Behavioral study of piled raft foundation on cohesionless soil for eccentricity

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Abstract*: The performance of piled raft foundation on sand is analyzed with reference to its bearing capacity and settlement. This paper presents an experimental study of the effectiveness of using piles on the behavior of an eccentrically loaded raft. The parameters that varied are the piles arrangements, piles length and load eccentricity. The improvement in the bearing capacity is represented by a non dimensional parameter called the load improvement ratio (LIR). The results of the tests show that the inclusion of piles at an eccentricity reduces the bearing capacity and also it decreases significantly as the eccentricity also increases leads to a reduction in raft settlement and tilts. However, the efficiency of the piled raft system depends on the load eccentricity ratio and pile arrangement. Based on the test results, the influence of different parameters is presented and discussed. However, the efficiency of the piled raft system depends on the load eccentricity ratio and pile arrangement. Raft foundations are often subjected to eccentric inclined loading because of the influence of lateral loads cause as a result of high wind and seismic actions and that may result in tilt of the structures particularly in case of high rise buildings. Using the settlement reducing piles beneath the raft in such cases may increase the soundness of the structure and may reduce the tilt of the raft. However, the piled raft subjected to eccentric and inclined loads has not been fully studied. Most of the research work was done on parametric numerical study for uniformly distributed load or concentrated column loads on piled raft. So that the study is necessary to gain more understanding of behavior of piled raft foundation for eccentric inclined load over cohesive soil/layered cohesive soil mass that creates overturning of the structure, which is commonly found in practice.

***Keywords*: Piled raft foundation, cohesion less soil**

I. INTRODUCTION

Piled rafts have been used successfully in a wide variety of geotechnical applications. However, behavior of piled raft placed in sand is not extensively studied. [1] Sven kabbenhoft et al., (2014): The bearing capacity of a strip foundation subjected to an inclined, eccentric load on cohesionless soil with different surcharges and friction angles of 25, 30, and 35 degrees is determined using lower-bound calculations based on the FEM. Following the Mohr-Coulomb failure criterion, the soil is considered to be fully pliable. The bearing capacity is graphed as a function of friction angle, eccentricity, inclination, and surcharge. These data were compared, and the lower-bound values are bigger for smaller eccentricity, except in the case of no surcharge, with the discrepancy rising with increasing surcharge. Positive load inclinations have a negative influence on bearing capacity for lower eccentricities, but may have a positive effect for larger eccentricities. Negative load inclinations have the opposite impact, and other values are significantly bigger than the lower-bound values, especially for tiny friction angles and large surcharges. [2] Ganesh R et al., (2016): This work proposes an empirical nondimensional reduction factor for calculating the ultimate bearing capacity of eccentrically and/or obliquely loaded shallow strip foundations immersed in sand. This was created after reviewing a number of laboratory model test findings on strip foundations that were published in the literature. The depth of foundation (D), eccentricity of load (e), and inclination of load ranged from 0 to 1B, 0 to 0.5B, and 0 to 20°, respectively. For determining the ultimate bearing capacity of shallow strip foundations under eccentric and/or inclined loads, the proposed reduction factor was shown to produce relatively good results. The produced results that were found to be in good agreement with widely used traditional methods in the literature. [3] George G et al., (1983): The ultimate carrying capacity of rigid piles and pile groups in sand has been calculated using a variety of eccentricity and load inclination combinations ranging from vertical to horizontal. The results of single model pile and freestanding group load tests are compared to theoretical estimates. Simple interaction relationships between the ultimate loads and moments, as well as between the axial and normal components of the ultimate load, can be used to depict the influence of eccentricity and inclination of the load on bearing capacity. On the basis of earlier theoretical and model test results, the influence of a pile cap sitting on the earth in piled foundations is investigated. [4] Mustafa EL Sawwaf et al., (2011): Their research was carried out by conducting the experiments on both structurally connected and structurally unconnected piles with eccentricity of loading. From their analysis, they concluded that the connected short piles have the great effect on raft than that of unconnected one. The arrangement of the pile has major effect on raft behavior.

