Behaviour of Contiguous Piles Group with Different Pile Diameters in Sandy Soil under Vertical Loading

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ABSTRACT

This study deals with identifying the behavior of contiguous pile groups subjected to vertical load and the corresponding soil failure. A wide range of geometrical parameters were represented in order to study the effect of these parameters on the behavior of pile group including spacing between piles and diameter of piles (D) in the group. To study the effect of diameter, the piles used in the laboratory tests were 3 and 5 cm in diameter and 35cm in length. D to 2D spacing between piles were also adopted. The sand used in the experimental program had two different densities. The tests were executed in a wide tank containing the sand as well as models of pile groups. Using the experimental model results, relations between load and settlement were utilized to estimate the bearing capacity of the pile group. From the test results, it was found that increasing the spacing between piles and diameter of piles in a group causes increase of the bearing capacity of the pile group. However, decreasing the pile spacing reduced the load capacity of the pile group.

INTRODUCTION

Piles are columnar elements in a foundation which have the function of transferring load from the superstructure through weak compressible strata or through water, onto stiffer or more compact and less compressible soils or onto rock. They may be required to carry uplift loads when used to support tall structures subjected to overturning forces from winds or waves. Piles used in marine structures are subjected to lateral loads from the impact of berthing ships and from waves.

Combinations of vertical and horizontal loads occur when piles are used to support retaining walls, bridge piers and abutments, and machinery foundations (Bowles, (1977).

There are two approaches when considering the bearing capacity of piles (Hansen,1959):

1- The designs which aim at preventing of a local failure which is usually termed "elastic analysis". The failure occurs when any pile in the piles group reaches its ultimate capacity.

2- The designs which aimed at preventing of a total failure which is usually termed "ultimate analysis". In this case, the pile group under a given load would not be expected to its ultimate until it becomes a mechanism.

The ultimate bearing capacity of piles group under loading is defined as the load at the displacement reaches its maximum, in this case it is necessary to have a marked break in the curve of the relation between load and deflection (Vesic,1969; Mayerhof and Ranjan,1973). The common criteria of pile group failure are:

1- The point where the slope of the curve for the load- settlement relationship reaches a certain value.
2-The value of load causing a net settlement after rebound in excess of a specific magnitude.
3-The value of load causing a gross settlement in excess of specific magnitude.

In recent years, the problems of the implementation and design of contiguous piles in sandy soils, as a deep foundation, have been observed, because the distances between piles are closer than stated in the code may lead to a change in the behavior of piles and the soil around them. Since it is difficult to simulate such geotechnical problems mathematically, the problem has to be tackle experimentally (Mostafa et al 2020).

These problems can be drawn in three case:

- First: When there are neighbor columns in the architectural drawings located above the piles row. The usual solutions are to increase the dimensions of the beam sections over the piles row and link them with the surrounding footings.
- Second: during design of the pile capes according to the loads and piles distribution, it can be found that overlapping between pile caps, as a result of distributing the piles with spacing 2.5-3D, according to the code. The usual solution is to provide a combined pile cap footing to keep the spacing between piles as specified in the Code.
- Third: when the conflict of the pile cap locations is found between drawings and site during execution, which leads to the displacement of the base and thus moving the column from its place as a result of increase of the

dimensions of the capes of piles with spacing according to the Code (Mostafa et al, 2020).

Solution of these problems can be increasing diameter of piles and decreasing the spacing between piles. Laboratory tests by making models representing cases of contiguous piles in sandy soil, were used to reveal their behavior in terms of the bearing capacity and settlement. Evaluation of parameters can then be obtained so that engineering design can be adequately performed (Mostafa et al, 2020).

The design of contiguous deep foundations subjected to vertical loads should be designed so that they satisfy three conditions: i) the pile group should be able to carry the load with an adequate margin of safety, ii) the settlement of the foundation under load should not be higher than the tolerable settlement of the structure it supports, iii) the soil around the pile should not be loaded so heavily that it reaches its ultimate load-carrying capacity (Mostafa et al, 2020).

