Behavior of Different Configuration of Piled Raft Foundation for a High-Rise Building by using FEM

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Abstract. In this paper, the numerical simulation is performed on two piled raft configurations having uniform loading on a piled raft foundation. To investigate the interaction between various parameters of pile soil foundation with varying components of its length of pile, diameter and raft thickness. These components are critical for increasing the foundation's bearing capacity. It’s important aspect to achieve a reliable design to optimize piled raft foundations subjected to uniformed load- settlement behaviors of the curves. These load – settlements are basically depending on the changing of their components piled raft foundation. These component of piled raft foundations to choose an optimal selection of embedded length of pile (L/dP), normalized diameter of pile (L/dP) and normalized raft thickness (tR/dP). The effect of load-settlement on distributions of shear force and bending moments is also investigated. In this study, a finite elements methods based on numerical tools ELPLA software is used for numerical simulation. The study’s findings validate the numerical analysis for the calculation of proper pile configuration arrangement, as a result of settlements. It will be generated as formation of contours patterns as shear stress and bending moments on the rafts, may be minimized with the total pile length. The conclusion drawn from the study validates the numerical analysis for the computation of proper pile arrangement can results in total and differential settlements, as well as generated shear stress and bending moments on the rafts, are all being reduced, with identical total pile length. Moreover, it captures the contours patterns of different behaviors of piled raft settlements, maximum shear force and maximum moments.

1. Introduction

Generally, high-rise buildings are frequently constructed on piled raft foundation which is needed to withstand with vertical, lateral as well as overturning loadings. High rise buildings should also be designed for wind and seismic loadings. The foundation carries a large amount of axial stress on the earth in the case of such structures. So, it is important in the case of high-rise buildings that the foundation should be designed such that It can withstand superstructure loads while also transferring them to the earth. Moreover, it can be effectively supported the stability of the buildings. In some re- searchers to design of conventional and traditional methods that are used to design to resist the heavy loads on pile foundations [1, 2, 3]. It is actually a hybrid of a pile and raft foundation, consisting of three components: raft, piles, and subsoil. This type of foundation provides sufficient bearing capacity to the soil can also control settlement. The use of effective methods for designing pile raft foundations for a high-rise structure in order to reduce settlements and increase the foundations' bearing capacity. The weight is divided between piles and raft in a PRF, so raft and piles take on some of the load from the superstructure [4]. The load settlement curve of the piled raft has been computed based on the stiffness of the structures, and the design of the piled raft foundation is generally detailed in several phases [4, 5]. The analysis of
the piled raft foundation for total and differential settlement, hybrid method is to be used [6] and analysis based on the group piling as well as optimum design of their rafts are analysed by many researchers in [7, 8]. The numerical analysis is done by a finite element method in which raft is modelled as a plate and piles treated as non-linear springs [9]. The interaction between the piled raft with deep foundations of various parameters are varied in terms of lengths parameters are subjected to their various loadings conditions by using the finite layer method [10].

Piled raft foundations (PRF) are in short supply has been highlighted in earlier research to enhance the overall stability of the building. Furthermore, numerous critical elements that affect foundation stability, Factors including raft thickness, pile length, and diameter affect stability. These elements influence the overall stability of structural systems; however, the aforementioned parameters must be chosen carefully. It also leads to the construction of a cost-effective piled raft foundation. For a 20-story super-structure with a total height of 60 m, detailed design for pile raft foundation systems with the best pile raft design by pile arrangement scheme is required. In this story, the total load of building is 330 MN is calculated manually for using various types Indian codes [11, 12, 13, 14]. So, in this paper the numerical studies are based on the FEM. This was done to see how the length of the pile, the diameters of the piles, the thickness of the raft, the number of piles, and their configurations affected the piled raft foundation.

2. Modelling and analysis

The overall designing is based on piled raft foundation by using traditional methods, in case of the applied load was carried out either by the pile or by the raft, considering all the factors of safety in each of the following cases. The analysis of piled raft performance the proposed model is evaluated and three broad classes of several different methods are computer-based have been developed by [15, 16, 17, 18]. This parametric study was performed using the finite element software ELPLA. These tools are used to analysed the parameters of variety of sub model to evaluate the performance of a piledraft foundation. The numerical analysis is based on the different types of subsoil models that are specially designed for 3D continuum methods. It can be constructed to be analogous to an elastic foundation is analysed by finite element tool ELPLA. The piled raft foundations were performed to validate the models with dimensions, soil properties, and loads that were carried out by [19] is shown in Fig. 1. The computed total load settlement (total load of 18 MN) relationships considered in this analysis are compared. The overall studies are performed to ELPLA software. The various methods for the center of the raft on 9 identical piles, by each column. Its components of high-rise building frame as seismic loading conditions are analysed with their case studies of different area [20].

