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

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ABSTRACT

This study is concerned 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 investigate the effect of these parameters on the behavior of the pile group including spacing between piles and number of piles in group. To study the effect of length, the piles used in laboratory tests were 3 cm in diameter and 30 cm in length. D to 2D spacing between piles were also adopted. The sand used in the experimental program had two different densities. The scope of research includes tests on vertical loaded contiguous pile groups in sand. The tests were executed in a wide tank containing the sand as well as models of pile groups. Using the experimental model results, relations 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 number of piles in a group causes increase of the bearing capacity of the pile group.

INTRODUCTION

PILE FOUNDATIONS are a type of foundations commonly used in engineering practice to carry the loads from heavy structures such as multi-storied buildings, bridges, highways, embankments, to the underlying soil safely without settlement problems (Katzenbach, 2000). The pile foundations are used when the near - surface soil with relatively low bearing capacity is unable to support foundation loads, or the possibility that settlement become excessive when foundations are executed at shallow depth. Therefore, shallow foundations are not practical or economical (Meyerhof, 1976).

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 cases, 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. 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)

To solve these problems by increasing the number of piles and decreasing the spacing between piles, laboratory tests were used by making models representing the cases of contiguous piles in sandy soil 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 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, and iii) the soil around the pile should not be loaded so heavily that it reaches its ultimate load-carrying capacity.

The behavior of pile and group at working loads and ultimate capacity is described in two basic considerations, the settlement and load transfer. At lower loads, the behavior of pile and group may be described as elastic behavior and the increasing of settlement is assumed approximately linearly with increasing the load (Vesic, 1969).

To determine the allowable load on pile or group, the ultimate capacity can be used as a guide. The allowable load is usually one-half to one third the ultimate. The ultimate capacity of a pile or group will be the limiting load value, if structural settlements are not of major concern (Hunter,1969). The behavior of pile group at ultimate capacity is usually analyzed with limit state design theory. Then, some factor is applied to describe group behavior under allowable loads. However, evidence suggests that the application of the factor may not be a valid design approach. Furthermore, in the elastic rang the pattern of load-deformation for the pile group may be quite different than that at ultimate group capacity (Bowles,1978).

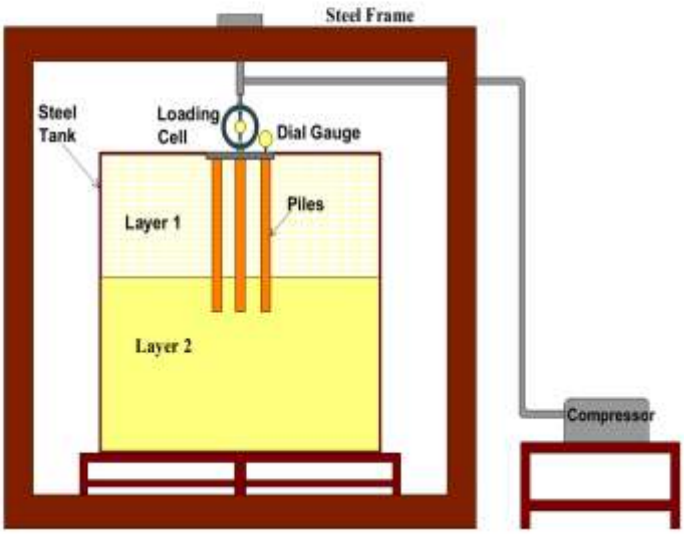
METHODOLOGY AND MATERIAL

The main purpose of the experimental work implemented in this paper is to study the load settlement behavior of contiguous pile groups with different configurations. The following sections describe the test setup used to perform the model test, the configuration of model pile group, material properties, the testing program and procedures.

Loading system

The loading system is shown in Figure (1a,b). This system was designed to be rigid and capable of sustaining the high stresses involved without suffering from excessive deflections.

