EXPERIMENTAL STUDY ON LOAD CARRYING CAPACITY OF INDIVIDUAL PILES IN A PILED RAFT FOUNDATION SYSTEM

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Abstract- Raft foundations are provided, in case isolated footing fills more than 70 % area of building under a superstructure. The term "piled raft foundation" refers to a foundation that incorporates the usage of piles and rafts. When high-rise buildings are constructed on soil of low bearing capacity or on fill material, piled raft foundation system have proven to be cost-effective without compromising serviceability and bearing capacity requirements. The use of tactically positioned piles beneath a raft can increases the raft's load bearing capacity and decreases differential settlements. Current study is focused on evaluation of individual piles' load carrying capacity in a piled raft foundation system embedded in poorly graded sand with relative density of 35 %. A small-scaled model was prepared in the laboratory containing galvanized iron piles and aluminum raft. The piles were instrumented through strain gauges in order to measure the load resisted by each pile. The piled raft model was placed in the center of sand container and subjected to vertical load. It was found that the load bearing capacity of piled raft is much greater as compared isolated pile and raft only.

Keywords- Piles, Raft, Piled raft foundation system, Load sharing capacity, small scaled model

1 Introduction

Foundations are the most significant and important part of civil engineering structures. The main function of foundation is, to take load from superstructure and transfer it into underlying soil to ensure structure stability and serviceability requirements. As foundation is one of the most important and critical part of any civil engineering structure so it should be designed very carefully because foundation failure will lead to failure of whole structure. The three main types of foundations for high rise buildings are, raft foundation, pile foundation and piled raft foundation. When the subsoil is having good bearing capacity like gravel and dense sand, raft foundation system is most economic option for high-rise buildings. Example are Trianon tower , Trianon tower is about 190 m high, and Main Plaza tower which is about 90 m high, both are good examples, in frankfurt In which settlement are less than 100 mm and tilting less than 1:800 [1]. When upper soil layer is weak, having low bearing capacity and unable to support load from superstructure, piles foundations are provided to transfer the load to hard strata. The load from superstructure is transferred to soil via skin friction or end bearing or by the combination of end bearing as well as skin friction. Piled raft foundation is an amalgamation of raft which is called shallow foundation, and piles (deep foundation) in which load is shared between raft and piles to enhance load carrying capacity of soil and reduce structural settlements. Arrangement of piles can be adjusted to reduce differential settlement of foundation system and improve load bearing capacity of raft. In traditional design philosophy of piled raft foundation, it was assumed that the total load from superstructure is resisted by piles while ignoring the contribution of raft [2]. As raft is directly get in touch with soil, so it bears a considerable portion of load from superstructure, making the traditional method of design of piled raft too conservative. If contribution of raft is ignored, the number and length of piles will be increased, making the design uneconomical. The design philosophy for piled raft foundation system is now changing, acknowledging the contribution of raft in a piled raft foundation system. Piles are not only designed to take load from superstructure but also work as to reduce settlements [3]. A piled raft foundation has composite soil structure interaction. Care be required to be taken in the analysis of pile soil interaction, raft soil interaction, pile, pile interaction and pile raft interaction [4]. For high rise buildings, the majority of piled raft foundations were constructed on Frankfurt clay using settlement-reducing piles[5]. The tactically positioning of piles can improve the raft's load bearing capacity and tend to decrease differential, settlements [6]. Davids conducted experimental study and showed that the load from superstructures is shared between raft as well as piles, in which piles resist about 50 to 80 % of the total applied load while the remaining load was beard by raft [7]. The part of vertical loading from the super structure is transferred to the underneath soil via raft contact pressure, which varies from 30 to 60 % of the total vertical applied load; depending on the condition of soil under raft. The above percentage is not constant, as the pile length decreases, the load carried by raft increases. Also, load carrying capacity of raft increases while increasing spacing between piles. They also demonstrated that, in the case of weak soil or soft clay, the piled raft system is suitable for high-rise buildings in terms of bearing capacity and serviceability requirements [8]. Hemsley predicted that, the contribution of raft is about 50 % of the total load from superstructure[9]. When designing a piled raft system, it was revealed that the raft resisted load in a piled raft foundation system ranged from 25 to 51 % of the total applied load applied, with an average assessment of 36 %. The load from superstructure is divided among raft and piles, while the piles system usually resisting about 50 to 80 % of the total applied load and transferring such load in deeper strata [10]. From previous few decades, high rise buildings especially in Gulf area has been constructed, on piled raft foundation system. Few of them include as Burj Khalifa in Dubai and QIPCO tower in Doha[11]. According to available research study, most of researcher worked on combined load bearing capacity of piles in a piled raft foundation system. The main purpose of this study is to explore the individual piles load sharing capacity in piled raft foundation system.

