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Effect of Relative Density on Behavior of Single Pile and Piles Groups Embedded with Different Lengths in Sand

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ABSTRACT

The present research investigates the effect of axial relative density on the ultimate load of model piles with different lengths driven in dry sandy soil having small scale model piles.

The materials used in this study are divided into three parts they are; sandy soil, steel piles and aluminum pile caps. A total number of 27 model tests are carried out using three relative densities (33%, 60%, and 80%) corresponding to loose, medium and dense sand, respectively.

A square section steel solid model piles are used with 18 mm width and (320, 420, 520) mm embedded length (L_d). A 6B distance between the piles center to center is selected to eliminate the effect of group interaction.

Two pile groups' configuration (1×2) and (2 × 2) are considered in this study connected by aluminum caps with smooth surface having a thickness of 25 mm.

The load applied on the models is measured by a pressure transducer connected to the main line of the hydraulic pressure system and applying up to failure. During all the experimental tests, the loading rate is kept at 3 mm/min.

It was founded that relative density has more impact on (2×2) pile group than on (1×2) pile group and single pile. The average rate of increase in the ultimate load from loose to medium is about 15% greater than the average rate of increase from medium to dense. Also, the ultimate load of pile increased about 96% with changing the sand density from loose to medium sand for single and piles group while the average increment is about 81% from medium to dense. The increase in embedded length of pile caused increasing the ultimate load capacity and decreasing the settlement ratio. The average rate of increase in the ultimate load when the embeddedlength changes from 32 cm to 42 cm is about 4% less than the average rate of increase when the embedded length changes from 42 cm to 52 cm. Also, use of (1×2) piles group instead of a single pile, the average rate of increase is about 6% less than the average rate of increase when change from (1×2) group to (2×2) pile group.

Finally, when the number of piles changes from single pile to (1×2) piles group, and to (2×2) piles group, the average of increase of ultimate load is about 102.5% and 108.5% respectively.

Keywords: Sand Density, Single Pile, Piles Group, Ultimate Load

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INTRODUCTION

Piles are structural members made of timber, concrete or steel, used to transfer surface loads to lower levels in the soil mass. This load may be resisted by the pile shaft or directly through the pile tip. Pile foundations are known to provide higher capacity, earthquake resistance and to significantly reduce the settlement of the structure. Piles may be designed to carry axial and lateral loads, also used as anchors e.g. for docks and hangers or subjected to high lateral loads (offshore structure). The engineer should be able to predict the capacity of these piles, the spacing and to determine whether the piles will act as group or individual piles.

According to the method of installation, piles can be classified as displacement piles (driven& jacked) and non -displacement piles (bored piles). For the displacement piles, soil displaces radially and vertically during piles installation. Displacement piles are favorable for soil compaction in case of cohesion-less soil and heave in case of cohesive soils. When several piles are clustered, it is reasonable to expect that the soil will be pressured laterally due to the side friction on the pile shaft or the point bearing. The superimposed lateral pressure produced by both the pile and the tip is depending on both the pile and spacing. In case of high loading there will be failure in the soil mass or the group will experience settlement or failure of the pile material. The stress intensity due to overlapping stress zones will obviously decrease with increase of pile spacing. [10].

In the previous literature, design theories are found on problems related to single piles rather than group of piles .This is due to mainly the difficulty in performing laboratory or field tests on pile groups .Accordingly, the group capacity was taken as the sum of the individual piles capacities.

Geddes and Murray, 1996 [11] reported that the ultimate lateral capacity of pile group depends on the length-to-diameter ratio of pile, pile frictional angle, pile group geometry, spacing of piles in group and sand placement density. It was noted that the group efficiency increases with an increase in pile spacing, for L/d=38, the group efficiency decrease with an increase in piles in-group configuration.

Mokwa, 1999 [12] conducted several experimental studies for computing the efficiency of pile groups. He introduced some factors that most significantly affect the overall group efficiency, these are: pile spacing, group arrangement, pile head fixity, soil type and density.

