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EXPERIMENTAL STUDY ON SETTLEMENT BEHAVIOUR OF PILE RAFT FOUNDATION IN DRY SANDY SOIL

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ABSTRACT

In case of dense sand or stiff clayey soil, the raft foundation for large civil engineering structure such as tall buildings does not satisfy the design requirement and raft sinks down causing settlement. To fulfil the design requirement of foundations, the component for reducing settlement of raft need to be added. The composite foundation system called as piled raft foundation. To study the behavior of piled raft foundation for settlement analysis and load sharing to piles and raft, laboratory experiments and parametric study simultaneously on the model piled raft to assess the effect of varying pile length, spacing of piles and combination of piles of different length on settlement behavior and load sharing to piles and rafts is carried out on dry sandy soil at 70% relative density. It is observed that, the pile numbers can be reduced to optimize the cost of foundation system with due consideration of design requirement also as the pile length increases the settlement decreases.

Keywords: Pile Raft, Settlement, friction angle, void ratio, Relative Density, settlement reduction ratio, load sharing ratio.

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1. INTRODUCTION

The stability of any civil engineering structure is dependent upon the soil-foundation system. In general the typical foundation system for mega structure is a shallow foundation system such as mat foundation to support and transfer structural loads to the beneath ground stratum. A raft or mat foundation is a large footing, supporting walls as well as columnsin several rows. The main function of piles is to reduce the average settlement of the structure and to provide suitable bearing support.

In the past few years, the piles are used below the raft as a settlement reducing members in the foundation system. This concept was first proposed by Burland et al (1977). A different approach involving use of piles as settlement reducers has been postulated by Burland (1977). This new approach is called as Piled Raft Foundation or

Combined foundation system. Many other researches were published on this concept of piled raft foundation by Poulas and Davis (1980), Randolf (1994), Horikoshi and Randolf (1996). Horikoshi had carried out the centrifuge test on piled raft. The behavior of the piledraft with sand as bed material has been studied by researchers like Balakumar and Ilamparuthi (2009), Sahu and Bajad (2009) and so on. The parametric studies have also been carried out by many researchers using 1gmodel studies (Balakumar2008) and centrifuge models (Horikoshi, 2003) extensively. In order to solve this complex problem of piled raft, several methods such as numerical and analytical model studies were done by using finite element methods using software like PLAXIS, ANSIS etc. With an advancement of the computer, more rigorous methods such as Finite Element Method (FEM) are also used in some of recent researches (Chow et. al, (2005), Liu et. al., (2009), Joy et. al, (2014).

In the modern era of Civil Engineering, the high rise construction has been concentrated in the areas catered to financial and business activity. This kind of high rise structures has become common and growing phenomenon in all over the world. The basic concept of piled raft foundation is that the settlement is reduced up to tolerable amount and the loads from superstructures are transmitted via raft to the piles and the foundation soil. The piled can be designed to optimize the number of piles so as to get best results and not required to provide unnecessary piles. In this paper observation of the experimental studies carried out on the model piled raft foundation in the laboratory to analyze the settlement behavior and load sharing mechanism of composite foundation system for different configurations of piles is presented. From the experimental program it is observed that, as the number of piles below raft foundation increases, the settlement of foundation system reduced to a large extent and design requirement is fulfilled. This is probably due to sharing of total structural loads by the raft as well as piles.

2. EXPERIMENTAL PROGRAMME

Several authors have carried out tests on the model piled raft foundation by considering different combinations of piles below the raft. In the present study, load-settlement behavior of piled raft foundation system is studied. Total fifteen tests were conducted in the laboratory with different pile configuration. The test program is presented in the Table 1. The pile configuration of model raft of piled raft is as shown in the Figure 1. Basically load testis done in the laboratory on raft with or without piles and settlement behavior of piled raft system is observed with respect to varying pile lengths and patterns.

2.1. Test Soil

The poorly graded sand (SP) collected from Wainganga River, Nagpur, Vidarbha Region, Maharashtra State, India is used in the study. Basic properties of sand such as maximum and minimum dry unit weight, relative density, uniformity coefficient, coefficient of curvature and angle of internal friction, elasticity modulus, etc. determined in the laboratory and test results are presented in the following Table 2. Typical particle size distribution curve of sand is shown below in Figure 2.

From the past literature reviewed it was observed that, the relative density of the sand in laboratory test setup was maintained in the range 60% to 80% (as shown in the Table 2). In the present work, the test sand is compacted in the tank so as to achieve relative density 70 %.

