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An Experimental Study on Lateral Contribution of Raft and Pile in a Piled Raft Foundation System

[a]Abrar Ullah*, [b]Naveed Ahmad, [c]Kiramat Ali

a: Civil Engineering, University of Engineering and Technology Taxila, engr.abrarullah@gmail.com
b: Civil Engineering, University of Engineering and Technology Taxila, Naveed.ahmad@uettaxila.edu.pk
c: Civil Engineering, University of engineering and Technology Peshawar, kiramatali30@gmail.com
* Corresponding author: Email ID: engr.abrarullah@gmail.com

Abstract- In the recent past, with increasing height of the buildings, the pile raft foundation is becoming an efficient choice to transmit the load safely to the ground. The high rise buildings and communication towers are exposed to vertical loads from superstructure and lateral loads from earthquake, wave action and wind etc. In such situation, to increase the load carrying capacity of the foundation and to decrease lateral and vertical displacement, piles are provided under the raft. This type of foundation system is call piled raft foundation system. In pile raft foundation system, the load is distributed between the piles and the raft, making the system economical as compared to old traditional methods in which the piles were taking all the loads. A lot of research work has been carried out on vertical contribution of raft in the pile raft foundation system. There is very limited literature available on contribution of raft to resist lateral loads. If raft contribution to resist lateral loads is considered, foundation design could be made more economical. In this research work, a small-scale model pile raft foundation model was used for experimentation. It was observed that a considerable amount of lateral load was resisted by the raft component. From the test results it came to know that with increasing the number of piles, the load carrying capacity/ contribution of raft decreases. It was also observed that rear piles resist more lateral load compared to the front piles in a pile group.

Keywords- Pile raft foundation system, Deep foundation, High rise structure, Lateral load contribution

1 Introduction

For many years, pile foundations have been used as load bearing and transferring systems. During the early days of civilization, the load bearing capacity of the ground was improved by driving timber piles into the ground by hand or digging holes and filling them with sand and stones. In1740, after the invention of pile driving equipment by Christoffoer Polhem, the use of pile foundation gained more popularity. During the designing of Tower Latinoamericana, Mexico in 1956, Dr. Leonardo Zeevaert introduced the concept of combined piled raft system to enhance the loading carrying capacity of underneath weak compressible soil. This was the first high rise building in which combined pile raft foundation was used; otherwise, the pile foundation was the only option for tall buildings before this concept. The tower gained attention of geotechnical society when it withstood at 7.9 magnitude earthquake in 1957. Now-a-days, if bearing capacity of soil is sufficient, raft foundation is provided under tall buildings to transfer the load to underneath soil safely, otherwise piles are provided in combination of raft to transfer the imposed loads to underlying soil strata [1]. In [2], the optimization of pile location in piled raft foundation and its effect on the reduction of differential settlement are studied.
In [3], the piled raft foundation which was designed for Messeturm tower in Frankfurt is studied, with more piles organized near the corners. It was determined from this practical case that the reduction of total and differential settlement is dependent on pile configuration and comparative stiffness of raft-soil system.
In [4], small scale piled raft model in the centrifuge test were studied with different pile configuration. The experimental study concluded that centralizing piles surrounding point load (i.e., where columns are located) reduces total as well as differential settlements, improving design cost-effective but also efficient. According to [5], load resisting of pile's varies with their position in a group, and ultimate lateral resistance within pile group is reduced due to stress zone overlapping in the surrounding soil. They also came to the conclusion that the lateral resistance of a pile group is function of row position within a group. Results in [6] demonstrated that, for a given displacement, piles in leading row sustained more load than piles in tailing row, and that, due to group effect; all piles in the group take less load than a single pile. It was discovered

in [7, 8] that pile spacing is directly related to average lateral resistance and group interaction has a considerable impact on lowering pile lateral resistance. Several experiments are also conducted to investigate pile behavior under various load combinations. The influence of lateral load and bending moment on load carrying capacity of a single pile and a pile group was calculated, and presence of lateral loads or bending moment resulted in significant decrease in vertical load carrying capacity [9].According to [10, 11], the lateral displacement of piled raft foundation increases under combined loads. According to the available literature, most researchers have done work on lateral response, but they only calculated lateral deflection with the conclusion that the raft contributes to lateral load resistance. The purpose of this research is to determine the potential of raft and piles in resisting lateral load in a combined piled raft foundation System using experiments on instrumented small scale models.