Al-Zayadi, 2010 [2] made laboratory piled raft models in sandy soil using smooth aluminum pipe piles having three different outside diameters. The embedment ratio L/d was equal to 20, 25, and 30. Pile diameter of 9 mm was used, and pile length of 200 mm. The spacing between piles was kept constant S =5cm with four configurations of piles group (2x1, 3x1, 2x2, and 3x2). It was noted that the percent of the load carried by piles increases with the increase of number of piles. For (3x1) group of piles with spacing to diameter ratio of five, the center piles can carry load up to 1.5 times the load carried by edge pile. For (3x2) group of piles, each one of the two piles at the center can carry load up to 1.25 times the load carried by edge piles.

Yilmaz (2010) examined settlement reducing piles foundations. The experiments have been done in model systems which consist of an aluminum model raft which has dimensions of 50 x 50 x 10 mm and brass model piles of 2 mm in diameter. It was clearly seen that introducing piles under the raft reduces the settlement considerably. As the pile number increases further, the decrease in the settlement gets smaller. In other words, there is no significant effect of increasing pile number as far as the settlement is concerned [18].

2. Experimental work

The main purpose of the experimental work implemented in this research is to study the load settlement

Behavior of a single pile and piles group with different relative densities was predicted.

The materials used in this study are divided into three parts they are: soil, steel piles and aluminum caps.

2.1Test setup

All model tests were conducted using the setup shown in Plate (1), which consists of loading frame, axial loading system, hydraulic pressure system, data acquisition, electrical control board and steel container. The vertical load was applied to the model piles by means of hydraulic compression jack.

The load applied on the model is controlled by a pressure transducer connected to the main line of the hydraulic pressure system. During all the experimental tests, the loading rate is kept approximately constant at 3 mm/min. The displacement of the model is measured by the shaft encoder. The output signals from the pressure transducer and the shaft encoder, which contacts touch the metal teeth, is connected to electrical source of electrical current which the PLC (Programmable Logic Controller) can deal with it and translated to a pressure, displacement reading. Finally, the measuring data is recorded at selected intervals in a data file in the computer. The entire testing process is run with the aid of computer software. Electrical signal which the PLC can deal with it and translated to a displacement reading.

The mechanical encoder accuracy is (0.001mm) and the scanning time not exceeding a few milliseconds. It is worth mentioning that this research was conducted using the apparatus manufactured by Rahil, (2007) [15] with making some necessary modifications to comply with the object of current research. Figure (1) shows the Front view of the apparatus.

2.2 Steel container

The container was used to prepare test sample, the internal dimensions are 1000 mm length, 750 mm width and 750 mm depth. Each part of container is made of steel plate of 5mm thick. It has four wheels and can move freely a long a rail made of inverted T-section.

2.3Pile driving hammer device

The model piles used in this study are steel solid piles. A driving system as shown in Plate (2) consists of two steel columns, three beams (700×65×40)mm made of aluminum, An aluminum rod and a steel base plate with (950 × 250) mm and (20) mm in thickness is used. This plate involves three holes (27) mm in diameter with a distance between the external holes center to center is 6B (where B width of the pile) for driving group piles, and the central third hole for driving single pile. All holes are considered as focus place to penetrate the piles in the container.

2.4Model pile groups and caps

The piles used are steel solid piles. It have a square cross section 18 mm width and the head of piles were manufactured as screw cylinder 7mm diameter and 25mm high fortightening with the above cap. Three lengths of piles are selected (400mm, 500mm, and 600mm) for embedment ratios (depth to width, Le/B) =18 , 23.6, 29 respectively, where (Le) represents the pile embedment length and (B) is the width of the pile. The piles group interaction factor which has been observed to have significant effect on the dynamic response on the system especially when the pile spacing is between 2.5D to 3D, where D is the diameter of the pile, [13]. To ignore the effect of group interaction factor, the centre to centre distance between the piles is at least more than 5D [9]. Therefore a 6B distance between the piles center to center is selected to eliminate the effect of group interaction.

