Finite Element Analysis of Piled Raft Foundation Using Plaxis 3D

Anupam Verma and Sunil K. Ahirwar

Abstract A piled raft foundation is a type of deep foundation capable for transferring the heavy load of superstructure into the soft soil by pile and raft support system. A numerical analysis of piled raft foundation is presented in this study. Various types of interactivity among components like pile-to-pile interactivity, raft-to-pile interactivity, pile-to-soil interactivity, and raft-to-soil interactivity are also being examined using a three-dimensional finite element software Plaxis 3D (Netherlands user manuals, [1]). The parameters taken in this study are raft thickness, pile spacing, pile cross-sectional shape, and pile length. These parameters were varied and compared with other available studies. The results obtained in the present studies are in good agreement with other research studies.

Keywords Piled raft · Soft soil · Foundation · Plaxis 3D

1 Introduction

The exponential increase in the number of high-rise structures of 150–300 m and more have presented a challenging situation among structural and geotechnical engineers in designing the foundation systems of such structures. Thus the mere application of conventional foundation design methods is insufficient for such structures; therefore, engineers are forced to follow more innovative and skillful designs. Instead of using piles and rafts alone, the concept of combination of the elements of foundations such as piles and raft can be applied to support a structure in which the role of piles is to reduce raft sinking and distinctive settlements and can also contribute to significant prudence without taking a trade-off between the safety and execution of the foundation. Such foundations can be called "piled enhanced raft" or "piled-raft foundations". A piled raft is a compounded geotechnical formation comprising foundation elements like piles, soil, and raft. It can be distinguished from the usual

A. Verma · S. K. Ahirwar (✉)
Department of Civil Engineering and Applied Mechanics, Shri G. S. Institute of Technology and Science, Indore, Madhya Pradesh, India
e-mail: skasgsits@gmail.com; sahirwar@sgsits.ac.in

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design of the foundation, where either the raft or piles transport the loads. The first to introduce the concept and design approach for piles under a raft foundation were Burland et al. [2] and called the piles "settlement reducing piles". The Combined Piled Raft Foundation (CPRF) has been successfully implemented in various parts of the world over the last four decades to optimize foundations for structures in civil engineering. During 1994–97, one of the International Society of Soil Mechanics and Foundation Engineering's (ISSMFE) technical committees based their efforts on piled raft foundations and provided detailed reports on collective knowledge on various design methods and case history.

First, the piled raft foundations were considered an alternative for high-rise building foundations on cohesive active settlement soils such as the Frankfurt clay, but as a result of extensive researches on its performance, pile-raft now has been preferred as a foundation for other soils too.

Clancy and Randolph [3] studied the spring model plate in which a plate element was taken in place of the raft and supported by the number of spring elements taken instead of the pile group as shown in Fig. 1 and described the interactivity between different elements. Poulos [4] conducted a similar study on the plate-spring model by performing 2D numerical analysis by examining the impact on load sharing of CPRF. The development of a numerical method carried out the study of piled raft bearing behavior by Reul [5]. The findings of variation in foundation geometry on differential and total settlements were studied by Prakoso and Kulhawy [6]. Sinha and Hanna [7] stimulated a 3D finite element analysis of a piled raft foundation and analyzed in ABAQUS software using modified Drucker-Prager Constitutive Law.

This paper compares current studies and research done by Sinha and Hanna [7] by Plaxis 3D [1] software.

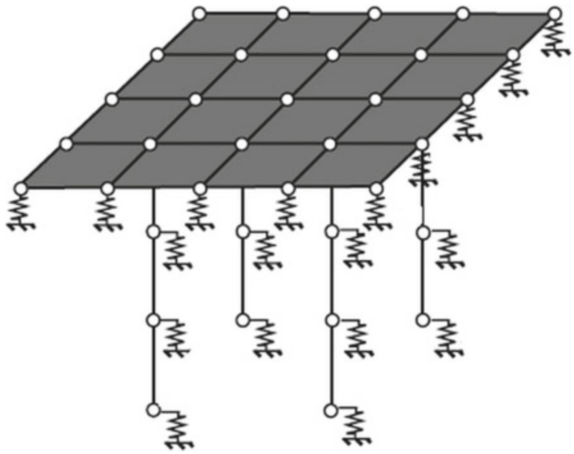

Fig. 1 Plate on spring model [3]

2 Numerical Model

The development of a three-dimensional numerical model was performed for the stimulation of the combined piled raft foundation. The model consisted of a soil block, the foundation elements, zone of contact, and prescribed displacements. The software program PLAXIS 3D [1] was used in the development of the model. Figure 2 presents the structural model of the foundation bed, and the deformed mesh of CPRF is shown in Fig. 3. Because of the symmetrical conditions, only the quarter part of the foundation is modeled and analyzed.

