Finite Element Analysis of Pile-Raft System Using PLAXIS 3D

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Abstract. Pile-raft foundation is a composite construction which consists of piles and raft is one of the alternatives over conventional pile or raft foundations. This study is directed to develop a numerical model capable to analyse and identify the parameters governing the performance of pile-raft system. The effect of number of piles, pile length and pile spacing on the behaviour of pile raft was studied. This study also focused on the influence of these parameters onthe settlement behaviour and the load sharing between the raft and piles of the system. The analysis was carried out by considering sand (at loose, medium and dense condition) as foundation soil. The results show that value of vertical deformation decreases as the result of the increase of pile number, pile length and pile spacing. However, the load carrying capacity of the pile-raft system increases only up to an optimum value on varying the pile parameters.

Keywords: Pile-raft System, Finite Element Analysis, PLAXIS-3D.

1 Introduction

Piles can be used with raft foundation in order to provide adequate bearing capacity or to reduce settlements to an acceptable level. The common design of piled raft is based on the assumption that the total load of the superstructure is supported by the piles, ignoring the bearing contribution of the raft. In the recent years, piled raft foundation has been more and more popularly applied to increase load capacity and reduce settlement in a very economical way comparing with traditional foundation concepts.

This study concentrates on the effect of engineering factors related to pile in raft foundation such as number of piles, pile length and pile spacing on the behaviour of the piled raft foundation. The analysis is carried out by 3D Finite Element Method via PLAXIS 3D Foundation software.

2 Finite Element Modelling

In this section, the details of the finite element (FE) model is discussed.

2.1 Model boundary and meshing

The lateral boundaries of soil domain are fixed at a distance of two and half times the width of the raft (B) from the raft edge on either side as shown in Figure 1. These boundaries are restrained against horizontal movement, but the vertical movement is allowed. The bottom soil boundary was placed at a distance of twice the length of the pile (L) from the raft base. The base portion is restricted from both vertical and horizontal translations. Such extent of model boundary has already been reported in literatures.

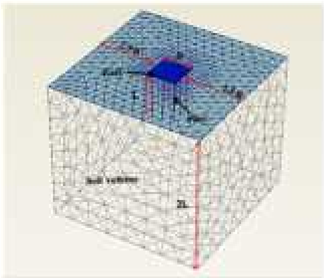

Fig. 1.FE model of piled raft foundation with mesh

To predict the behavior of piled raft foundations at large settlements a non-linear analysis is required. Therefore, the behavior of the soil was considered as non-linear. There are many constitutive models used to simulate the soil behavior such as the Linear Elastic Model, Mohr-Coulomb model, Cam Clay Model, Drucker-Prager, Hardening Soil Model and Lade's Single Hardening Model. The elastic perfectly-plastic Mohr-Coulomb model was used to simulate the behavior of the soil. The Mohr-Coulomb model is a non-linear model which is based on soil parameters that are well-known in engineering practice. For this model, the modulus of elasticity of soil, E, and Poisson's ratio, μ, are used for the soil elasticity while the friction angle, φ, and the cohesion, c, are used for the soil plasticity and the dilatancy angle is needed to model the increase of volume.

2.2 Model Footing

The piles were assumed as embedded concrete piles. The raft was considered as a reinforced concrete slab. The behavior of the raft and the piles was assumed linear. Therefore, the linear-elastic model was utilized to simulate the materials behavior of the piles and the raft. For the linear-elastic model two main parameters are used, which are the modulus of elasticity, E, and Poisson's ratio, μ.

3 Details of the study

An 8x8x1m piled raft with massive circular piles which have diameter of 0.4m is used as numerical example for parametric studies. Foundation is subjected to a 100 kN/m2 uniformly distributed load. Number of piles was varied to investigate their effect on the settlement of foundation with different layout such as: raft foundation without piles, raft foundation with various pile layouts. This raft was also used to consider the influence of the pile length and the pile diameter and pile spacing. Studies were taken into consideration to analyze the exact behavior of pile raft system in sandy soil under loose, medium and dense density conditions.