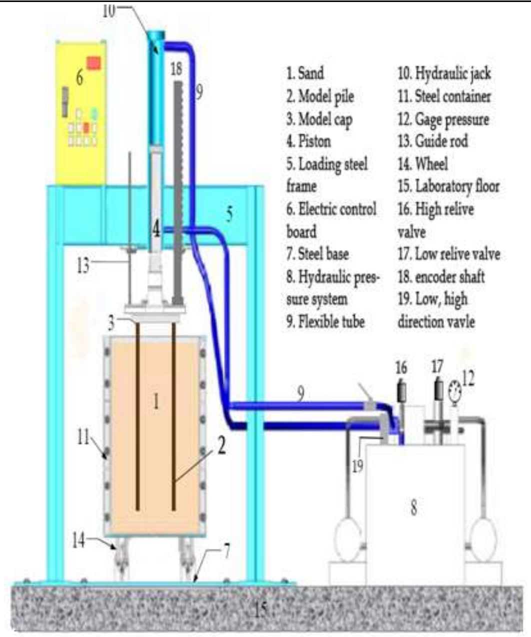

Plate (1): Testing model.Figure (1): Front view of the apparatus.

The caps used for piles group were made of aluminum plate with smooth surface having a thickness of 25 mm. two aluminum caps with smooth surface; (162×60) mm, (162×162) mm for (1×2), and (2×2) group piles respectively. The cap used for two piles contain two holes (9mm diameter), and the cap used for four piles contain four holes (9mm diameter). The holes for fixing piles were including a cushion at the top of the cap 7mm height and 27mm diameter.

Plate (2): Piles hammer device.

2.5 Configurations of piles caps

Piled cap configurations used to maintain symmetrical shape as shown in Plate (3). Two different configurations of piles are used in the piled cap models. The model groups consist of (1×2), (2×2) piles.

(2×2) piles (1×2) piles

Plate (3): Piled cap configuration

Soil properties

The soil used for the model tests is air dry sand, brought up from Bedra City. The maximum and minimum dry unit weights of the sand were determined according to the ASTM (D4253-2000) [6] and ASTM (D4254-2000) [7] specifications, respectively, the specific gravity test is performed according to ASTM (D854-2005) [8], the grain size distribution is analyzed according to ASTM (D422-2001) [5] specifications and direct shear test according to the ASTM (D 3080-1998) [4].

Figure (2) shows the grain size distribution of the sand. Tables (1) and (2) summarize the physical properties of the tested sand. The angle of internal friction is determined using the direct shear test which was carried out for the three relative densities of sand (one type in three different densities).

The sand deposit is prepared using a modified compactor manufactured for this purpose. Three cases of relative densities are chosen (33% for loose sand, 60% for medium sand and 80% for dense sand), this mean that the weight required to achieve the relative density is predetermined since the unit weight and the volume of the sand are predetermined also, the weight is divided into equal four weights each of it represents that it required for each layer.

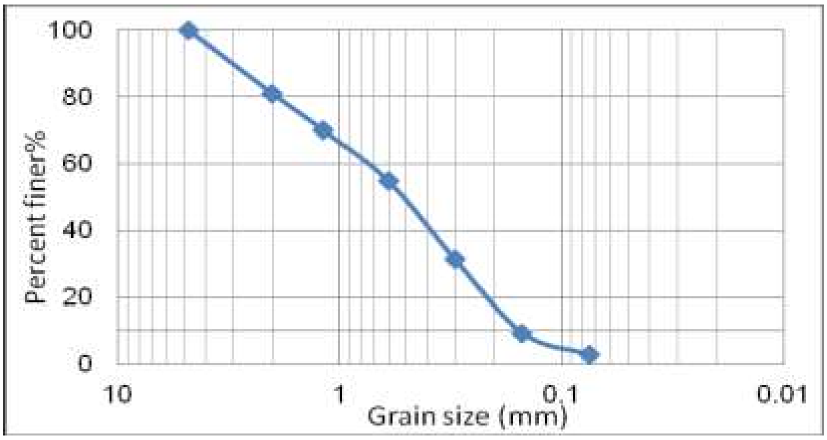

Figure (2): Grain size distribution of the sand.

The soil of each layer is compacted to a predetermined depth. After completing the final layer, the top surface is scraped and leveled by a sharp edge ruler get as near as possible a flat surface. Figure (3) represents the steps of the sand deposit preparation.