Table1 Testing program

Configurations	Test No	No. of piles	Outer pile length, mm /corner piles	length of central pile, mm	Pattern	
Basic	**1**	**0**	**0**	**0**	**Raft Only**	
C1	2	9	100	100	Regular	-
	3	9	200	200	Regular	-
	4	9	400	400	Regular	-
C2	5	4	100	100	Diamond	-
	6	4	200	200	Diamond	-
	7	4	400	400	Diamond	-
C3	8	5	100	100	Star	-
	9	5	200	200	Star	-
	10	5	400	400	Star	-
C4	11	9	100	200	Regular	-
	12	9	200	400	Regular	-
	13	9	100	400	Regular	-
C5	14	9	200	400	Regular	(100mm-Diamond)
	15	9	100	400	Regular	(200mm-Diamond)

2.2. Test setup

The model scale of 1: 100 is adopted in the entire tests performed. The square piled raft with varying pile length is selected. This represents the behavior piled raft foundation for multi-storey building. The experimental set up is fabricated which consists of piled raft model made up of mild steel plate having a square shape having dimension 150 mm x 150 mm with thicknesses of 15 mm with smooth surface. The model piles were made up of the mild steel of diameter 12 mm. The plate has 9 screwed holes from the bottom surface with 10 mm depth and 12 mm diameter, spaced with 50 mm center to center. The pile lengths of 100 mm, 200 mm and 400 mm is used in the experiments. The soil tank is made up of steel having inner diameter 800 mm and height of 900 mm. It is obvious that the dimensions of the soil tank are large enough to overcome the scaling effects and the boundary conditions on the piled raft assembly response as the ratio between the tank diameter and the raft side dimension is 5.0.The model piled raft foundation is inserted into soil media by driving method.

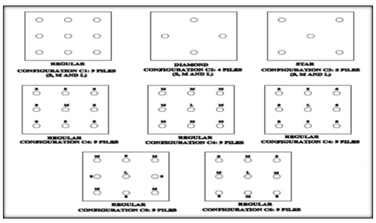


Figure 1 Configurations of piled raft model

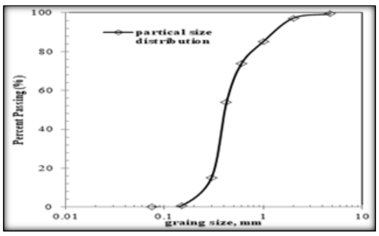


Figure 2 Particle size distribution curve for sand

Table 2 Typical properties of sand

Sr. No.	Name of Author	G	γ_{max}	$\gamma_{min.}$	Cu.	Cc	I_D(%)	ϕ	E (MPa)
1.	Harry G. Poulos (2011)	-	-	-	-	-	-	-	3000
2	Jaymin D. Patil (2014)	2.65	16.90	14.40	1.36	1.03	60	36.5	10.725
3	AngelinSavio (2015)	2.67	18.11	15.27	2.87	0.86	82	43.5	-
4	Kais Shlash (2015)	-	20	-	-	-	-	41	60
5	A.Z. Elwakil (2016)	2.56	-	15.00	2.90	-	65	-	-
6	B. M Anjankar, (2018)	2.66	18.71	16.47	1.75	0.92	70	34	-

The main purpose of the experimental work is to study the load-settlement behavior of piled raft foundation system and load transfer mechanism between the raft and piles with raft of thicknesses 15 mm and different pile configurations such as regular, diamond and star pattern. Total Fifteen tests were conducted in the laboratory. The dimensions of model pile and raft were chosen to ensure no stress concentration at the boundary of the tank. The height of soil is considered as two times greater than the pile lengths to avoid the effect of a rigid base of the soil tank on the behavior of piles. The dry sand is filled into the tank in layers of 100 mm by rainfall method and filled up to 800 mm height and with fixed weight to achieve the 70% relative density. Maximum 9 piles in a 3 by 3 grid pattern with spacing 50 mm c/c are provided. A calibrated proving ring of 20kN maximum capacity is used and is mounted over the plunger which is placed at plate. To measure vertical displacement of the plate, two dial gauges of 0.01 mm least counts are placed on diagonally opposite end of the plate. The load was applied vertically and concentrically on the pile raft model. The schematic arrangement of experimental set up for piled raft foundation is shown in Figure3.