APPARATUS, MATERIAL AND TESTING TECHNIQUE

The essential objective of the laboratory work implemented in this paper is to study the behavior of the load settlement curves for contiguous pile groups with different arrangements. The following sections describe the test setup used in the model tests, the arrangement of piles in the group, the physical properties of the material and the program and procedures of the test.

Test Setup

The model test is shown in Fig. (1). It consists of: steel frame, soil tank, model pile, loading machine and two dial gauges for measuring the displacement and load.

Fig. (1): Set up of the model test

Physical Properties of Soil

The physical properties of the sand used in the tests are shown in the following table. The grain size distribution is shown in Fig. (2).

1	Density of top layer	14.2 kN/m3
2	Density of bottom layer	18.1 kN/m3
3	Friction angle of top layer	31°
4	Friction angle of bottom layer	40°
5	Specific gravity (Gs)	2.62

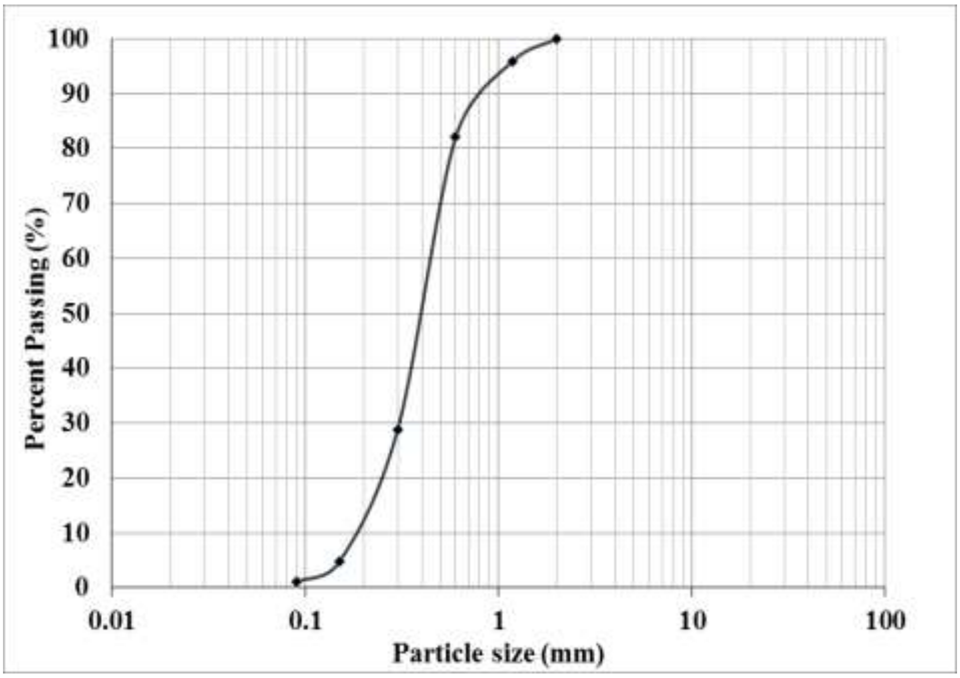

Fig. (2): Grading Characteristics of the Used Sand

The Materials of Piles and Caps

- The dimensions and materials of the piles used in these test are as follows:
  - Solid wood cylinders are used in tests simulating piles.
  - Piles diameter =30, 50 mm, pile length = 350 mm.
  - The pile cap is made of steel plates with various sizes according to the piles configuration in a group.

The configuration of pile groups is shown in Fig. 3.

Fig. (3): Configuration of pile group, (a) : piles with D= 3 cm, (b) piles with D = 5 cm.

Tank Used in Tests:

There is a direct relation between the dimensions of the sand container and the model pile size. The choice of the dimensions of the container was made according to the following two criteria (Hirayama, 1988):

1. The size should be big enough (depth and width) to minimize the effects of the rigid boundary on the test results.
2. The size of the container should be as minimum as it could be to minimize the effort of filling and emptying with sand.