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Table (1): Physical properties of the sand used

Property	Value
Grain size analysis	
Effective size, D_{10}, D_{30},D_{50}, D_{60}	0.16,0.30,0.50,0.72
Coefficient of uniformity, C_u	4.5
Coefficient of curvature, C_c	0.78
Classification (USCS)*	SP
Specific gravity, G_s	2.66
Dry unit weights	
Maximum unit weight, γd (max.) kN/m^3	18.70
Minimum unit weight, γd (min.) kN/m^3	15.70
Void ratio	
Maximum void ratio, e_{max}	0.66
Minimum void ratio, e_{min}	0.40
Relative density	
Loose	33%
Medium	60%
Dense	80%

* USCS refers to Unified Soil Classification System according to ASTM D2487 [3].

Table (2): Selective properties of the sand used

Type of sand	Dry unit weight (γd) kN/m^3	Angle of internal friction (φ)	Relative density (R.D)	Void ratio (e)
Loose	16.55	33°	33%	0.58
Medium	17.35	38°	60%	0.50
Dense	17.96	41°	80%	o.45

2.7. Installation of model driven piles

After the bed of sand is prepared with controlled density required as mentioned before, the driving hammer is fixed on the container and the guide line plate put below the base of pile driving hammer device to drive the model piles to the required length with a counted set based on a height of falling (H) estimated according to Ali, 2012 [1]. The model piles are vertically installed in the hole that is being in the hammer plate and the rod of hammer is lowered on the model piles until to the top of the pile enter inside the helmet. Figure (4) represents the steps of the installation of model piles.

Weight of hammer that used to drive the model piles which was equal to (2.166 kg) .This weight was chosen depending on the weight of pile to hammer ratio (WP/Wr),about (1-1.5) [16]. Table (3) summarized the height of fall and number of blows for different length of piles.

3. Test Procedure

After the completion of the preparation the sand deposit inside the steel container, the installation of the model piles, and fixing the aluminum cap on the top of the piles, the container was then moved along the rails and fixed in position in such a manner that the center of the aluminum base plate of the piston coincided with the center of the group piled model.

Figure (3): represents the sand deposit preparation.

Figure (4): Installation of model piles.

The aluminum base plate of the piston was then brought in contact with top surface of the cap of the group piled model, while the single pile tested directly under the aluminum base plate of the piston without the cap. The loading was applied gradually through the hydraulic jack whom operates at a controlled displacement of 0.03mm/sec. So the test was a strain- controlled test. Process of the loading is continuing till failure occurs.

Table (3): Height of fall and number of blows for different length of piles

Length of pile (cm)	H (cm)	No. of blows (loose)	No. of blows (medium)	No. of blows (dense)
40	8	3	7	12
50	9	4	8	15
60	10	5	10	20

4.Presentation and discussion of results

The results of 27 model tests, performed on the dry sand subjected to a vertical compression load using different relative densities. The study focuses on the influence of parameters such as relative density, the embedded length of piles and number of piles, on the behavior of piles.

It is normally assumed that the efficiency falls to unity when the spacing is increased to five or six diameters. Since present knowledge is not sufficient to evaluate the efficiency for different spacing of piles, it is conservative to assume an efficiency factor of unity for all practicalpurposes [13]. Accounting for the relationship between the applied vertical axial load and the settlement of the piles, the ratio (S/B) (defined as the settlement divided by the pile width).

For all model tests, the failure criterion adopted is that proposed by Terzaghi (1943) [17] by which the failure load is defined as the load required to cause settlement corresponding to 10% of the footing width.

Navy-Mckay, (1982) formula which is applied for dynamic purposes is executed in all single pile tests of model driven piles to calculate the expected loads and compare these values with the observed loads obtained from the laboratory tests [14].

$$Q_u = \eta \times E / (S_e \times (1+0.3W_p/W_r)) \qquad ...(1)$$

Where: η= Efficiency of blows, E= energy of hammer in (kg.cm), S_e= number of blows corresponding to a penetration 2.5cm in (cm/blow), W_p= weight of pile with the extensions in kg, W_r = weight of hammer arm in kg.

The comparison between the values of ultimate bearing capacity computed experimentally for single piles as shown in Figures (5) to (7) with those that have been calculated by Navy-Mckay formula is shown in Table (4).

The single pile, and free standing pile groups are installed in dry sand at different densities and embedded length of piles, Figures from (5) to (7) shows the load-settlement ratio curves for single pile, and Figures (8) to (10) shows the curves for a (1×2) piles group, while Figures (11) to (13) are plotted for (2×2) piles group.