In this present study, the raft was modelled as a concrete element with an area of the piled raft is 20 m × 20 m with loading applied on their rafts. It investigates the maximum settlement, bending moment on a pile raft foundation. In this study to investigate the two cases of piled raft configurations that are taken to analyse the effective foundation. The optimal selection of above parameters for designing leads to an economical design of pile raft foundation. The numerical simulations are based on the piled raft foundations in ELPLA software was carried out by [21]. In piled raft foundations are basically design with their raft as well as piled with varying all parameters and good aggregate between their results of settlements [22]. In this present study to investigate the changes the various parameters such as the number of piles in a different pile configuration, pile length (Lp), pile diameters (dp), and raft thickness (tR). These parameters are mostly based on the design for the foundation systems was carried out by using two different components such as raft and piles are isolated form of embedded in the soil layered on the foundation systems. The conditions of the soils and foundations proper ties are presented in the soil layers are available for pilling in case of loose, medium and dense soil are 0-4 m, 4-15 m, 15-35 m. The details Model configuration and properties are used in this analysis as Fig. 1 and all the various materials are used for numerical analysis of the pile raft foundation as shown in Table 1. So, a compressive numerical study based on finite element tool ELPLA software. It was carried out to see if there was any influence on the length of the piles in a pile group, effects on diameters of piles on a pile group, the effect on spacing between the piles, and the effect on raft thickness.
Figure 1. (a) model conditions with piles and rafts, (b) configuration of pile A, and (c) configuration of pile B

Table 1. Properties of soil types, Pile and raft

| Parameter                  | Soil type | Pile | Raft |
|----------------------------|-----------|------|------|
|                            | Loose     | Medium dense | Dense | 3×10^4 | 2×10^4 |
| Youngs modulus, E (MPa)    | 10        | 20   | 24   |       |
| Unit weight (kN/m³)        | 16        | 18   | 20   | 25    | 25    |
| Friction angle, φ (°)      | 24        | 32   | 37   | -     | -     |
| Cohesion, c (kN/m³)        | 1         | 2    | 2    | -     | -     |
| Poisson’s ratio, µ         | 0.3       | 0.3  | 0.3  | 0.18  | 0.25  |

In this study to investigate the two different types of pile configurations A and B are analysed with appropriate parameters. The configurations of pile A and B with the total number of piles in these configurations are 16 and 25 piles are analysed. In configurations (B) with 9 piles are types (P2) and (P3) with constant pile length 10m. It also changes the various parameters of pile configurations with different diameter of piles and raft thickness to analyse the behavior of maximum and differential settlements. It changes the parameters of pile raft that have been greatly affected on the maximum settlement are reduced and the bearing capacity of the foundation has been improved. Furthermore, to investigate the optimal selection of the leading parameters to an economical design of the pile raft foundation. In detail model of pile configurations (A) and (B) are shown in Fig. 2 and Fig. 3.
Figure 2. Pile configurations (A) with magnified view of piled raft foundation with loadings

Figure 3. Pile configurations (B) with magnified view of piled raft foundation with loading

So, the above parameters are based on numerical studies that used the finite element approach to evaluate the influence of pile embedded length, effect of diameter of piles, and effect of raft thickness to an economical design of pile raft foundations. In the first case study to variation of pile type (P1) as a normalized pile length (Lp/dp) with constant diameter of pile 1.0 m from 10 to 30. In the second case study to analyse the behavior of pile raft is subjected to the variation of pile type (P2) lengths are varies from 10 to 30m and constant the pile length (L = 10m) in pile type (P3). It also constant the diameter of the piles and raft thickness is 1.0 m. The variation of embedded length of piles (L/2) ranging from 1 to 3 in configuration B. These variations of pile lengths are analysing to choose an optimum selection of embedded pile length. Furthermore, to investigate the diameter of piles to an optimum selection of diameters is required to satisfy the both design criteria of the normalized diameter of piles and normalized pilespacing. The normalized diameter of pile (Lp/dp) varies in configuration A and B from 16 to 52 and 1.5 to 5.5. It also varying the normalized raft thickness (tR/dP) in configuration A and B from 0.5 to 1.5 and 0.4 to 1.2. These variation of increasing the raft thickness is effectively reducing the differential settlements and also increasing maximum moment. It is noted that increasing the raft thickness to resisting the punching shear from their loading conditions.

3. Results and analysis

In this study, the numerical analysis is conducted to evaluate the optimum design of pile configuration A and B for the designing of various parametric studies is done. In configuration A, the variation of normalized pile length from 10 to 30 with constant dp as a 1.0 m. These studies
were also investigated the behavior of pile raft was analysed in pile configuration B with varying the length ($L_1$) ranging from 10 m to 30 m in a pile type (P2). It also constant the pile length ($L_2$) is 10 m in a pile type (P3) and constant the pile diameter and raft thickness are 1m considered in this present study. In the lengthof pile required to improve the bearing capacity of the foundation by varying the pile length from 10 m to 30 m i.e., the variation of embedded pile length ($L_1/L_2$) ranging from 1 to 3 were investigated in these configurations. The provisions of the optimum selection of the length of pile ($L_1$) are investigated for reducing the maximum and differential settlement for the stability of the structures. It shows that the variation of settlements in pile configuration A and B as shown in Fig. 4.