The dimensions of the steel tank used in the experimental work are 80 x 80 cm in plan, and 80 cm depth, as shown in Fig. 4. The four steel sides of the tank were stiffened with steel plates. Plates were welded at the sides of tank every 266 mm. These stiffeners were be adopted to ensure the tank rigidity.

Fig. (4): Details of steel tank used in model tests

Test procedure

According to the test setup, tests on contiguous pile groups were carried out with the following methods:

1. The required weight of each layer of soil to be placed in tank is calculated by knowing the volume of the soil and its density.

2. Compacted sand is placed in five layers; each layer was dynamically compacted by rod weighing 4.5 kg over the whole area.
3. The piles are placed in the center, and the soil is well compacted under piles and next to them.
4. The piles are set in their place and the soil for the upper layer with known weight is placed around the piles and leveled.
5. The tank is set in its place on the base of the frame with steel rod connected with the compressor to apply load on piles group.
6. The compaction load and settlement are measured by dial gauge.
7. The test was repeated with the same steps, but with changing the configuration of piles.

RESULTS AND DISCUSSIONS

- As mentioned before, the aim of this research is to identify the bearing capacity of contiguous pile groups subjected to vertical load. To achieve this goal, the load-settlement curves were drawn for each test.
- The load-settlement curves in terms of load were obtained by plotting the relationship between applied vertical load and its corresponding settlement, as shown in Figs.5 to 9.
- The pile loading program was carried out using wood piles with diameters of 30 mm. The effect of changing of spacing between piles with different diameters on the capacity of pile groups can be noted by the shape of curve and the inferred values.
- By knowing the values of piles group capacity from the laboratory test, we can compare these values with that for plies group with spacing equal 2.5D and slenderness ratio (L/D > 10) according to Egyptian Code.
- Figure.10 exhibits the variation of piles group capacities between this study case and according to the E.C. It is notes that, the value of group capacity decrease with the same number and dimensions of piles when the decreasing the spacing between piles, therefore the capacity of the pile will decrease by the following ratios (as shown in Fig.11) :

  - About 10% at spacing equal 2D,
  - 12% at spacing equal 1.5 D, and
  - 17% at spacing equal D.

where: D = Diameter of pile.

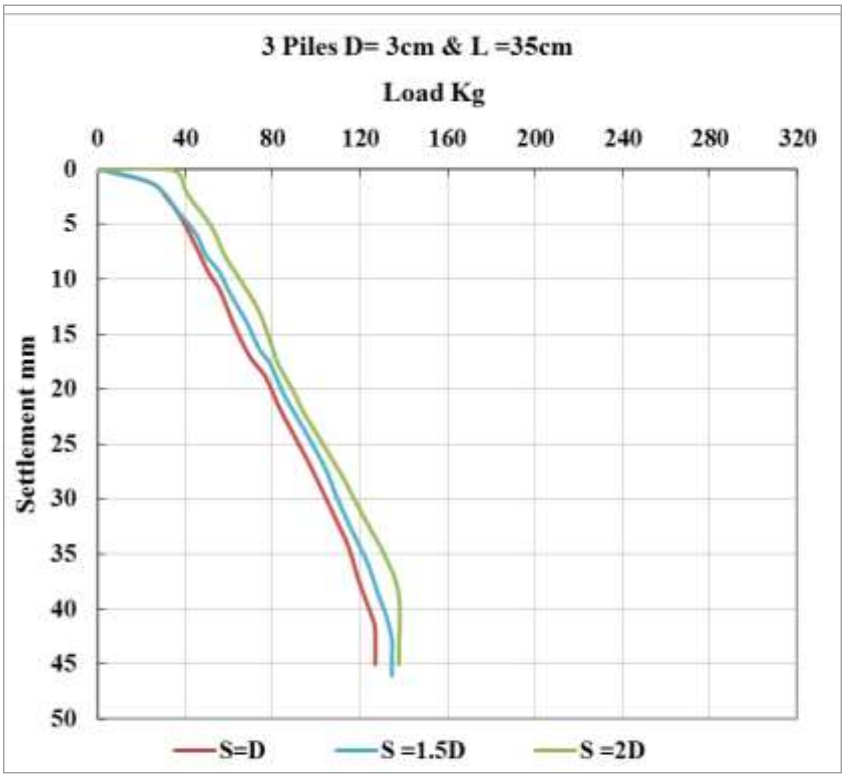

Fig. (5): Load –Settlement curve for (3 x1) pile group with spacing (S =D, 1.5D and 2D) and diameter equal 3 cm