4.1 Effect of relative density

Figures (5) to (13) demonstrate that the average of increasing in ultimate load from loose to medium sand is about 96% forsingle and piles group while the average increment is about 81% from medium to dense.

4.2 Effect of embedded length of the piles

Figures (5) to (13)demonstrate that the average of increasing in ultimate load for piles with embedded length change from 32cm to 42cm is about 34.5% for single and piles group while the average increment is about 38.5% for piles with embedded length change from 42cm to 52cm.

4.3 Effect of the number of piles on the load carrying capacity

The Figures above show that the increase of the number from single pile, (1×2) piles group, and (2×2) piles group lead to increase the ultimate bearing capacity .the average of increasing in ultimate load is about 102.5% for increases piles from one pile to (1×2) piles group and 108.5% for increases piles from (1×2) to (1×2) piles group.

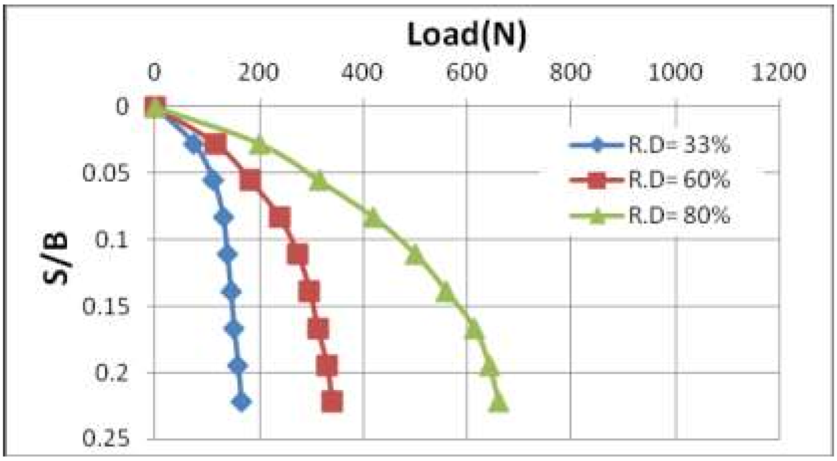

Figure (5):Results at different relative densities for a single pile with length=40cm.

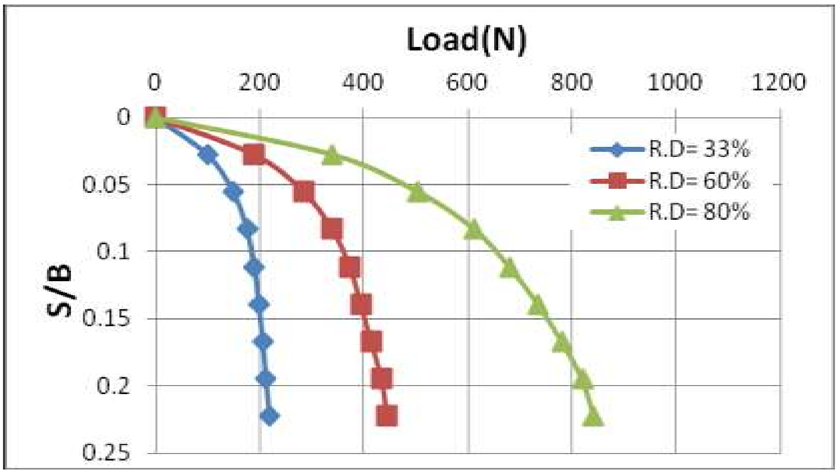

Figure (6): Results at different relative densities for a single pile with length=50cm.