Number of piles was varied to investigate the effect on the settlement of foundation with different layout such as: raft foundation without piles, raft foundation with various pile layouts from one to nine piles. This raft was also used to consider the influence of the pile length, pile diameter and pile spacing.

4 Numerical Analysis

Modelling of piles in a 2D finite element as a plate has limitation to model the pile-raft interaction, which is strongly 3D phenomena, hence numerical analysis was carried ou by PLAXIS 3D 2013.1. The software program consists of three basic components, namely Input, Calculation and Output. In the input program the boundary conditions, problem geometry with appropriate material properties are defined. The model includes an idealized soil profile, structural objects, construction stages and loading. Soil modelling and model of pile raft shown in figure 2 and figure 3.

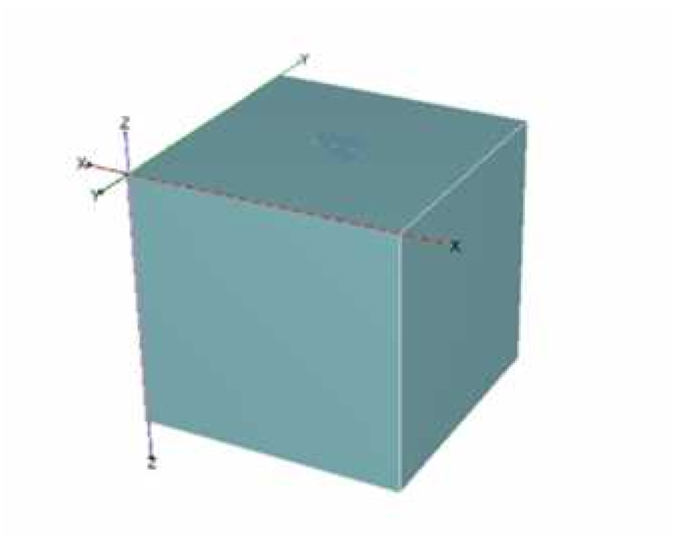

Fig. 2. Soil modelling using borehole

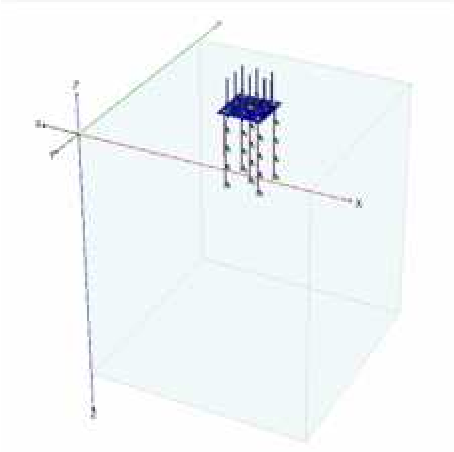

Fig. 3. Pile raft model

The soil properties which were obtained from laboratory tests were given and assigned. Since Mohr-coulomb model was adopted, there are five input parameters. These input parameters for soils considered in the study are given in the following tables.

Table 1. Input parameters for soil

Material properties	Loose	Medium	Dense
Modulus of Elasticity E (kN/m^2)	20000	40000	80000
Poisson's ratio, μ	0.3	0.3	0.3
Angle of internal friction, ϕ (degrees)	30	36	42
Cohesion, c (kN/m^2)	1	1	1
Dilatancy angle, Ψ	0	6	12

Table 2. Input parameters of model footing

Modulus of Elasticity, E (kN/m^2)	2.5 x 10^6
Poisson's ratio, μ	0.38

After assigning all the geometry parameters, meshing can be done. Mesh dimension should be appropriately defined, to prevent boundary conditions. Very fines mesh should be avoided in order to reduce the number of elements, thus reduce the memory consumption and calculation time. In PLAXIS 3D, foundation is provided as staged construction. In every calculation step, the material properties, geometry of the model, loading condition and the ground water level can be redefined. During the calculations in each construction step, a multiplier that controls the staged construction process denoted by $\sum M_{stage}$ is increased from zero to ultimate value 1. After staged construction the PLAXIS results were obtained.