In this study, the soil is taken as a homogenous, isotropic, and single-phase medium. Tables 1 and 2 list the soil and other component parameters.

The water table effect was not taken into consideration. A comparison of study has been made between Sinha et al. [7] and the current study by taking the similar properties in later cases and modeling the parameters in Plaxis 3D [1].

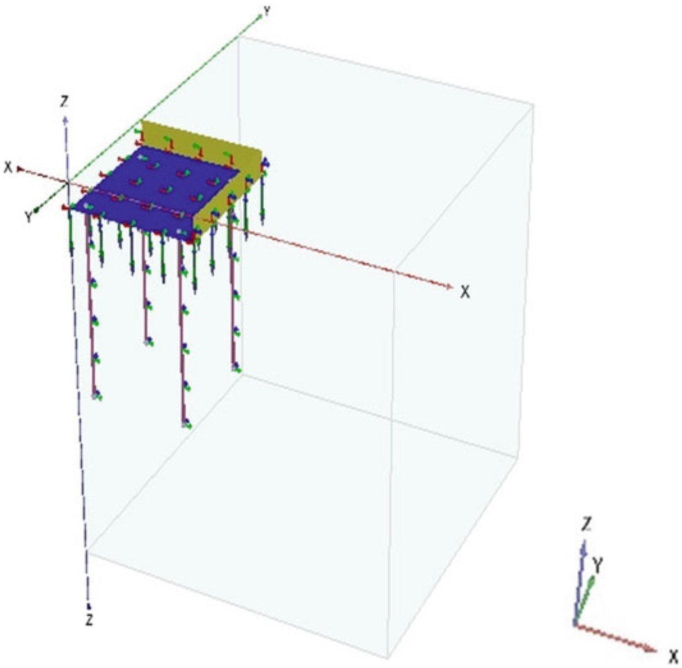

Fig. 2 Structural model of CPRF

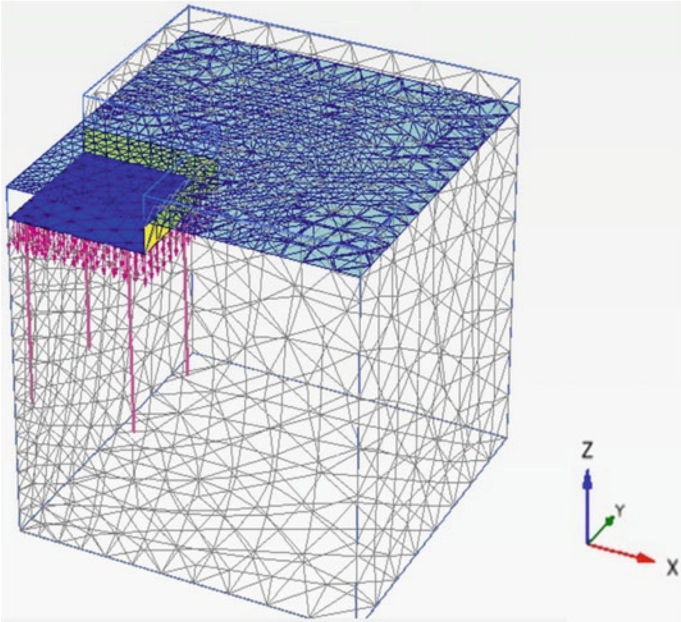

Fig. 3 Deformed finite element mesh of CPRF

Table 1 Properties of material used in the model

Parameter	Unit	Soil	Raft	Pile
Modulus of elasticity (E)	N/mm^2	30×10^3	34×10^6	25×10^6
Poisson's ratio (υ)		0.1	0.2	0.2
Dry density (γ)	N/m^3	19×10^3	25×10^3	25×10^3
Saturated density (γ')	N/m^3	20×10^3		
Internal friction angle (°)		6		
Soil cohesion (C')	Pa	20×10^3		

Table 2 Raft size and number of piles according to pile spacing used in the model

Spacing of piles	Size of raft (m)			Pile number
	L	B	H	
2d, 3d, 4d and 6d	24	24	2	144, 64, 36 and 16
7d	28	28	2	16
8d	32	32	2	16
10d	40	40	2	16

3 Study of Parameters

The parameters studied for the load and displacement characteristics of combined piled raft foundations are examined in the corresponding section. The results of variation of structural models are compared with the previous study using different software, and the variation in results is discussed.