2 Experimental Study

2.1. Scope

The main purpose of this research is to study the lateral load contribution of piles and raft in a combined piled raft foundation system under a constant vertical load. For this purpose, a small-scale model was prepared in the laboratory and subjected to uniformly increasing lateral loading in the presence of constant vertical loading. The contribution of piles and raft is determined against every lateral loading.

2.2. Experimental Setup and Equipment

To study the lateral load contribution in a combined piled raft foundation system, a small scale instrumented piled raft model was prepared in the laboratory. The container was filled with loose sand having relative density of 35%. The modeled raft was square in shape and made of aluminum with dimension of 30 x 30 cm and 2.54cm thickness.Total 25 holes with 1.3 cm diameter and 6.35cm center-to-center spacing were drilled into raft surface for installation of 1.905cm diameter galvanized iron piles in different configurations. The piles were made circular and hollow from inner side having length of 45cm. They were attached with raft using nut and bolts assembly. Calibrated strain gauges were installed on each pile to measure the lateral load contribution of each pile connected in combined piled raft model. A calibrated vertical load cell with maximum capacity of 08 ton was also installed to measure the applied vertical loads. Linear Variable Displacement Transducers (LVDTs) with their tips resting laterally on raft were installed on each side of raft. The accuracy of LVDTs was 0.01 mm and their purpose was to measure lateral displacements. The Schematic and pictorial view of the experimental setup and its parts are shown in Figure1 and Figure 2, respectively.

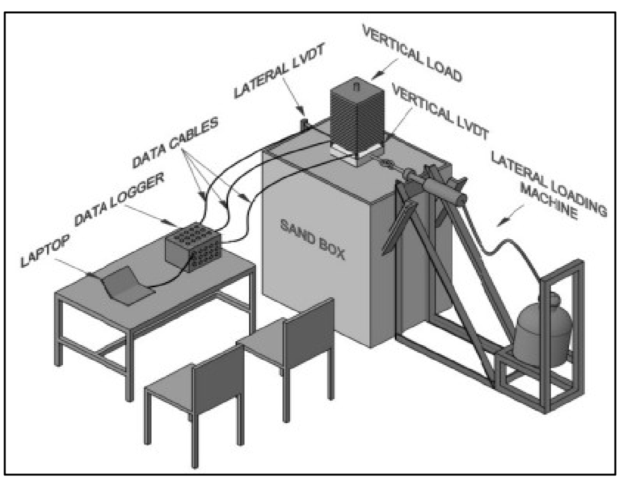
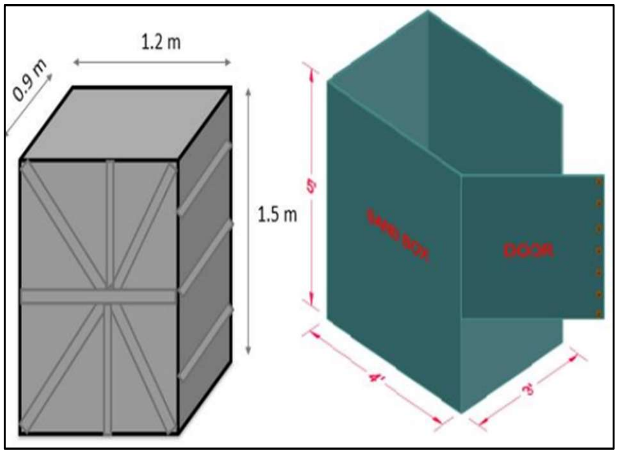


Figure 1: Schematic view of experimental setup

Figure 2: Pictorial view of experimental setup

The piled raft model was placed accurately in the center of rectangular soil container with dimensions of 1.5m height, 1.2m length and 0.9m width as shown in Figure 3. The soil container was filled with sand of required relative density of 35%

using mobile pluviator as shown in Figure 4. Two pile configurations were used during current study. Four piles with center to center spacing of 254mmand 5piles with same layout but having an extra pile in the middle of the 4 piles setup were used for testing purposes. The lateral load was applied perpendicular and concentrically to the raft under constant vertical load of 5000N. The lateral displacement was noted with the help of LVDTs via data logger.