[5] Jaymin et al., (2016) had verified the tests shown that the addition of piles away from raft edges not only significantly increses the bearing capacity but also leads to a reduction in raft settlement and tilts. However, the efficiency of the piled raft system depends on the load eccentricity ratio and pile arrangement. The eccentricity near to the C.G of the piled raft system carries greater load. Load is increased with the pile

number and length of pile. The density of sand also has a major impact on raft and pile behavior. The addition of the short piles has the more influence on improving the behavior the eccentrically loaded raft.

The present research paper is mainly focused to assess the behavior of eccentrically loaded square raft connected to different length of piles in different arrangement and resting on the sand. The load was applied with varying eccentricity (e) to raft width (B) ratios of 0.1 and 0.15. Experiments were conducted with a square of size 100mm X 100mm raft connected to 0,4,6 and 9 numbers of piles in different arrangements. The results were analyzed and compared with unpiled raft, the average bearing pressure increased almost two times for piled raft having 6 piles corresponding e/B = 0.15. For rafts with 6 numbers of piles the average settlement reduced to almost one-third in most cases as compared to rafts without pile. Corresponding to identical e/B ratio = 0.1 and 0.15, the increase in number of connected piles from 0 to 9, the load improvement ratio is decreased compared to concentric loading respectively.

Table 1: 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	Maximum void ratio	0.725
6	Minimum void ratio	0.468
7	Uniformity coefficient, Cu	3.15
8	Coefficient of curvature, Cc	1.22
9	Soil classification	SP

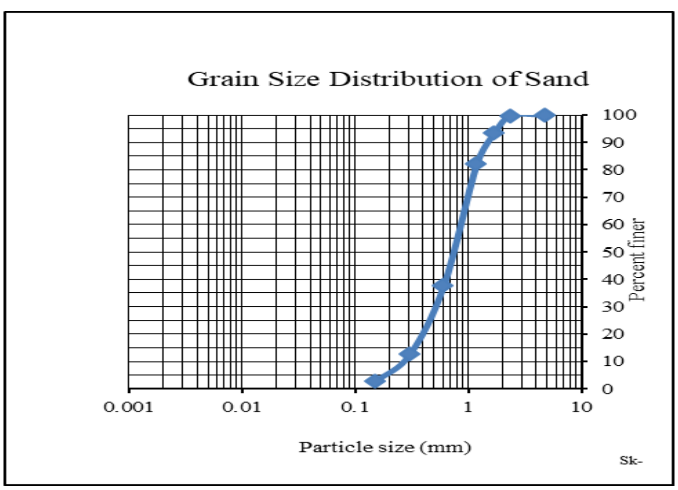

Figure1: Grain size distribution curve

II. MATERIALS

Cohesionless Soil: A dry sand sample is used as foundation soil in this research. The sand was tested for its geotechnical properties as per IS 2720 and the results are tabulated in Table 1. The specific gravity of sand was found to be 2.62. The minimum and maximum dry unit weights of sand were found to be 14.9 kN/m3 and 17.5 kN/m3, respectively. The particle size distribution was determined using the dry sieving method and results are shown in fig 1. The uniformity coefficient (Cu) and coefficient of curvature (Cc) for the sand were 3.15 and 1.22 respectively. According to the Indian standard soil classification, the soil is classified as poorly graded sand, SP. The sand was poured in the tank at a unit weight of 14.40 kN/m3 i.e. at 25% relative density.

Figure 2: Sand

Circular test tank: A circular test tank of diameter 500mm and 390mm height is used for the experimental work. The tank is welded with the steel rods to make provision for placing the dial gauges to measure the settlement.

Figure 3: Model Test Tank

Mild Steel Raft**:** The model raft was made up of mild steel plates having a square shape with 10 mm thicknesses. The dimension of raft are 100mm x 100m x 10mm respectively.

Figure 4: Mild Steel Raft

Mild Steel Piles: In the laboratory test, the model piles were made up of the mild steel of diameter 10mm.The piles of different lengths such as of 50mm,100mm,150mm and 200mm are used in the experiments, represents slenderness ratio of 5,10,15 and 20 at eccentricity to width of raft ratios as 0.1,0.1. The model steel piles used in the present research work are shown in fig 2.

