially loaded pile are affected by several complex factors and, therefore, are 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. The methods available to predict the ultimate load of a single pile are: (i) theory of bearing capacity of the soil foundations; (ii) the pile load test; (iii) empirical methods based on dynamic driving formulae which have been superseded by a more refined and consistent method, known as stress wave analysis; and (iv) semi-empirical methods using in-situ penetration test results. Still the most reliable method to determine the bearing capacity of a pile is by static load test; Baligh *et al.* [8]. Single pile is rarely used, but always used in a group, therefore single pile load tests are carried out to obtain an idea of the load-settlement behavior of group of piles when exposed to vertical load. Empirical formulae were suggested by different codes of practice. Many of these formulae are based on either a limited number of pile load tests or on load tests in certain soil foundations not giving a wide spectrum of soil properties; Baligh *et al.* [8].

This research is carried out to investigate the performance of vertically loaded single bored pile in sandy soil. The major objectives of this research are: (i) determination of pile resistance obtained from different methods such as Osterberg Cell (O-Cell), Conventional Method, Egyptian Code for Soil Mechanics and Foundations; [13], (ii) determination of individual parts of pile resistance, shaft and base resistance separately, (iii) studying the load-settlement behavior of a single pile with different L/D ratios, and (iv) studying the effect of sand relative density (D_r).

2. EXPERIMENTAL WORK

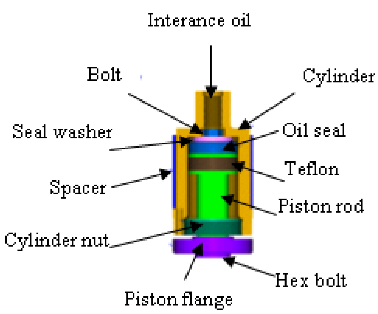
In the following sections, descriptions of the components of the experimental model along with method of carrying out the experiments are presented.

2.1. Test piles and Osterberg cell Model

In this study four circular pipe piles are used. The piles have the same length of 60 cm and have external diameters 12 cm, 10 cm, 8.6 cm, and 6 cm to give pile length to pile diameter ratios (L/D), 5, 6, 7, and 10, respectively. A head and Osterberg cell (O-cell) were attached at the base of each pile model. To roughen the external surface of the piles, sandpaper was stacked to simulate the practical piles roughness. The O-cell model is a small hydraulic jack consists of a casing incorporated moving piston as shown in Fig. 1. A calibration for O-cell model was done by using a suitable proving ring attached directly on the pile head. It was designed to give two equal loads and opposite in direction. When shaft resistance reaches to failure, a stopper is used to cease the shaft motion to complete the test up to failure in soil at pile base as shown in Fig. 2. The downward and upward displacements of the pile were measured by using a mechanical dial gauge with accuracy 0.00245 cm.

2.2. Steel Tank and Main Frame

The test model consists of steel tank and a main frame. The tank is resting on a steel base. The tank is a steel box of dimensions 120 x 120 cm in plan and 120 cm height. The box dimensions were selected to ensure that no effects of the boundary walls on the behavior of a single pile. The steel tank is divided into two equal parts each has 60 cm height. The tank was provided by vertical stiffeners (i.e., angle 50x50x5). The main frame consists of two vertical I beams and horizontal I beam.



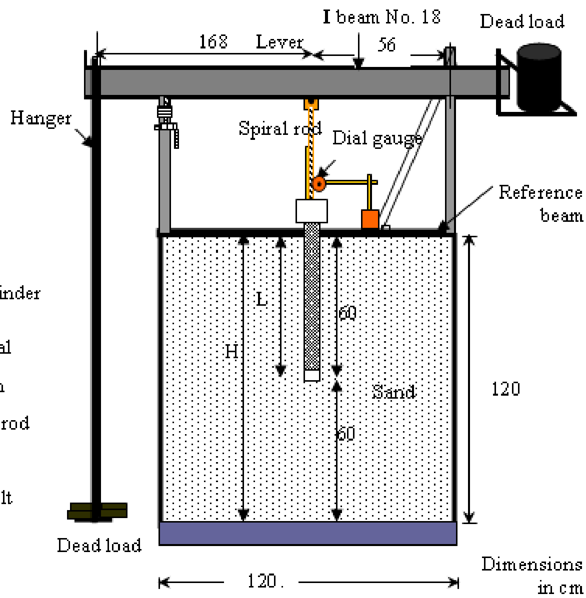


Figure 1. Components of O-cell **Figure 2. Elevation view for the conventional pile test**

2.3. Soil Description

The used soil for the tests is well graded sand. The maximum and minimum dry densities are equal to 18.7 KN/m^3 and 15.0 KN/m^3, respectively. The sieve analysis test was carried out to determine the grain size distribution curve of the tested sand as shown in Fig. 3. The properties of used sand such as effective diameter (D_{10}), D_{30}, D_{60}, uniformity coefficient (C_u), and coefficient of curvature (C_c) is shown in Figure 3. To obtain any certain value of relative density, the sand is placed into a box having a known volume by a specific designed weight. Three values of relative density (D_r) for the sand soil, 60%, 70%, and 81.8% were used.