3.1 Variation in Raft Thickness

In this case, a 24 m square raft, 6d pile spacing, and 15 m pile length are examined. The variation in raft thickness was examined over the thickness as 0.5 m, 1 m, 1.5 m, 2 m, and 2.5 m. These variations are also compared with the behavior of an unpiled raft 0.5 m thick. The raft was subjected to the prescribed displacement of 0.5 m which was applied on the raft surface, and corresponding loads are obtained from the Load versus Settlement plot of the model. Figure 4 represents the results obtained by the analysis of the model in the form of load settlement curves. It was observed that for smaller thickness raft, the load-bearing capacity was higher as compared to thicker raft for the same pile spacing. These values were obtained for a given raft size, pile spacing and loading conditions; thus, the optimization in design can be done to obtain more economical and safe construction.

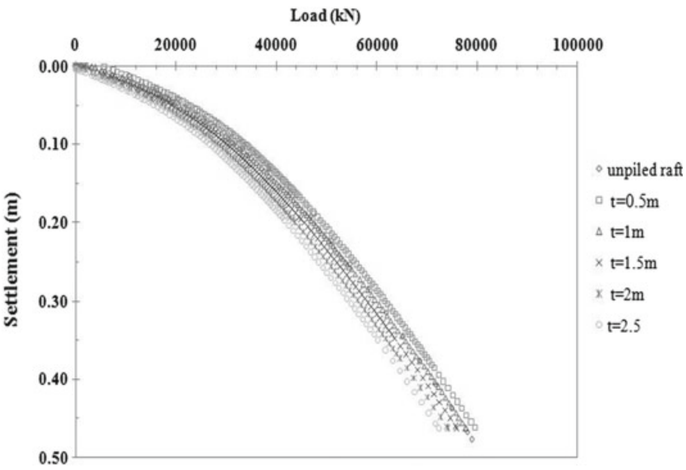

Fig. 4 Load versus settlement for variation in raft thickness

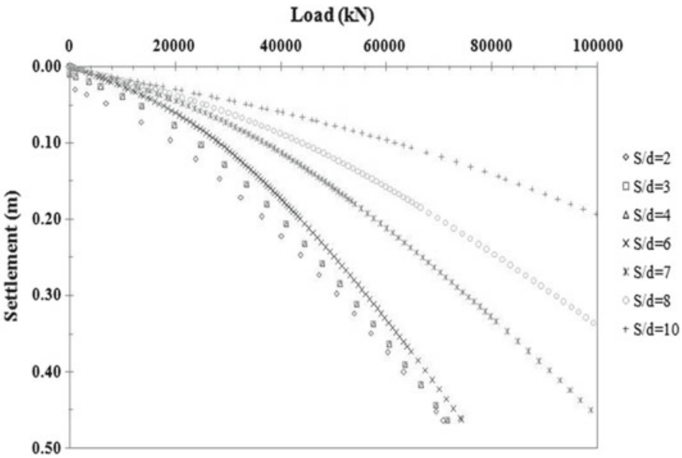

Fig. 5 Load versus settlement for variation in pile spacing

3.2 Variation in Pile Spacing

In this case, a raft of 2 m thickness and piles of 1 m diameter and 15 m length were examined. A prescribed displacement of 0.5 m was given to the raft, and analysis was performed for pile spacing varying from 2d, 3d, 4d, 6d, 7d, 8d, and 10d, where d represents the pile diameter taken into account. Figure 5 represents the load settlement relation for variation in pile spacing. The observation was recorded that the increment in load-carrying capacity of the CPRF was less up to spacing 6d, beyond that drastic increment in load carrying capacity was found for higher spacing as it can be believed that the contribution of larger size raft was more dominant, resulting in compensation for loss of capacity of the system. In addition, in the studies conducted by Sinha and Hanna [7], there was a decrease in load-carrying capacity up to 6d beyond which the authors observed a similar type of pattern. This contradicts the conventional design philosophies, which show a limit of the maximum pile spacing to 3.5d as it was an observation indicate that a decrement in pile interactions was observed beyond 3.5d, which in turn decreases the system's capacity.