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



(a) (b)

Fig. (1a,b): Details of the loading system

Soil Properties

The sand used for the model test is well graded. Figure (2) shows the compaction characteristics of the sand. The properties of sand are summarized as below.

- Density of sand :
  - For upper layer (1) = 14.2 kN/m3
  - For lower layer (2) = 18.1 kN/m3
- Angle of internal friction:
  - For upper layer (1) = 31°
  - For Lower layer (2) = 40°

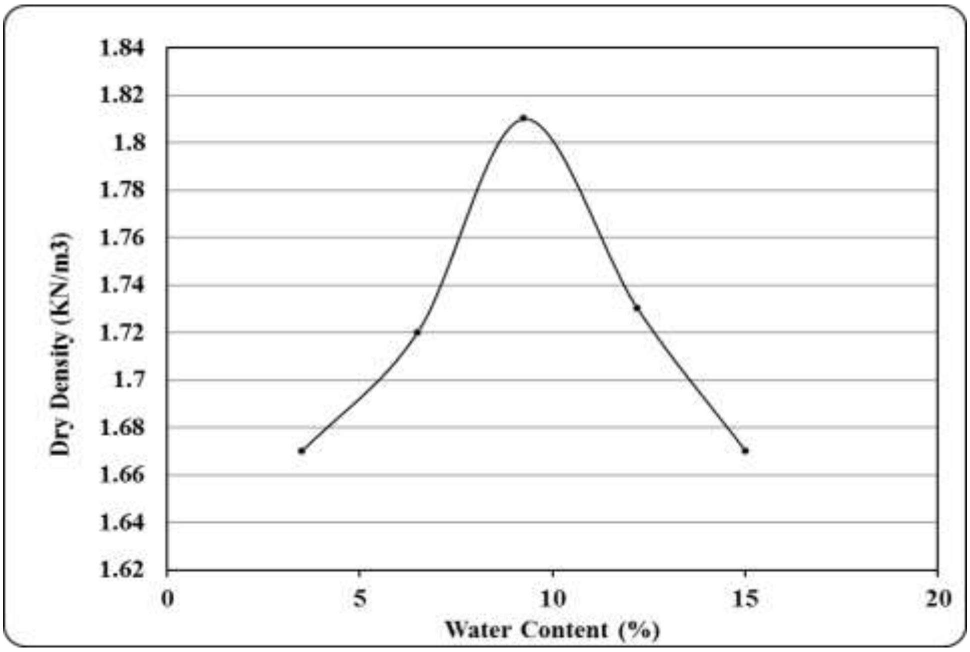


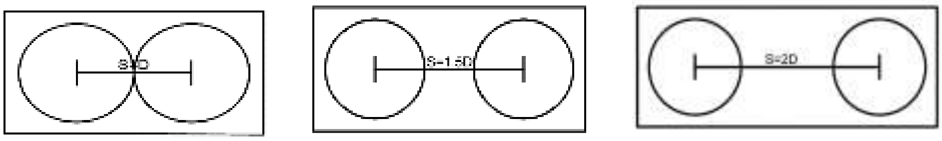
Fig. (2): Compaction characteristics of the used Sand

Pile and Pile Cap Materials

The dimensions and materials of piles used in this test are as follows:

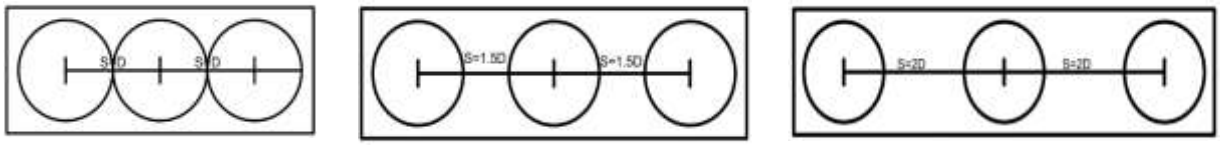
- The piles used in this test are solid wood posts.
- The diameters of piles (D) =30 mm, the length (L)= 300 mm.
- The pile cap used in the tests were made of steel to form a good bond with the piles. Its size varied according to the number of piles in a group and the spacing (S) between piles.
- Screw bolts were used to bond the wood piles with the steel pile cap.