D_{10} = 0.24 mm
D_{30} = 0.45 mm
D_{60} = 0.74 mm
C_u = 3.08
C_c = 1.14

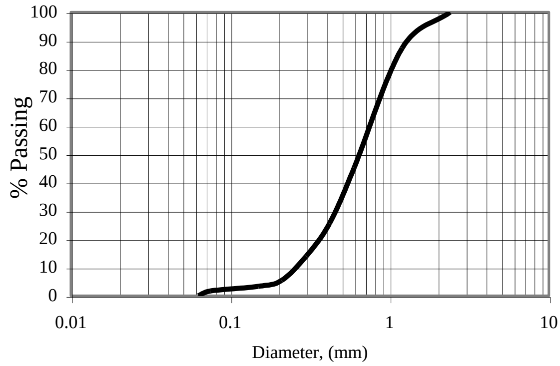


Figure 3. Grain size distribution curve for the tested sand soil

Triaxial compression test is used to determine the angle of internal friction (φ). The values of angle φ for different relative densities of sand are 35.5^o, 37^o, and 41^o, respectively. The direct shear box test is used to determine the roughness of the pile surface, the angle of friction (δ) between the external surface of the pile and the soil. The values of angle (δ) for different relative densities of sand are 34.1^o, 35^o, and 39^o, respectively.

3. TEST PROCEDURES

The experiment was started with placing the sand soil in the steel tank in layers. The maximum layer thickness was 10 cm. The total height of the tank was divided into intervals from inner side by marking every 10 cm height to help put a specific weight in a specific volume and compact it to get the required relative density. To obtain the corresponding relative density, the sand is compacted by using a special rammer without water content. The compaction continued until the sand was compacted to fill each 10 cm layer. The O-cell produces two equal and opposite loads. One load is acting downward on the pile base, and the second is acting upward on the pile shaft. The downward and upward displacements of a single bored pile were recorded at the end of each load increment by using mechanical dial gauges with accuracy 0.00254 cm as mentioned by Hussein *et al.* [11] and Towfeek [12]. When testing the pile following the conventional procedure, the method reported in the Egyptian Code for Soil Mechanics and Foundations was implemented[13]. In the conventional method, the total loads (skin friction and end bearing loads) were recorded at the end of each load increment. Three groups of tests were performed for three different values of relative density. Each group includes four tests according to different values of pile diameter.

4. ANALYSIS OF RESULTS AND DISCUSSIONS

In the following sections, the results obtained from experimental tests are presented and discussed. The conducted tests consist of 12 tests. Three groups of tests for three values of relative density (D_r = 60%, 70%, and 81.8%) were performed. Each group includes four tests for pile diameters (D = 12cm, 10cm, 8.6cm, and 6cm). For O-cell, conventional method tests and equation of Egyptian code, values of the ultimate pile resistance corresponding to a settlement equal to 10 % of the pile diameter are given in Table 1. These values include the ultimate shaft loads obtained from O-cell tests ($Q_{s\ O\text{-}cell}$), the ultimate base loads obtained from O-cell tests ($Q_{b\ O\text{-}cell}$), the ultimate loads obtained from conventional method ($Q_{u\ Conv}$), and from equation of Egyptian code ($Q_{u\ EC}$). The coefficients of lateral soil pressure on pile shaft obtained from O-cell tests ($K_{H\ O\text{-}cell}$) and from Egyptian code ($K_{H\ EC}$), which includes (K_{HC}) or (K_{HT}) in the case of compression or tension piles respectively, are tabulated in Table 1. Also, the bearing capacity coefficients obtained from O-cell tests ($N_{q\ O\text{-}cell}$) and these obtained from Egyptian code ($N_{q\ EC}$) are tabulated in Table 1.

Table (1): **Values of pile resistance, coefficient (N_q), and coefficient (K_H) obtained from experimental results and Egyptian code**

Diameter, cm	12	10	8.6	6	12	10	8.6	6	12	10	8.6	6
L/D	5	6	7	10	5	6	7	10	5	6	7	10
D_r (%)	81.8				70				60			
φ	41°				37°				35.5°			
δ	39°				35.5°				34.15°			
$Q_{s\ O\text{-}cell}$	2.16	1.63	1.31	0.78	1.69	1.24	0.91	0.42	1.20	1.00	0.75	0.45
$Q_{b\ O\text{-}cell}$	10.32	7.11	4.70	2.10	6.51	4.10	2.65	1.10	4.27	3.04	2.10	0.90
S_1	0.21	0.23	0.28	0.37	0.26	0.30	0.34	0.38	0.28	0.33	0.36	0.50
$Q_{u\ O\text{-}cell}$	12.48	8.74	6.01	2.88	8.20	5.34	3.56	1.52	5.47	4.04	2.85	1.35
S_2	0.17	0.19	0.22	0.27	0.21	0.23	0.26	0.28	0.22	0.25	0.26	0.33
$Q_{u\ Conv}$	12.12	8.10	6.5	2.94	8.50	5.69	3.86	1.69	5.88	4.59	3.12	1.51
$Q_{u\ EC}$	11.54	8.08	6.02	2.98	7.11	5.02	3.75	1.89	5.22	3.71	2.78	1.42
$K_{H\ O\text{-}cell}$	2.21	2.00	1.87	1.60	2.00	1.77	1.51	1.00	1.53	1.53	1.34	0.92
$K_{H\ EC}$	K_{HC} = 0.7 – 1.5 and K_{HT} = 0.4 – 1.0											
$N_{q\ O\text{-}cell}$	85.0	84.3	75.4	69.2	55.1	50.0	43.7	37.2	37.0	38.0	35.4	31.2
$N_{q\ EC}$	120				66				52.5			
R_1	1.08	1.08	1.00	0.97	1.15	1.06	0.95	0.80	1.05	1.09	1.03	0.95
R_2	1.05	1.00	1.08	0.99	1.19	1.03	1.03	0.89	1.13	1.24	1.13	1.06

