PARAMETRIC STUDY ON THE BEHAVIOUR OF COMBINED PILE RAFT FOUNDATION FOUNDED ON MULTI-LAYERED SOIL USING PLAXIS 3D

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ABSTRACT: The uses of pile raft foundations are common in recent years. The combined effect of pile and raft as foundation can lead to the reduction in total and differential settlements in problematic soil conditions. Many researchers have been done studies to predict the effect of combined pile raft foundations (CPRF) on the response of soil under heavy loads. But most of the numerical studies were done by considering soil as a single layer. The present study aims to find out the effect of pile raft in multi-layered soil using a three dimensional finite element software PLAXIS 3D. The current parametric study includes the effect of diameter and spacing of piles with varying raft thickness on settlement. It is observed that raft foundation undergoes more settlement than pile raft foundation. The effect of raft thickness has a very little effect on reducing total and differential settlements. The effect of pile diameter and pile spacing was also given useful insight into the behavior of multi layered soil.

Key words: combined pile raft foundation, PLAXIS 3D analysis, multi-layered soil.

1 INTRODUCTION

The scarcity of land for the future construction has made the man to build high rise buildings. These buildings will impart huge axial and lateral loads to the soils underneath their foundations. The load transfer mechanism from superstructure to substructure is usually done by providing suitable foundations. The foundation is the first element of the building where construction starts, but when it fails; it can cause many defects in the building including failure or collapse of the building. The repair of defect in the foundations is most difficult and very costly, so it is most important to design foundation to avoid such failure of building. There are different types of foundations to enhance load transfer mechanism. Raft foundations are one among them to carry the loads from columns and distribute the load in the whole base area of building. When allowable soil pressure is low, or the building loads are heavy, the use of spread footings would cover more than one-half of area and it may prove more economical to use raft foundation. The raft foundation can satisfy the bearing capacity requirement but fails to keep differential as well as total settlement below the maximum allowable limit. Another alternative to the huge load transfer is giving deep foundations. Pile foundation may be adopted instead of a raft foundation where no firm bearing strata exists in any reasonable depth and the loading is uneven. The coastal region of India is found mainly by soft soil and pile foundations are adopted as the best solution to overcome the low bearing capacity of soft soils. The pile foundation is a deep foundation in which the loads are taken to deeper level. Sometimes the length of the pile foundations will be very large to achieve the load bearing capacity. The challenges from raft or pile foundation alone can be avoided using the combination of both which is generally known as the Combined pile raft foundation (CPRF) system. In piled rafts, the raft directly interacts with soil and it is supported by group of piles of various configurations. The recent projects proved that the pile raft foundation will give most economical length of piles with minimum differential settlement.

2 REVIEW OF LITERATURE

Burland et al.(1977) studied the CPRF system and found that pile is the only load bearing part. But later studies showed that the raft system also takes load. The load sharing by the pile and the raft was studied by many researchers (Shukla et al. 2013., Davids. 2008, Randolph, 1994) and made designs according to that. Recent studies carried out by Nirmal et al (2014) reported that CPRF is best to provide larger diameter piles to reduce the maximum and differential settlement. Few researches have done studies on the behavior of combined pile raft foundations in layered soils which is very common in the field. Gopinath et al (2010) presented that the increase in raft thickness decreases the overall settlement of pile raft foundation when it is found on layered soils. While it is mentioned that even though the raft thickness does not have any significant effect in layered soils, the raft thickness has a major contribution in reducing the differential settlement (Oh et al.,2008). So this particular paper tries to give more insight into the response of CPRF on layered soil using finite element method.

3 SOIL MODEL

The general stratum of subsoil consists of two soil layers mainly a loose sand layer of 15m deep overlaid by the next layer of stiff clay of thickness 15m. The properties of soil layers taken for the model studies are given in Table 1. The ground water table was at 3m below ground surface. An extensive parametric studies were carried out by varying surface loads of intensities 200 kN/m^2, 400 kN/m^2, 600 kN/m^2 and 800kN/m^2 to simulate the loads coming from high rise buildings .

Table 1: Properties of sub soil used for model studies

Properties	Loose sand	Stiff clay
Thickness (m)	15	15
Unit weight (kN/m^3)	15	16
Saturated unit weight(kN/m^3)	18	19
Undrained cohesion (kN/m^2)	0	80
Friction angle (Degress)	28^0	0
Young's modulus (kN/m^3)	6000	20000
Poison's ratio	0.3	0.35

4 4 FINITE ELEMENT MODELING IN PLAXIS 3D

The combined response of sand and clay layer was analysed using finite element method. Three dimensional analysis were conducted using the software PLAXIS 3D AE. The soil behavior of soil was captured by Mohr Coulomb model which is an elastic perfectly plastic model. The piles were modeled as linear elastic models. The length and width of the soil model was taken as 50m and the thickness was given as 30 m. The boundary conditions were fixed in such way that the boundary effects to the model should be minimal. The sides of the model were allowed to move freely in vertical direction but restrained in both X and Y directions. The bottom was fixed in all direction and top of the soil layer was free to displace according to the external loads. The finite element model was analyzed with total stress approach.