3.3 Variation in Pile Length

In this case, analysis was conducted on a pile length of 5 m, 10 m, and 15 m. The spacing adopted was 6d, and 2 m thick raft was taken into consideration. The pile diameter was kept as 1.0 m, and the size of the raft was taken as 24 m × 24 m. A prescribed displacement of 0.5 m was given in Plaxis 3D, and the corresponding load was obtained by a load-settlement curve. Since the continuum of raft and soil is symmetrical, only a quarter part has been modeled to save computation and model

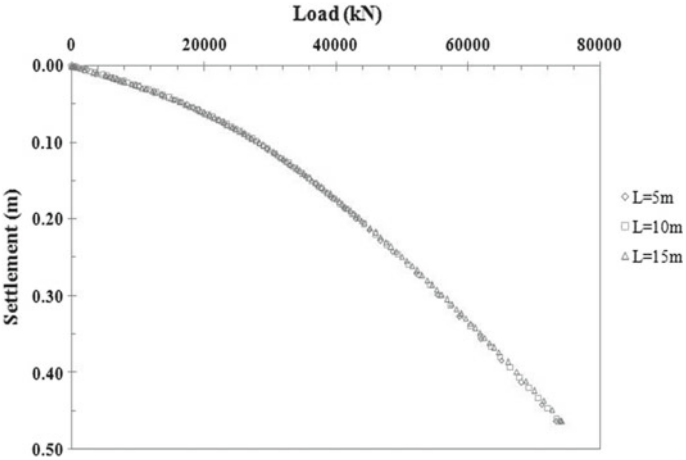

Fig. 6 Load versus settlement for variation in pile length

time. The results obtained by the analysis in the form of the load versus settlement curve are represented in Fig. 6. In the load-carrying capacity of the system, a slight increase has been observed, so there can be compensation in the design between pile length and pile spacing for the more economical design of the foundation.

3.4 Variation in Pile Cross-Section

In this case, the square cross-section was analyzed; its sides varied as 0.4 m, 0.8 m, and 1.2 m. 6d pile spacing and a 24 m and 2 m thick square raft were adopted. A prescribed displacement of 0.5 m was given in Plaxis 3D, and a corresponding load was obtained from the load settlement curve. As a symmetrical raft was adopted, so the only quarter part was modeled to save computational time. Figure 7 represents the results obtained from analysis in the form of load versus settlement curve. It was interpreted from the analysis that there was no significant effect observed by the variation in the cross-sectional size of piles. Hence it is up-to-the structural and geotechnical designers to adopt a suitable cross-section and size of the pile for the economical and safe design of the foundation.

4 Conclusions

In order to examine the effects of various parameters, FE analysis was conducted to evaluate the performance of piled raft foundations. The PLAXIS 3D [1] software program is used for successful problem stimulation. From this study, the following

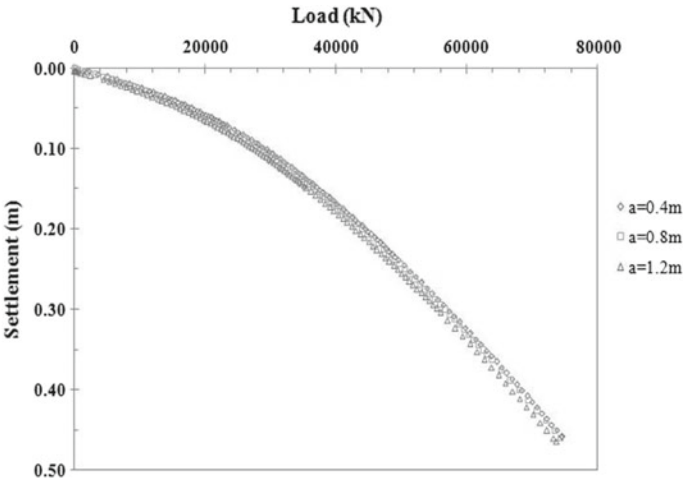

Fig. 7 Load versus settlement for variation in pile cross-section

conclusions can be made from the examination of different parameters of piled raft foundations:

1. Raft settlement increases as pile spacing increases and decreases as pile size and length increase. The system acts as a raft when the spacing between piles exceeds six times the pile diameter.
2. Increased spacing between piles diminishes the aid of increased size and length of the piles in settlement reduction. A swap between spacing, size, and length of piles should be considered to create an affordable design.
3. For the variation in raft thickness, it was noted that the system capacity increased with an increase in raft thickness of up to 1.5 m, beyond which the settlements increased due to raft self-weight, resulting in system failure and less load-carrying capacity. A thinner raft results in unequal load sharing among components of CPRF, and a thicker raft will result in excessive settlements due to more load on piles.

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