Note: Q in KN

The relation between ultimate shaft resistance ($Q_{s\ O\text{-}cell}$) and ultimate base resistance ($Q_{b\ O\text{-}cell}$) obtained from O-cell tests was represented by ratio S_1 and calculated using Eq. (1). Also, in this Equation, the relation between ultimate shaft resistance ($Q_{s\ O\text{-}cell}$) and ultimate pile resistance ($Q_{u\ O\text{-}cell}$) obtained from O-cell tests was calculated and represented by ratio S_2.

$$S_1 = \frac{Q_{s(O-cell)}}{Q_{b(O-cell)}} \qquad and \qquad S_2 = \frac{Q_{s(O-cell)}}{Q_{u(O-cell)}} \tag{1}$$

From Table 1, it can be seen that, for the same pile diameter, the values of ratios S_1 and S_2 increase as the ratio L/D increases and as the relative density (D_r) decreases and this due to increasing in base resistance. To compare the results obtained from O-cell and conventional tests with these obtained from the equation of Egyptian code, ratios R_1 and R_2 were calculated using Eq. (3) as,

$$R_1 = \frac{Q_{u(O-cell)}}{Q_{u(EC)}} \qquad and \qquad R_2 = \frac{Q_{u(Conv)}}{Q_{u(EC)}} \tag{2}$$

It can be seen that the values of ultimate pile loads obtained from O-cell and conventional tests are approximately agree with these calculated from Egyptian code except certain values.

Figures from 4 to 7 show the load-displacement relationships obtained from O-cell tests, where, a sand soil of relative density (D_r= 70%) was chosen as an example for these figures. Each Figure represents the relation between shaft resistance ($Q_{s\ O\text{-}cell}$) versus upward displacement and end bearing resistance ($Q_{b\ O\text{-}cell}$) versus downward displacement. As shown in these Figures, the upward or downward displacement increases as shaft or base resistance increases. Also, the shaft resistance reaches to failure first, whereas, the base still resists the load until reaches to failure.

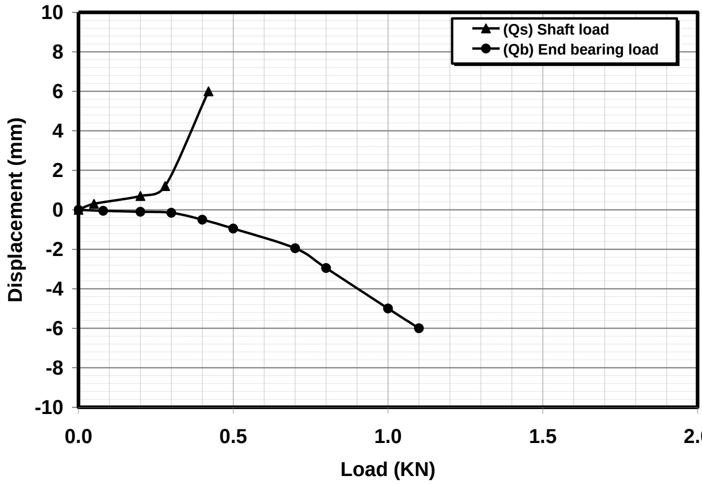


Figure 4. Load-displacement relationship (O-cell tests, Dr = 70%, D=6cm, L/D = 10)

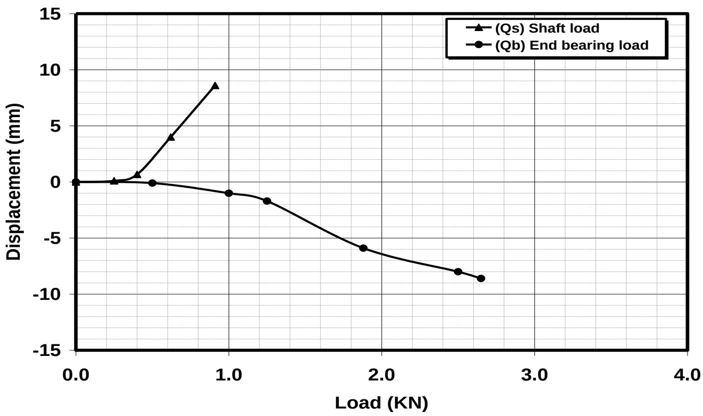


Figure 5. Load-displacement relationship (O-cell tests, Dr = 70%, D=8.6cm, L/D = 7)

