Experimental Investigation of piled raft foundation on Cohesionless Soil

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***Abstract*: The combination of piles and raft foundation is known as piled raft foundation. Piled raft foundations have proven to be more cost-effective and capable of meeting safe bearing capacity and serviceability norms in the case of high-rise buildings on cohesionless soil. The behavior of a stacked raft foundation is influenced by the piles, raft, and soil. The stacked raft system's bearing capacity is improved and settlement is minimized when the ground beneath the raft foundation bears the burden of supporting the applied loads. The piled raft foundation minimizes total settlement and improves bearing capacity more than the raft foundation.**

When isolated footings cover more than 70% of the building area under a superstructure, raft foundations are used, and the present study focuses on the vertical load bearing capability of piled raft foundation systems on cohesionless soil for concentric loading. The use of strategically positioned piles increases the load capacity of the raft while reducing differential settlement. The present study sheds some light on the use of piles as raft foundation settlement reducers, as well as the behavior of a piled raft in sand. A series of small-scale model experiments were carried out. The present investigation studies by varying pile length and alignment on the ultimate load of piled raft foundation. The results indicate that for a 10mm raft thickness, installing 4 piles, 6 piles, and 9 piles by varying L/D ratios of 5,10,15,20 carries significant load. In this present work for a 50mm length of pile, and the value of load improvement ratio increases by 36 percent, 60 percent, and 68 percent, respectively, when compared to plain raft.

***Keywords:* Piled raft foundation, cohesion less soil, Load improvement ratio**

I. INTRODUCTION

The term "piled raft foundation" describes a foundation that uses both piles and rafts. Piled raft foundations have proven to be more cost-effective and capable of meeting safe bearing capacity and serviceability standards in the case of high-rise buildings on clay. The behavior of a piled raft foundation is determined by the piles, the raft, and the soil. Due to the intricate interaction between the piles and their cap with the soil, the applied loads are assumed to be carried solely by piles, with no contribution given to the soil beneath the raft when building a pile group. This interaction improves the bearing capacity of the piled raft system and lowers settlement when the earth beneath the raft foundation shares in carrying the applied loads. The piled raft foundation minimizes total settlement and enhances bearing capacity more than the pile groups and raft foundation from the previous study, according to the findings.

