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Development Bearing Capacity of Piles Embedded in Clayey Soil

***Abstract**- The load carrying capacity of piles resulting from base resistance and shaft resistance, the load transfer mechanism of piles is complicated since the mode of failure of these components is different in addition to the effect of pile installation on the soil surrounding of piles .The intended task of this paper is studying the behavior of pile group model driven in clayey soil subjected to vertical axial loading, and the assessment of the development of resistance of each of the two components, tip resistance and skin friction of the piles of during loading. Twelve piles group tests are conducted at three grades of undrained shear strength (cu) of clayey soil which are (20 or 40 or 60 kPa) where 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 (Sp) used are (3D) and (5D). It was observed 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) , however, the development of full shaft resistance of piles appears at a low displacement range and is only of about (1 to 2 %) of the pile diameter while the pile end bearing will mobilize at a higher displacement range in the range of (5 to 10%).The changing of undrained shear strength of clay from (20 to 60 kPa) has no significant effect on the load transfer mechanism and the mobilization of shaft resistance and end bearing with increasing the settlement. It was concluded that a low ratio load sharing of piles tip, especially with increasing slenderness ratio (L/D) , which supports the fact that the piles in the weak clayey soils behave as a floating pile which leads to neglecting end bearing capacity in calculating the total pile load capacity as indicated by some references.*

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

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1. Introduction

Piles are structural members made of steel, concrete or timber that are used to build the pile foundation, which is used when the bearing capacity of the shallow top soil is not capable of supporting the structure via using any of the shallow foundation types. The load carrying capacity of piles resulting from the base resistance and the shaft resistance, the load transfer mechanism of piles is complicated since the mode of failure of these components is different in addition to the effect of pile installation on the soil surrounding of piles.The studying the load transfer mechanism by some researchers such as [1] and [2] from number of load tests indicates that the slip to develop skin friction is about (5 to 10 mm) and independent of pile diameter or pile length. However, according to [3] the maximum point resistance will not be mobilized until the tip of pile has moved about (10 to 25 %) of pile width Based on the available literature, it can be reported that there was a lack observed regarding an experimental study of the behavior of the base and the shaft pile resistance in clayey soil deposits due to the limited research in these types of soils which make the behavior is difficult to understand.The intended task of this paper is studying the behavior of pile group model driven in clayey soil subjected to vertical axial loading, and the assessment of the development of resistance of each of the two components, tip resistance and skin friction of the piles of under loading . It was decided to use a small-scale model, which is relatively inexpensive and can be performed under controlled soil conditions, and can provide an appropriate boundary condition for investigation. The tests are conducted at three grades of undrained shear strength (cu) of clayey soil which are (20 or 40 or 60 kPa) which simulates the clayey soil formation encountered in a large part of the central and southern areas of Iraq.

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2. Apparatus, Materials, and Testing Techniques

I. Testing box

A steel box is fabricated to contain the clay soil that supports the raft 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 due loading the piles during the 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 Plate (1).

III. The Soil

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

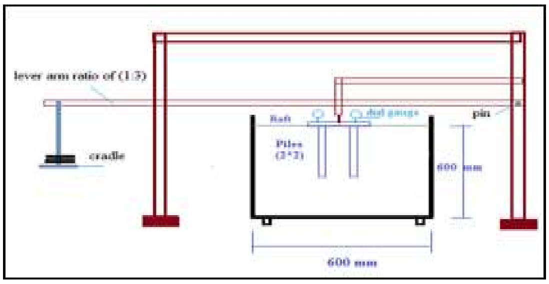

Plate 1: The loading system.

IV. 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 with that of an equivalent 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 pile cap 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.

Table 1: Physical properties of clay soil used.