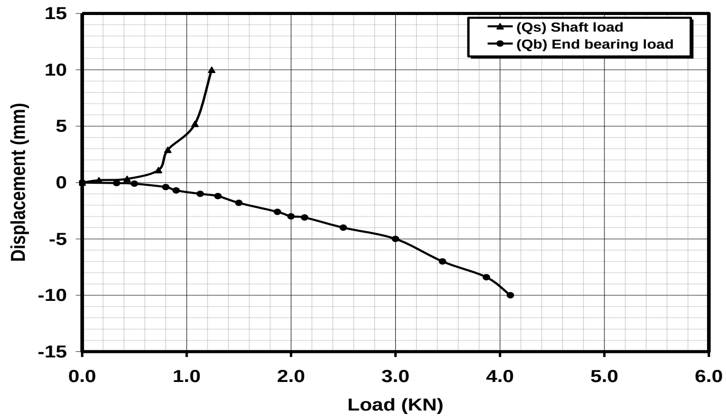


Figure 6. Load-displacement relationship (O-cell tests, Dr = 70%, D=10cm, L/D = 6)

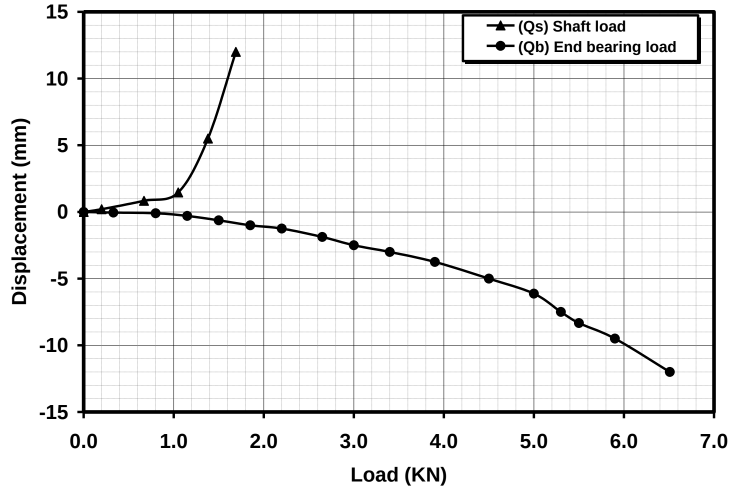


Figure 7. Load-displacement relationship (O-cell tests, Dr = 70%, D=12cm, L/D = 5)

From these figures it can be noticed that the shaft resistance ($Q_{s\ O\text{-}cell}$) reaches to 65 % of the ultimate shaft load when displacement reaches to a value ranged from 1.0 mm to 2.0 mm. This means that ultimate shaft resistance occurs when displacement reaches to 10 % of pile diameter. On the other hand, it can be found that the base resistance ($Q_{b\ O\text{-}cell}$) reaches to 35 % of the ultimate base resistance when displacement reaches 1.6 % of pile diameter and the last 65% of the ultimate base resistance occurs when displacement reaches to 10 % of pile diameter.

The ultimate pile resistances obtained from O-cell tests, conventional method, and equation of Egyptian code were plotted in figures from 8 to 11.

Figures from 8 to 11 show the effect of relative density on the values of ultimate pile resistance. It can be found that, the ultimate pile resistance obtained from O-cell test is in agreement with these obtained from conventional tests and equation of Egyptian code. It can be noticed that, the ultimate pile resistance increases as the relative density increases. From these Figures, it can be observed that the ultimate shaft resistance slightly increases linearly as relative density increases, whereas, the ultimate base resistance highly increases as relative density increases. It can be found that, in the case of O-cell tests, the ultimate resistance for pile base is more affected by relative density than that for pile shaft. Also, this effect clearly increases as pile diameter increases.

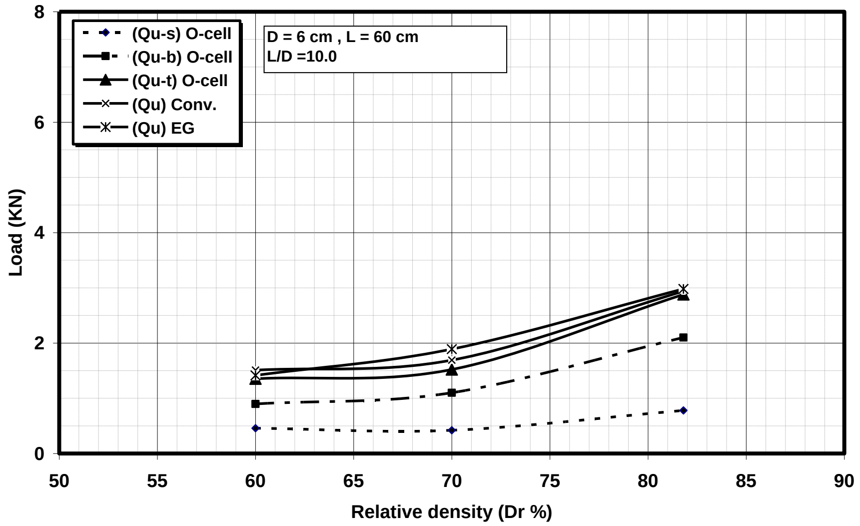


Figure 8. Ultimate load-relative density relationship (D=6cm, L/D = 10)