2.3. Test procedure

- Initially the marking is done in white colour inside the soil tank at 100 mm height interval to fill the sand uniformly.
- Sand poured in the tank by rainfall method alongwith sand compaction by rammer assembly of 200 mm square size in order to achieve desired density of 17.98 kN/m3 in all test setup.
- After pouring sand up to a height of 800 mm from bottom of tank, the sand is levelled using sharpened steel plate. Then, piled raft assembly was inserted into the sand by absolute vertical driving technique. No inclination in piles or raft is permitted.
- The load was transferred to model raft through plunger attached to proving ring. Then, two dial gauges were placed at the middle side of the raft, to measure vertical settlement of piled raft model.
- A calibrated proving ring of 20 kN capacity is connected to manually operated loading system. The model raft was loaded incrementally and at the end of each load increment vertical settlement was measured. The rate of loading was 0.56 kN/min(1.25revolution/min). The loading was continued upto 20 kN or failure of piled raft.

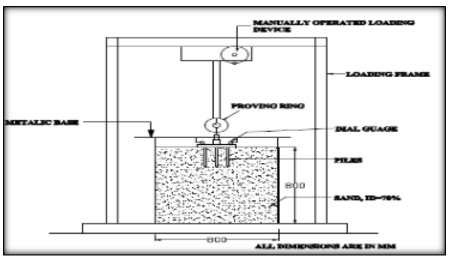
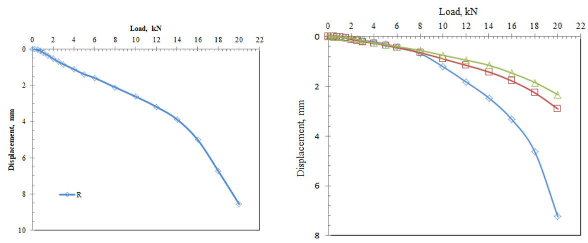


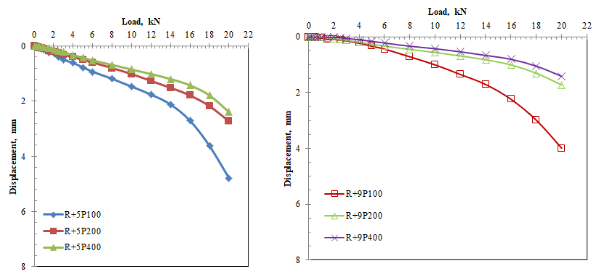
Figure 3 Experimental setup

3. SETTLEMENT ANALYSIS OF PILED RAFT FOUNDATION

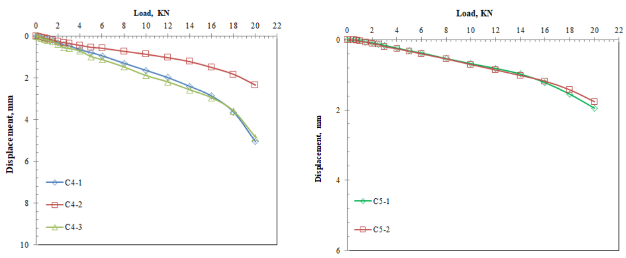
Following Figure 4 shows the test results of piled raft foundation systems with different configurations such as raft without piles, piled raft with different pile lengths 100 mm (small pile), 200mm (medium pile) and 400mm (large pile) and of different patterns such as regular, square, diamond patterns. From the Figure 4 it is observed that, the settlement is reduced as the number of piles increases. At 20 kN test load, displacement observed for raft was 8.55 mm. For piled raft system with 9 piles attached, the settlement of the system was respectively 3.99 mm, 1.725 mm and 1.425 mm for 100 mm, 200 mm and 400 mm length of piles. For configuration C5 wherein corner piles are of shorter in length i.e., 100 mm and 400 mm at central pile and rest piles of 200mm length shows more settlement reduction (nearly 1.415 mm) among all configurations. These observations are similar that was experienced by Angelin Savio el al [10]. This shows significant reduction in settlement of piled-raft foundation system with the increase of pile length and pile numbers.



a Raft Only **b** C2 Configuration



c C3 Configuration **d** C1 Configuration



e C4 Configuration **f** C5 Configuration

Figure 4 Load displacement behaviors for different piled raft foundation systems

3.1. Load sharing ratio (αPR)

In case of piled raft foundation, the total weight of structure is generally transferred to ground through the components i.e., raft and piles. This means that the some part of load is shared by raft and balance load is taken by piles. The amount of load carried by raft and piles can be computed by determining the load sharing ratio (αPR).

$$\alpha PR = \frac{(Ppr - Pr)}{Ppr}$$

Where, αPR –Load sharing ratio,

Pr-Load carried by raft and Ppr- Load carried by piled raft.