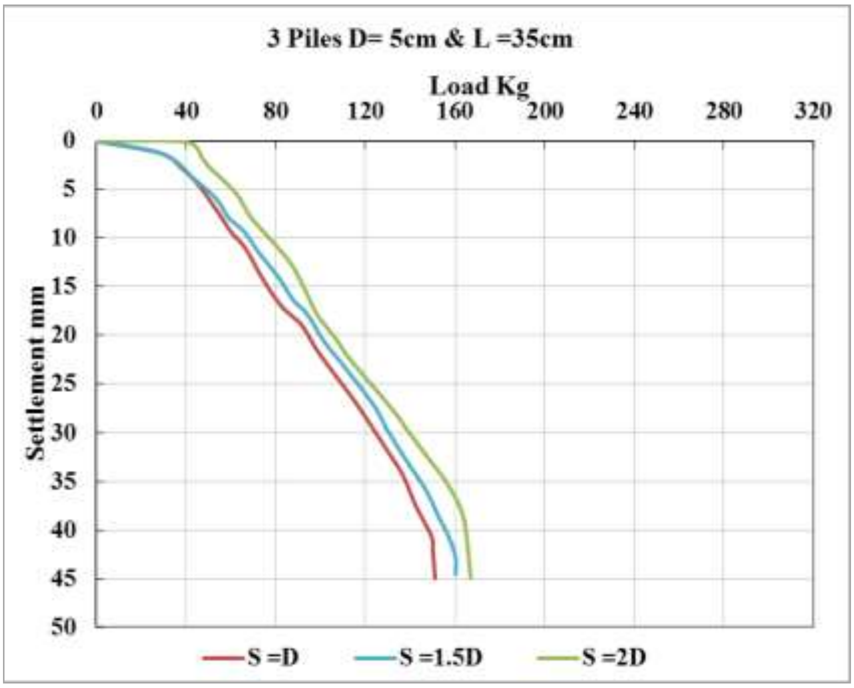

Fig. (6): Load –Settlement curve for (3 x1) pile group with spacing (S =D, 1.5D and 2D) and diameter equal 5 cm