5 VALIDATION OF THE MODEL

The model was validated for various spacing between the piles under 200 kPa surface load. The model includes five layers of soil. The spacings of pile were taken as 3d, 4d, 5d and 6d with pile diameter as 1m and 0.8m thick raft. The results obtained from the studies done by Oh et al. (2008) were very well converged with the plaxis results. Fig. 1 shows the validation of the model by plotting the variation of pile spacing with settlement under surface load of 200 kN/m^2.

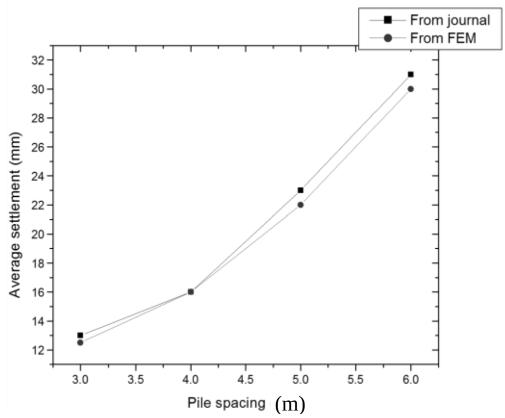

Fig. 1 Average settlement vs. pile spacing

6 PARAMETRIC STUDIES

Parametric studies were planned to investigate the settlements of piled raft under the changes in parameters such as diameter of pile, spacing of piles and raft thickness. The raft was modeled as concrete element, while piles are modeled as series of concrete embedded piles. Various case studies were taken into consideration to analyse the exact behavior of pile raft foundation system. The area of pile raft foundations and length of piles were fixed as 20m× 20m and 18m respectively. All studies were carried out considering the two soil strata. The details are listed below:

- Case 1: The effect of raft thickness was analyzed in Case 1 with a constant pile spacing of 4d, where diameter (d) of the pile which was taken as 0.6m. In this case, piled rafts with varying raft thickness as 0.3m, 0.4m, 0.6m, 0.8m, 1m were modeled and found out the maximum and differential settlements under the surface loads ranging from 200 kN/m^2, to 800 kN/m^2 with an increment of 200kN/m^2.
- Case 2: Case 2 is mainly focused to find out the effect of pile spacing under different loading

intensities. In Case 2, pile raft with raft thickness of 0.8m was modeled by varying the pile spacing as 3d, 4d, 5d, 6d, 7d. The same surface load increments and pile diameter was taken as that of Case 1.

- Case 3: Case 3 was included to study the influence of pile diameter on the response of CPRF systems. The other parameters were adopted as the same as that of Case 1.

7 RESULTS AND DISCUSSIONS

The influence of various parameters such as the raft thickness, pile spacing and pile diameter in a CPRF system are described in detail in the following sections.

7.1 EFFECT OF RAFT THICKNESS

The results obtained from Case 1 analysis are shown in Fig. 2 which shows the variation of maximum settlement with respect to raft thickness. There was a significant increase in both the settlements with increase in surface loads. The maximum settlement was found to be 20cm under all surface loads except at the maximum surface load of 800kN/m^2. It can be concluded that the maximum settlement decreases as the raft thickness increases in all loading cases (Fig. 2). On the other hand, the comparison of raft thickness on maximum settlement shows that there was little effect on the maximum settlement when raft thickness was varied from 0.3m to 1m. In addition to that the construction becomes uneconomic if raft thickness increases beyond 1m. In view of these reasons it can be summarized that the increasing the raft thickness do not have much significant influence in combined pile raft foundation and it is uneconomical after certain limits. The maximum and differential settlements were increased with increase in surface loads under multiple layers of soils (Fig 2 and Fig. 3). Fig. 3 also defines the variation differential settlement with raft thickness.