Property	Value Index	Specification
Liquid limit (L.L)	48	ASTM-D4318-2010- [3]
Plastic limit (P.L)	25	ASTM-D4318-2010- [3]
Plasticity index (P.I)	23	ASTM-D4318-2010- [3]
Specific gravity (Gs)	2.69	ASTM-D854-2010-[4]
Gravel (larger than 4.75 mm)	0 %	ASTM-D422-2010-[5]
Sand (4.75mm to 0.0٧٥mm)	4 %	ASTM-D422-2010-[5]
Silt (0.0٧٥ mm to 0.005mm)	٤5 %	ASTM-D422-2010-[5]
Clay (less than 0.005 mm)	٥1 %	ASTM-D422-2010-[5]
Soil Classification	CL	USCS

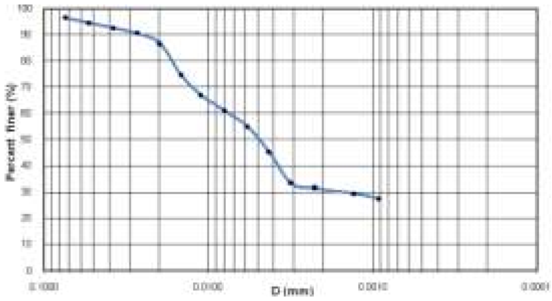

Figure 1: Grain size distribution of the used clay soil

V. Pile Cap

The pile cap model was simulated using a steel square plate of (5mm) thick and two sizes were used which are (150mm X 150 mm) for spacing (3D) and (210 mm X 210 mm) for (5D) spacing. A schematic diagram of the two-pile cap with piles group layout used in the experimental tests is shown in Figure 2.

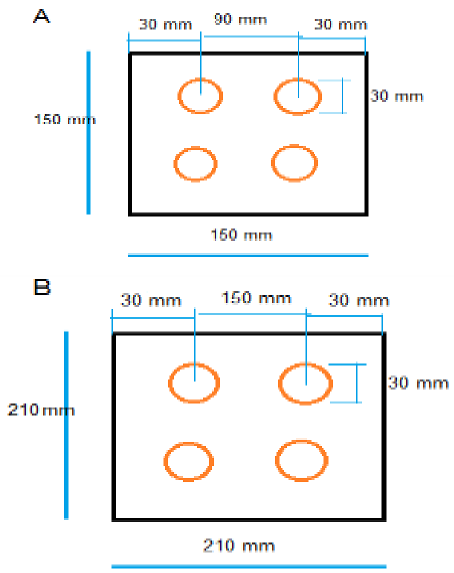

Figure 2: Piles group layout used in the experimental tests.

VI. 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, one load cell is used in each test, that is placed below the pile tip to measure the end bearing load during the test. The capacity of the load cell used is (1 kN) with (0.001 N) sensitivity, the load cell was calibrated and the output signals from the load cell was amplified by a factor of (1) to give the load in newton, A photograph of the instrumented model piles with load cell is shown in Plate (2).

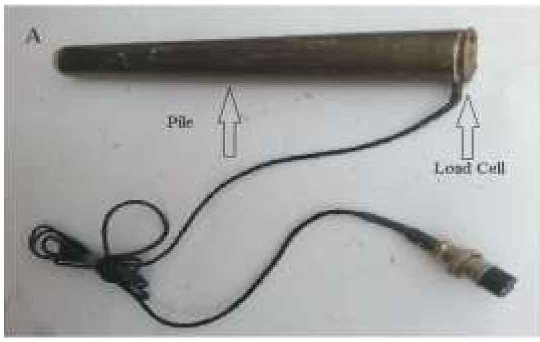

Plate 2: Instrumented model pile with load cell..

VII. Data Acquisition System

A 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 can be seen in Plate (3). 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.

VIII. Test Preparation

1. Calibration Test

Several trial tests were performed to construct a relation between shear strength and water content. Samples of soil were prepared individually and placed in three layers in CBR molds, each layer was tamped gently with special hammer to extract any entrapped air. The samples were then covered with polyethylene sheet and left for a period of two days to achieve a uniform distribution of moisture content.