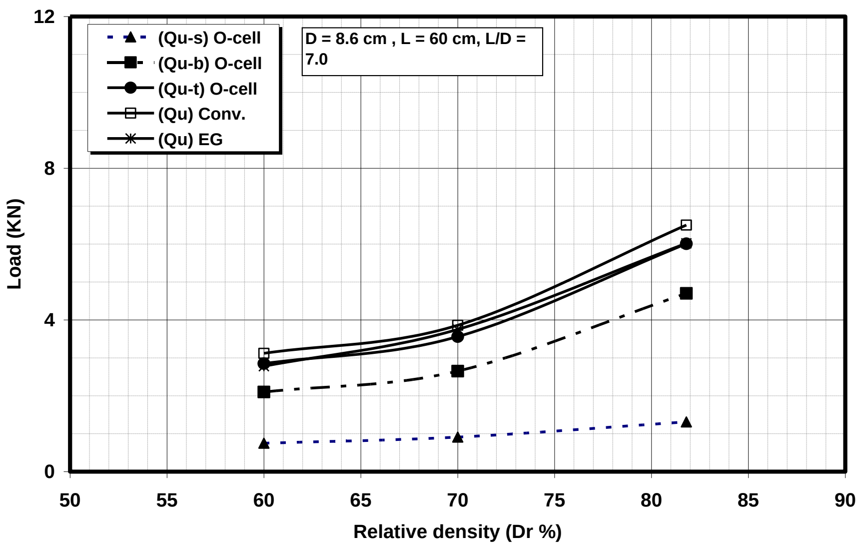


Figure 9. Ultimate load-relative density relationship (D=8.6cm, L/D = 7)

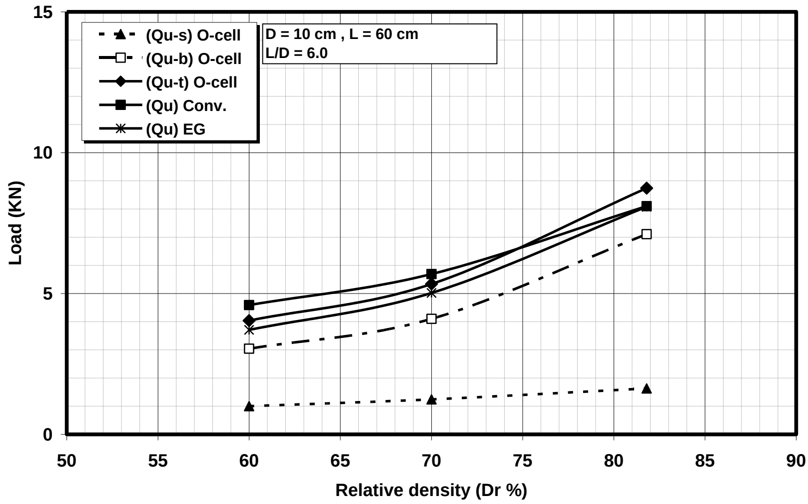


Figure 10. Ultimate load-relative density relationship (D=10cm, L/D = 6)

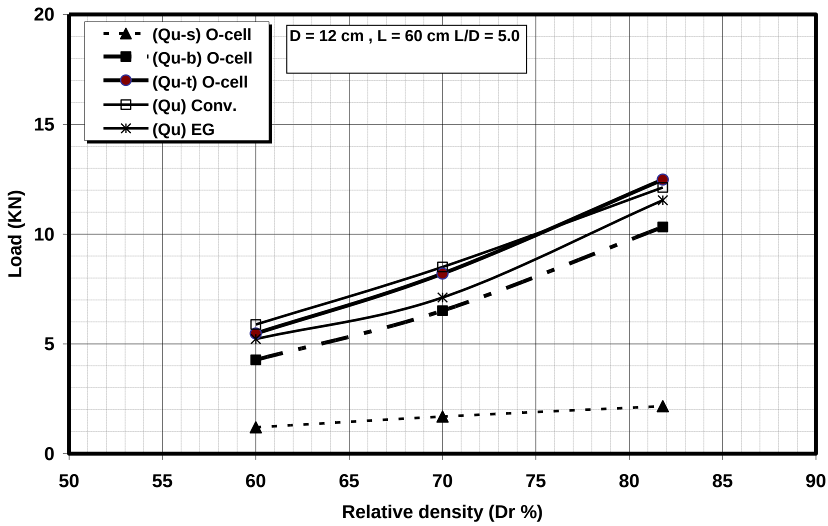


Figure 11. Ultimate load-relative density relationship (D=12cm, L/D = 5)

The relationships between ultimate resistance and L/D ratio in the case of relative density (D_r=70%) for the results obtained from O-cell tests, conventional tests, and equation of Egyptian code are tabulated in Table 1 and illustrated as shown in Fig. 12. It can be found that, the ultimate pile resistance decreases as L/D ratio increases. This is due to decreasing in pile diameter which leads to decreasing in the ultimate base load. Also, it can be noticed that, both ultimate resistance for pile shaft and pile base decrease as L/D ratio increases, but the range of decreasing in ultimate resistance for pile base is more than that for pile shaft.

