STUDY ON BEHAVIOUR OF PILED RAFT FOUNDATION BY NUMERICAL MODELLING

Rajendra Singh Bisht[1*], Baleshwar Singh[2]

[1*] Corresponding Author, PG Student, Department of Civil Engineering, Indian Institute of Technology Guwahati, India,
E-mail: r.bisht@iitg.ernet.in
[2] Associate Professor, Department of Civil Engineering, Indian Institute of Technology Guwahati, India,
E-mail: baleshwar@iitg.ernet.in

ABSTRACT

A foundation must carry weight of a superstructure and transfer it to underlying subsoil layers without any excessive settlement. It is common practice to first consider a shallow foundation system for any structure. A raft foundation is one such system which covers the entire plan area of the structure. When the raft foundation has adequate bearing capacity but the settlement is not within allowable limit, a group of piles is added under the raft to reduce the settlement. The behaviour of the piled raft foundation system is influenced by various factors such as raft thickness, pile length, pile spacing and number of piles, which must be considered for an economical and effective design. A numerical analysis has been carried out by using geotechnical finite element software, PLAXIS 2-D, to investigate the influence of the above various factors. The aim is to optimally utilize the load-carrying capacity of both the raft and the pile group.

Key words**:** Piled raft, Settlement, Numerical modelling, Foundation

1. INTRODUCTION

A foundation of building must satisfy both design criteria i.e. the foundation must have adequate bearing capacity and also the settlement should be within allowable limits. Excessive settlement of foundation not only affects the stability of its superstructure but also can damage the already existing surrounding buildings. The settlement of foundation is usually treated as secondary design criteria which are inappropriate in a case of a raft foundation which can satisfy the bearing capacity requirement but the excessive settlement is a problem. In such a situation adding a group of settlement reducing pile under raft is more effective and economical rather than replacing raft foundation with fully pile foundation. So the primary function of piles in piled raft is to reduce settlement. Once the decision has been made that piles are required then the major design question comes is how many piles are required to control the settlement. Due to lack of proper design method the conventional design method of piled raft foundation designs the piles to carry the whole superstructure load without considering the contribution of raft which results in overdesign of foundation. A piled raft foundation behaves differently than a conventional pile foundation and there are various other design factors which influence its performance. Extensive research has been carried out to understand the behaviour of piled raft. Clancy and Randolph [6] and Poulos [5] have reported the design of piled raft foundation considering the piles as settlement reducers. Cooke [2] pointed out that overall settlement have less effect on the performance of the building compare to differential settlement. Randolph and Horikoshi and Randolph [3,5] reported different design approaches based on fact that whether piles are used to reduce overall settlement or to reduce differential settlement. Butterfield and Banerjee, Cooke and Maharaj and Gandhi [1, 2, 8] studied the load sharing between piles and raft and among piles. Horikoshi and Randolph, Poulos, Prakoso and Kulhawy, and Noh et. al. [5, 6, 7, 9] carried out parametric studies and presented its effect on performance and behaviour of piled raft.

The present paper describes the influence of pile length, pile spacing, number of piles and raft thickness on the settlement behaviour of piled raft. Here the role of each of these factors in controlling the overall settlement and differential settlement of foundation is investigated using a finite element computer program and a plane strain model of piled raft.

2. METHODOLOGY

In this sudy a 42 m x 42 m raft with 1m diameter piles were analysed using a software PLAXIS-2D. A plane strian finite element model was used to model the piled raft foundation. The raft and piles were assumed to be linearly elastic. The Mohr-Coulomb yeid criteria was used to represent soil as elastic-perfctly plastic material. A single layer soil with very deep water table was assumed for the study. Here an undrained condition was assumed and the total stress analysis was carried out. The various soil, raft and piles material properties are tabulated in Table 1.

Table 1:Soil, pile and raft properties

Properties	Value
Soil modulus, E_s	20 000 [kN/m^2]
Cohesion of soil, C	80 [kN/m^2]
Poison's ratio of soil, ν_s	0.4
Angle of friction, Φ	0 [degrees]
Dilatancy angle, Ψ	0 [degrees]
Modulus of raft, E_r	20 [GN/m^2]
Modulus of pile, E_p	20 [GN/m^2]
Poisson's ratio of raft, ν_r, and pile, ν_p	0.25
Length of raft, L_r	42 [m]
Breadth of raft, B_r	42 [m]

In order to examine the effect of pile group geometry and raft thickness on the overall and differential settlement behaviour of piled raft foundation the thickness of raft, pile length, pile spacing, and number of piles were the variables in this study. The various parameters used in this study are mentioned in Table 2.