Typical results for (cu) versus water content are illustrated in Figure 3, according to results illustrated in this Figure, several water contents are selected and are (30, 25 and 22 %) which will assure getting undrained shear strength (cu) of (20,40 and 60 kPa) respectively.

Plate 3: Data Acquisition System.

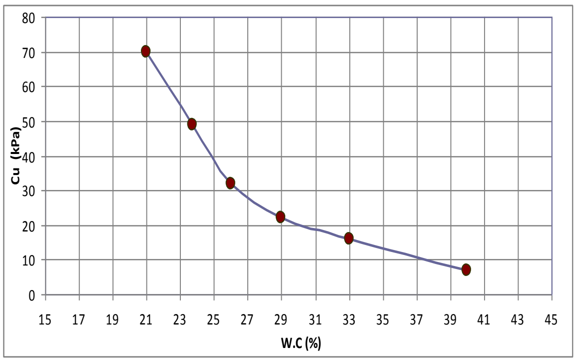

Figure 4: Variation of undrained shear strength versus water content of the clay.

٢. Preparation of Testing Box Soil

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 in 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, 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.

3. 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 mass (shown in Plate (4), and care is taken to avoid 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. 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, as shown in Plate (5). 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. After that, the undrained shear strength of soil is measured using a Vane shear device.

Plate 4: Installation of the model pile in the clay

Plate 5: Preparation of a clay surface prior to connecting the pile cap to piles

IX. Test Procedure

The pile cap simulating a steel plate is installed to leave a gap about (25 mm) between the raft and the soil surface to have the load being applied on the pile cap being transmitted to the piles only and not to the soil subgrade underlying this pile cap. One load cell is used in this case and is placed at the pile tip to measure the pile end bearing and the total load is solely applied on the piles through the raft plate, 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 is kept constant for a time interval of not more than (15 min) according to the quick test of (ASTM- D1143M/2013) [6]. Vertical displacement is measured at the top pile cap surface using two displacement dial gauges and so the load settlement curve is then obtained, the loading assembly is shown in Plate (6).

Plate 6: Loading assembly of the test.

3. Results and Discussions

Twelve tests of freestanding pile group are conducted with two different spacing (Sp) of (3D) and (5D), where (D) is the pile diameter, and with two different pile lengths of (300 mm) and (450 mm). The group of piles tests named as (GP) are divided into four categories, as shown in Table (2), where each one was conducted in three levels of clay strength (cu = 20, 40 and 60 kPa):

Table 2: Categories of Pile Group Tests

Test Name	Slenderness Ratio (L/D)	Spacing/Pile Diameter (S_p /D)
GP (L=300mm, S_p =3D)	10	3
GP (L=300mm, S_p =5D)	10	5
GP (L=450mm, S_p =3D)	15	3
GP (L=450mm, S_p =5D)	15	5

The maximum load sustained by the pile group from the load settlement curve is considered the ultimate load capacity. The load responses of pile group under loading are shown in Figures 4 to (16).

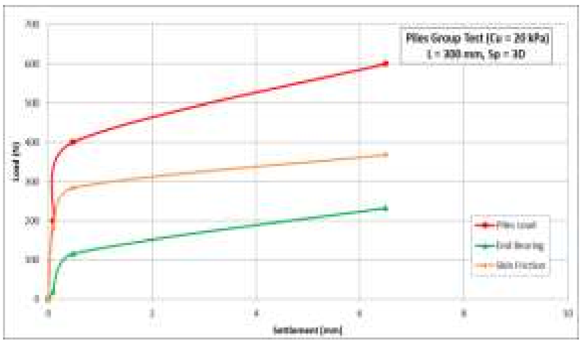

Figure 4: Pile Group Test (L= 300 mm, S_p = 3D, c_u = 20 kPa).

