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Parametric Investigations into the Analysis of Piled Raft for Multi-Storeyed Building

H.S. Chore[1*], M. J. Siddiqui[2], Ashish Kishore[3]

[1]Associate Professor and [3]Research Scholar, Department of Civil Engineering,
Dr B R Ambedkar National Institute of Technology Jalandhar (Punjab), India, chorehs@nitj.ac.in
[2]Assistant Professor, Department of Civil Engineering,
School of Technology, Anjuman- E- Islam Kalsekar Technical Campus, New Panvel (Maharashtra), India

Abstract

This paper presents the analysis of the piled raft for a 50 storeyed building using approximate method to estimate the settlement and load distribution of the foundation. The pile and soils are considered as interacting springs, and the raft is represented as a thin plate. The model takes into account both the resistance of the piles and the resistance of the raft foundation. It is calculated how the raft, soil, and pile interact. The suggested technique enables the use of the finite element based programme ETABS to quickly address the issues of small non-uniformly arranged rafts and big non-uniformly ordered rafts. The effect of different pile length and diameter is evaluated on the behaviour of piled raft. With increase in pile lengths, the moments in raft are found to increase while settlement of pile, decrease. Further, increase in pile diameter is found to increase the moments in the raft while decrease the settlement of raft. The parameters such as pile diameter and pile length have a considerable effect on the response of a foundation considered in the present study

Keywords: *Piled raft, raft, pile, pile diameter and pile length*

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I. INTRODUCTION

The magnitute of the loads on a tall structure's foundation and the kind of supporting strata determine the foundation's type and design. A shallow foundation (raft) is sufficient in case founding stratum is within a reasonable depth. If the material is weak, however, the loads must be transferred down to strata that can support them using deeper basements or piles. This is true, particularly in cases where the frames of multistory buildings sit on unstable subsoil strata and when significant structural loads operating on the frames must be safely transferred down to stable strata.

Since a few decades ago, there has been a growing understanding that using pile groups in addition to the raft might result in significant savings without sacrificing the safety and performance of the foundation. By bringing settlements down to acceptable levels, the piled-raft idea has also shown to be a practical solution to increase the serviceability of foundation performance. The piled-raft idea has mostly been used in high-rise building new construction, but it might also be helpful in corrective work and intermediate height structures.

The foundation idea for piled rafts is different from typical foundation design, which assumes that the loads will be borne by either the raft or the piles while taking into account the safety considerations in each situation. Approximation techniques, finite element methods, boundary element methods, hybrid finite element and finite layer methods, and variational approaches are some of the techniques that have evolved over time for evaluating stacked rafts..

II. BRIEF REVIEW OF LITERATURE

There have been many alternative approaches created in recent years for examining the piled-raft foundation system stated in the previous section. All of these methods differ in terms of the level of complexity of the formulations, the quantity and kind of input parameters needed, the assumptions made, and the applicability to actual pile-soil-raft scenarios. In the lines that follow, some of the important research are briefly discussed in terms of their technique.

Butterfield and Banerjee [1] brought out the significance of the interaction between pile group and pile cap. Ottaviani [2] presented three-dimensional finite element analysis of vertically loaded pile groups. Chow [3] reported the axial and lateral response of pile group embedded in non-homogeneous soil. Liu and Novak [4] presented the interaction analysis of soil- pile-

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pile cap system by resorting to the finite and infinite elements. The raft was represented as a thin plate, the piles as springs, and the soil as an elastic continuum in Chen et al. [5] approximation technique. Additionally, the interaction effects between the piles were disregarded. A method to calculate the interaction between a single pile and a circular raft was proposed by Randolph [6]. Clancy and Randolph [7] used a hybrid approach that included analytical solution with finite elements. Two-dimensional thin plate finite elements were used to represent the raft, one-dimensional rod finite elements were used to model the piles, and an analytical solution was used to determine the soil reaction. Poulos [8] used a finite difference approach for the raft while taking into account the impacts of interactions between the piles and raft. Katzenbach and Reul [9] and Prakoso and Kulhawy [10] presented the design and performance of piled rafts. Using a hybrid model in which the flexible raft is portrayed as thin plates, the piles as elastic beams, and the soil is handled as springs, Kitiyodom and Matsumoto [11] created a simpler technique of numerical analysis.