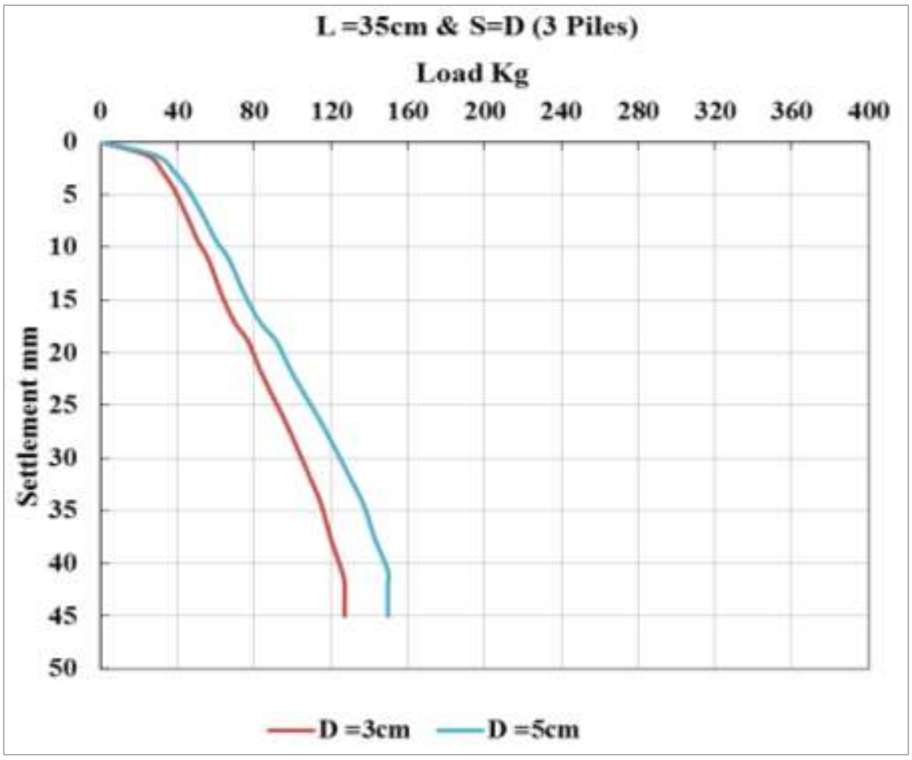

Fig. (7): Load –Settlement curve for (3 x1) pile group with spacing (S =D) and diameter (D= 3 ,5 cm)

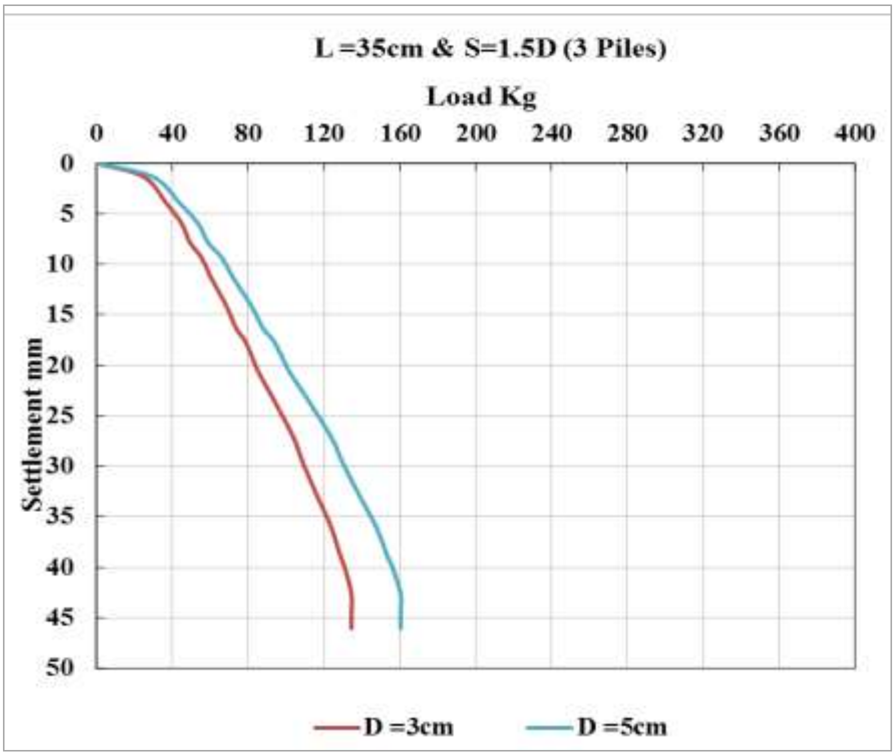

Fig. (8): Load –Settlement curve for (3 x1) pile group with spacing (S =1.5D) and diameter (D= 3 ,5 cm)