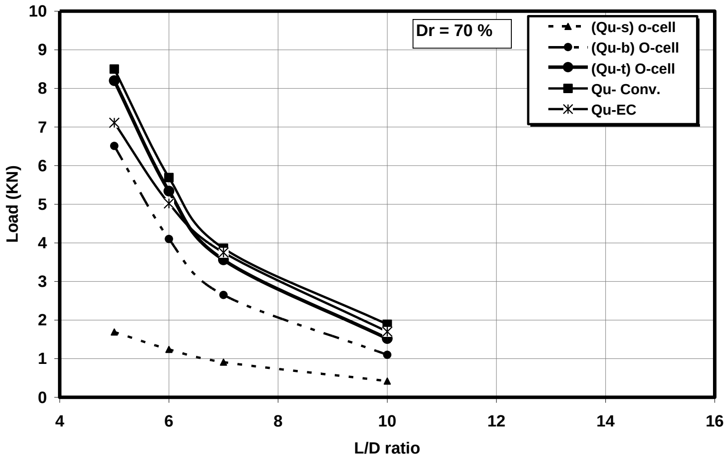


Figure 12. Ultimate load -L/D ratio relationship (D_r = 70 %)

The relationship between L/D ratio and bearing capacity factor (N_q) obtained from O-cell tests for different cases of relative density (D_r) was tabulated in Table 1 and plotted in Fig. 13. Also, the relationship between relative density and bearing capacity factor (N_q) obtained from O-cell tests and equation of Egyptian code was tabulated in table 1 and plotted in Fig. 14. It will be seen from Fig. 13 that value of N_q decreases as L/D ratio increases, also, value of N_q increases as relative density increases. Figure 14 shows a comparison of observed value of N_q obtained from O-cell tests and that obtained from Egyptian code. It can be noticed that values of N_q obtained from O-cell tests depend on L/D ratio of pile and relative density of sand soil. Whereas, values of N_q established by Egyptian code, for case of bored piles, take into account only the angle of internal friction (φ) which represented here by relative density. The values of N_q obtained from O-cell tests are smaller than these obtained from Egyptian code. It will be seen from Fig. 14 that there is a rapid increase in N_q for high values of D_r, giving high values of base resistance. This is clear in the difference between the values of N_q in the case of D_r = 60% and 70% and the difference between their values in the case of D_r = 81.8% and others.

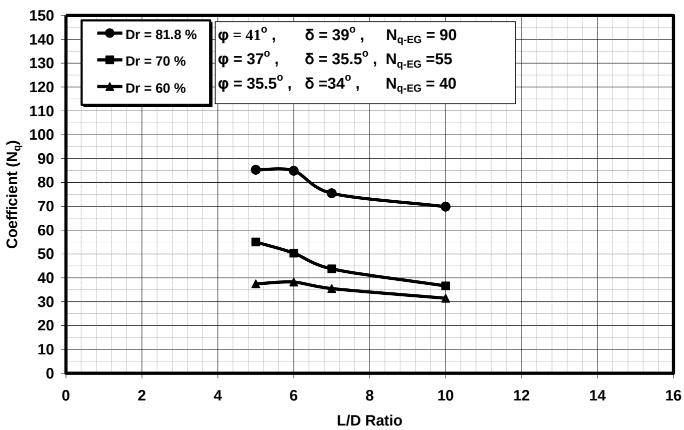


Figure 13. Relationship between coefficient (N_q) and L/D ratio (O-cell tests)

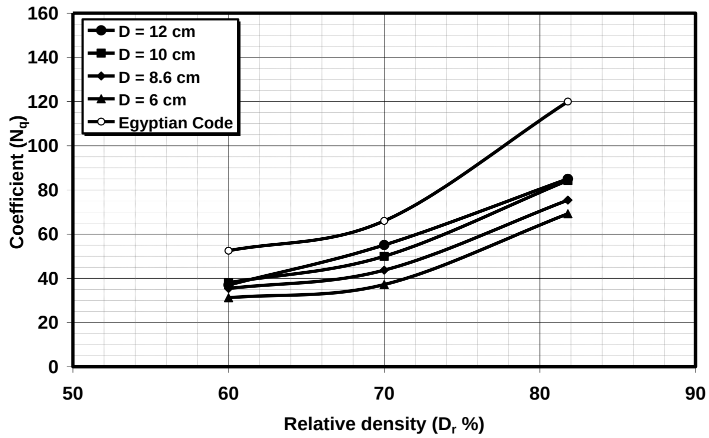


Figure 14. Relationship between coefficient (N_q) and relative density (O-cell tests)

From Fig. 14, it can be found that the values of N_q obtained from Egyptian code are overestimated if compared with the measured values.