5 Results and discussions

The geotechnical properties of sandy soil were determined as per IS specifications. The test results were summarized in Table 3.

Table 3. properties of soil sample (sandy)

Properties		values
Natural moisture content (%)		24
Specific gravity		2.67
Minimum dry density (kN/m^3)		14.2
Maximum dry density (kN/m^3)		17
Uniformity Coefficient, C_u		3
Coefficient of curvature, C_c		0.9
Particle size distribution	Gravel sized particles (%)	2
	Sand sized particles (%)	96
	Percentage of Fines (%)	2

5.1 Results from PLAXIS 3D analysis

Effect of parameters such as pile length, pile number, spacing between the piles on the settlement and load sharing behavior of pile raft system was determined using finite element analysis. The foundation soils were considered as homogeneous sandy soil. The behavior of pile raft system in three different density conditions (loose, medium, and dense) were analyzed.

5.2 Effect of variation of length and number of piles

Dense Sand

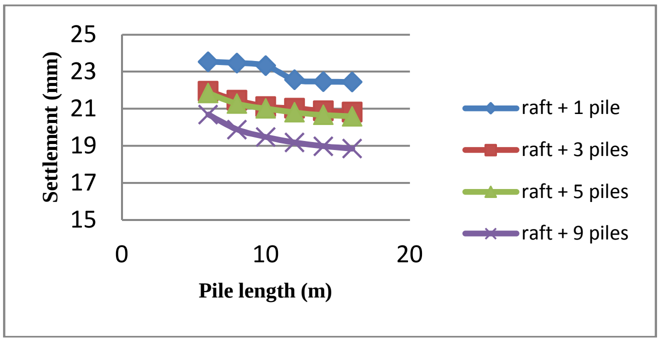

Fig. 4. Effect of pile length on total settlement of pile raft system on dense sand

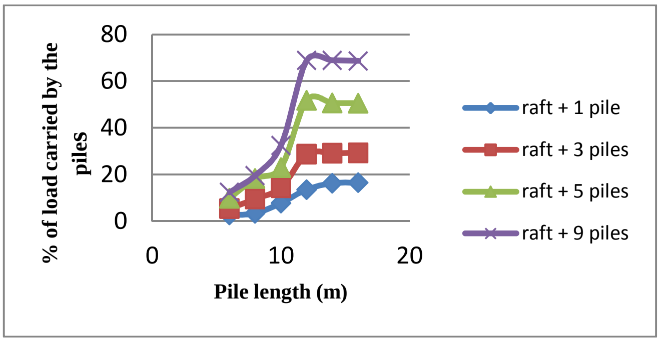

Fig. 5. Effect of pile length on the % of load carried by the piles in dense sand

Medium dense sand

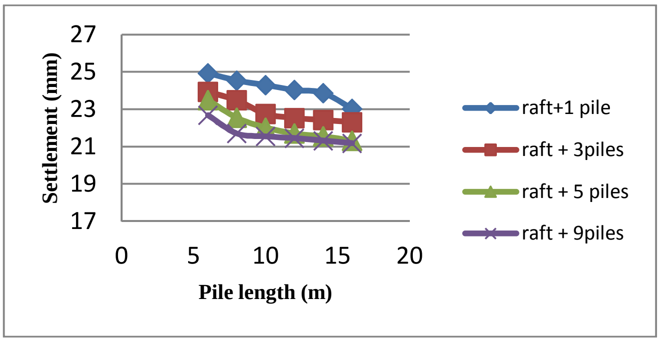

Fig. 6. Effect of pile length on total settlement of pile raft system on medium dense sand