Figure 5: Raft with 4 piles arrangement

Figure 6: Raft with 6 piles arrangement

Figure 7: Raft with 9 piles arrangement

Test Procedure

1. The sand was poured in 3 layers of 120mm thickness into the cylinder after the surface of each layer was levelled and the sand was compacted by tempering with a smooth wooden board.
2. Required amount of sand for each layer was calculated based on the relative density of 30% (Dry density = 15.69kN/m3). A clearance of 30mm was provided at the top for placing pile raft model and load connector and also to avoid any spilling of sand.
3. After the preparation of sand bed, the pile raft model was placed at center of the cylinder and proving ring was attached to the loading arm along with the placement of connectors as shown in Figure 8.
4. Dial gauges are fixed to the cylinder for measurement of settlement. Multiple dial gauges are fixed for knowing the average settlement. Then load is applied till the settlement of 25mm.
5. Proving ring readings are recorded simultaneously for every 0.5mm settlement.
6. Then the load versus settlement graphs is plotted to determine the effect of Length of piles, number of piles at an eccentricity to breadth ratios of 0.1,0.15 loading on loose sand bed.

Table 2: Test Program

Test Program	Pile configuration	L/D	S/D	e/B	Number of Test Performed
Unpiled Raft					1
Raft + 4 piles	2 X 2	5	4	0.1,0.15	8
		10			
		15			
		20			
Raft + 6 piles	3 X 2	5	3	0.1,0.15	8
		10			
		15			
		20			
Raft + 9 piles	3 X 3	5	3	0.1,0.15	8
		10			
		15			
		20			

Figure 8: Model Test setup for plain raft foundation

III. RESULTS AND DISCUSSION

3.1 Unpiled raft

Figure shows the load-settlement curves for the unpiled raft models of 10mm raft thickness. It can be noted that the load carrying capacity of the unpiled raft slightly increase with the increase in settlement (for eg.25mm settlement). The ultimate load carried by the raft alone is found to be 2.46kN.

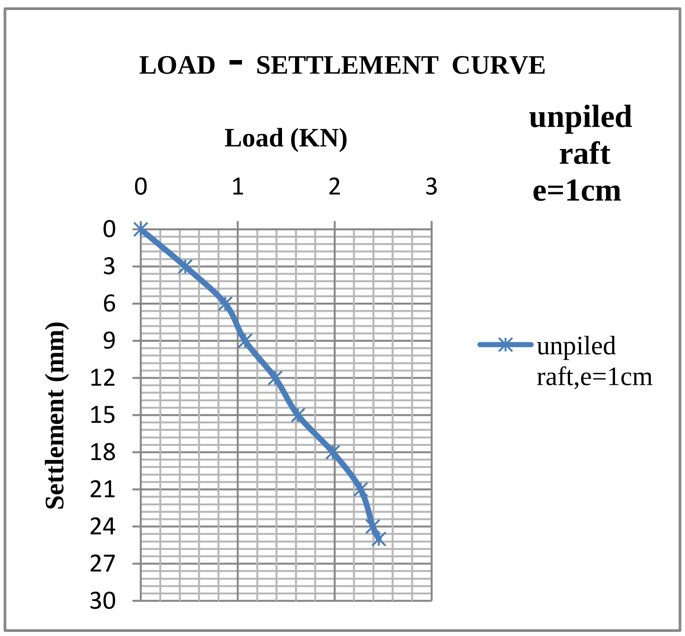

Figure 9: Load-settlement curves for unpiled raft

3.2 Load settlement characteristics of group of Piled raft foundation on sand under Eccentric loading:

Effect of load on plain raft and pile rafts with 4 numbers,6numbers and 9 numbers are studied and the corresponding graphs are plotted to find out the ultimate load bearing capacity of the cohesionless soil at an e/B ratio equal to 0.1.