One of the effective methods for analysing the intricate raft-piling problems is the finite element approach. Sometimes the difficulties are reduced to an axi-symmetric or a plane-strain problem in order to simplify the computing work. Several researchers [12- 29] made noteworthy contributions using this method. While some researchers studied circular piled rafts, others reported on the effectiveness of piled- raft foundations in case of multi storyed buildings. Several investigations were conducted for studying non-linear behaviour of soil. While some research took sand into account, only few did so for the cohesive sub-soil. A investigation even took layered soil into account. A complete 3-D FE analysis was used in certain investigations, while reduced finite element models were used only in limited number of studies.

As just the boundary needs to be discretized, boundary element (BE) technique is a strong tool that may be used in engineering applications. This method solves problems faster and require less computer memory than FE or FD methods. This approach offers an immediate and precise answer to the analysis. It is also quick and needs only a little amount of computer storage. Numerous studies [30–34] have utilised the approach to solve the issue of stacked rafts imbedded in various types of soil. For modelling various parts of the foundation in question, several idealizations were produced.

Some researches [14,19,35-37] have used a hybrid boundary element and finite element approach when integrating benefits and drawbacks. For the purpose of assessing the stacked raft in layered soil, Small and Booker [38–39] devised a method based on the finite layer technique in conjunction with FEM. Few researchers [22, 40-41] studied in the similar fashion as that of Small and Booker [38]. The variational strategy uses the idea of minimal potential energy for simulating as to how the foundation would react [42]. Only at the point where the raft and the earth meet do discretizations need to be used. Many researchers [41, 43-44] further expanded the approach.

In the recent past, several studies have been reported. Wulandari and Tjandra [45] analyzed piled- raft embedded in soft soil stratum by resorting to the PLAXIS 2-D. They considered coupling between the stiffness of superstructure, piled- raft and the soil, Ko et al. [46] presented non-linear three dimensional interaction analysis of structure and piled- raft. Nasrollahi and Hosseininia [47] present a two-phase analytical strategy, a simplified analytical approach, to analyse a vertically loaded piled-raft foundation. Through 3D finite element modelling, Deb and Pal [48] performed the numerical analysis on the pield raft subjected to combined vertical and lateral force. Using 3-D finite element analysis, Chanda et al. [49] investigated the behaviour of stacked raft foundations in sand under the interaction of vertical, horizontal load along with moment (V-M-H). Numerical analysis on the impact of pile head connections on a piled raft foundation under static and vertical stress was studied study by Kumar and Vasanwala [50]. To comprehend the behaviour of massive heaped rafts on hard clay, Modak and Singh [51] conducted numerical calculations in three dimensions. Through an experimental simulation and parametric investigation with numerical approach, Deb [52] presented the structural analysis of a stacked raft foundation immersed in soft soil.

On the backdrop of the previously studied literature, the present study aims at conducting the parametric study to evaluate the piled raft foundation for a multi storied (G+50) building frame through finite element analysis using ETABS software. Effect of pile length and pile diameter is studied on the response of the piled raft. The response considered includes vertical settlement and moment in pile.

III. Idealizations Made in the Mathematical Modeling

An industry-standard computer programme called ETABS is employed for analysis. In the beginning, piles are modelled as column (spring) and raft is modelled as beam on elastic basis to examine the behaviour of stacked raft. The raft distributes the weight from the superstructure to the pile and the earth; a portion will be borne by raft and a portion by pile. The soil surrounding the pile is represented by a line spring or point spring, and the soil beneath the raft is represented by a spring with an identical stiffness. The idealised structural design for a stacked raft with supporting subsoil is shown in Figure 1.

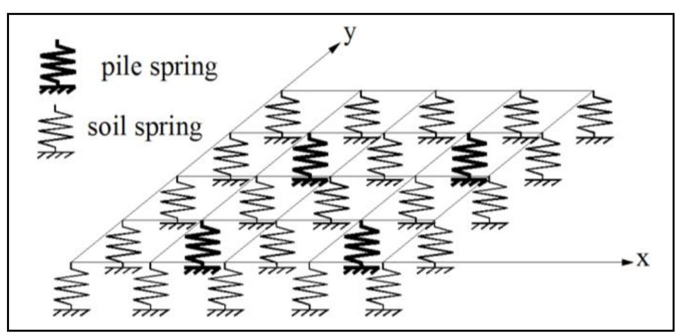

Fig. 1. Structural idealization for piled raft and supporting soil

IV. Assessment of Accuracy of the Procedure

For the purpose of the analysis of this kind of foundation documented in the literature [28] is taken into consideration for the aim of validating the numerical process suggested to be executed using ETABS. The problem's specifics are listed below. The results obtained using ETABS in the present study and the one reported in the literature are shown in Table I. The results are indicated graphically in Fig.3.