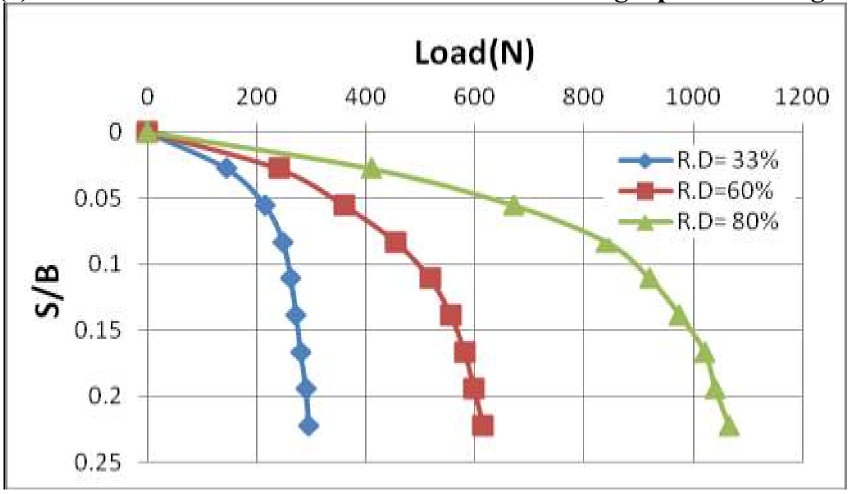

Figure (7): Results at different relative densities for a single pile with length=60cm.

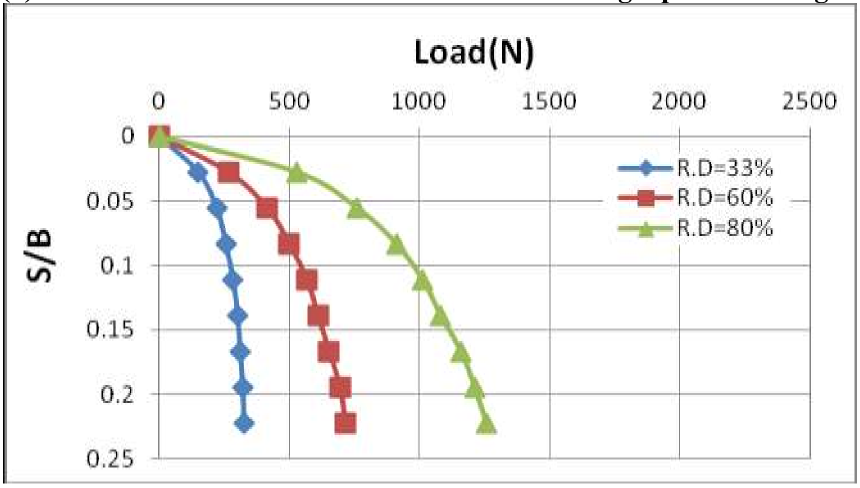

Figure (8): Results at different relative densities for (1×2) free standing pile group with length=40cm.

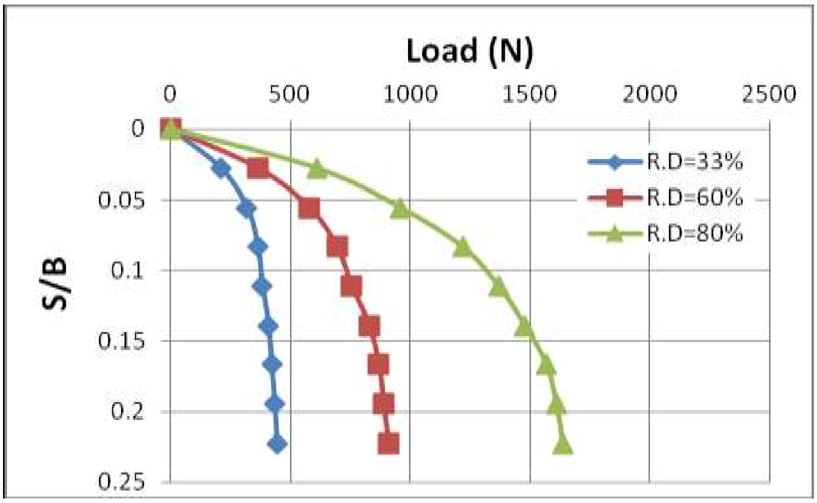

Figure (9): Results at different relative densities for (1×2) free standing pile group with length=50cm.