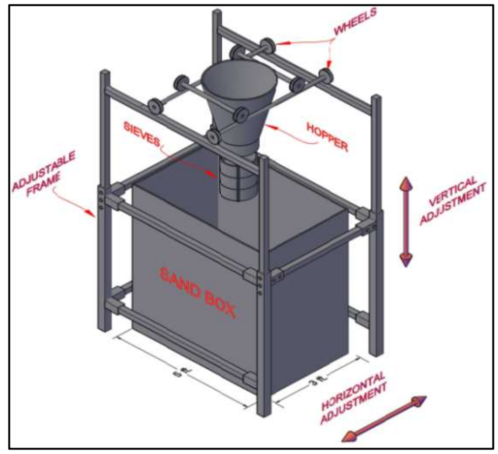


Figure 3: Model sa *Figure 4: Mobile pluviator*

Experimental Procedures

The grain size distribution curve was plotted after carrying out of sieve analysis on the testing soil according to ASTM D-422 as shown in Figure 5. The uniformity coefficient (Cu) was 3.12 and the coefficient of curvature (Cc) was 0.72 as per the plotted grain size distribution curve. The testing soil was classified as poorly graded sand. The maximum and minimum unit weight of the testing soil found 106pcf and 92pcf respectively as per ASTM D-4253 and D-4254.

The piled raft modes testing were conducted in testing soil having relative density of 35%. The targeted relative density of testing soil was achieved through sand raining technique using mobile pluviator. Several trials were carried out to find the exact height of fall to achieve 35% required relative density. The required relative density was achieved by falling sand from a height of 9.5 inches. In order to maintain uniformity of sample, a shutter with 13mm holes was attached at the bottom of sand cone and the 1.5m high sand container was filled in 10 layers with each layer of 15cm thickness.

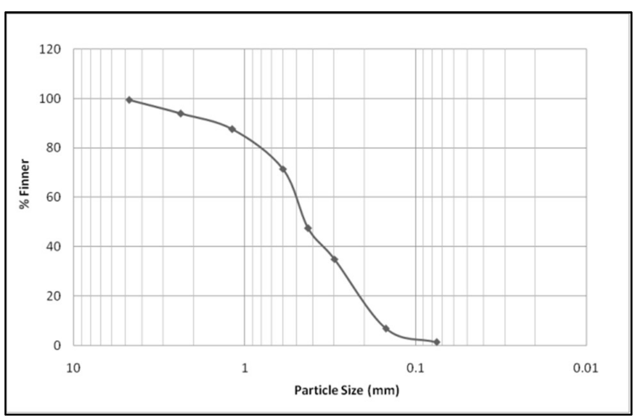


Figure 5: Grain size distribution curve

The piles were placed at their respective location when the container was filled up to 1.2m height. After placing the piles, the sand raining again started till the container filled completely. The raft was then fixed by a nut and bolt system with the already placed piles, and a little downward pressure was applied on the raft to make full contact of the raft with the soil. The schematic and pictorial representations of the detailed experimental study are shown in Figure 1 and 2. The installed load cells, strain gauges and LVDTs were connected with data logger to record the required data. Lateral load was applied after application of a constant vertical load of 5000N and data was recorded.

3 Results and Discussion

Two cases with following pile and raft configuration were used for this study:

a. Four piles attached with raft as shown in Figure6 and 8.
b. Five piles attached as shown in Figure 7 and 9.