- Young's modulus (E) = 2.48 × 10^7 kN/m^2, Poisson's ratio (μ): 0.3,
- Thickness of the raft: 0.45 m, 0.9m, 1.5m,
- Dimensions of raft: 10 m × 10 m,
- Piles with length 3m and diameter 300mm (0.3m) under columns,
- Modulus of subgrade reaction (kN/m^3): 40000, 100000, 200000, 400000
- As shown in Figure 2, the loads are as follows: 800 kN on columns located in the corners, 1500 kN on middle columns along margins, and 2500 kN on the central column.800 kN on columns placed in the corners, 1500 kN on the middle columns along edges, 2500 KN on the central column.

For the value of the modulus of subgrade response to be 40000 kN/m^3, it is found that there is a 33% discrepancy between the maximum deflection values produced using ETABS and the one described in the literature [28]. Similar differences are seen for greater levels of soil modulus in the following ranges: 1%, 14%, and 27%. The results presented above show that there is a reasonable agreement between the maximum deflection found in the current investigation utilising ETABS and the one described in the literature. Both results (Figure 3) showed a high degree of agreement, demonstrating the correctness of the numerical method used in this investigation.

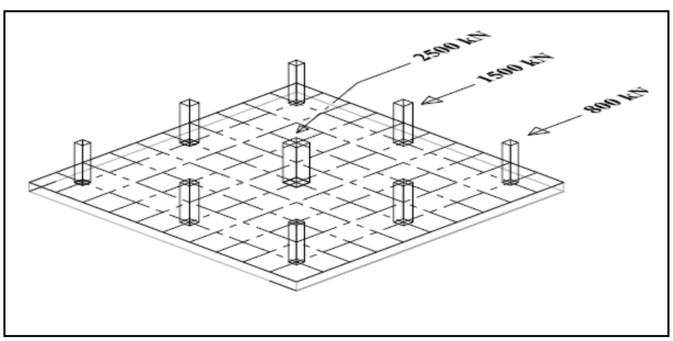

Fig. 2. Load Pattern considered in analysis

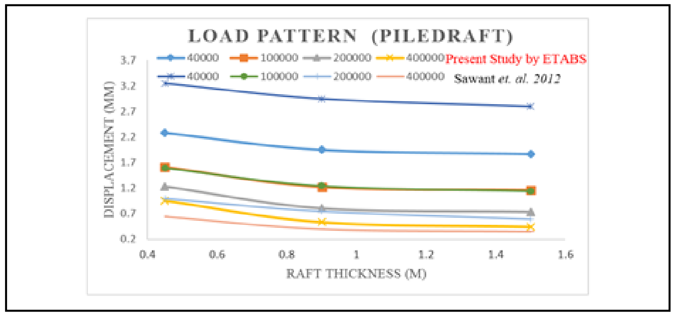

Fig. 3. Comparison of Displacement

TABLE I. MAXIMUM DEFLECTION FOR DIFFERENT SOIL MODULII (KN/M^3)

Soil Modulii	***40000***	***100000***	***200000***	***400000***
	0.45 m thick raft			
Present study	2.26	1.59	1.22	0.95
Sawant et al. [28]	3.25	1.6	1	0.65
	0.9 m thick raft			
Present Study	1.95	1.22	0.81	0.54
Swant et al. [28]	2.95	1.25	0.75	0.4
	1.5 m thick raft			
Present Study	1.87	1.16	0.74	0.46
Sawant et al. [28]	2.8	1.15	0.6	0.35

V. PARTICULARS OF THE PROBLEM

A foundation (piled raft) for a multi storied (G+50) building frame, the plan of which is shown in Fig. 4., is considered in the present study.

The building is rectangular having very large length as compared to the width. The building structure consists of columns as well as shear walls. The size of beams and columns satisfy the structural requirements specified in the code recommended for the practice of plain and reinforced concrete. The building is analyzed for the static load.