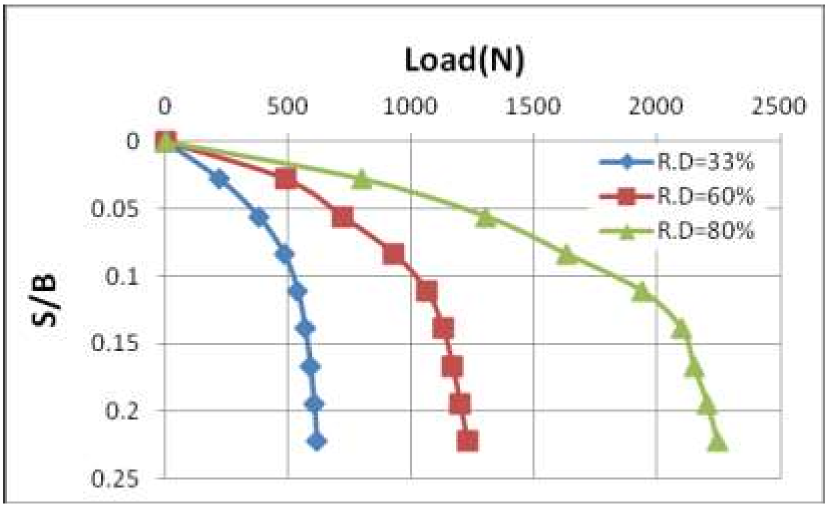

Figure (10): Results at different relative densities for (1×2) free standing pile group with length=60cm.

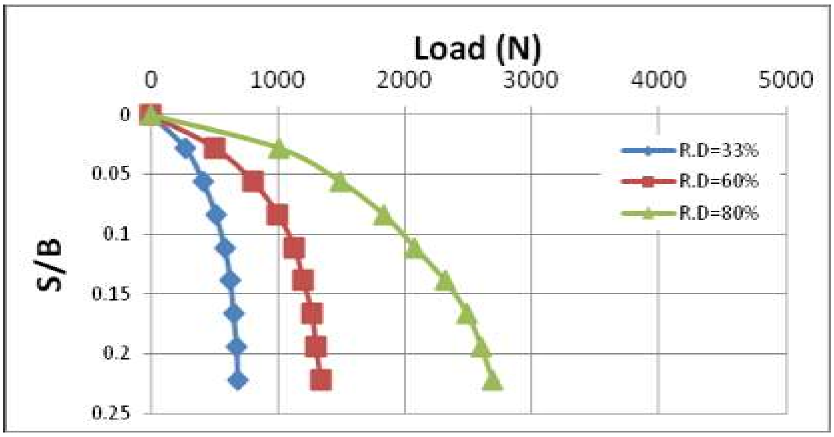

Figure (11): Results at different relative densities for (2×2) free standing pile group with length=40cm.

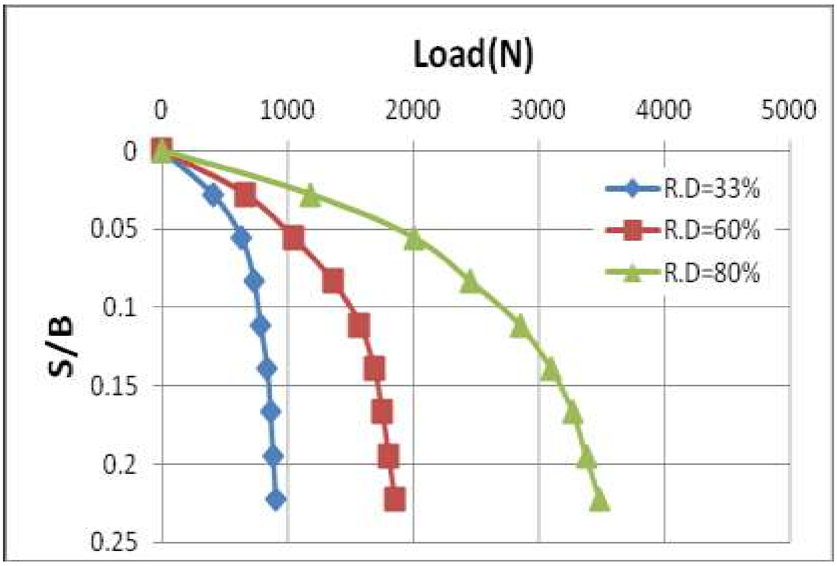

Figure (12): Results at different relative densities for (2×2) free standing pile group with length=50cm.