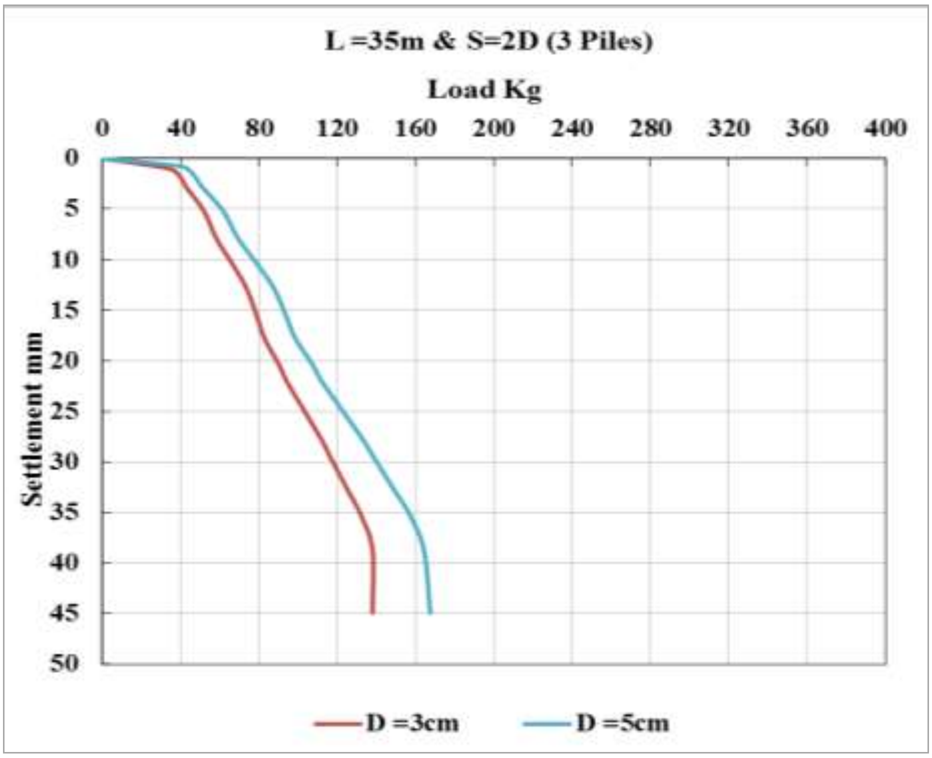

Fig. (9): Load –Settlement curve for (3 x1) pile group with spacing (S =2) and diameter (D= 3 ,5 cm)

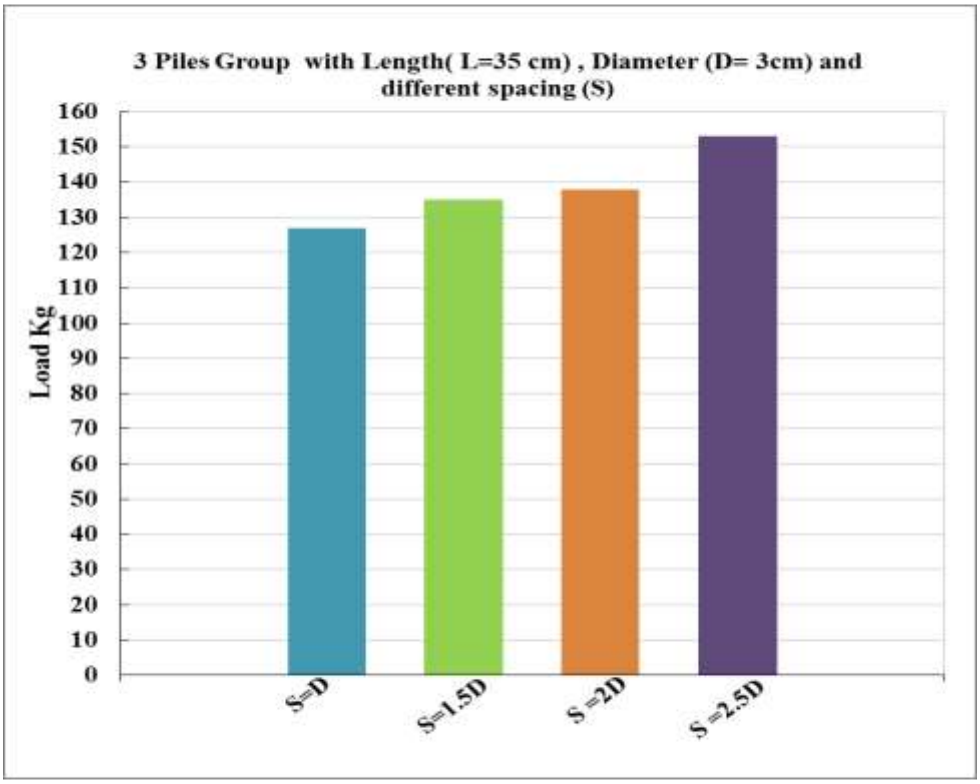

Fig. (10): Comparison between piles group capacities with different spacing between piles