Details of pile group is shown in Figures (3) and (4).



(a) (b) (c)

Fig. (3) : Pile group arrangements for 2 Piles with spacing between piles (a): S=D, (b) =1.5D and (c) =2D



(a) (b) (c)

Fig. (4) : Pile group arrangements for 3 Piles with spacing between piles (a): S=D, (b) =1.5D and (c) =2D

Soil Tank:

A steel tank was used in the experimental work with internal dimension 80 x 80 cm in plan and 80 cm deep, as shown in Fig. (5). The four steel sides of the tank were stiffened with plates every 266 mm. These plates were welded at the sides of tank, as shown in Fig. (5). These stiffeners were adopted to ensure the tank rigidity.

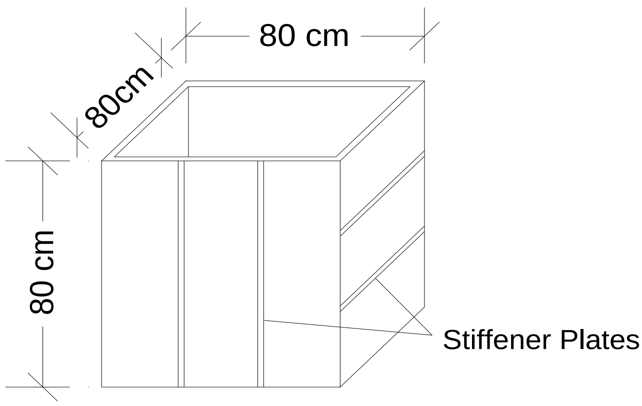


Fig. (5): Details of Steel tank used in model test

Test procedure

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

1. Knowing the volume of the soil and its density, the required weight of each density of soil to be placed in the model is calculated.

2. The calculated weight of sand for the lower layer (layer 2) is placed in five layers. Each layer was dynamically compacted by means of a compaction rod weighing 4.5 kg over the whole area.
3. The surface of the soil is levelled using a straight steel rod.
4. The piles are placed in the center, and the soil is well compacted under piles and next to them.
5. The piles are set in their place and the soil for the upper layer with known weight is placed around the piles and leveled.
6. The tank is set in its place on the base of the frame.
7. The load is applied to piles group by the steel rod connected with the compressor.
8. The compaction load and settlement are mean by dial gauge.
9. The test procedure was repeated with changing the arrangement of piles.

PRESENTATION OF 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 Fig. (6 to 10). The pile loading program was carried out using wood piles with diameters of 30 mm. To study the effect of spacing and number of piles on the values of bearing capacity, the spacing between piles in the pile group was D, 1.5D and 2D and number of piles of 2 and 3 (Mostafa et al 2020).