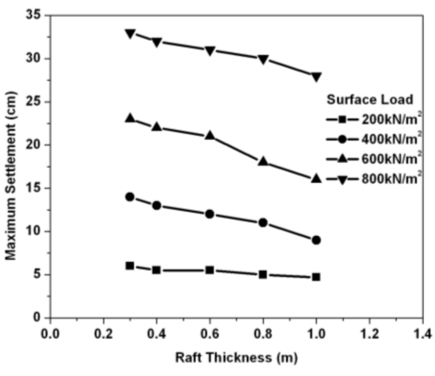

Fig. 2 Maximum settlement with varying raft thickness

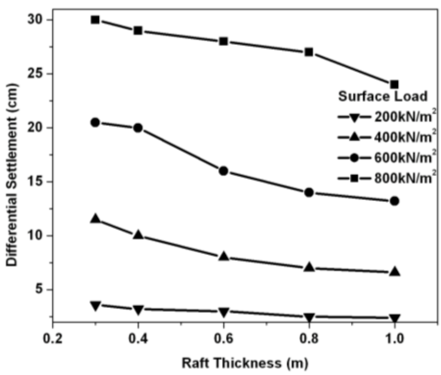

Fig. 3 Differential settlement with varying raft thickness

7.2 EFFECT OF PILE SPACING

The variations in settlement due to different pile spacing are shown in Fig. 4 and Fig. 5. When the intensity of loading greater than 200 kN/m^2, the increase in pile spacing has an adverse effect on the maximum and differential settlement under various loads.

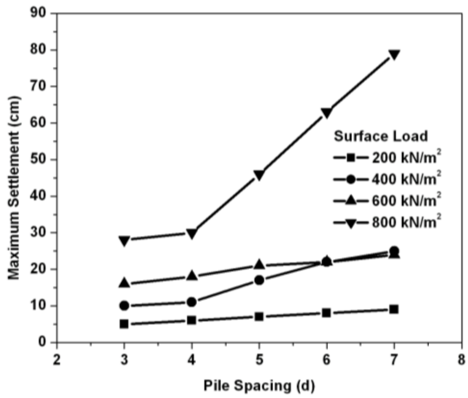

Fig. 4 Maximum settlement with varying pile spacing

The results showed that for 200 kN/m^2 and 400 kN/m^2 both settlements were less than 10cm while the spacings between the piles were taken as 3d and 4d.

The differential settlements were found to be less than the maximum settlement in all cases. When the surface loads were increased from 200kN/m^2 to 800 kN/m^2, the analysis with multilayer soil strata has proved that the difference between the total settlement and differential settlement was decreased significantly (Fig. 5).

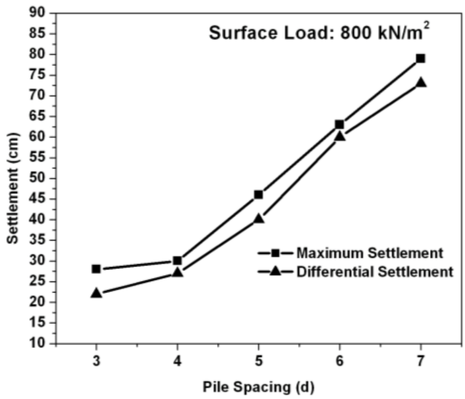

Fig. 5 Differential settlement with varying pile spacing

7.3 EFFECT OF PILE DIAMETER

The diameter has a major effect on reducing the settlements. Fig. 6 depicts the variations of settlement under various pile diameters and surface loads. It was found that both differential and total settlement of structure increases drastically at high values of vertical load intensity. The variation is found to be non-linear (Fig. 7).

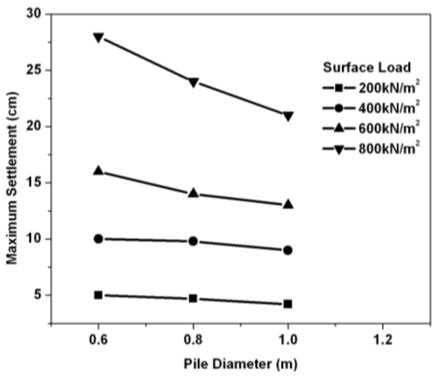

Fig. 6 Maximum settlement with varying pile diameter

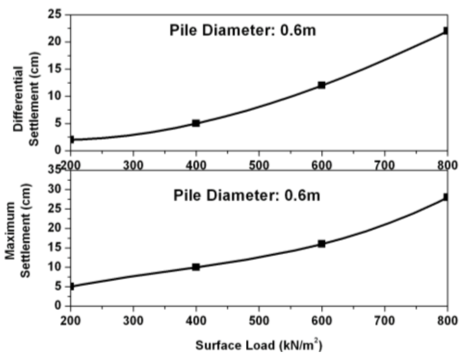

Fig. 7 Non-linear variation of settlement with load

When pile diameter increased from 0.6 m to 1m the reduction of both settlements were less than 20% for all vertical load intensities except 800kN/m^2. The surface load of 800kN/m2 gave very high value of both maximum and differential settlement.

8 CONCLUSIONS

A set of studies were conducted on pile raft foundation in multi-layered soil to measure the soil response. The following conclusions can be drawn from the present studies.

- The raft thickness does not have significant effect on maximum and differential settlement.
- Pile spacing has important role on the performance of piled raft foundation. Both maximum settlement and differential settlement reduce with decrease in pile spacing.
- The pile diameter also plays an important role in reducing the settlements. Increase in pile diameter shows a decrease in maximum and differential settlement under all loading intensities.

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