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Comparison of the Behavior for Free Standing Pile Group and Piles of Piled Raft

Abstract- *The intended task of this paper is studying the behavior of free standing pile groups and piles of piled raft driven in clayey soil under axial loading. The raft-piles interaction is investigated as well through the two series of tests. Each one of these series includes twelve tests, the two series are conducted with the same configuration, spacing, size of piles and undrained shear strength of soil except that in the free standing group there is a gap of about (20-25 mm) between the raft and the soil surface to have the applied load transferred to the piles only in order to compare the behavior of piles in the two cases. Three grades of undrained shear strength (c_u) of clayey soil are selected which are (20 or 40 or 60 kPa) and the configuration of the pile groups used in all tests is (2 x 2). Two different pile lengths (L) are selected (300 and 450 mm). These lengths represent the slenderness ratio (L/D) of (10) and (15) respectively, so that the center-to-center spacing between the piles (S) used are (3D) and (5D). It is observed that piles exhibited a very high stiffness at initial loading stages till the settlement is about 0.5mm, beyond this level, even for a small increment in the load, the pile settled rapidly, which means that once the friction is overcome the piles failed instantaneously. In addition, most of the load capacity of piles is mobilized at settlement of around (1 – 2 mm), corresponding to (5 %) of pile diameter. Moreover, the increasing the undrained shear strength of clay from (20 to 60 kPa) has no significant effect on the load transfer mechanism of piles in the two cases . It can be concluded that the load capacity of the free standing pile group is about equal to the piles in piled raft case, indicating that the interaction effect is not significant, therefore, it is suggested to apply an efficiency factor (α_G) of (1) in designing the piled - raft foundation in clayey soil when calculating for pile load* share.

Keywords- *model test, free-standing piles, end bearing, skin friction, clay.*

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1. Introduction

Piles are mostly installed in groups, it can be divided into two main types based on the connectivity of the pile cap with the underlying soil; freestanding groups, in which the pile cap is not in contact with underlying soil and piled foundations, in which the cap is in contact with the underlying soil [1]. For both types of pile groups, it is naturally expected that piles interact and influence each other's capacity.In case of raft in contact with underlying soil, the interaction between the raft-soil and the pile group depends upon several factors like the geometry of the raft, type of soil, pile length and spacing between piles. Understanding of this interaction is more complicated than the free-standing pile group as the raft in contact with the ground influences the confining pressure, making the interaction behavior more complicated. The complex interaction can become favorable like increase in the group capacity or unfavorable like causing additional settlement [2]. Moreover, according to references [3-5], in case of the piles raft is in contact with soil the load is partially transferred from the raft to the shallow soil and partial to the pile heads, and from the piles it is diffused through the shaft and the base for deeper soil: contact piles act as settlement reducers by reducing the amount of load transmitted to the shallow soil. The load transmitted to the ground surface produces an increase in the vertical and horizontal stresses in the soil surrounding the piles and gives rise to an increase in the pile shaft capacity.

Based on the available literature, it can be reported that there was a lack observed regarding studying the behavior of these two cases of piles in clayey soil deposits due to the limited research, which make their behavior not well understood.

The intended task of this paper is studying the behavior of a free standing piles group and piles of piled raft driven in clayey soil under axial loading. It also covered the investigation of the raft-pile interaction through the results of the two

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series of model tests. Each one of these series includes twelve tests, the two series are conducted with the same configuration, spacing, size of piles and undrained shear strength of soil except that there is a gap of about (20-25 mm) between the raft and the soil surface to have the applied load transferred to the piles only in order to compare the behavior of piles in the two cases. Three grades of undrained shear strength (c_u) of clayey soil are selected which are (20 or 40 or 60 kPa) and the configuration of the pile groups used in all tests is (2 x 2). Two different pile lengths (L) are selected (300 and 450 mm). These lengths represent the slenderness ratio (L/D) of (10) and (15) respectively, and the center to center spacing between the piles (S) used are (3D) and (5D).