2 Experimental Study

2.1 Scope

The core purpose of this study is to evaluate the load sharing capacity of individual piles in a piled raft foundation system under vertical load. For this purpose, a small scale model was prepared in the laboratory and subjected to vertical loading to predict individual piles load sharing capacity, as inadequate research has been carried out on individual behavior of piles under vertical loading. So the modern age demand to conduct experimental study using small scale model to predict individual piles load carrying capacity. This study also aims for the estimation of piled raft settlement against applied vertical load.

2.2 Test Equipment

To study the individual piles' load sharing capacity in a piled raft foundation system, a small scale piled raft model was prepared in the laboratory and filled with loose sand. The raft was modeled square with dimension of 30 x 30 cm and 2.54 cm thickness. The raft was made of aluminum with modulus of elasticity 69 GPa. Holes were provided within raft surface for installation of piles in different configurations. In total 25 holes with 1.3 cm diameter and 6.35 cm center-to-center spacing were drilled into raft surface. The piles were made of Galvanized iron having modulus of elasticity of 200 GPa. The piles were made circular and hollow from inner side. Diameter of the piles was 1.905 cm and they were attached with raft using nut bolts assembly. Nine (09) piles were manufactured in the laboratory having length of 45 cm. Calibrated strain gauges were installed on each pile to predict the load taken by individual piles. A calibrated vertical load cell with maximum capacity of 08 ton was also installed to verify the load taken by piles as observed by strain gauges. LVDTs (Liner Variable Displacement Transducer) with their tips placing vertically on raft were installed on each side of raft. The accuracy of LVDTs was 0.01 mm and their purpose was to measure vertical displacements (Settlements) and rotation of piled raft in case of differential settlement. The general view of the load test equipment and description of each part is shown in figure.1

Figure 1: General view of vertical loading test arrangements

1. Vertical load arrangements
2. Vertical load cell
3. Raft
4. Sand container
5. Frame supporting for pluviator
6. Data logger
7. LVDTs

Load was applied concentrically and vertically on the piled raft model and vertical displacement (settlements) were recorded with the help of LVDTs as installed at raft surface via data logger. The soil container was rectangular with dimensions of 1.50 m height, 1.20m length, and 0.90m width and was made of steel. The dimension of sand container is large enough to satisfy boundary condition. The sand container was made large enough in order to satisfy boundary conditions. The soil container was strengthened by providing supports to the side walls of container. The purpose of providing extra supports was to prevent the container from bulging while applying load on pile raft model. The piled raft model was placed accurately in the center of sand container. To ensure the horizontal and vertical leveling of test model, spirit level was used.

3 Experimental Procedures

The soil used for this study was poorly graded sand. Grain size distribution analysis was carried out using a set of sieves as per ASTM D-422. The grain size distribution curve has been plotted and presented in figure 2. Coefficient of curvature (Cc) and uniformity coefficient (Cu) calculated were 0.72 and 3.12, respectively. The sand has been classified as poorly graded. The properties of sand have been listed in table 1. As per ASTM D-4254 and D-4253, the minimum and maximum unit weights were 106 pcf and 92 pcf, respectively. Testing was carried out at relative density of 35%. This density was obtained through mobile pluviator. The mobile pluviator was calibrated by falling sand from sand cone through different heights. The desired density was obtained by falling sand from height of 9.5 inch. In order to maintain uniformity of sample a shutter with 13mm holes is attached at the bottom of sand cone. As the height of sand container is 1.50 m so it was filled in 10 layers while each layer of sand is 15 cm.

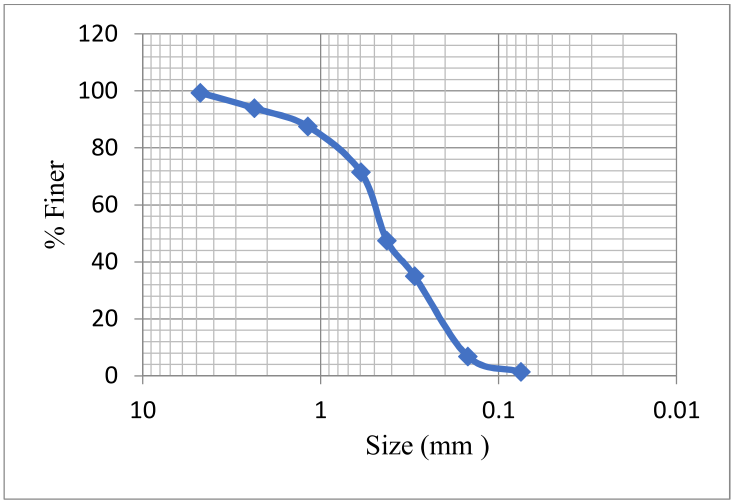

Figure 2: Sieve Analysis

Parameter	Value	Remarks
D60	0.5	
D50	0.46	
D30	0.24	
D10	0.16	SP because $C_u < 6$ and $C_c < 1$
Coefficient of Uniformity (CU)	3.12	
Coefficient of curvature (CC)	0.72	
Maximum unit weight	106 PCF	
Minimum unit weight	92 PCF	