Table 2: Raft and pile geometry parameters

Parameters	Magnitude	Standard value
Raft thickness, t	0.5m,1m,1.5m, 2m, 2.5m	2m
Pile length, L	10m,20m,30m, 40m	40m
Pile spacing, S	3m, 4m, 5m, 6m	4m
Pile diameter, d	1m	1m
Pile group	5x5,7x7,9x9, 11x11	11x11

The piles, raft and soil were discretised as 15 noded triangular elements. The piles and raft were modelled using a plate element . As the piled raft foundation is symmeteric so only half portion of piled raft was modelled as shown in Figure 1. The side skin friction in piles were modelled using interface elements. The vertical displacements obtained from the analyses were used directly as overall settlement and the differential settlement considered here is the centre-edge differential settlement of raft.

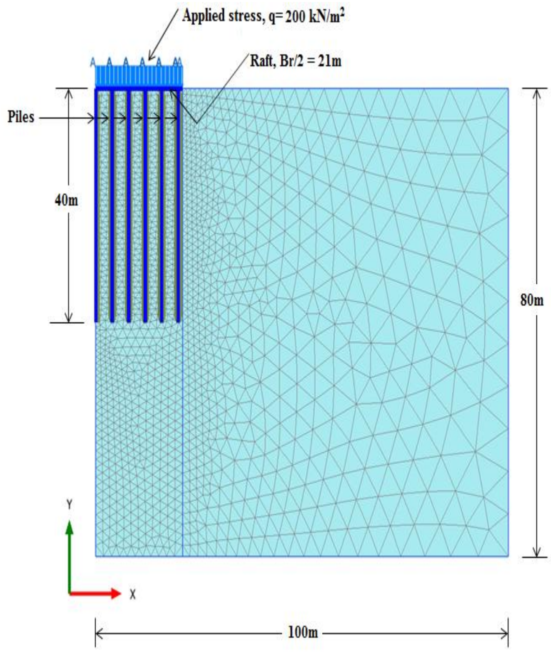

Figure 1: Finite element mesh of piled raft foundation.

3. RESULTS

3.1 Effect of raft thickness

Here a piled raft foundation with 11x11 pile group was loaded with a uniformly distributed load of 200 kN/m^2. A standard value of pile spacing and pile length were taken and the raft thickness was varied between0.5 to 2.5m.

Figure 2 shows the settlement of piled raft foundation along the width of raft for various values raft thickness.

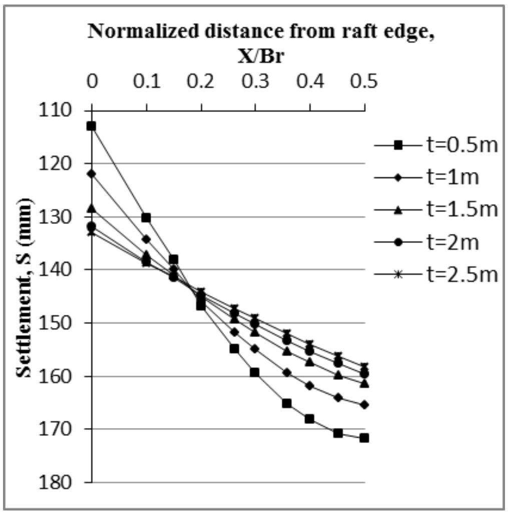

Figure 2: Effect of raft thickness.

The settlement of piled raft decreases with the increase in raft thickness. At the raft thickness of 0.5m the maximum settlement at the centre of piled raft is 171.2mm whereas when the raft thickness changed to 2.5m the settlement at the centre of piled raft is 158.3mm which shows the decrease in settlement is not very significant. However the decrease is more pronounced in the case of differential settlement. The centre-edge differential settlement of piled raft decreased from 58.8mm to 25.3mm as the raft thickness changed from 0.5m to 2.5m.The settlement values of piled raft are almost same when the thickness changed from 2m to 2.5m.