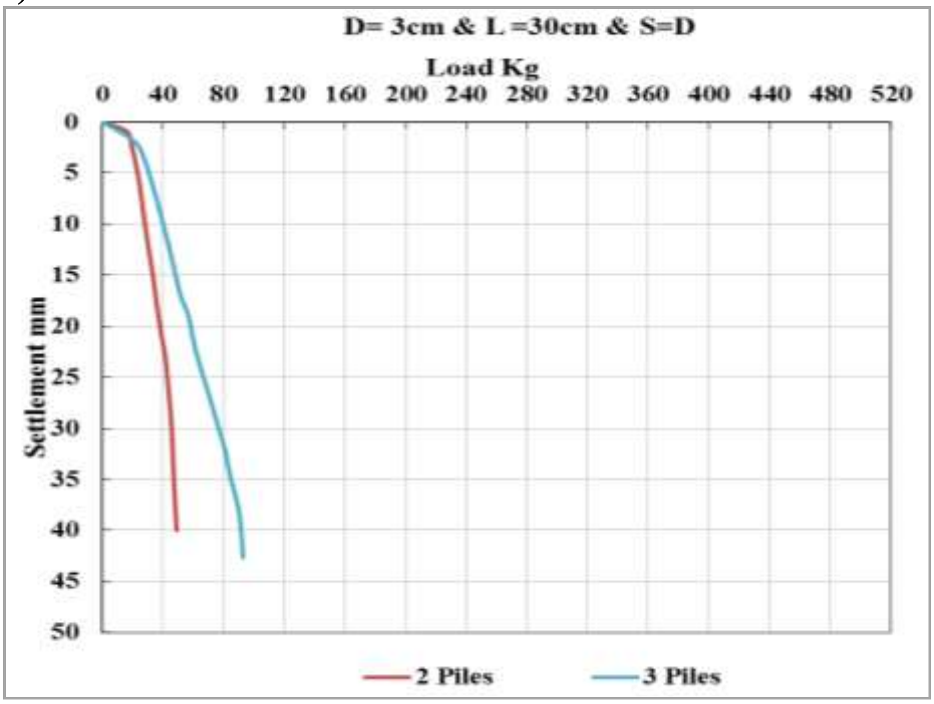


Fig. (6): Load –Settlement curve for (2 x1) and (3 x1) pile group with spacing (S =D)

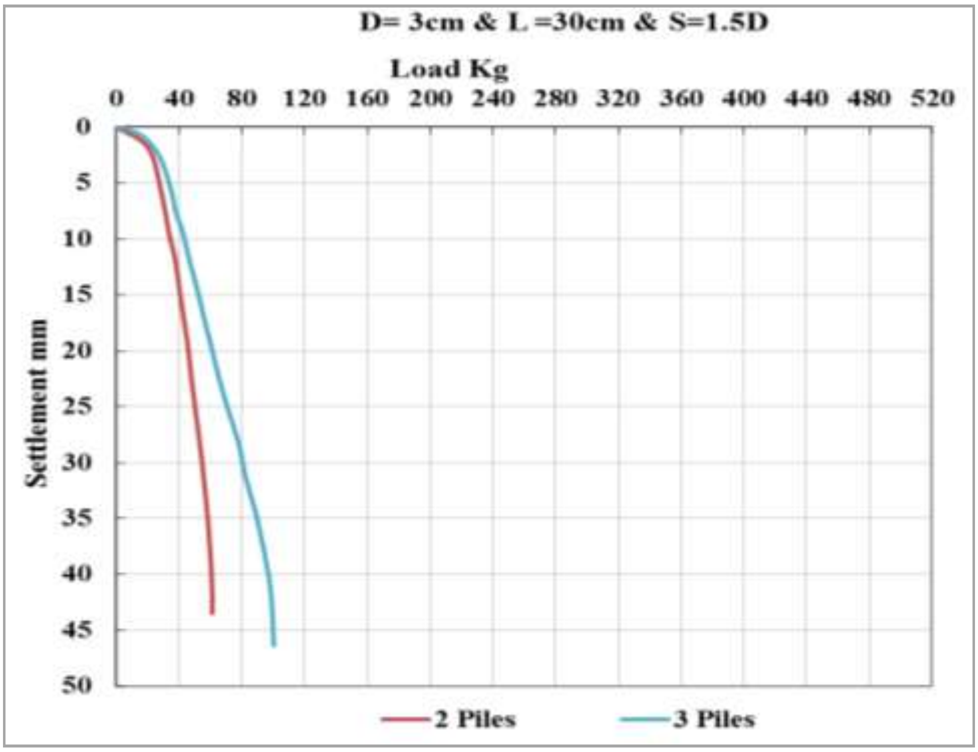


Fig. (7): Load –Settlement curve for (2 x 1) and (3 x 1) pile group with spacing (S=1.5D)