It is observed that as the number of piles increases, load sharing ratio increase. Similar observations were obtained by Angelin Savio et al [10].

4. TEST RESULTS AND DISCUSSION

Various researchers have studies the behavior of Piled raft foundation in sandy soil. The parametric study of piled raft foundation for optimization of cost of piled raft foundation so as to satisfy the design requirement is carried out in the present study. The results obtained from the experimental observation on piled raft model foundation are discussed below:

4.1. Effect of pile length

The effect of Pile length on settlement and load sharing mechanism: A 3x3 pile group is analysed with pile constant spacing. The pile length is varying as 100 mm, 200 mm and 400 mm. It is observed that, as the pile length increases, the settlement decreases and thereby resulting into increase of load carrying capacity.

4.2. Effect of number of piles on ultimate load capacity

As the number of piles increased the ultimate load carrying capacity of the foundation system also increases. Following Figure 5 shows the effect of number of piles on ultimate load capacity.

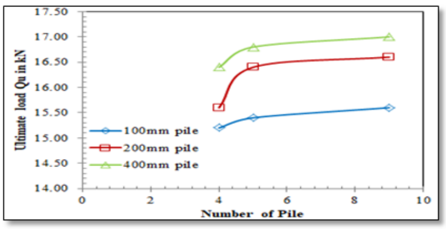


Figure 5 Ultimate load capacity Vs. Number of piles

4.3. Effect of number of piles on settlement reduction ratio

It is observed from the Table 3 that, as the length of pile increases settlement reduction ratio also increases. Also, with increase in the number of piles in piled raft foundation system, overall increase in the settlement reduction ratio is seen.

Table 3 Settlement reduction ratio (SR) for different piled raft configuration

Configuration	Length of Pile (mm)	Applied Load, kN											
		0.5	1.0	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0
C1	100	0.750	0.775	0.833	0.795	0.725	0.663	0.618	0.578	0.560	0.554	0.556	0.533
	200	0.917	0.900	0.880	0.826	0.794	0.788	0.787	0.786	0.789	0.800	0.806	0.798
	400	1.000	1.000	0.963	0.906	0.863	0.842	0.838	0.833	0.829	0.840	0.844	0.833
C2	100	0.750	0.875	0.806	0.813	0.744	0.679	0.538	0.429	0.294	0.335	0.312	0.153
	200	0.917	0.875	0.769	0.759	0.716	0.696	0.658	0.639	0.634	0.644	0.664	0.660
	400	0.833	0.850	0.889	0.772	0.747	0.738	0.713	0.704	0.703	0.707	0.726	0.727
C3	100	0.167	0.300	0.528	0.451	0.419	0.439	0.441	0.449	0.455	0.460	0.462	0.440
	200	0.083	0.225	0.593	0.638	0.628	0.623	0.614	0.604	0.611	0.643	0.677	0.681
	400	0.917	0.800	0.778	0.705	0.675	0.677	0.677	0.682	0.693	0.716	0.734	0.720

4.5. Effect of number of piles on load sharing

Following Figure 6 shows the effect of number of piles on load sharing ratio.

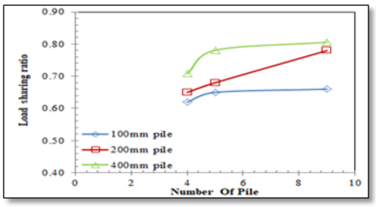


Figure 6 Load sharing ratio (αPR) Vs. Number of piles

4.6. Effect of L/B ratio on ultimate load capacity

As the pile length increases, the total surface area for resistance is increased which produces significant increase in shear strength of soil and respective increase in ultimate load. Therefore, as L/B ratio increases, the ultimate load capacity increases. The effect of L/B ratio is shown in the Figure 7 below;

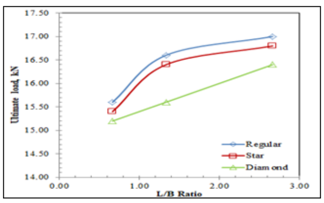


Figure 7 Ultimate load Vs L/B ratio

5. CONCLUSION

From the experimental observations on piled raft in dry sandy soil at 70% relative density, it is observed that:

- The settlement of piled raft foundation is decreased with the increase in pile length.

- The load bearing capacity of piled raft increases as the number of piles beneath the raft increases.
- The settlement reduction ratio increases with the number piles.
- The percentage of load carried by raft increases for small pile length. Also, relatively more settlement observed for small piles.
- Load shearing ratio increases with the number and length of piles.

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