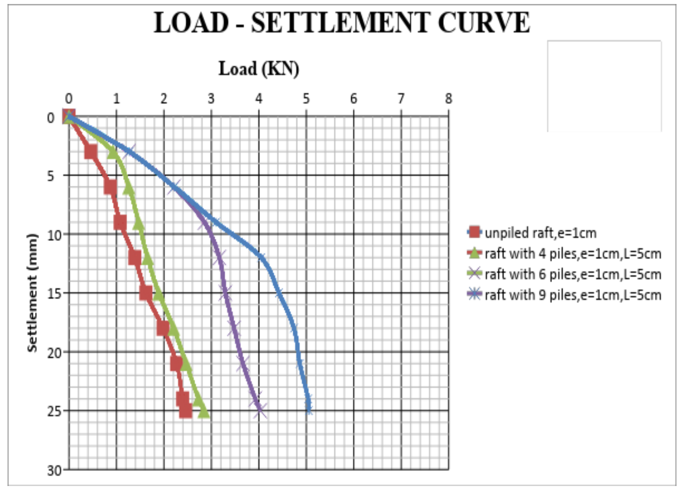

Figure 10: Load versus Settlement of piled raft at e/B = 0.1 (Pile length=50mm).

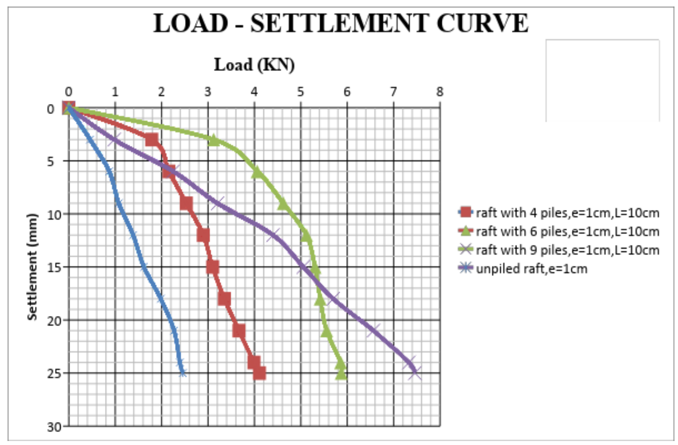

Figure 11: Load versus Settlement of piled raft at e/B = 0.1 (Pile length=100mm).

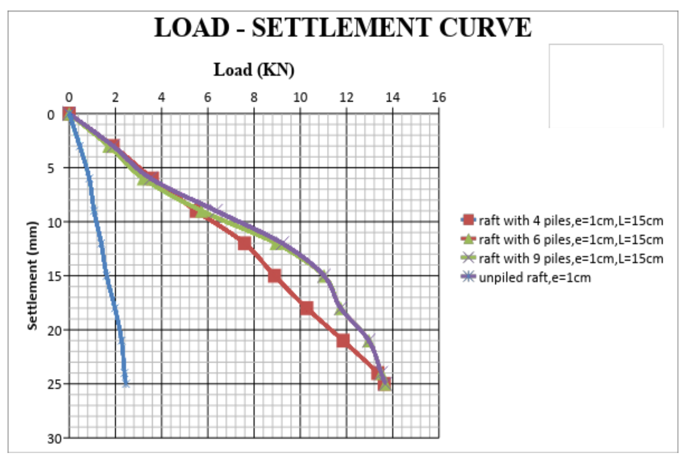

Figure 12: Load versus Settlement of piled raft at e/B = 0.1 (Pile length=150mm).

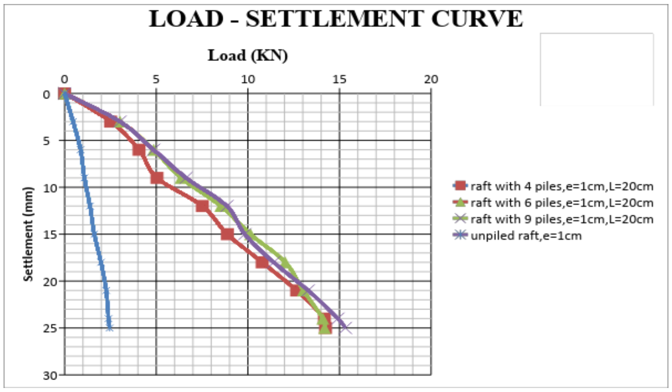

Figure 13: Load versus Settlement of piled raft at e/B = 0.1 (Pile length=200mm).