3.2 Effect of pile length

The settlements at different pile length are plotted in Figure 3. The effect of pile length, L on settlements was investigated using pile length of 10m, 20m, 30m and 40m. A group of 11x11 piles with a spacing of 4m and a raft thickness of 2m was used for the analysis of piled raft. As figure shows the settlements decreases with the increase in pile length. The maximum overall settlement at centre of piled raft decreased from 216.65mm to 159.59mm as the pile length changed from 10m to 40m. Here a significant change is observed in the case of overall settlement but a similar trend was not found out for the centre-edge differential settlement. The differential settlement changed from 34.31mm to 27.68mm as the pile length increased from 10m to 40m. There is a decrease in differential settlement with the increase in pile length but the change in differential settlement was negligible as the pile length changed from 10m to 40m.

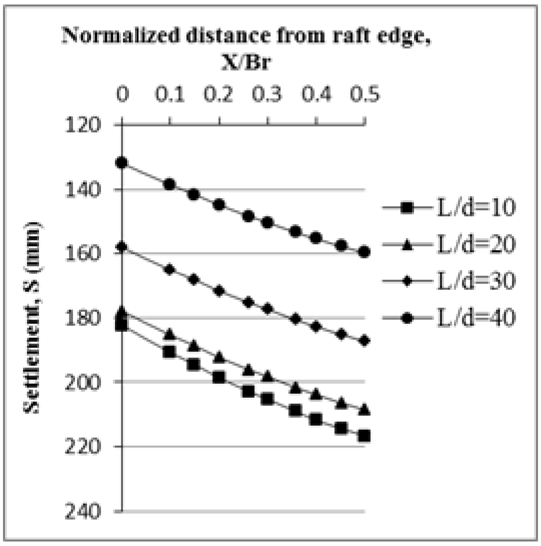

Figure 3: Effect of pile length

3.3 Effect of pile spacing

The piles should not be placed too close to each other or too far from each other. When the piles are placed too close to each other then due to stress overlap the foundation failure takes place and when the piles are far from each other then there will be no group effect and piles act as an individual pile which reduces the strength of foundation. So the effect of pile spacing on the settlement behaviour of piled raft was studied using a 5x5 pile group under a 2m thick raft and placing them at a spacing of 3d. 4d, 5d and 6d.A pile diameter of 1m and pile length of 40m was used for the analysis. Figure 4 shows the variation in settlement with the change in pile spacing. The overall settlement at the centre of the raft increased from 174.2mm to 180.5mm when the pile spacing changed from 3d to 6d however this increase in overall settlement is very less. There was a increase in differential settlement from 2.25mm to 24.55mm which is a very significant change. The increase in pile spacing is not very advantageous in controlling the overall and differential settlement and the pile spacing less than 3d results in stress overlap which is not recommended.

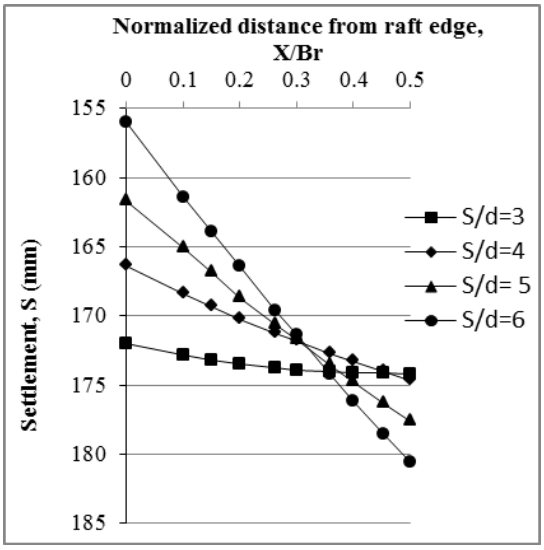

Figure 4: Effect of pile spacing

3.4 Effect of number of piles

A 42m x 42m raft was analyzed with 5x5, 7x7, 9x9 and 11x11 pile group. The raft of thickness 2m with pile diameter of 1m and 40m long piles were used for the analysis and the piles were kept at constant spacing of 4m. The effect of number of piles on the Settlement behaviour of piled raft is shown in Figure 5. The maximum overall settlement at centre of piled raft decreased when the number of piles was increased from 5x5 to 9x9 however there is a slight increase in overall settlement when the number of pile increased from 9x9 to 11x11 which suggest that using more number of piles are not always helpful. In the case of centre-edge differential settlement of piled raft it was found that the differential settlement increased with the increase in number of piles. The maximum value of differential settlement was obtained when the number of piles was 11x11 and the minimum value of 8.25mm was obtained when the number of piles was 5x5 because the 5x5 group of pile was located only at the centre part of raft and hold up centre where the settlement was maximum.