2. Set Up Used

I. Testing Box

A steel box is fabricated to contain the clay soil that supports the piles models, the internal dimensions of the box are 600 mm in length, 600 mm in width and 650 mm depth. The box size is chosen to be large enough to keep its sides and bottom away from the influence zone of the stress bulb induced during the loading tests.

II. Loading System

The loading system is designed and constructed as load-controlled system that imposes a vertical concentrated load on the pile group, which is capable of reaching the ultimate load capacity of this foundation. The loading system consists of a loading frame with a lever arm ratio of (1:3). It is possible to apply a large load using this frame in a safe and easy manner. The steel frame consists mainly of a two double (U) section (poles) and one horizontal lever. Each one of the two columns is fixed at its bottom end through a base of steel section, 1000mm×100 mm, to the ground. A space of (25 mm) is allowed between the two (U) sections of each column pole to allow for installing the lever arm section within this space. The lever arm is pin connected to the pole within this space, allowing free movement of the lever. The load is transferred to the footing system using a weight hanger attached to the lever arm with a pin connection at the free end. The load is applied by placing slotted dead weights on the cradle. The steel frame and the loading system are shown in Figure 1.

3. Materials Used

I. The Soil

Soil used in this study is borrowed from the area of Al Taji, north of Baghdad city, standard tests were performed to determine the physical properties of the soil, the properties of the soil and the results of the consistency limits tests are given in Table 1. The soil is brown silty clay and the grain size distribution of the soil used is shown in Figure 2, the soil is classified as, low plasticity clay (CL) according to the unified soil classification system.

II. Piles Model

The piles are modeled by aluminum pipes (closed end) in order to simulate the properties of concrete pile, since the modulus of elasticity of the hollow aluminum tube is comparable to that of an equivalent diameter of the solid concrete shaft. The aluminum pipes have an outside diameter of (30 mm) and a thickness of (2.5 mm). Embedded pile lengths of (300 mm) and (450 mm) were used in the experiments; these lengths represent slenderness ratios (L/D) of (10) and (15) respectively. The top head of each pile was closed and provided with a nut for a bolt of (4 mm) in diameter to connect the raft to the piles. A compression test was conducted to evaluate the overall modulus of elasticity of the hollow aluminum pipe of (30) mm length and was found to be equal to (19) GPa.

III. Pile Cap

The pile cap model was simulated using a square steel plate of (5mm) thick and using two sizes which are (150mm X 150 mm) and (210 mm X 210 mm) in dimension, the configuration of the pile groups used in all tests is (2 x 2).

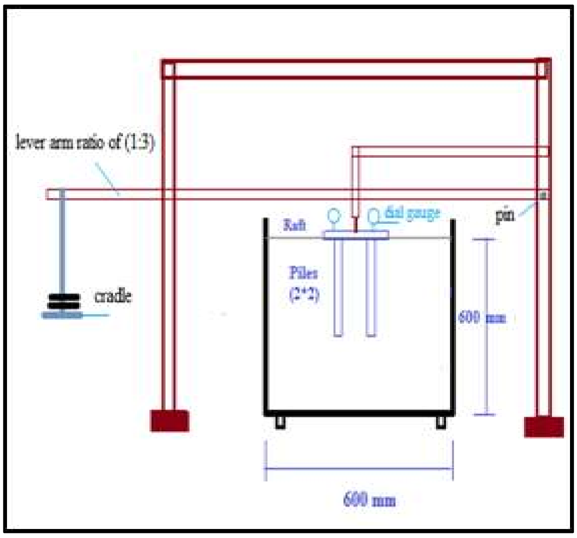


Figure 1: The loading system

Table 1: Physical properties of clay soil used.