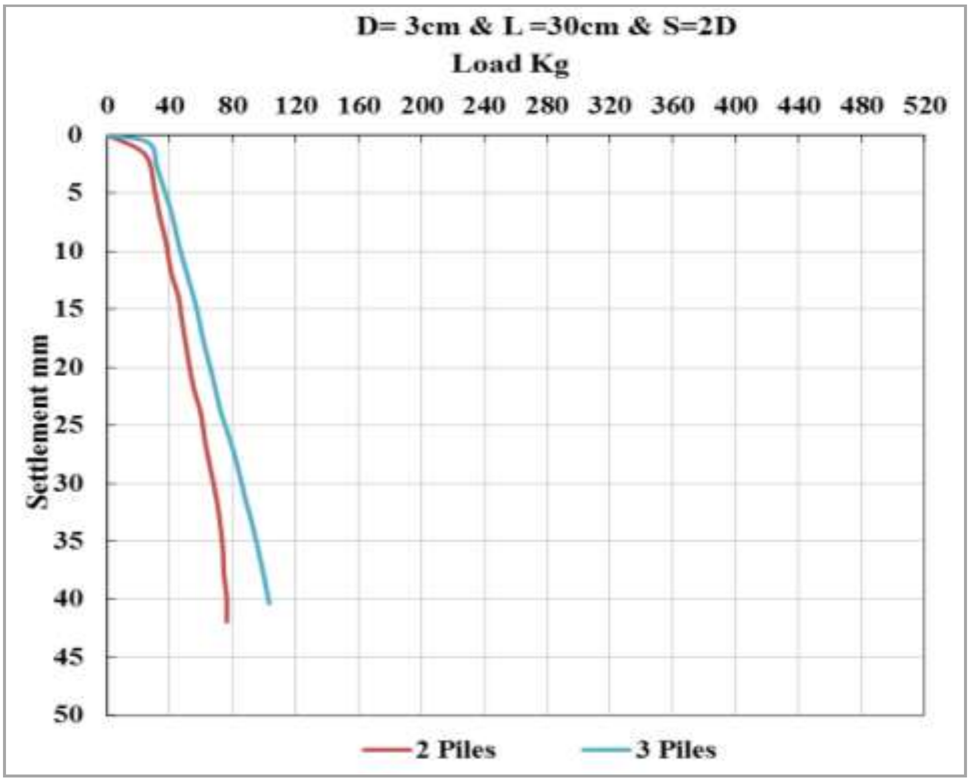


Fig. (8): Load –Settlement curve for (2x1) and (3x1) pile group with spacing (S = 2D)