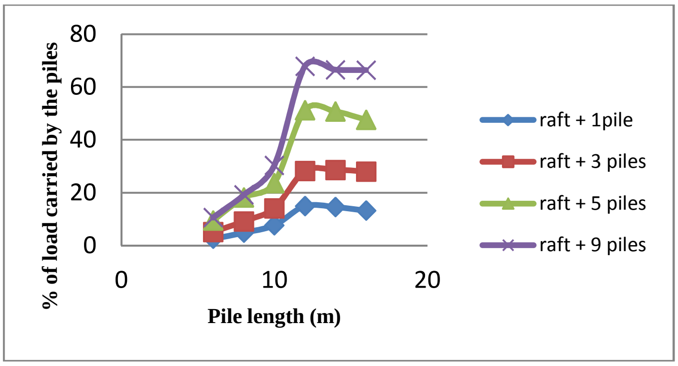

Fig. 7. Effect of pile length on the % of load carried by the piles in medium dense sand

Loose sand

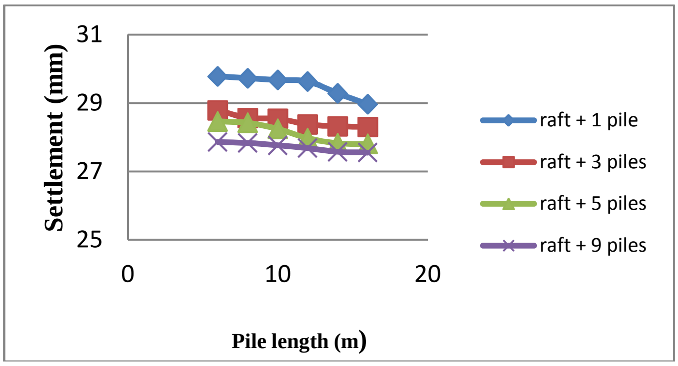

Fig. 8. Effect of pile length on total settlement of pile raft system in loose sand

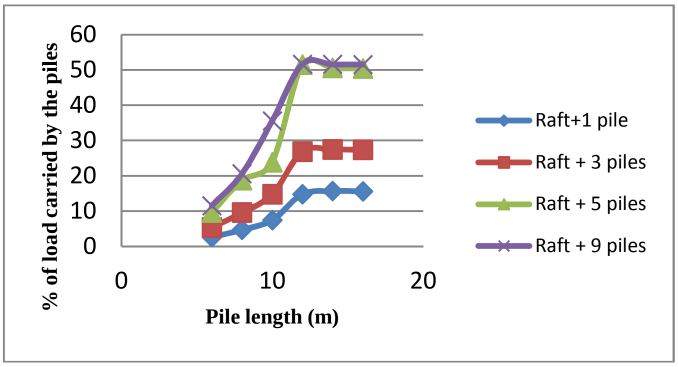

Fig. 9. Effect of pile length on the % of load carried by the piles in loose sand

5.3 Effect of variation of spacing and diameter of piles

Dense sand.

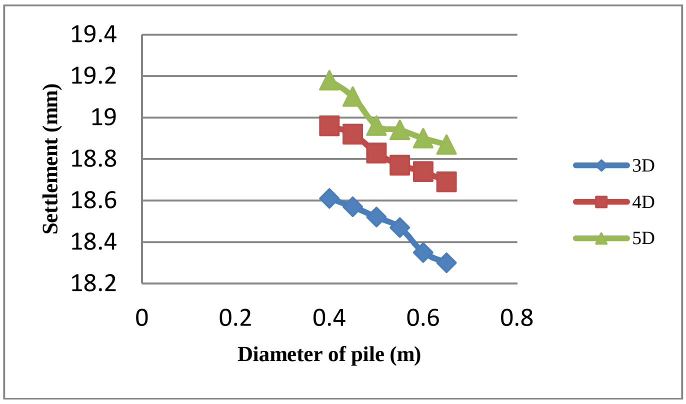

Fig. 10. Effect of pile diameter and spacing on total settlement of pile raft system in dense sand