Property	Value Index	Specification
Liquid limit (L.L)	48	ASTM-D4318-2010- [6]
Plastic limit (P.L)	25	ASTM-D4318-2010- [6]
Plasticity index (P.I)	23	ASTM-D4318-2010- [6]
Specific gravity (Gs)	2.69	ASTM-D854-2010- [7]
Gravel (larger than 4.75 mm)	0 %	ASTM-D422-2010- [8]
Sand (4.75mm to 0.0٧٥mm)	4 %	ASTM-D422-2010- [8]
Silt (0.0٧٥ mm to 0.005mm)	٤5 %	ASTM-D422-2010- [8]
Clay (less than 0.005 mm)	٥1 %	ASTM-D422-2010- [8]
Soil Classification	CL	USCS

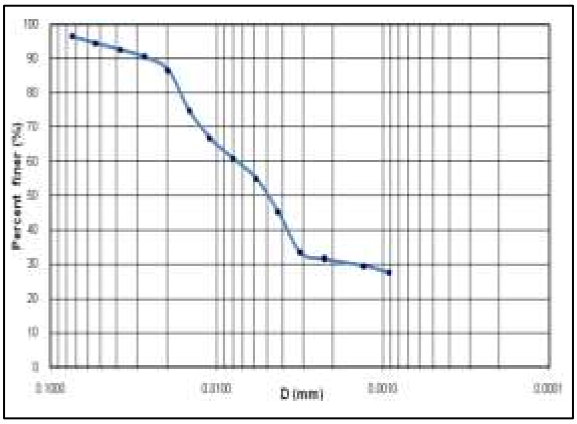


Figure 2: Grain size distribution of the used clay soil

4. Testing Technique

I. Load Measurement

In an aim to study the development of resistance of each of the tip resistance and skin friction of the piles under loading from the total load applied on the piles, load cell monitoring was taken into consideration. To achieve this goal a special load cell with its accessories are designed and manufactured especially for this study. In tests of piled -raft foundations (where raft in contact with soil), three load cells are used in each test, one is placed under the tip to measure the end bearing and the other two are attached at the top of two piles (between the raft and piles) to measure the pile load capacity. Each one of the load cells that are placed at top of piles are provided with a screw at each of its top and bottom surface to connect the raft to piles. In the tests of freestanding pile group, one load cell is used in each test that is placed below the pile tip to measure the end bearing load during test. The capacity of the load cells used is (1 kN) with (0.001 N) sensitivity, where, a photograph of the instrumented model piles with load cells are shown in Figure 3.

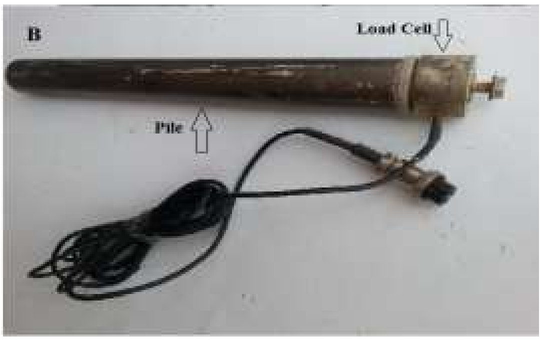
II. Data Acquisition System

Four-channel data logger is used during the test to monitor and store the readings of the load cells , the signal of the load cell transducers is transmitted to a computer through the data logger, as shown in Figure (4). All data collected by the data logger from the load cells are automatically recorded by the laptop connected to it which later can be reviewed and analyzed using special software compatible with this data logger.

5. Model Preparation and Test Procedure

I. Clay Strength- Moisture Correlation

Several trail tests were performed to construct a relation between shear strength and water content after a period of two days and the results are illustrated in Figure 5, where the undrained shear strength was measured by using the portable vane shear device. According to results illustrated in Figure 5, several water contents are selected and are (22, 25 and 30 %) which will assure getting undrained shear strength (c_u) of (60,40 and 20 kPa) respectively.



a - Load cell at pile tip- b - Load cell at pile head.
Figure 3: Instrumented model piles with load cells.

