New equation to determine the load percentage carried by raft in piled raft foundations

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ABSTRACT

Piled raft foundations are an effective and economical system in case of high-rise buildings and are a suitable alternative to conventional deep foundations. In this type of foundations, raft is in direct contact with the soil and hence it carries a significant portion of load. Regarding to the design of piled raft foundations, one of the most important issues is to determine the proportion of load carried by raft. In this paper, numerical analyses using Finite Element Method (FEM) were carried out by developing 3D finite element models and with considering interaction effects for a piled raft foundation, the effective factors and their impact on load percentage carried by raft, are investigated. In addition, a new equation for determining the load percentage carried by raft in granular soil is proposed for a group less than a 9×9 pile configuration. The developed model is verified with available experimental results. The results of numerical analyses show that the load percentage carried by raft is significantly affected by several parameters, such as the distance of the piles from each other, the diameter of the piles, the internal friction angle of soil and the number of piles in group. In the current study, from the numerical analyses, it has been observed that the percentage of the raft carried load in piled raft system varies from 15% to 42% of the applied load.

KEYWORDS

Cap, Granular soil, Piled raft, Finite Element Method, ABAQUS

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Introduction

The concept of a piled raft system was first introduced by Davis and Poulos in 1972 [1]. To determine the proportion of load sharing of the raft, several studies have been performed by many researchers. Cook et al. (1986) first stated that rafts can carry up to 30% of the total structural loads [2]. Hemsley (2000) reported that the raft can carry up to 50% of the building loads [3]. Other researchers, by conducting various studies, have estimated the bearing capacity of the raft from the total load to be more or less between 20% and 60% [4-7].

The overall objective of this study focuses on investigating the bearing behavior of a piled raft foundations on granular soils under vertical loading by using 3D analysis model in ABAQUS finite element software. The validation of the present piled raft model was done by a comparison with a Small scale model tests, which was carried out by Elwakil and Azzam (2015) [8]. Then, a series of numerical analyses was performed for various distances and diameters of the piles, different number of piles in the pile group and three internal friction angle of soil, so the proportion of load taken by raft from the total load in different conditions is determined. Finally, a relation is provided to determine the load percentage carried by raft in piled raft foundations.

Numerical modeling

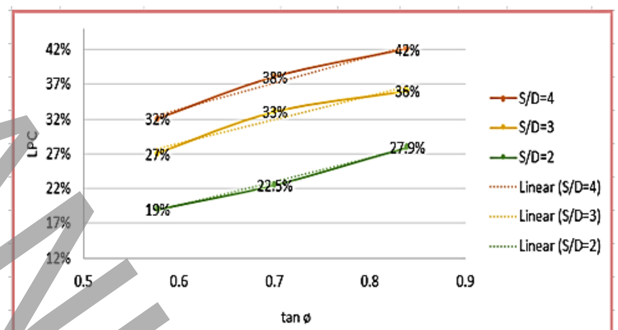
Numerical analysis of present research has been done using ABAQUS 3D software and mesh discretization was done by using the 10 node elements. Regarding boundary conditions, since simple distant boundaries are typically used in static analysis, are closed in the X and Y directions and the lower side in all three directions. It has also been noted that the soil-structure interaction and the constraints on the problem are well defined. These soil structure interactions include the interaction between pile sleeve and soil, pile tip and soil and raft subsurface interaction with soil. Geotechnical properties of soil and mechanical properties of pile and raft used in the analysis, are in accordance with the soil parameters of Elwakil and Azzam (2015) study. The constitutive modeling used in numerical simulation is the hardening soil (HS) constitutive model.

To determine the bearing capacity of the raft, several numerical analysis has been performed and 36 numerical models have been made in which the effect of four factors has been investigated. These factors are: connection situation of the raft to the soil surface, internal friction angle of soil (φ), number of piles in group (n), And the ratio of center-to-center distance of piles to pile diameter which is called pile spacing ratio (S/D).