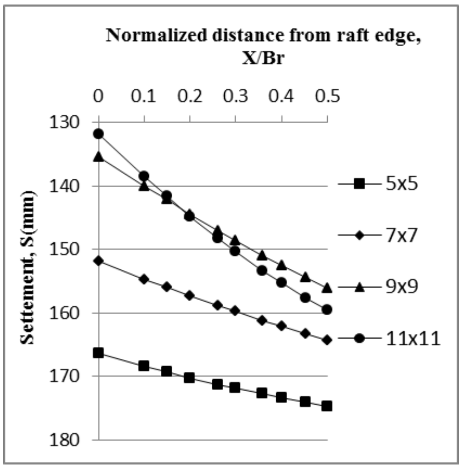

Figure 5: Effect of number of piles

4. CONCLUSIONS

This paper discussed the displacement based design methods for piled raft foundation where the piles are primarily used to minimize the displacements. Analysis of vertically loaded piled raft was conducted using the non linear plane strain finite element models. From the result of analysis the main conclusion drawn are as follows. The raft thickness does not have a pronounced effect on the overall settlement but it does minimize the differential settlement. However at higher thickness the overall and differential settlement are found to be same so the thick raft are not recommended from economical point of view. The overall settlement for a 40m long pile was found to be less compared to a 10m long pile but the pile length does not have any significant effect on differential settlement. The pile spacing is a factor which has a major influence on both overall and differential settlement. Both the settlement increases with increase in pile spacing however greater influence was observed in the case of centre-edge differential settlement which was increased from 2.25mm to 24.55mm as the pile spacing changed from 3d to 6d. So the pile should be closely spaced where differential settlement of foundation is major problem but less than pile spacing of 3d is not recommended. The use of large group of pile is not always beneficial from both economical as well as settlement point of view. The overall settlement decreases with increase in number of pile but the differential settlement does not change in similar fashion. The minimum differential settlement of 8.25mm was obtained when 5x5 group of pile was used and the maximum of 27.67mm was obtained for 11x11 pile group. So the differential settlement is less when a small group of pile was placed at the centre of raft.

5. REFERENCES

[1]. R. Butterfield, and P.K. Banerjee “The problem of pile group-pile cap interaction,” Geotechnique, Vol. 21, no. 2, pp. 135-142, 1971.

[2]. R.W. Cooke, “Piled raft foundation on stiff clay–a contribution to design and philosophy,” Geotechnique, vol. 36, no. 2, 169-203, 1986.

[3]. M. F. Randolph, “Design methods for pile groups and pilled raft: state -of-the- art report,” Proc. 13th Int. Conf. Soil Mech. Found. Engg., New Delhi, 5, 61-82, 1994.

[4]. K. Horikoshi, and M. F. Randolph, “Centrifuge modelling of piled raft foundation on clay,” Geotechnique, vol. 46, no. 4, pp. 741-752, 1996.

[5]. K. Horikoshi, and M. F. Randolph, “A contribution to optimum design of piled rafts,” Geotechnique , vol. 48, no. 3, pp. 301-317, 1998.

[6]. H.G. Poulos, “Piled raft foundations: design and application,” Geotechnique, vol. 51, no. 2, pp. 95-113, 2001.

[7]. W.A. Prakoso, and F.H. Kulhawy, “Contribution to piled raft foundation design,” Journal of Geotechnical and Geoenvironmental Engg., vol. 127, no. 1, pp. 1024-1090, 2001.

[8]. D. K. Maharaj, and S. R. Gandhi, “Non-linear finite element analysis of piled-raft foundations,” Proc. of the Institution of Civil Engg. Geotechnical Engg., vol. 157, pp. 107-113, 2004.

[9]. E. Y. Noh, Q. M. Bui, C. Surarak, and A. S. Balasurbamaniam, “Investigation of the behaviour of piled raft foundation in sand by numerical modelling,” Proc. 19th Int. Offshore and Polar Engg. Conference, Japan, June 2009