Figure 4: Data Acquisition System

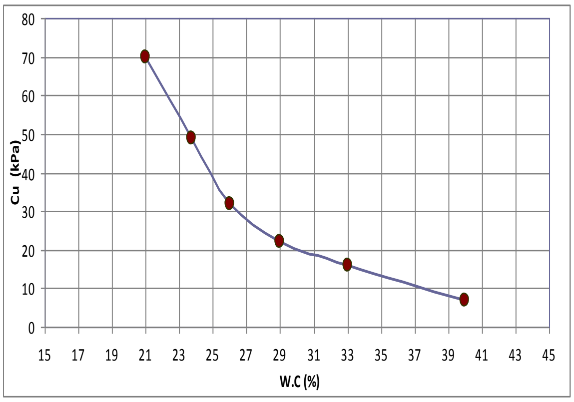


Figure 5: Variation of undrained shear strength versus water content of the clay

II. Soil Preparation

The clay soil is mechanically grounded in the laboratory and then the water content is adjusted as per the required undrained shear strength and this was controlled with the aid of pre-determined corresponding water content for each selected shear strength. A mechanical blender of (120 Liter) capacity is used to assure a thorough mixing of clay and the added water to get a homogenous even moisture distribution. The obtained wet clay is spread in successive six layers inside the testing box. After each layer is gently tamped with steel tamper (75 mm × 75 mm) in section in an aim to get rid any entrapped air in the soil. The top surface of each layer is scratched to assure good interface binding with the next top layer. After completion of all six layers the final layer is scraped and leveled and then covered with polyethylene sheet to avoid moisture loss from the prepared clay soil mass. A steel plate of (4 mm) thickness is then installed to cover the entire top surface of the finished clay mass in the testing box. After that a seating load of (5 kPa) was applied on top of the installed steel plate for a period of (24 hours) to assure homogeneity of the soil mass.

III. Installation of the Model Piles

After removing the seating pressure and steel plate, the model piles of a specified length are driven one by one vertically in the clay , shown in Figure 6, and care is taken to avoid the pile inclination while driving, the pile cap plate is placed over the piles and each pile is connected to the raft plate by a bolt. For the tests conducted on piles raft, firm contact between the soil bed and the raft was ensured. The closed top head of each pile is provided with a nut for a bolt of (4 mm) in diameter to connect the raft to the piles, as shown in Figure (7). The top surface of the soil was then covered with polyethylene sheet and left for a period of (2-3 days) to regain part of its strength.

6. Test Procedure

In tests of piled-raft (where the raft is in contact with soil), the load is applied in controlled steps (the loading system is load-controlled), each step being about one-twentieth of the estimated maximum load capacity and the load is kept constant for a time interval of not more than (15 min) according to the quick test of (ASTM-D1143M/2013) [9]. The loading is continued until the settlement was more than (10 %) of width of the raft; vertical displacement is measured at the raft surface using two displacement dial gauges. The loading of the piled-raft case is shown in Figure 8. In tests of free-standing groups, the pile cap simulated by a steel plate is installed to leave a gap about (25 mm) between the raft and the soil surface, as shown in Figure 9, to have the load being applied on the pile cap being transmitted to the piles only which represent the total piles resistance. The piles are loaded until failure in controlled loading steps, each step of about one-tenth of the estimated group load capacity, where each load increment remains for a time interval of not more than 15 min.

Figure 6: Installation of model piles in the clay

Figure 7: Preparation of a clay surface prior to connecting the pile cap to piles

Figure 8: Loading of piled raft test

Figure 9: Loading of freestanding pile group test

7. Results and Discussion

As mentioned earlier the testing program included two series where each of them is divided into four groups as illustrated below and each group is conducted at three different levels of clay shear strength, i.e. 20, 40 & 60 kPa.

1. Group of piles with spacing equals (3D) and length of piles (300 mm).
2. Group of piles with spacing equals (5D) and length of piles (300 mm).
3. Group of piles with spacing equals (3D) and length of piles (450 mm).
4. Group of piles with spacing equals (5D) and length of piles (450 mm).