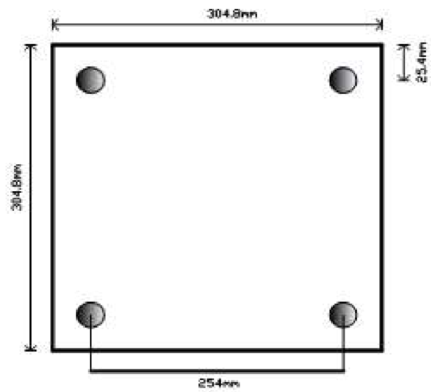


Figure 6: Plan view of 4-Piled Raft Model

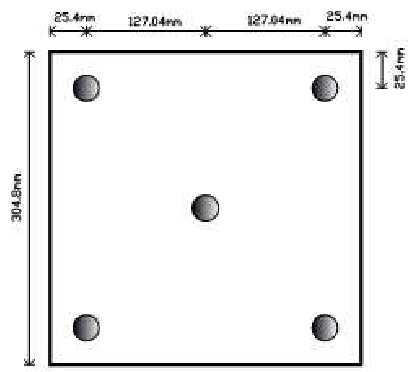


Figure 7: Plan view of 5-Piled Raft Model

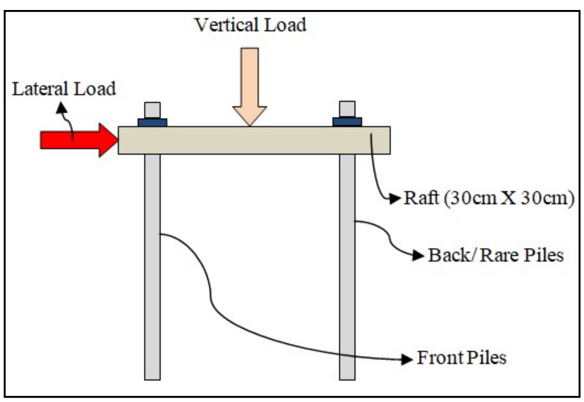


Figure 8: Sectional view of 4-Piled Raft Model

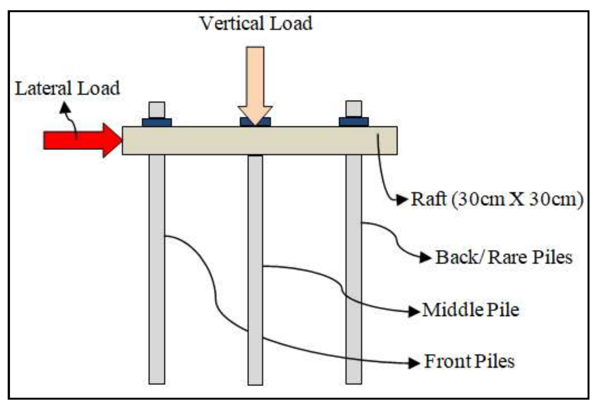
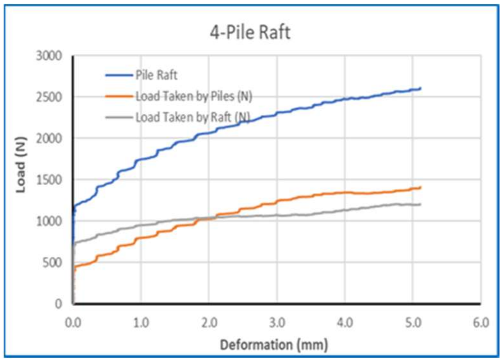


Figure 9: Sectional view of 5-Piled Raft Model

3.1 4-Piled Raft Model

Four piles with center-to-center distance of 254mm were rigidly connected to the raft by nut bolt system as shown in Figure 9. Initially, the system was subjected to constant vertical load of 5000N followed by lateral loading through hydraulic jack. Figure10 shows that initially all the load is taken by raft due to high stiffness and it mobilizes at very small strain. Raft contribution to resist lateral load is also dependent on the lateral displacement because at large displacement the contact between the soil and the raft may vanish. At approximately 2 mm lateral displacement, the pile contribution exceeds the raft contribution as the soil in front of the piles gets compacted and hence results in an increase in soil stiffness. Figure11shows that back piles take more load throughout the lateral displacement, compared to front piles. This is because the soil available in front of the back piles has high stiffness due to confinement. This behavior is against the pile group where front piles take more load because the front pile leaves free space behind and due to this free space, the soil stiffness decreases in front of the back piles.