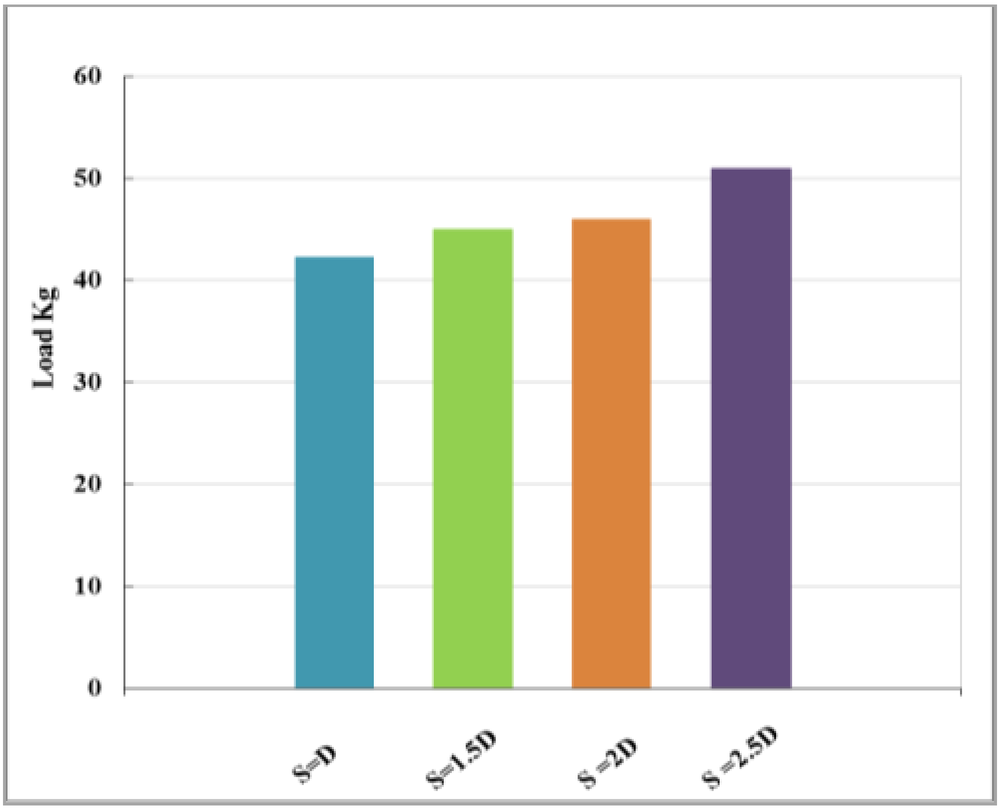

Fig. (11): Comparison between pile capacities in groups with different spacing between piles

CONCLUSIONS

Based on the experimental work carried out, the following are the main conclusions:

- At the initial stage of settlement, the bearing capacity of pile group will not be changed with change of the spacing between piles.
- At the middle and later stages of settlement, increase of bearing capacity of the pile group is noted. The trend of the load settlement curve drops gently.
- The load of pile group increases as the diameter of piles increases at the same spacing between piles.
- The load of pile group increases as the spacing between piles increases at the same number and diameter of piles in the group.
- The piles group capacities obtained from this study compared with the E.C is about 10 to 17%, depending on the decrease of spacing between piles in the group.
- To solve the aforementioned problems, the value of the pile capacity is reduced, the diameter increased and the distances between the piles reduced to preserve the value of the design group's capacity without having to move the piles cap and column location, or change the architectural design.
- The use of contiguous piles is an economical way to solve implementation and design problems and reduce costs.

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