For comparison purposes, the load settlement relation of pile tip together with the total pile load of the free standing pile group test are drawn with those for pile of piled raft test of the similar size of piles and undrained shear strength of soil, as shown in Figures 10 to 21. It can be seen from these figures, in general, that in the initial stages of loading till the settlement reached about (0.5 mm), the piles were exhibiting a very high stiffness, while beyond this level, even for a small increment in loading, the pile settled rapidly, which means that once the pile friction resistance is overcome the piles failed instantaneously. Also, it can be observed that in the initial stages of loading till the settlement reached about (1 mm) the pile group capacity increase remarkably and then increase at a lower rate so that the most of the load capacity of piles is mobilized at settlement of around (1–2 mm), corresponding to (5 %) of pile diameter (D). The pile settlement or displacement required to mobilize the maximum skin friction is quite small and is only of about (1%) of the pile diameter, while the pile base resistance requires a greater downward displacement for its full mobilization which is in the range of (5 to 10%) of the pile diameter, these findings are in agreement with the criterion illustrated in [10]. In addition, the variation of undrained shear strength of clay from (20 to 60 kPa) has no significant effect on the load transfer mechanism of piles for the two cases. In the tests of piles group, it is observed that when the full mobilization of the base resistance is accomplished, the pile plunges downwards without any decrease in the skin friction. The presence of the raft on piles has not influenced the behavior of piles that is part of a piled raft in comparison to the piles of freestanding pile group, so that the behavior of the two cases is almost the same. It can be seen that the load capacity of free standing piles group is approximately similar to the piles in piled raft case except some tests which may be attributed to the possibility of changing of soil characteristics in model tests, indicating that the interaction effect was not significant , and the presence of raft do not influence the behavior of piles, therefore, it can be concluded from these tests that the load capacity efficiency factor (α_G) is equal to one for piled raft in clayey soil, this efficiency factor represents the ratio of total load capacity of piles that are making part of piled raft system to the load capacity of piles in piles group due to the interactions that may occur between foundation components of piled rafts during apply the load, which is in agreement with the results found by [11].

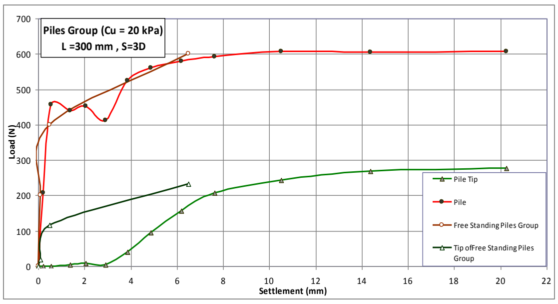


Figure 10: Load-settlement response of free standing pile group and piles of piled raft (L = 300 mm, S= 3D, c_u = 20 kPa)

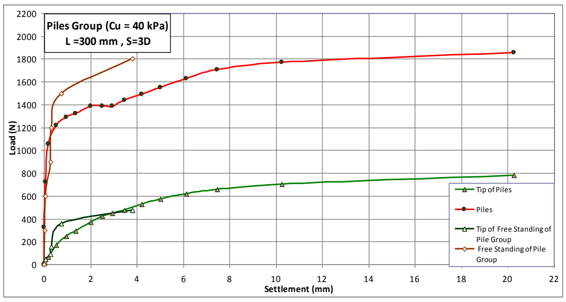


Figure 14: Load-settlement response of free standing pile group and piles of piled raft (L = 300 mm, S= 3D, c_u = 40 kPa).