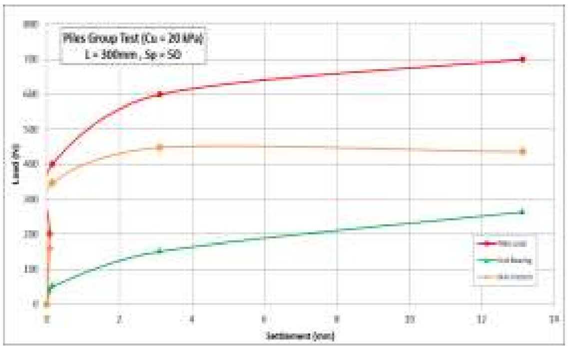

Figure 5: Pile Group Test (L= 300 mm, S_p = 5D, c_u = 20 kPa).

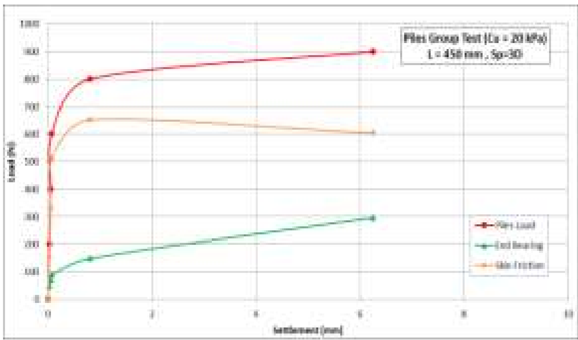

Figure 6: Pile Group Test (L= 450 mm, S_p = 3D, c_u = 20 kPa).

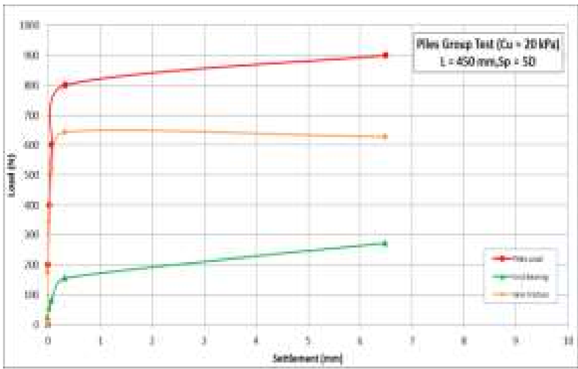

Figure 7: Pile Group Test (L= 450 mm, S_p = 5D, c_u = 20 kPa).

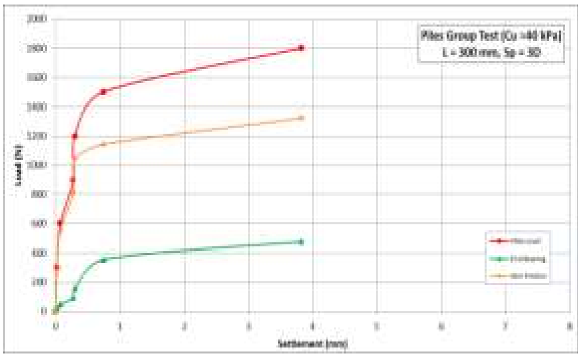

Figure 8:Pile Group Test (L= 300 mm, S_p = 3D, c_u = 40 kPa).

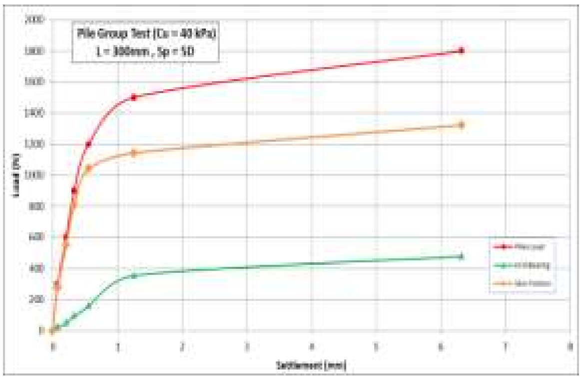

Figure 9: Pile Group Test (L= 300 mm, S_p = 5D, c_u = 40 kPa).