When raft (mat) foundations are supported by a piling group, they have been demonstrated to be capable of supporting extremely large loads. When estimating the contribution of both raft and piles to carrying the surcharge loads, the stiffness and strength of the soil linked elements in the system, i.e. piles, raft, and surrounding soil, are taken into account. When the focus of the research is on the vertical load bearing capability of a piled raft foundation system on soil for both concentric and eccentric loading. Raft foundations are employed when isolated footings occupy more than 70% of the building area under a superstructure. The use of strategically positioned piles increases the load capacity of the raft while reducing differential settlement. This research sheds some information on the use of piles as raft foundation settlement reducers, as well as the behavior of a piled raft in sand. Small-scale model experiments are carried out. Experimentally, the effects of pile length and alignment on the ultimate load achieved are investigated. [1] Eslami et al., (2011): Three case studies of connected and non-connected pile-raft systems are explored using finite element analysis to see how different parameters, such as pile spacing, embedment length, piling configuration, and raft thickness, affect the design. [2] El-Garhy, B et al., (2011): studied the raft behavior on Settlement Reducing Piles, and found that raising the subsoil stratum stiffness can greatly reduce settlements and raft internal bending moments in non-connected piled-raft systems.[3] Gahlot et al., (2018), analyzed the effect of different length in pile raft foundation. The layout and combinations shown to be crucial in achieving the desired settlement reduction and load sharing with the smallest number of piles in the design on load carrying capability. [4] Poulos et al., (2011), analyzed the effect of soil subgrade reaction and stiffness on the settlement and bending moment. [5] Jaymin D Patil (2014) The impact of pile numbers and raft thickness on load improvement and settling reduction ratios is provided and explored. The tests reveal that as the number of piles beneath the raft rises, the load improvement ratio and settlement reduction ratio also, while the proportion of weight borne by the raft declines. In addition, increasing raft thickness has a modest influence on load improvement ratio and settlement reduction ratio, while raft thickness has a small effect on the load carried by the raft. Investigated the behavior of piled raft foundations experimentally. [6] Alwakil A.Z et. al., Model studies were carried out on a small scale. The effects of pile length and alignment on the ultimate load achieved were explored experimentally. Depending on the outcomes of the study, it has been determined that as the length and number of piles decrease, the load supported by the raft increases. Moreover, the best and optimal settlement ratio (S/B percent) for designing the piled raft as a settlement reduction was determined to be 0.7 percent. When isolated footings cover more than 70% of the building area under a superstructure, raft foundations are used. They conducted the laboratory tests on both structurally connected and structurally unconnected piles with eccentricity of loading. [7] Mustafa EL Sawwaf et al., (2010): According to their findings, connected short piles have a greater impact on the raft than those that are not connected. The way the piles are arranged has a big impact on how the raft behaves. As the number of piles and their length increases the load also increases. Sand density has a significant impact on the behavior of rafts and piles. The addition of short piles improves the eccentrically loaded raft's behavior significantly. [8] XIAO DONG CAO et al., (2004): They carried out the experiment on model raft on the reinforced sand, here piles are used as the reinforcement. For experimental study, rigidity of the raft, pile length and number and pile arrangements are varied. They also carried out investigation for connected and unconnected piles. Results obtained from the test conducted on the model raft resting on sand with or without the reinforcement indicated that both settlement and differential settlement is reduced when the settlement reducing piles were added.

*Experimental Program***:** The primary goal of the research was to investigate the load-settlement behavior of a piled raft foundation system as well as the load transfer mechanism between the raft and piles with various pile lengths and configurations. In Laboratory, total thirteen tests were conducted. One test was conducted on an unpiled raft, whereas twelve tests were conducted on piled rafts. Table 1 shows the laboratory model test schedule for unpiled raft and stacked raft foundations. Figure 1 depicts the pile configurations and measurements of a model raft of piled raft. The size of the model pile and raft were determined to ensure that there would be no stress concentration due to boundary conditions. To avoid the effect of a rigid soil tank foundation on pile behavior, the soil tank's height was two times bigger than the pile length (Horikoshi & Randolph, 1999).

Table 1: Summary of the model tests on unpiled and piled rafts.

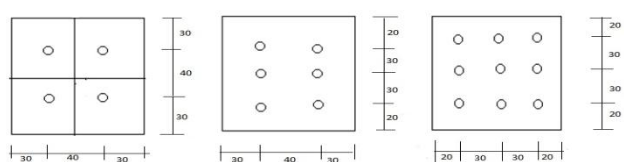
Test Explanation	Model Raft dimensions (mm xmmxmm)	L/D	S/D	No.of tests performed
Unpiled Raft	100x100x10			1
Raft + 4 piles	100x100x10 100x100x10 100x100x10 100x100x10	5, 10, 15, 20	5	1 1 1 1
Raft + 6 piles	100x100x10 100x100x10 100x100x10 100x100x10	5, 10, 15, 20	4	1 1 1 1
Raft + 9 piles	100x100x10 100x100x10 100x100x10 100x100x10	5, 10, 15, 20	3	1 1 1 1

Tested soil: The foundation soil in this study was a dry sand sample. Sand was discovered to have a specific gravity of 2.65. The maximum and minimum dry unit weights were discovered to be 14.9 kN/m3 and 17.5 kN/m3, respectively. The dry sieving method was used to determine the particle size distribution, and the results are presented in figure 2. The sand tested were found to had a uniformity coefficient (Cu) of 3.15 and a coefficient of curvature (Cc) of 1.22, respectively. According to the Indian standard soil classification, the soil is poorly graded sand, SP. The sand was put into the tank at a density of 25% relative density and a weight of 15.4 kN/m3. The results are tabulated in Table 2.