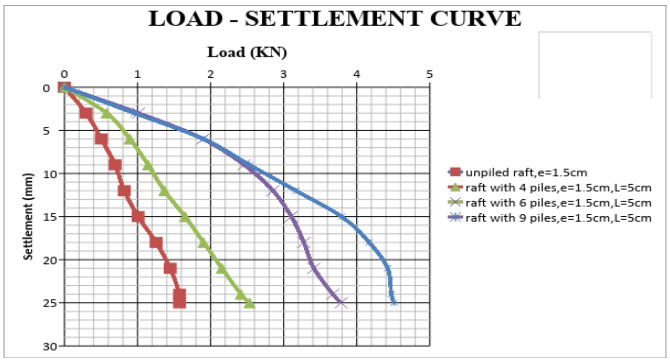

Figure 14: Load versus Settlement of piled raft at e/B = 0.15 (Pile length=50mm).

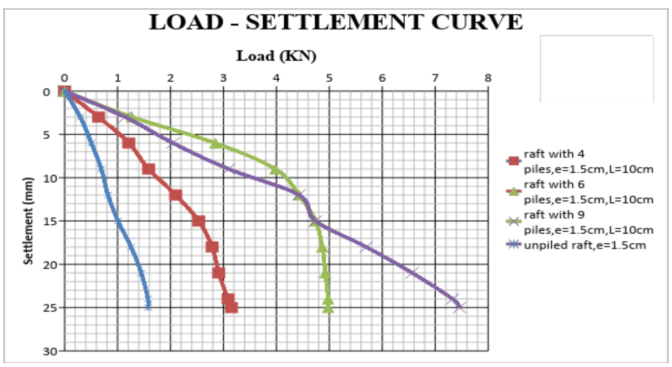

Figure 15: Load versus Settlement of piled raft at e/B = 0.15 (Pile length=100mm).

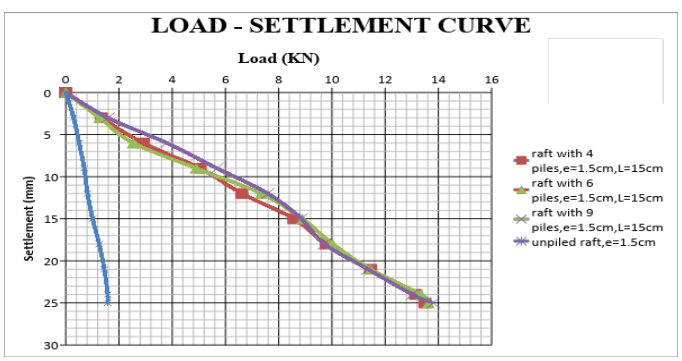

Figure 16: Load versus Settlement of piled raft at e/B = 0.15 (Pile length=150mm).

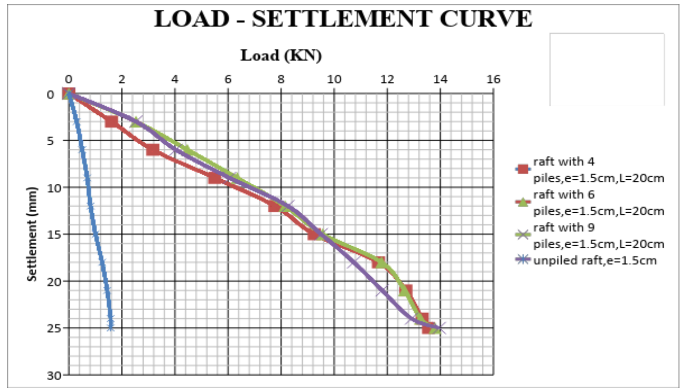

Figure 17: Load versus Settlement of piled raft at e/B = 0.15 (Pile length=200mm).