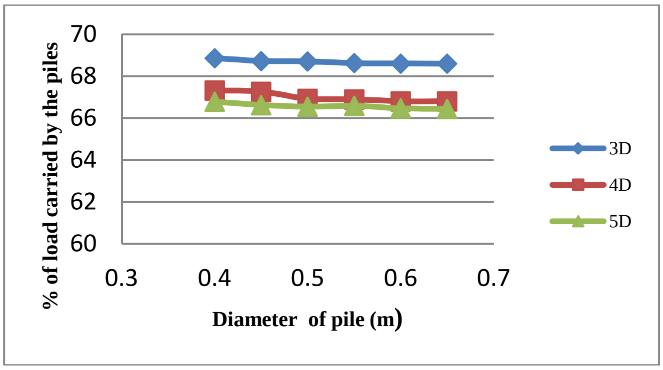

Fig. 11. Effect of pile diameter and spacing on the % of load carried by the piles in dense sand

Medium Dense Sand

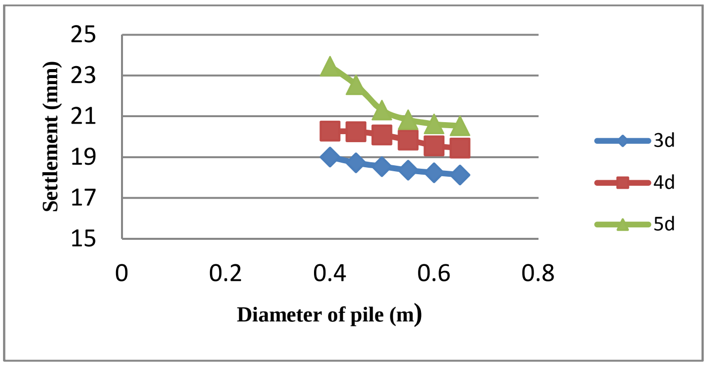

Fig. 12. Effect of pile diameter and spacing on total settlement of pile raft system in medium dense sand

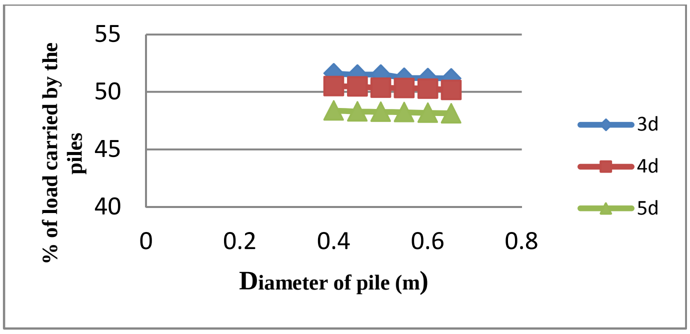

Fig. 13. Effect of pile diameter and spacing on the % of load carried by the piles in medium dense sand

Loose Sand

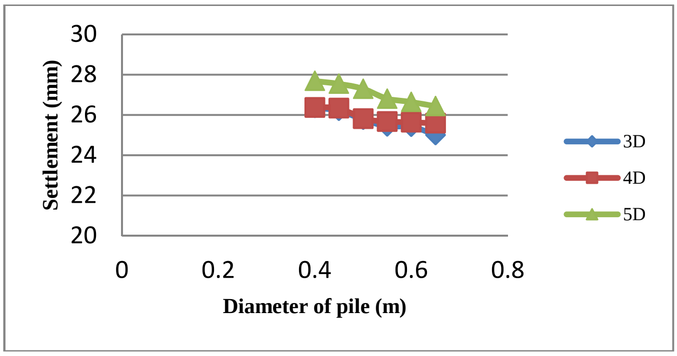

Fig. 14. Effect of pile diameter and spacing on total settlement of pile raft system in loose sand