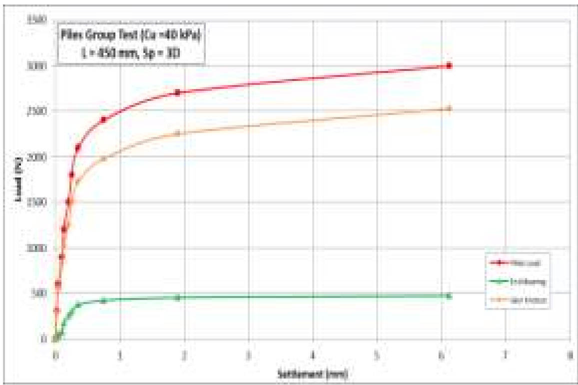

Figure 10: Pile Group Test (L= 450 mm, S_p = 3D, c_u = 40 kPa).

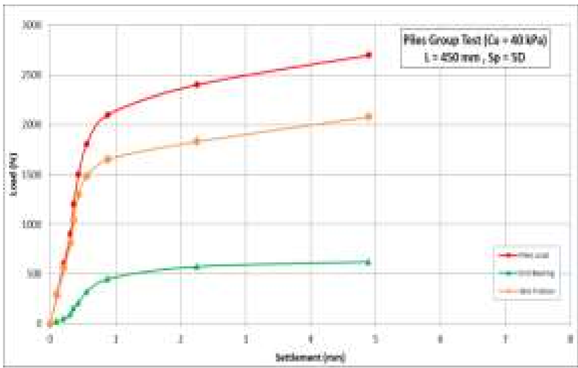

Figure 11: Pile Group Test (L= 450 mm, S_p = 5D, c_u = 40 kPa).

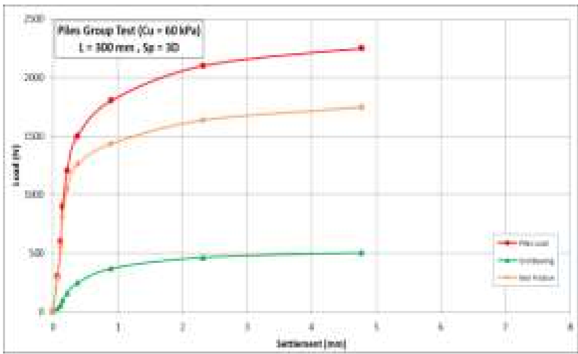

Figure 12: Piles Group Test (L= 300 mm, S_p = 3D, c_u = 60 kPa).

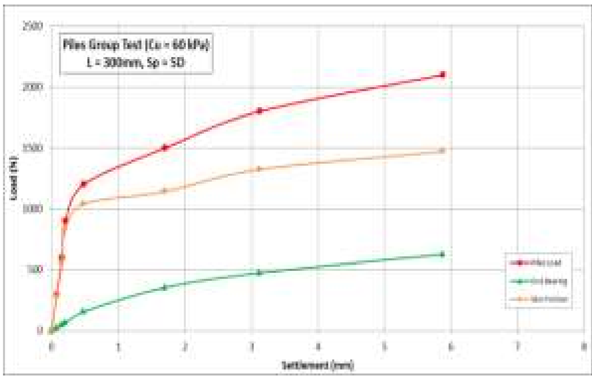

Figure 13: Pile Group Test (L= 300 mm, S_p = 5D, c_u = 60 kPa).