From the above O-cell test results shown in Figs. 13 and 14 and regression analysis, an equation to estimate value of N_q for different case of densities and pile diameters is as follows:

$$N_q = a_1 D^{b_1} \tag{3}$$

Where

$$a_1 = 247.31\ (\phi) - 139.54 \tag{4}$$

$$b_1 = -165.74\ (\phi)^2 + 221.52\ (\phi) - 73.33 \tag{5}$$

Where D is the pile diameter in cm and φ is the angle of internal friction in radians. The above equations have coefficients correlation (R^2) range from 0.883 to 1.0, which are considered very good.

The relationship between L/D ratio and the coefficients of lateral soil pressure on pile shaft (K_H) obtained from O-cell tests and Egyptian code for different cases of relative density was tabulated in Table 1 and plotted in Fig. 15. Also, the relationship between relative density and coefficient (K_H) obtained from O-cell tests and Egyptian code was tabulated in Table 1 and plotted in Fig. 16. It will be seen from Figure 15 that values of K_H decrease as L/D ratio increases. Because pile length is constant, the change in K_H values due to change in pile diameter. From Fig. 16, it can be found that values of K_H increase as relative density increases. It may be argued that increasing the soil density results in increasing in the value of φ. From this discussion, it can be concluded that, the coefficient of lateral soil pressure on pile shaft (K_H) depends not only on angle of internal friction (φ) but also on pile diameter.

From Figs. 15 and 16, it can be found that, for O-cell tests, value of K_H ranges between 2.21 to 0.92, whereas, in the case of Egyptian code, K_H ranges between 0.7 to 1.5 for compression piles (K_{HC}) and 0.4 to 1.0 for tension piles (K_{HT}). The procedure of O-cell tests was carried out to push the pile upward. This means that O-cell test is suitable for case of tension piles. It can be found that the values of K_H obtained from Egyptian code are underestimated if compared with the measured values.

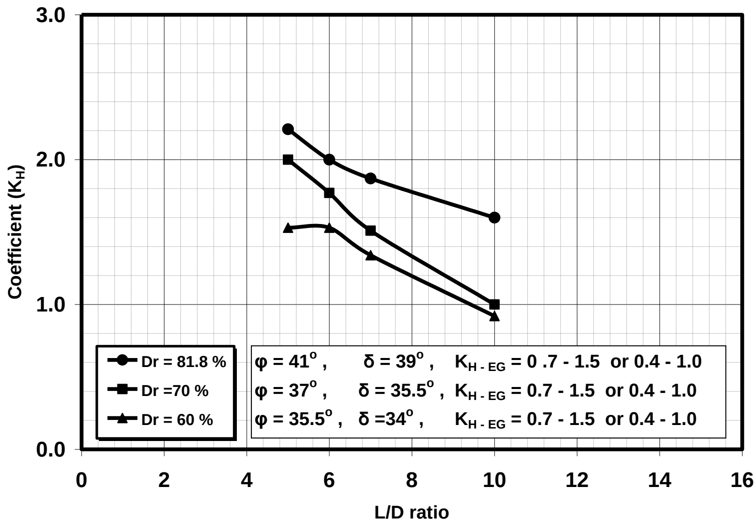


Figure 15. Relationship between coefficient (K_H) and L/D ratio (O-cell tests)

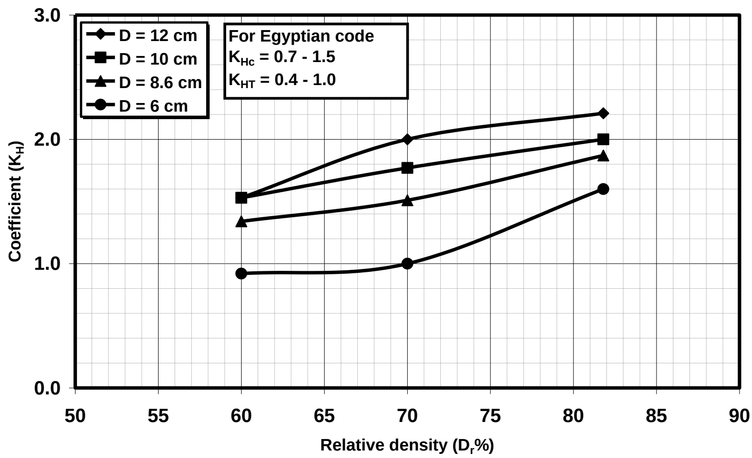


Figure 16. Relationship between coefficient (K_H) and relative density (O-cell tests)

From the above O-cell test results shown in Figs. 15 and 16 and discussions, a linear equation to estimate value of K_H for different densities and pile diameters is as follows:

$$K_H = a_2 D + b_2 \tag{6}$$

Where

$$a_2 = -13.8\,(\tan\phi)^2 + 21.7\,(\tan\phi) - 8.4 \tag{7}$$

$$b_2 = 5.03\,(\tan\phi) - 3.46 \tag{8}$$

The above equations have coefficients of correlation (R^2) range from 0.883 to 1.0, which are considered very good.