In figures, are clearly shows that the settlement decreases with increases in pile length. The provisions of the proportion load borne by the piles are unaffected by the pile length embedded in the ground, varying the length of the pile with no major difference between the maximum length, while as a settlement. In the configuration A, the maximum settlement curve decreasing throughout their variation of normalized embedded pile length ($L/dp$) 10 to 30. Its aforementioned study to selection of optimum maximum settlement is achieved at 26. In this case, to consider here, there is little or no benefit in increasing the embedded pile length ($L_1/L_2$) above about 2.6 in pile configuration B.

Further to investigate the diameter of piles for selection of optimum diameter of piles to improve the overall stability of the foundations and in a previous case study to obtain the optimum pile length (i.e., $L/dp = 26$ and $L_1/L_2 = L = 2.6$). It considered that the embedded pile length at (L = 2.6) and constant the values of raft thickness as 1 m in this analysis further investigate the diameter of pile. In this analysis, the interaction factor for the vertically loaded pile is 332 kN/m² applied on their piled raft. The behavior of loading conditions in the raft and raft load transfer through their piles. The maximum settlement curves are found in forms of the normalized diameter of pile ($L/dp$) ranging from 16 to 52 and 1.5 to 5.5 in configuration A and B. The settlement of the curve is showing the relationship between the maximum settlement and the piles' normalized diameter as shown in Fig. 5. The variation of the differential settlement is influenced by changing the diameter of pile is greatly influences the performance of the pile raft foundations as shown in Fig. 9. In configuration A and B to achieved that the optimum design of pile diameters is adopted as 1.0 m (i.e., $d/p = 21$ and $L/dp = 2.1$) because the diameter of the piles increases but according to the applied load there is also reduced the settlements beyond which very little additional amount settlement would be obtained.

![Figure 4. maximum settlement with the length of piles in pile configuration A and B](image-url)
Also, further estimation of the pile raft foundation, the parameters are usually affected on the overall stability of the foundation systems. In the case of pile configuration, the raft thickness is a very important thing to design a pile raft system and provisions of the optimum raft thickness. To investigate the raft thickness on behalf of the design of piled raft configurations to estimate the variation of the raft thickness ranging from 0.5-1.5 m i.e., raft thickness (tR/dp) ranging from 0.4 to 1.2. The maximum settlement with the raft thickness is assessed for tR/dp ranging from 0.4 to 1.2 as shown in Fig. 6. In a pile raft configuration for providing a thin raft, the raft thickness has little effect on the maximum settling. The result from the linear analysis was obtained by the variation of (tR/dp) to achieve an optimum value of the raft thickness is 1.0 m. In according to their variation of normalized raft thickness is obtained on the behalf contours patterns of a normalized raft thickness corresponding to their maximum settlement as considerable at 1.0 m as a raft thickness shown in Fig. 7 and Fig. 8.

Figure 5. Maximum settlement with diameters of pile (Lp/dp) in pile configuration (A) and (B)

Figure 6. The curve is drawn between the Settlements v/s raft thickness (tR/dp) in configuration of pile (A) and (B)
In the case of the pile configuration, raft thickness increases significantly with decreases in the settlement. The provisions of each load are transferred by their piles are insensitive to the raft thickness and in a case, to consider the little amount or no benefit in increasing the thickness of rafts above about 1.0 m. It also shows that the variation of maximum moments curve also increases with increases the thickness of rafts is shown in Fig. 9. It shows that the selection of contour patterns at $(t_R/d_p=1)$ an optimum maximum moment in configuration of pile (A) and (B).
Figure 9. Maximum moment increases with increases of thickness of rafts (tR/dp) in pile configuration (A) and (B)

4. Conclusion

This paper shows that the numerical modelling of various parametric studies is done. It employs pile raft foundations to evaluate the total efficiency in managing settlement and enhancing the foundation's bearing capacity while developing high-rise buildings. To analyse the different types of parameters for designing optimum piled raft configurations systems. This study shows that optimizing the parameters and configuration provide the design aspect for pile raft with optimum consumption of the pile materials are as follows.

1. It is most economical design to improves a piled raft foundations to observed that piles length (L/dp = 26 & L1/L2 = 2.6) has a great influence on improves on a foundations designs of the capacity are improved.