Table 2: Physical properties of sand

Sl.No	Properties	Results
1	Specific Gravity(G)	2.62
2	Particle size distribution	
	Percentage of Gravel size	0.8%
	Percentage of Sand size	99.20%
3	Minimum Dry unit weight	14.9kN/m^3
4	Maximum dry unit weight	17.5 kN/m^3
5	Minimum void ratio	0.468
6	Maximum void ratio	0.725
7	Uniformity coefficient, Cu	3.15
8	Coefficient of curvature, Cc	1.22
9	Soil classification	SP

Figure 1: Studied cases of piled raft foundation (unit: mm)



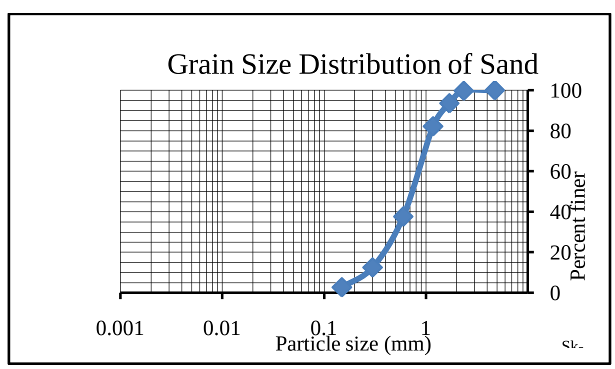


Figure2: Grain size distribution curve

Piled raft model: The model raft was made up of mild steel plates having a square shape with the thickness of 10mm and dimensions were 100mm x 100mm respectively.

Figure 3: Fixing of piles and raft according to the test requirement

Mild Steel Piles: In the laboratory test, Mild steel with a diameter of 10mm was used to make the model piles. In the present study, piles of various lengths such as 50mm,100mm,150mm, and 200mm were used, representing slenderness ratios of 5,10,15, and 20 respectively. The model steel piles used in the present work are shown in figure 4.

Figure 4: Model Steel Piles.

Experimental setup: The circular test tank is used for the experimental work having diameter of 500 mm and 390 mm in depth. The beam consists of hand operated hydraulic jack fixed at the centre and calibrated load cell of 10 kN capacity was attached to the jack to measure the load. Two linear displacement transducers (LVDTs) of 0.01 mm accuracy were as shown in Figure5 to measure vertical displacement.

Figure 5: Model test set up with connector, proving ring and dial gauges

Test procedure:

1. In order to achieve the requisite density in all of the experiments, sand is poured into the tank using the rainfall method. The tank's overall height was divided into 50 mm intervals. To attain a relative density of 25% and a unit weight of 15.4 kN/m3, sand was poured into the tank to a height of 350mm, to maintain lower relative density.
2. Because the piles are non-displacement piles, sand was first poured up to a height of 50mm from the tank's bottom. in 7 layers, then piled-raft having length 50mm,100mm,150mm and 200mm, were

placed in vertical position at the center of the tank to achieve adequate seating, a 10mm penetration into the sand is used. The piles are maintained in place until the tank is completely filled.

3. After the model piles have been installed, the load is applied through hydraulic jack.
4. The load was conveyed to the model raft via a loading plate that was attached to the raft. Then, to measure vertical displacement, three LVDTs were installed.
5. The hydraulic jack is coupled to a Proving ring load cell with a 50 kN capacity. The model raft was loaded incrementally, and vertical settlement was measured at the conclusion of each load increment. The loading rate was 0.1kN/min. The application of load is continued till the raft settlement is 25 mm.