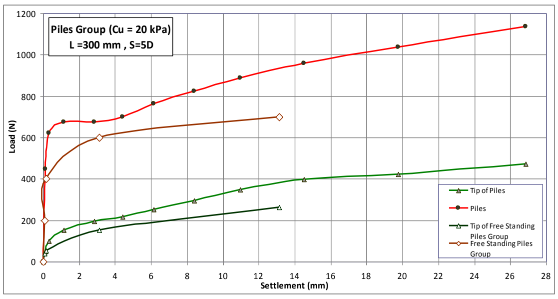


Figure 11: Load-settlement response of free standing pile group and piles of piled raft (L = 300 mm, S= 5D, c_u = 20 kPa)

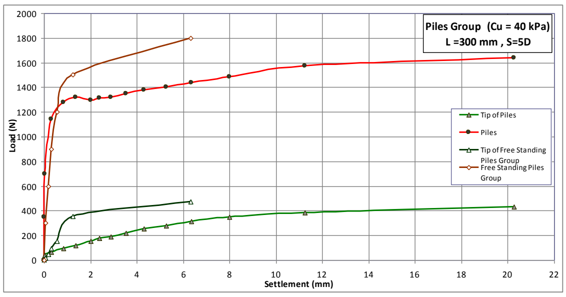


Figure 15: Load-settlement response of free standing pile group and piles of piled raft (L = 300 mm, S= 5D, c_u = 40 kPa)

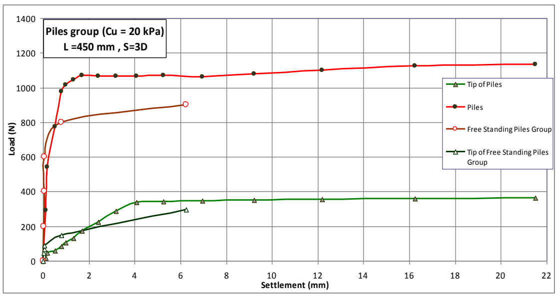


Figure 12: Load-settlement response of free standing pile group and piles of piled raft (L = 450 mm, S= 3D, c_u = 20 kPa)

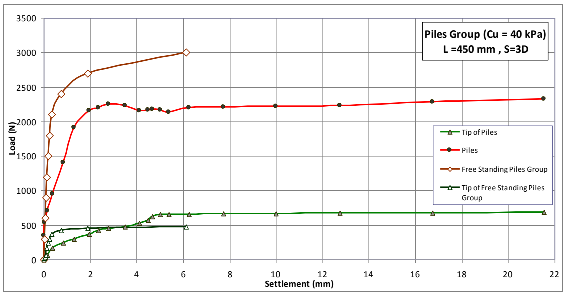


Figure 16: Load-settlement response of free standing pile group and piles of piled raft (L = 450 mm, S= 3D, c_u = 40 kPa)

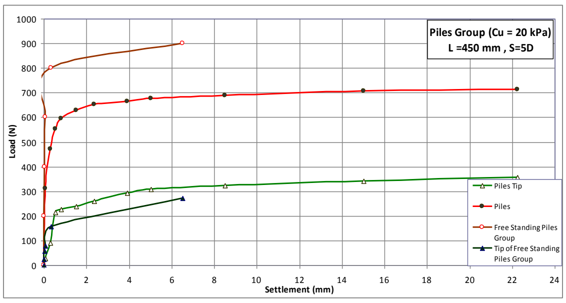


Figure 13: Load-settlement response of free standing pile group and piles of piled raft (L = 450 mm, S= 5D, c_u = 20 kPa)

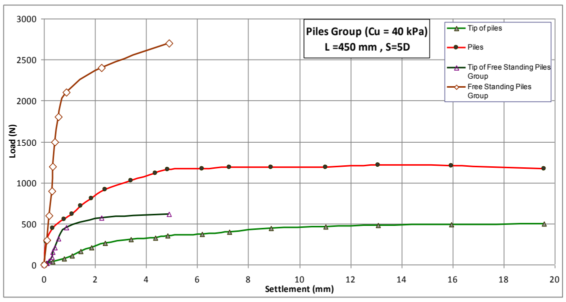


Figure 17: Load-settlement response of free standing pile group and piles of piled raft (L = 450 mm, S= 5D, c_u = 40 kPa)