2. In a comparison of configuration of pile, A is more effective than A, it reduces (34%) the total settlement of foundations. In the piled raft foundation to use different configurations of piles to decreases the settlements and also improves the bearing capacity of the foundations.

3. It also found that improving the foundation of structures should be an optimum diameter of the piles should be taken as (dp = 1.0 m). It also would be taken as the normalized diameter of pile was achieved at (Lp/dp = 2.1). It reduces the settlement in pile raft configuration A is 7% and pile raft configuration B is 27%. It provides the pile raft configuration B, i.e., it is economical other than configuration of pile A.

4. It is noted that the optimum thickness of raft (tR) has to decrease the total settlement of the buildings and provided an optimum normalized raft thickness (tR/dp = 1.0) in both configuration of piles A and B.

5. There are recommended for using configuration of pile B as compared to both configuration of pile A and B. It is slightly economical as compared to pile raft configuration A.
5. Reference

1. Das, Braja M.: Principles of foundation engineering. Seventh edition (1984).
2. Tomlison, M., Woodward, J.: Pile design and construction practice. Fourth edition https://doi.org/10.1201/b12838 (1994).
3. Bowles, J.E.: Foundation Analysis and Design. 5th Edition, McGraw-Hill Companies, Inc., Singapore (1996).
4. Poulos, H. G.: High-Rise Building Foundations-A Limit State Design Approach. Art of Foundation Engineering Practice. doi:10.1061/41093(372)25 (2010).
5. Poulos, H. G.: Piled raft foundations: design and applications. Géotechnique, 51(2), 95–113. doi:10.1680/geot.2001.51.2.95 (2001).
6. Horikoshi, K., Randolph, M.: Estimation of overall settlement of piled rafts. Soils and Foundations, 39(2), 59-68 (1999).
7. Randolph, M. F.: Design Methods For Pile Groups and Piled Rafts. Proc. 13th Int. Conf. SoilMech. Found. Engng, New Delhi 5, 61-82 (1994).
8. Horikoshi, K., Randolph, M.: A contribution to optimum design of piled rafts. Geotechnique: international journal of soil mechanics, 48(3), 301-317. https://doi.org/10.1680/geot.1998.48.3.301 (1998).
9. Russo, G.: Numerical analysis of piled rafts. International Journal for Numerical and Analytical Methods in Geomechanics, 22(6), 477–493. doi:10.1002/(sici)1096-9853(199806)22:6<477::aid-nag931>3.0.co;2-h (1998).
10. Chow, H. S. W., Small, J. C.: Behaviour of piled rafts with piles of different lengths and diameters under vertical loading. Advances in Deep Foundations. doi:10.1061/40778(157)20 (2005).
11. IS 1893 Part 1.: Criteria for earthquake resistant design of structures: General provisions and buildings. Bureau of Indian Standards, New Delhi (2016).
12. IS 875 Part 1.: Code of practice for design loads (other than earthquake) for buildings and structures-dead loads-unit weights of building materials and stored materials. Bureau of Indian Standards, New Delhi, India (1987).
13. IS 875 Part 2.: Code of practice for design loads (other than earthquake) for buildings and structures-imposed loads. Bureau of Indian Standards, New Delhi, India (1987).
14. IS 875 part 3.: Design loads (other than earthquake) for buildings and structures-code of practice for wind loads. Bureau of Indian Standard, New Delhi, India (2015).
15. H.G Poulos et.al.: Comparison of some methods for analysis of piled raft. Proc.14 ICSMFE, Hamburg, 2:1119-1124 (1997).
16. Poulos, H. G., Davis, E. H.: Pile foundations analysis and design. John wiley and sons, p. 397 (1980).
17. Butterfield, R., Banerjee, P. K.: The Elastic Analysis of Compressible Piles and Pile Groups. Géotechnique, 21(1), 43–60. doi:10.1680/geot.1971.21.1.43 (1971).
18. Burland, J. B.: Piles as Settlement Reducers. Keynote address, 18th Italian congress on soil mechanics, Pavia, Italy (1995).
19. Rabiei, M.: Effect of Pile Configuration and Load Type on Piled Raft Foundations Performance. Deep Foundations and Geotechnical In Situ Testing. doi:10.1061/41106(379)3 (2010).
20. Poulos, H. G.: Lessons learned from designing High-Rise Building Foundation. 19th SEAGC & 2 AGSSEA (2016).
21. El Gendy M, El Gendy A.: Analysis and design of raft and piled Raft-Program ELPLA. GEOTEC Software Inc., Calgary (2020).
22. Kannauiya, P., Jaiswal S., Chauhan V.B.: Studies on the Piled Raft Foundation for a High-Rise Building Using Finite Element Modeling. Advance in Geo-Science Geo-Structure. Lecture Notes in Civil Engineering, Vol 154. Springer, Singapore. https://doi.org/10.1007/978-16-1993-926 (2021).