Figure 5: Model Test setup for plain raft foundation

Effect of Pile length:

In this section, the effects of pile length and number of piles on the behaviour of piled raft are investigated and described in this section. The following Figures 6-9 illustrate the load-settlement curves of unpiled raft and raft supported by 4, 6 and 9 piles for varying pile lengths of 50mm,100mm,150mm and 200mm respectively. As shown in these figures, the load carrying capacity of piled raft increases as the number of piles supporting the raft increases. This increase is mainly due to the increase of proportion of load shared by the piles due to the increase of the number of piles. In this study, due to the presence of piles under the raft, the improvement in load capacity of raft, at 25mm settlements is represented by non-dimensional parameter called Load improvement ratio, which was define as the ratio of load carried by the piled raft and unpiled raft at 25mm settlement.

Balakumar V et al., (2009): has observed and obtained the non – dimensional parameter "The Load improvement ratio" using the following formula.

Load Improvement Ratio:

Load Improvement Ratio,LIR = $(Q_{pr}-Q_r)/Q_{pr}$

Where,

LIR =Load improvement ratio,
Qr= Ultimate load of the raft,
Qpr=Ultimate load of the raft with pile,

Load settlement characteristics of group of Piled raft foundation on cohesionless soil:

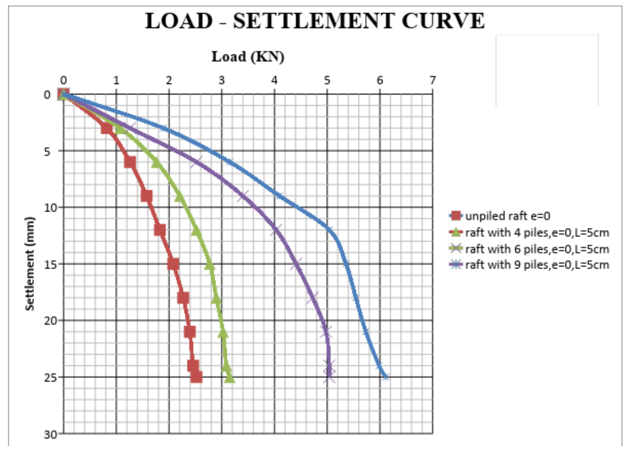


Figure 6: Load settlement curves of piled raft foundation (L/D=5).

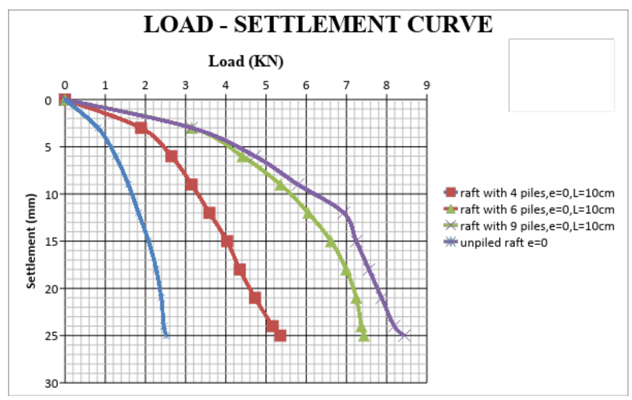


Figure 7: Load settlement curves of piled raft foundation (L/D=10).

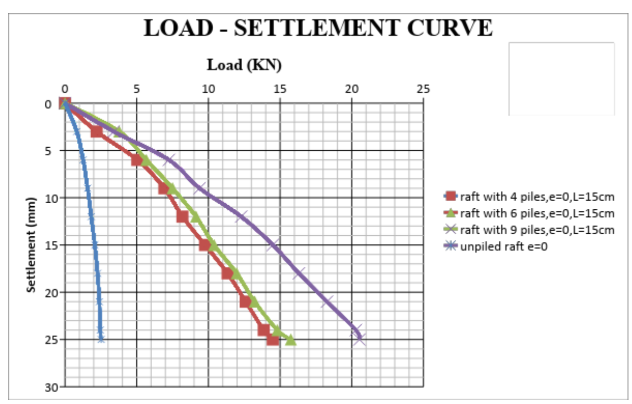


Figure 8: Load settlement curves of piled raft foundation (L/D=15).