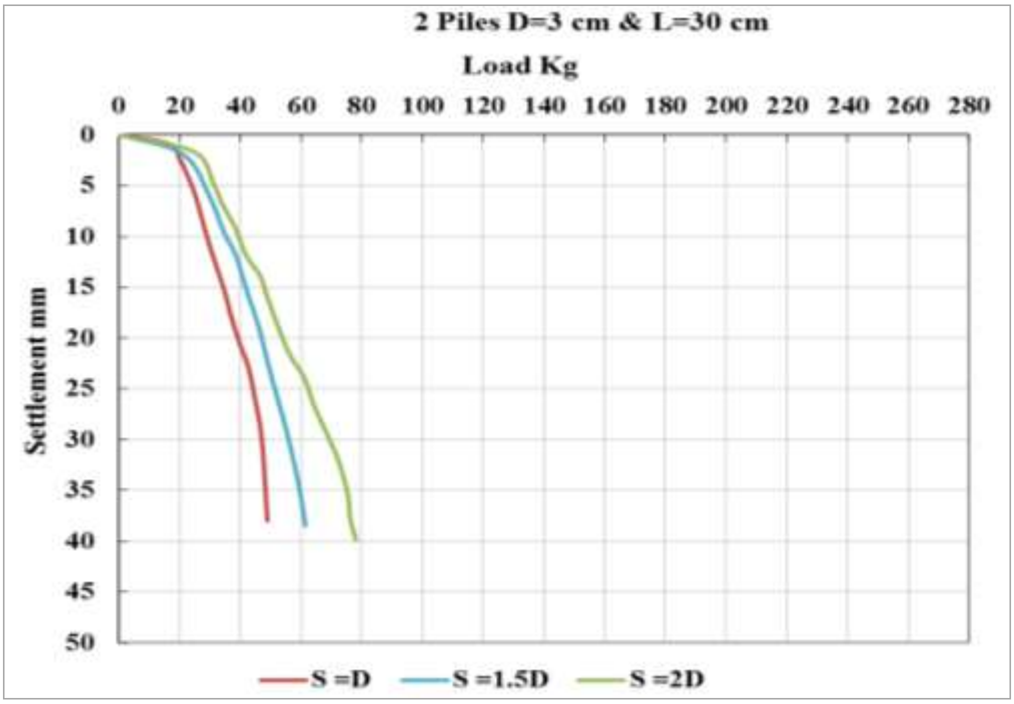


Fig. (9): Load –Settlement curve for (2 x 1) pile group with spacing (S = D,1.5D and 2D)

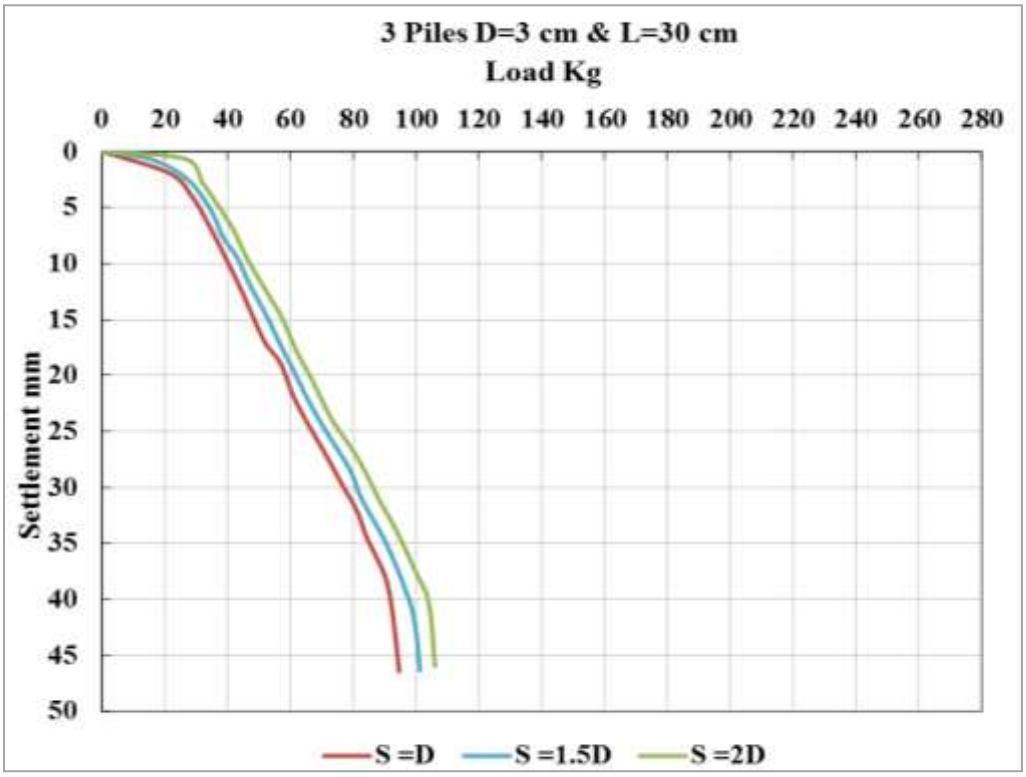


Fig. (10): Load –Settlement curve for (3x1) pile group with spacing (S= D,1.5D and 2D)

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 cannot 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 and the performance of the load settlement curve drops gently.
- The load of pile group increases as the number 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 of piles in the group.
- To solve the aforementioned problems, the value of the pile capacity is reduced, the number 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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