Table 1: Properties of sand

4 Results and Discussion

Following different configurations were made and will be discussed in subsequent sections.

a. Single pile only
b. Raft only
c. 04 piled raft

4.1 Single pile

Load bearing capacity of single pile was determined by subjecting pile to vertical load. The pile was installed at the centre of sand container and LVDTs were installed to measure settlement. At a load of 272 N, a very high settlement value of 6.8mm was measured, that is about 36% of pile diameter. Load settlement curve for tested pile has been shown in figure 3. A linear relationship was observed.

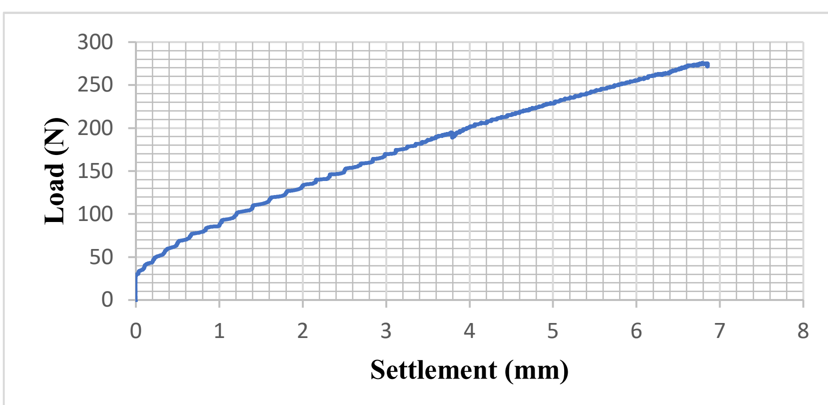

Figure 03: Load verse Settlement curve of single pile

4.2 Raft only

The behaviour of raft to vertical loading was observed by placing raft in the centre of sand container after sand pluviation. 5000 N vertical load was applied and load verse settlement curve was plotted as illustrated in figure 4. From figure, it is clear that the raft settles 7.6 mm at 5000 N load. Although, settlement to load ratio for raft is less than that of single pile but still it is too high to be not allowed for practical situations.

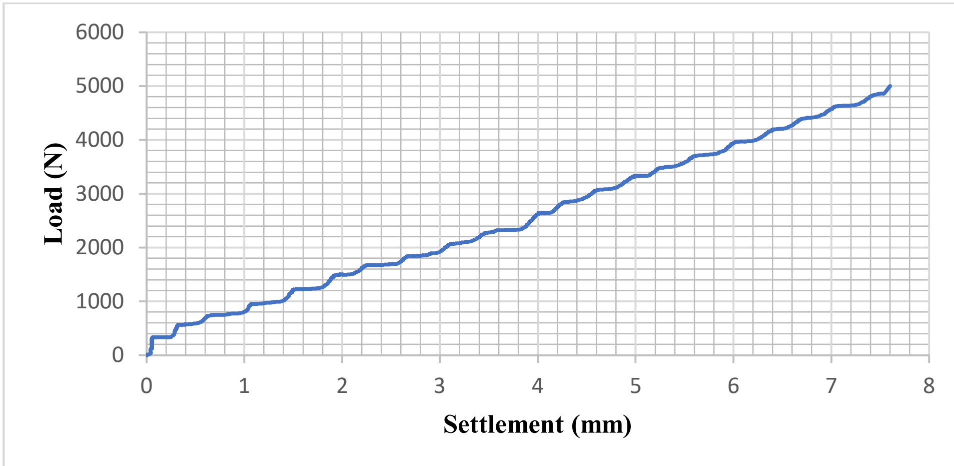

Figure 4: Load verse settlement curve of raft

4.3 04 Piled Raft

Four piles were attached rigidly with the help of nut and bolt to raft with centre to centre distance of 25 cm and subjected to vertical loading up to 5000 N. The contributions of piles to vertical loading are presented in figure 5. As it is clear from graph that a total of 5000 N vertical load was applied to piled raft. The load taken by piles in this case was 57.7% and load beard by raft was 42.3% at settlement of about 3.6 mm. Initially the contribution of raft is less but as vertical load increases, the soil beneath the raft gets compacted and stiffness of soil increases causing an increase in its load sharing. It is clear from figure that with further increase in load, the contribution of raft increases, at some point beyond 4.1mm the raft contribution to load reaches to 50 %. So, it is clear that for a piled raft foundation system constructed on loose sand, initially load sharing of raft is less but with increase in load, the soil gets compacted and raft contribution tend to increase.