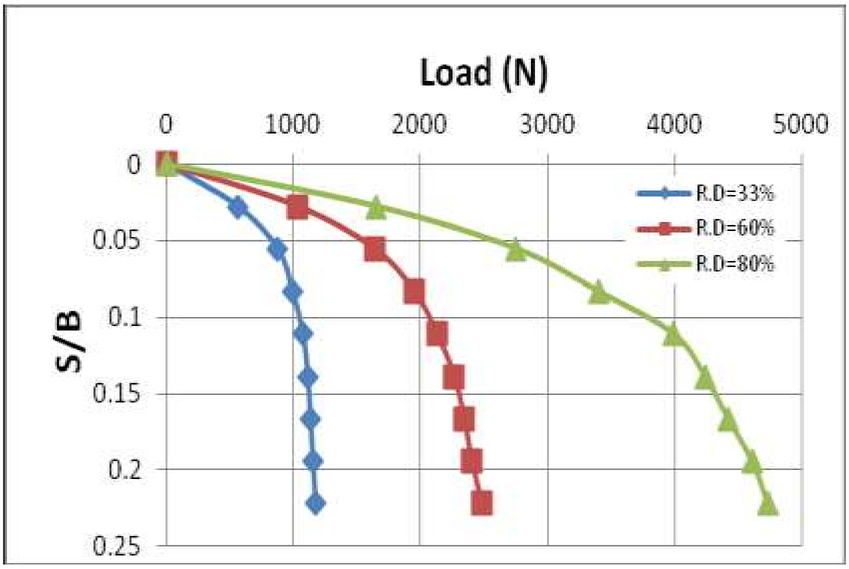

Figure (13): Results at different relative densities for (2×2) free standing pile group with length=60cm.

Table (5) summarizes the results of the experimentally ultimate bearing capacity for (1×2) and (2×2) piles group with different embedded length and relative densities of sand under monotonic load test.

Table (4): Comparison between ultimate bearing capacityfor single piles experimentally and theoretically.

L (cm)	Se cm/bl	W_p /W_r	E (N.cm)	Q_u (N)	$Q_{u\,eq.}$ (N)
Loose Sand					
40	0.75*	1.246	169.936	136	123.7
50	0.625	1.36	191.18	182	162.94
60	0.5	1.466	212.42	253	221.3
Medium Sand					
40	0.357	1.246	169.936	265	260.1
50	0.3125	1.36	191.18	355	325.875
60	0.25	1.466	212.42	497	442.6
Dense Sand					
40	0.208	1.246	169.936	477	445.64
50	0.167	1.36	191.18	645	609.89
60	0.125	1.466	212.42	900	885.58

η=0.75 *2.25/bl

Table (5): Summary of ultimate bearing load of piles group

L (cm)	Q_u (N) (1×2) pile	Q_u (N) (2×2) piles
Loose Sand		
40	275	560
50	370	755
60	515	1055
Medium Sand		
40	538	1100
50	730	1505
60	1025	2115
Dense Sand		
40	977	1989
50	1325	2745
60	1860	3879

CONCLUSIONS

From analysis of the results, the following conclusion can be drawn:

1- Under the same conditions (relative density of sand, energy of hammer), the number of blows is increased with the increasing of the embedded length of pile.
2- The mode of the shear failure of loose sand is a punching type and it is gradually changes towards the general shear failure of dense sand.
3- The load capacity of singleand pile groups increases when the density of sand increases due to increase the friction area. The sand density has more effect on (2×2) pile group than on (1×2). The ultimate load is increasing at a rate of about (96%) form loose to medium sand and (81%) from medium to dense sand.
4- The ultimate bearing capacity increases while the settlement decreases, when the embedded length of pile becomes larger as a result to increase stiffens of soil – pile system due to skin friction. This effect was found much than in single pile on the (1×2) pile group foundation, and more than on (2×2) pile group. Average increasing in the ultimate load of about (34.5%) and (38.5%) for embedded length changes from 32cm to 42cm, and for embedded length increases from 42cm to 52cm, respectively.
5- Increasing the number of piles within the group leads to increasing in the ultimate bearing capacity of the pile foundation. Average increasing in the ultimate load of about (102.5%), and (108.5%) for single pile to (1×2) pile group and for (1×2) to (2×2) pile group, respectively.
6- The increasing rate of bearing capacity of pile is a function of (number of piles, sand density, and pile embedded length).

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