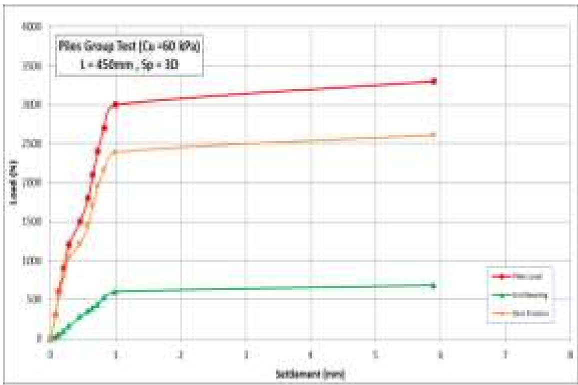

Figure 14: Pile Group Test (L= 450 mm, S_p = 3D, c_u = 60 kPa).

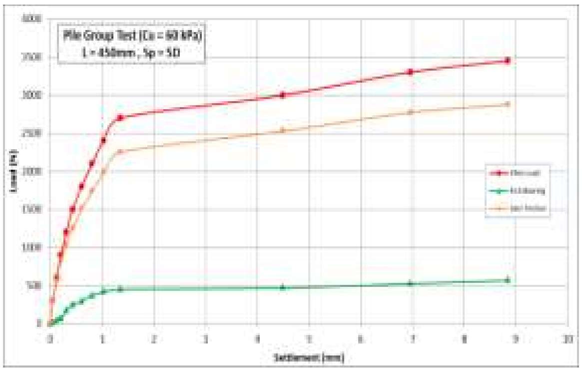

Figure 15: Pile Group Test (L= 450 mm, S_p = 5D, c_u = 60 kPa).

Table 3: Summary of the ultimate piles group capacity for the tests performed.

No.	Test	Ultimate piles group capacity (N)		
		c_u =20	c_u =40	c_u =60
1	GP (L = 300 mm, S_p = 3D)	600	1800	2250
2	GP (L = 300 mm, S_p = 5D)	600	1800	2100
3	GP (L = 450 mm, S_p = 3D)	900	3000	3300
4	GP (L = 450 mm, S_p = 5D)	900	2700	3450

It can be observed from Figures 4 to 15) in general, that in the initial stages of loading till the settlement reached about (1 mm) the pile group capacity increase markedly and then increase moderately so that the load capacity of piles is almost fully mobilized at settlement of around (1 – 2 mm), corresponding to (5 %) of pile diameter (D) which is in agreement with the results observed from centrifuge load tests conducted by [7]. Moreover the shaft resistance is mobilized before the end bearing, however 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 [8].

In addition, when the loading will have reached maximum capacity, applying a small increment in the load, the pile group settled rapidly, which means that once the friction is overcome the pile group failed instantaneously. While observing the result shown in Table (3), it was noticed that the increase in pile spacing from (3D) to (5D), there is not a significant effect on the ultimate piles group capacity. The changing of undrained shear strength of clay from (20 to 60 kPa) has no significant effect on the load transfer mechanism and the mobilization of shaft resistance and end bearing with increasing the settlement.

It was noticed that a low ratio of piles tip load sharing, especially with piles of length (450 mm) that represents the slenderness ratio (L/D) of (15) , which supports the fact that the piles in the weak clayey soils behave as a floating pile which leads to neglecting end bearing capacity in calculating the total pile load capacity as indicated by some references.

4. Conclusions

Based on the results of the tests of driven model piles in clayey soil 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 the 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 development of full shaft resistance of piles appears at a low displacement range and is only of about (1 to 2 %) of the pile diameter while the pile end bearing will mobilize at a higher displacement range in the range of (5 to 10%), but, as the loading increases there is no further increase in the load transferred as a skin friction and the tip load will reach its maximum value.
3. The changing of undrained shear strength of clay from (20 to 60 kPa) has no significant effect on the load transfer mechanism and the mobilization of shaft resistance and end bearing with increasing the settlement.
4. A low ratio of piles tip load sharing is noticed, especially with increasing slenderness ratio (L/D), which supports the fact that the piles in the weak clayey soils behave as a floating pile, which leads to neglecting end bearing capacity in calculating the total pile load capacity as indicated by some references

The following symbols are used in this study:

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

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