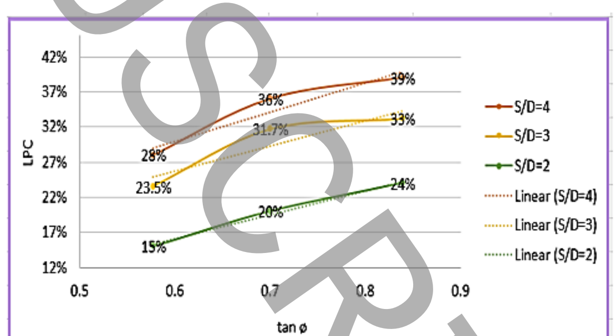
The results of numerical analyses

After completing the FEM analysis steps, the force of the piles and raft and the load percentage for different settlement of the system were determined. Out of a total of 36 numerical models made, 18 models are related to connected cap piles, known as piled raft foundations. Using the results, in the piled raft foundations, as the number of piles in the group increases, the proportion of load taken by raft decreases and the load sharing by piles increases. Also, the raft has a greater impact and share in participation and bearing in areas with higher internal friction angle of soil. Investigation of pile spacing ratio also shows that the larger *S/D*, the higher the bearing capacity of the raft and with decreasing this ratio, the share of the raft decreases.

Based on the performed analysis, the changes in Load Percentage Carried by Cap (raft) which is briefly indicated by *LPC*, are plotted in terms of the internal friction angle of soil as well as the pile spacing ratio *S/D* for 5.5-inch settlement and the 16 and 36 pile groups by graphs. In Figure (1), *LPC* changes are observed in terms of *tanφ* and in Figure (2), *LPC* changes are observed in terms *S/D* ratio.

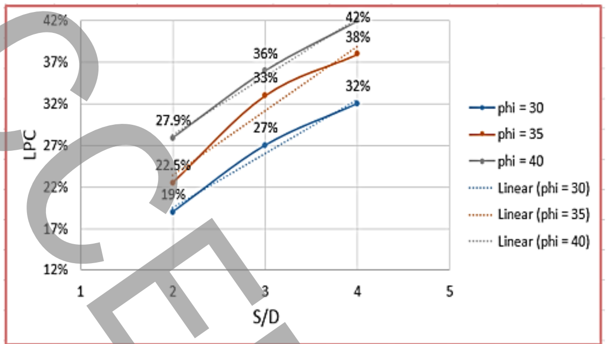


(a) 16-pile groups

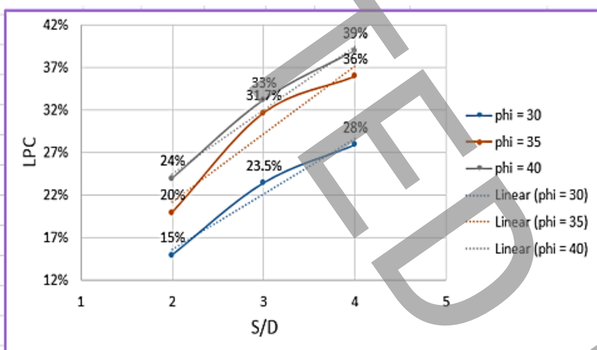


(b) 36-pile groups

Figure 1. ***LPC* changes with *tanφ* for 5.5 inches' settlement**



(a) 16-pile groups



(b) 36-pile groups

Figure 2. ***LPC* changes with S/D for 5.5 inches' settlement**

By considering the fitting curve equation of each of these diagrams, the equation (1) for piled raft foundations with *S/D*<10, group of piles for less than a 9×9 pile configuration in granular soils is obtained.

$$LPC = A \times \left(\frac{S}{D}\right) + B \times \tan\varphi - C \qquad (1)$$

$$A = 0.071$$

$$B = 0.375 - 0.004n$$

$$C = 0.126 - 0.001n$$

In this equation, *LPC* is Load Percentage Carried by Cap (raft) in terms of percentage, φ is internal friction angle of soil and n is the number of piles.

Conclusions

Based on the numerical analyses performed in the present study, the following results were observed in the piled raft foundations embedded in granular soil:

1- The percentage of the raft carried load in piled raft systems varies from 15% to 42% of the applied load

2- The larger the *S/D* ratio, as the other parameters are constant, the higher the bearing capacity of the raft.

3- In the group of piles with constant *S/D* ratio, for a certain number of piles, the larger internal friction angle of the soil, the higher bearing capacity of the raft. Also, by reducing the number of piles in the group and keeping the internal friction angle of soil constant, the bearing capacity of the raft will increase.

4- Introducing a new equation to determine the load percentage carried by cap (raft) in piled raft systems in granular soil for a group less than a 9×9 pile configuration, with pile spacing ratio (*S/D*) less than 10.

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