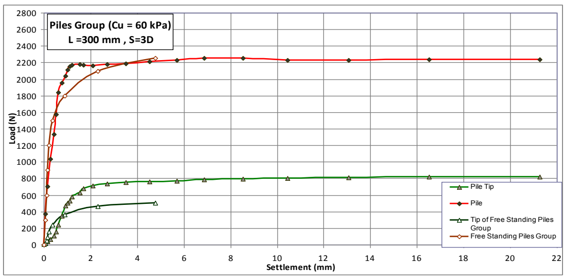


Figure 18: Load-settlement response of free standing pile group and piles of piled raft (L = 300 mm, S= 3D, c_u = 60 kPa)

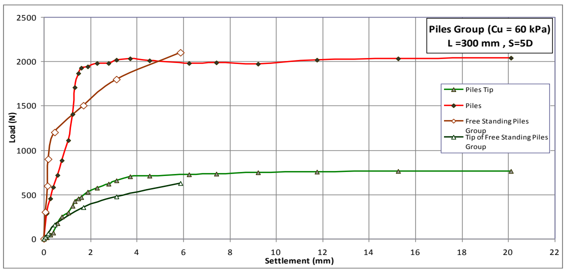


Figure 19: Load-settlement response of free standing pile group and piles of piled raft (L = 300 mm, S= 5D, c_u = 60 kPa)

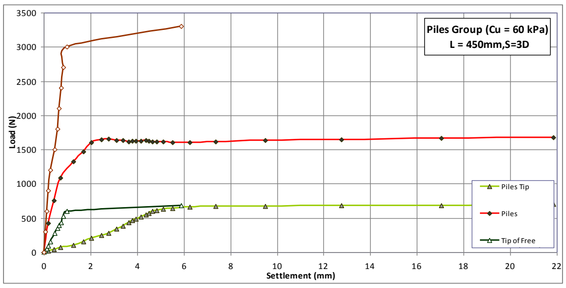


Figure 20: Load-settlement response of free standing pile group and piles of piled raft (L = 450 mm, S= 3D, c_u = 60 kPa)

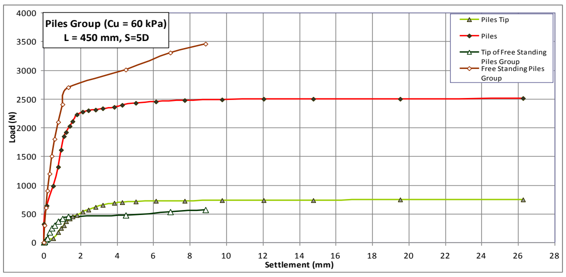


Figure 21: Load-settlement response of free standing pile group and piles of piled raft (L = 450 mm, S= 5D, c_u = 60 kPa)

8. Conclusions

Based on the results of the tests conducted throughout this task, it can be concluded that:

1. The pile group capacity apparently increases within the initial settlement range up to about (1 mm), and then the rate of increase is reduced considerably indicating that most of the load capacity of piles is mobilized at settlement of around (1– 2 mm), corresponding to (5 %) of pile diameter (D).
2. The pile settlement or displacement required to mobilize the maximum skin friction is quite small and is only of about (1%) of the pile diameter, while the pile base resistance requires a greater downward displacement for its full mobilization which is in the range of (5 to 10%) of the pile diameter.
3. The variation the undrained shear strength of clay from (20 to 60 kPa) has no significant effect on the load transfer mechanism of piles in the two cases.
4. The load capacity of the free standing pile group is about equal to the piles in piled raft case, therefore, it was concluded that the efficiency factor (α_G) of one can be used in designing piled raft in clayey soil.

Notations

The following symbols are used in this study:

c_u : Undrained strength of the clay.
D : Diameter of pile.
L : Length of pile.
S: Spacing between piles.

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