Table 3: Load Shared by Unpiled Raft and Piled Raft with eccentric loading for L/D =5 at eccentricity =1cm.

Description	Load taken by Unpiled Raft	raft with piles		
Number of piles		4	6	9
Load (kN)	2.46	2.84	4.03	5.05
LIR (%)		13.38	38.95	51.28

Table 4: Load Shared by Plain and Piled Raft with eccentric loading for L/D =10 at eccentricity =1cm.

Description	Load taken by Unpiled Raft	raft with piles		
Number of piles		4	6	9
Load (KN)	2.46	4.11	5.87	7.46
LIR (%)		40.14	58.09	67.02

Table 5: Load Shared by Unpiled Raft and Piled Raft with eccentric loading for L/D =15 at eccentricity =1cm.

Description	Load taken by Unpiled Raft	raft with piles		
Number of piles		4	6	9
Load (kN)	2.46	13.63	13.68	13.68
LIR (%)		81.95	82.01	82.01

Table 6: Load Shared by Unpiled Raft and Piled Raft with eccentric loading for L/D =20 at eccentricity =1cm.

Description	Load taken by Unpiled Raft	Raft with piles		
Number of piles		4	6	9
Load (kN)	2.46	14.24	14.19	15.32
LIR (%)		82.67	82.55	83.92

Table 7: Load Shared by Unpiled Raft and Piled Raft with eccentric loading for L/D =5 at eccentricity =1.5cm.				
Description	Load taken by Unpiled Raft	raft with piles		
Number of piles		4	6	9
Load (kN)	1.58	2.53	3.79	4.51
LIR (%)		37.54	58.31	64.96

Table 8: Load Shared by Unpiled Raft and Piled Raft with eccentric loading for L/D =10 at eccentricity =1.5cm.				
Description	Load taken by Unpiled Raft	raft with piles		
Number of piles		4	6	9
Load (kN)	1.58	3.15	4.98	7.46
LIR (%)		49.84	68.27	78.82

Table 9: Load Shared by Unpiled Raft and Piled Raft with eccentric loading for L/D =15 at eccentricity =1.5cm.				
Description	Load taken by Unpiled Raft	raft with piles		
Number of piles		4	6	9
Load (kN)	1.58	13.50	13.63	13.81
LIR (%)		88.29	88.40	88.55

Table 10: Load Shared by Unpiled Raft and Piled Raft with eccentric loading for L/D =20 at eccentricity =1.5cm.				
Description	Load taken by Unpiled Raft	raft with piles		
Number of piles		4	6	9
Load (kN)	1.58	13.56	13.80	13.96
LIR (%)		88.34	88.55	88.68

IV. CONCLUSIONS

The conclusions are drawn from the experimental results of small-scale laboratory model test on sand, to investigate the load-settlement behavior under eccentric loading. From the results of this study, the following conclusions are drawn.

1) From the present study, it can be concluded that as the number of piles is increased the load carrying capacity of piled raft increases and further it can be observed that for the eccentric loading for length of pile of 50mm with introducing 4 Nos,6Nos and 9Nos of piles to plain raft, the value of load improvement ratio increases by 13.38%,38.95% and 51.28% compared to plain raft.
2) The load carrying capacity of piled raft increases as the number of piles increases beneath the raft with increase in length of pile up to 150mm length whereas with further increase in length of pile to 200mm, the Load improvement ratio have not shown much improvement in LIR.
3) There is significant increase in load carrying capacity of piled raft system for eccentric loading with e/B ratio equals to 0.1(e/B =0.1) when compared to eccentric loading with e/B equals to 0.15.
4) Also, it can be inferred that in weak soils instead of designing piles for a longer length, with load taken entirely by piles, it leads to uneconomical design. It is economical to design the piled – raft system with optimal pile length as it carries maximum load and decreases the settlements and hence the length of piles can be decreased.
5) It can be inferred that in weak soils it is better to design piles for an eccentricity which is near to the C.G of the piled raft in order to avoid tilting and over turning.

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