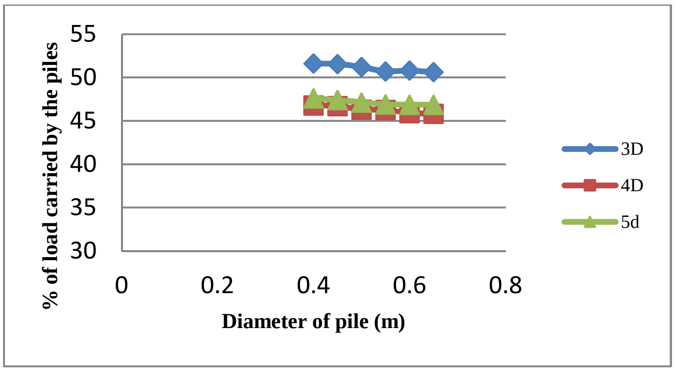

Fig. 15. Effect of pile diameter and spacing on the % of load carried by the piles in loose sand

The increase in pile length and number of piles shows an increase in the load carried by the piles. Increase in length above 12m doesn't show any increase in the percentage of load carried by the piles.After this particular length the percentage of load carried by the pile group is not affected by change in the pile length.

A gradual increase in settlement was observed with increase in the spacing between the piles and there is an increase in the percentage of load carried by the piles with increase in spacing. Pile diameter showed a small effect on the load sharing. The percentage of load carried by the piles decreases as the diameter of the increases but this decrease is very small which will not cause any significant change in the pile raft system.

The study shows that addition of piles beyond optimum number, increasing length, diameter of piles and spacing between them does not have significant effect in the reduction of pile raft settlement and load sharing. So, for an economic design it needs to determine the optimum values.

Pile-raft system is a combination of shallow foundation (raft) and deep foundation (pile group) in which the role of pile group is as settlement reducers. The following bar diagram shows a comparison of settlement of pile-raft system with piles and without piles.

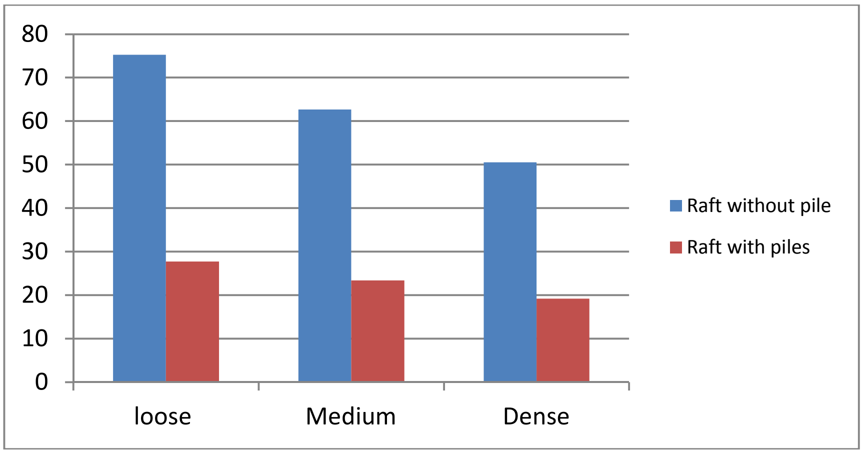

Fig. 16. Comparison of results

It shows that pile raft system has reduced the total settlement to about 60%-70%. This validates the purpose of the addition of piles as settlement reducers to the raft soil foundation system.

6 Conclusions

- From the present parametric study almost, a same trend is observed in the behaviour of pile raft system in the three cases considered(loose, medium and dense sand)
- Settlement of pile raft system decreases with increase in length of pile and number of piles up to a limit and there after the changes becomes negligible
- Maximum settlement is observed towards the centre of the raft
- An increase in settlement was observed when pile spacing was increased beyond 3D
- Percentage of load carried by the piles decreases as the spacing increases but it has no significant effect on the diameter of the piles
- Percentage of load carried by the piles increases with increase in length of pile
- After a particular length the percentage load carried by the pile group is not affected by the change in pile length

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