Load shared by individual piles in a piled raft foundation system is presented in figure 6. From figure, it is clear that all the piles carry almost same amount of load. So, we can say that some portion of load was beard by raft and remaining load was uniformly shared with piles. Figure 7 summarized the above discussion by presenting the percentage load carried by raft, piles and individual piles.

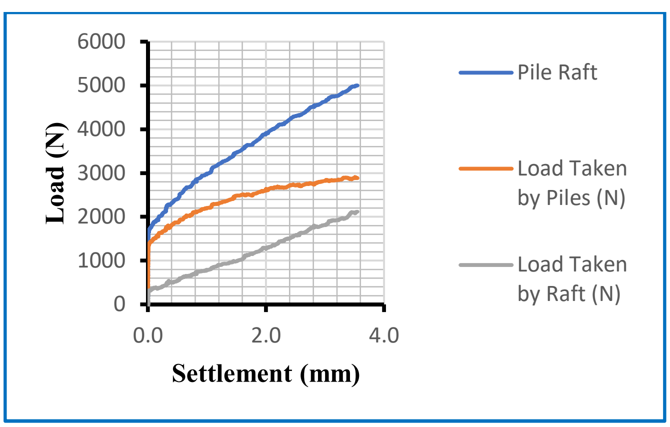

Figure 5: Load verse settlement curve of 04 piled raft

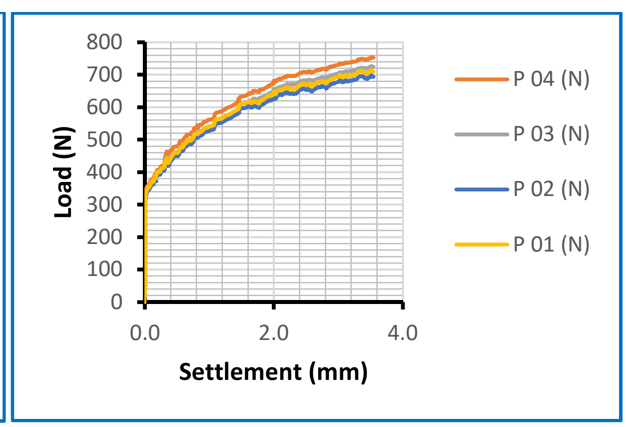

Figure 6: Load verse settlement curve of individual piles pileraft

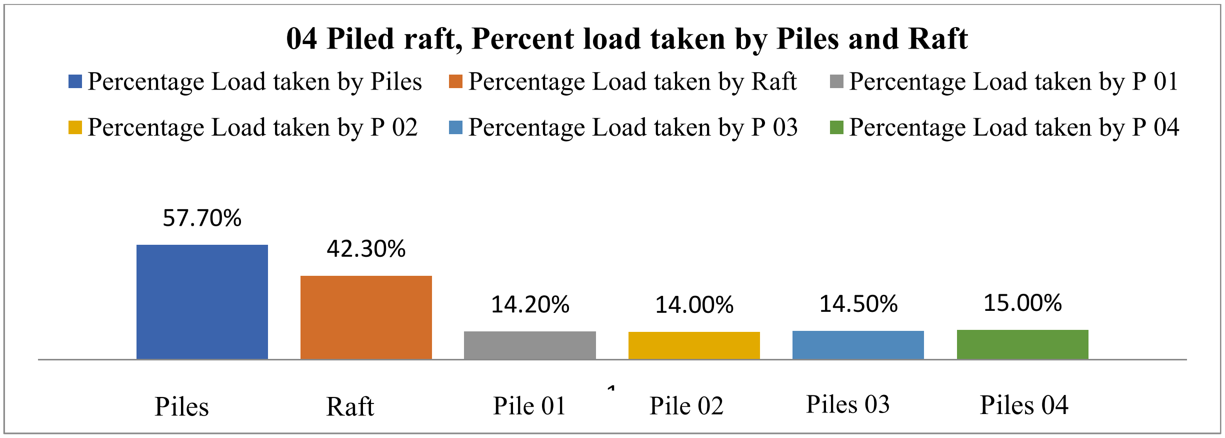

Figure 7: Percentage load taken by piles and raft

5 Conclusions

Based on current experimental study, the following conclusions can be made:

1. Single pile is not efficient to take vertical loads and settles down significantly under nominal load. By providing raft, settlement will be reduced.
2. In piled raft foundation, the piles not only take load as transferred via raft but also act settlement reducer.
3. Raft with no pile bears load of 5000 N at a settlement of 7.6 mm but with the addition of 4 piles with the same raft and same loading conditions, the settlement was reduced to 3.6mm. With the addition of 4 piles the settlement was reduced about 50%.
4. In a piled raft foundation system with four piles, applied vertical load is uniformly distributed among all the piles.

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