5. CONCLUSIONS

The present study is concerned with the investigation of shaft and base resistance of a single bored pile using Osterberg cell. In the O-cell tests, the ultimate resistance for pile shaft (Q_s) and pile base (Q_b) was measured separately. The results obtained from O-cell tests were compared with these obtained from conventional method and equation of Egyptian code for soil mechanics and foundations. A sand soil with different relative densities and different pile diameters were studied.

Based on the presented discussion and analysis of experimental results, the following main conclusions are noted:

(1) The ultimate resistance for pile base is more affected by the relative density than that for pile shaft. Also, this effect clearly increases as pile diameter increases.
(2) The shaft resistance reaches to failure before base resistance.
(3) When displacement reaches approximately to 1.6% of pile diameter, shaft resistance reaches to 65% of ultimate shaft resistance and base resistance to 35% of ultimate base resistance.
(4) Both ultimate resistances for pile shaft and pile base decrease as L/D ratio increases, but the range of decreasing in ultimate resistance for pile base is more than that for pile shaft.
(5) Both bearing capacity factor N_q and coefficient of lateral soil pressure (K_H) depend not only on angle of internal friction but also on L/D ratio.
(6) The values of bearing capacity factor N_q obtained from Egyptian code is overestimated if compared with the measured values.
(7) Coefficient of lateral soil pressure (K_H) obtained from Egyptian code is underestimated if compared with the measured values.

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دراسة على مقاومة جذع و قاعدة خازوق مدفون مفرد باستخدام خلية أوستربرج

نظراً للتوسع في استخدام الأبراج الشاهقة في المنشآت الهندسية ولضخامة الأحمال الناتجة عنها على التربة عند منسوب التأسيس مما يجعلها تحتاج إلى مساحة كبيرة من الأساسات السطحية حتى تفي بقيم سعة الارتكاز و الهبوط المسموح بهما وللتغلب على ذلك يتم اللجوء إلى الأساسات الخازوقية.

تعتبر الأساسات الخازوقية من الموضوعات الهامة في مجال الهندسة الإنشائية. والخوازيق تنقل الأحمال إلى التربة إما بالاحتكاك عن طريق جذعها أو بالارتكاز عن طريق قاعدتها السفلية أو بالاثنين معاً. وقدم الكود المصري لميكانيكا التربة وتصميم وتنفيذ الأساسات معادلات لحساب حمل الخازوق المنفرد حسب نوع الخازوق ونوع التربة. ولاختبار الخوازيق ذات قدرة التحميل العالية للحصول على الحمل التصميمي فإن الطريقة التقليدية تصبح مكلفة للغاية وذلك لاحتياجها لردود أفعال كبيرة, ولذلك فقد أبتكر العالم أوستربرج طريقة جديدة لأجراء تجارب تحميل الخوازيق وذلك بوضع خلية عند قاعدة ارتكاز الخازوق وتم إجراء العديد من التجارب الحقلية في اليابان و الولايات المتحدة الأمريكية لتقييم مدى صلاحية استخدامها. وتتميز طريقة أوستربرج بأنها يتم التأثير على الخازوق بقوتين متساويتين ومتضادتين في الاتجاه أحدهما لأسفل لتحديد الحمل المنقول بواسطة قاعدة الخازوق بالارتكاز (Q_b) والثانية لأعلى لتحديد الحمل المنقول بواسطة جذع الخازوق بالاحتكاك (Q_s) في حين أنه فى الطريقة التقليدية يتم الحصول على الحمل التصميمي الكلى. والفصل بين Q_b و Q_s فى غاية الأهمية لمعرفة كل واحدة بمفردها وهذا مفيد خصوصاً لخوازيق الشد التي تنقل حملها إلى التربة بالاحتكاك فقط.

في هذا البحث تم دراسة سلوك الخازوق المدفون في تربة رملية مع دراسة بعض المتغيرات مثل قطر الخازوق (D) ونسبة طول الخازوق الى قطره (L/D) وكذلك الكثافة النسبية للرمل (D_r) والتي تؤثر بدورها في زاوية الاحتكاك الداخلي (φ). وقد تم دراسة أربع أقطار مختلفة من الخوازيق مع ثلاث حالات من الكثافة النسبية للرمل المدموك. كذلك تم دراسة بعض المعاملات مثل معامل قدرة تحمل

التربة (N_q) ومعامل ضغط التربة الجانبي على جذع الخازوق (K_H) والتي تم الحصول عليها من تجارب أوستربرج وتم مقارنة هذه القيم مع مثيلاتها بالكود المصري.
تم تقديم معادلات تجريبية لحساب قيم المعاملات (N_q) و (K_H) في حالة التربة الرملية. وقد وجد أن المعاملات (N_q) و (K_H) تعتمد على كلاً من قطر الخازوق و زاوية الاحتكاك الداخلي كما أن قيم (N_q) والتي تم الحصول عليها من تجارب أوستربرج على الرمل المستخدم اقل من مثيلاتها في الكود المصري وأن قيم (K_H) و التي تم الحصول عليها من تجارب أوستربرج على الرمل المستخدم اكبر من مثيلاتها في الكود المصري.