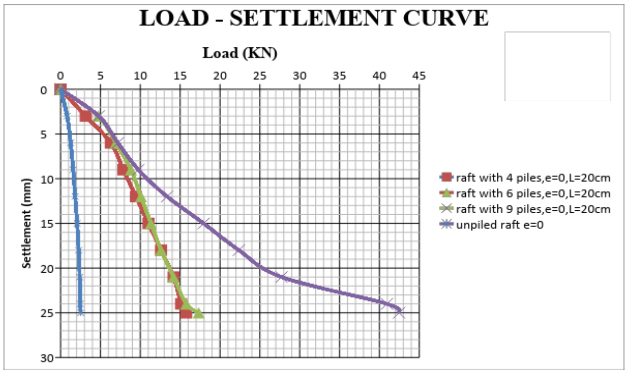


Figure 9: Load settlement curves of piled raft foundation (L/D=20)

From the graph it is seen that ultimate load for raft with 9 number of piles(L=5cm) with L/D ratio =5 and S/D ratio =4 is 6.1KN for 25mm settlement. So, raft with 9 number of piles of length 5cm takes more load. Comparing the behavior of the plain raft and the piled raft through the load-settlement characterization curves, it can be seen that, an addition of a small number of the piles to the raft, enhances the performance of the foundation system It is seen that at the maximum settlement of 25 mm (all the tests were conducted upto the settlement of 25 mm), the stiffness of the combined system is very close to that of plain raft indicating that at higher settlement the piles tend to behave as settlement reducer and not primarily a load bearing member.

The first phase of the curve up to a settlement level of around 2 mm represents the elastic behaviour of the entire system. The second phase shows (upto 6 mm settlement) gradual loss of system stiffness (the pile group loses its elastic behaviour) and beyond this stage the loss of stiffness is rapid and at 25 mm settlement (the maximum settlement at which all the tests were terminated) the stiffness is close to that of plain raft. In other words, beyond a settlement level of 3% of the least lateral dimension of the raft, the piled raft system behaves more like plain raft.

Load Shared by Unpiled Raft and Piled Raft with L/D ratio=5 (constant)

Description	Load taken by unpiled raft	raft with piles		
Number of piles		4	6	9
Load (kN)	2.52	3.15	5.04	6.1
LIR (%)		20	50	58.75

Load Shared by Unpiled Raft and Piled Raft with L/D ratio=10 (constant)

Description	Load taken by unpiled raft	raft with piles		
Number of piles		4	6	9
Load (kN)	2.52	5.35	7.43	8.44
LIR (%)		52.89	66.08	70.12

Load Shared by Unpiled Raft and Piled Raft with L/D ratio=15 (constant)

Description	Load taken by unpiled raft	raft with piles		
Number of piles		4	6	9
Load (kN)	2.52	14.49	15.75	20.54
LIR (%)		82.60	84.0	87.73

Load Shared by Unpiled Raft and Piled Raft with L/D ratio=20 (constant)

Description	Load taken by unpiled raft	raft with piles		
Number of piles		4	6	9
Load (kN)	2.52	15.75	17.33	42.46
LIR (%)		84	85.45	94.06

II. CONCLUSIONS

The findings are based on the outcome of a small-scale laboratory model test conducted on sand to investigate load-settlement behavior and load sharing between the piles and raft. The following conclusions are derived from the tests:

1) According to the findings, the value of load improvement ratio improves by 20 percent to 94 percent for increase in lengths of piles from 50mm to 200mm compared to unpiled raft.
2) As the number of piles beneath the raft increases, so does the load bearing capacity of the raft. As a result, it can be deduced that as the length to diameter ratio increases, the load improvement ratio was found to increase.
3) There is significant improvement in load carrying capacity linearly with increase in the slenderness ratio.
4) The number and length of piles have a major impact on the settlement reduction. Because the addition of piles stiffens the soil.

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