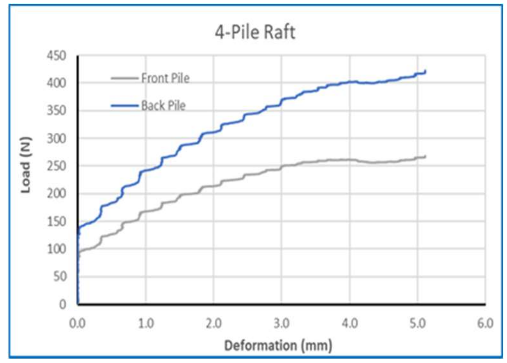
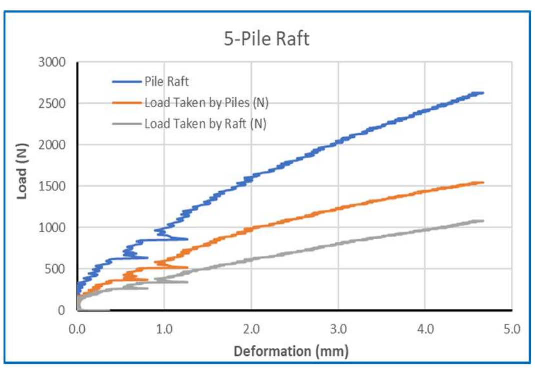


Figure 10: Load distribution b/w piles, raft and piled raft model

Figure 11: Load distribution b/w front pile and back pile

3.2. 5-Piled Raft Model

The same layout was maintained as in pile raft with 4 piles with an additional pile installed at the center of raft. Before application of lateral load, a constant vertical load of 5000N was applied. Figure 12shows that initially total load is resisted by raft. After raft mobilization, the piles started resisting lateral load. Initially, the raft showed very high stiffness, followed by sudden degradation of stiffness. This is because the raft resists lateral load only by skin friction between raft and the underlying soil. In contrast to the 4-Pile raft, where the pile contribution exceeded the raft contribution at 2 mm, in this case the raft and pile contribution continued and never cross each other. This is because the center pile provides resistance to avoid overturning/tilting of the system. As piles number increased from 4 to 5, the raft load reduced from 750 N to 200 N at 1mm displacement. From Figure13, it is clear that again back piles take more load, but up-to 1 mm displacement the difference between the loads taken by piles is very small. After 1 mm lateral displacement, the difference gets predominant. The middle pile and back pile take same load upto 1.5 mm displacement after that the stiffness of middle pile decreased, reaching a constant stiffness at very high displacement.



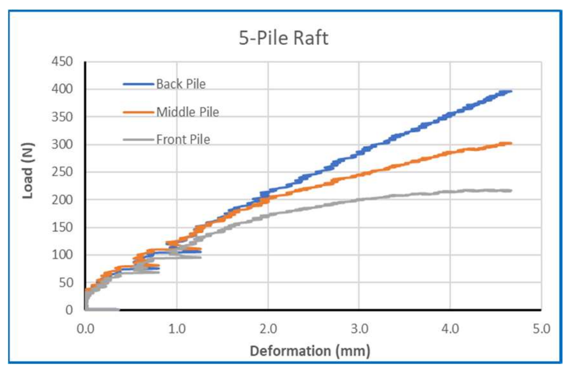


Figure 12: Load distribution b/w piles, raft and piled raft

Figure 13: Load distribution b/w front piles, middle and back piles.

4 Conclusions

1) At small or no lateral strain, more lateral load is taken by the raft compared to piles.After 2mm displacement,the soil in front of the piles gets compacted increasing stiffness of the piles and so their contribution in lateral load sharing.
2) Contrary to group piles behavior, back piles take more load compared to front piles in case of pile raft foundation system.
3) With increase innumber of piles, the load sharing by raft decreases and that of piles increases at a given lateral displacement value.

5 Acknowledgment

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6 References

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