As the framed structure consists of 50 stories, secondary effect is also expected to be induced in the column. For this purpose P-Delta analysis is performed using iterative method due to which deflection at top is increased marginally. The slab is provided with rigid diaphragm. Since the width of structure is considerably less than its length, the deflection of a structure parallel to width is much more than that in a direction parallel to length. For this purpose, all the shear walls are provided parallel to width. The particulars considered in the afore-mentioned study are as below (Fig 4).

a) Dead load: 1.5 kN/m^2 (sunk slab is loaded with 350mm equivalent brickbat koba along with DL).

b) Live load: 2.0 kN/m2 (LL of 3 kN/m^2 and 5 kN/m^2 were provided for passage and stair case slab)

c) The size of columns and walls are provided for deflection control in EQ i.e. (h/500) wind i.e. (h/250)

d) Siporex blocks of density 8 kN/m^2 are used for walls and Grade of Concrete : M20

e) The SBC of soil is 350 kN/m^2

f) Equivalent sub-grade modulus is 35000 kN/m^2 /m.

g) Rigid diaphragm is provided and wind load is applied as per IS: 875

h) The grade of concrete used for the analysis is M30 and M70,

i) Poisson's ratio (μ) = 0.2

j) Substructure embedded in medium dense sand

k) Raft slab: 1.5m thick

l) Pile length = 8m, 11m, 14m

m) Pile diameter = 1m, 1.2m 1.5m

n) Floor to floor height: 3.6m

o) Plan of a 50 Story building

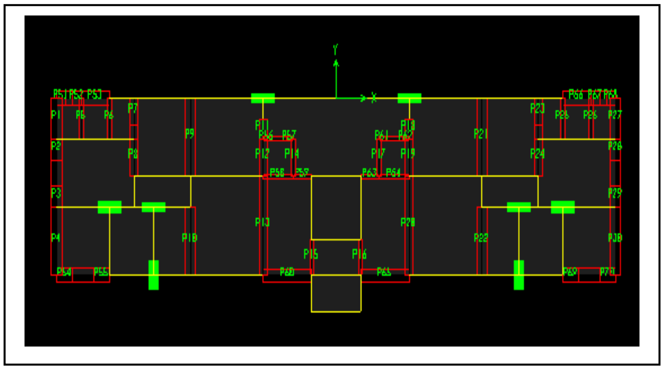

Fig. 4. Plan of a 50 story building

VI. Parametric Study

The structure is analyzed using ETABS. The three dimensional (3-D) extrude analytical modeling of the frame resting on the pile-raft is shown in Figure 5. For a 50 storeyed building with the pile length of 8m, 11m and 14m, respectively and the pile diameter 1.0 m, 1.2 m and 1.5 m with the entire superstructure modeled with substructure having medium dense sand.

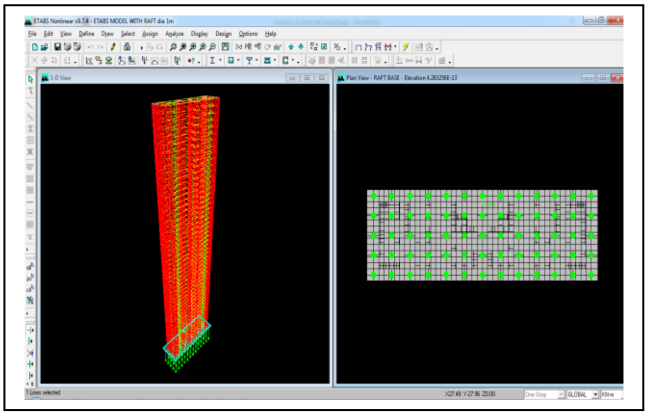

Fig. 5. 3-D model of a 50 storey building with piled raft foundation using ETABS

A. *Effect of varying diameter and pile length*

The effect of varying diameter and varying length of pile are discussed in the subsequent paragraphs.

The values of the maximum sagging and hogging bending moment along with the settlement of raft for various pile diameters in respect of 8 m, 11 m, 14 m long piles are shown in Table II. The variation of settlement of piles for different pile diameters in respect of various pile lengths is indicated in Figure 6. Similarly, the variation of moment for different pile diameters in respect of the afore-mentioned piles is indicated in Figure 7.

It is observed that with increase in pile diameter, settlement is found to decrease. Similarly, settlement is found to decrease with increase in pile length. It is further observed for 8 m long pile that with increase in pile diameter, the settlement of piled raft decreases to the tune of 13%- 19%. For 11 m long pile, the corresponding decrease is observed to be in the range of 15% to 21%. Similarly, for 14 m long pile, the decrease in the settlement of raft is found to be in the range of 18%- to 22%. This clearly indicates that the increase in pile diameter and further, that in length results in the decrease in settlement of raft.

It is, further, vivid from the values of the moments depicted in Tables 2 and indicated in Fig. 7, that as with increase in pile diameter, the moments in the raft increases. It is seen, further, that the moments in raft increases with the increase in length of pile. The moment in the raft is found to increase by 1.5% with the increase in pile diameter from 1 m to 1.5m in respect of 8 m long pile. Further, in respect of 11 m long pile, the increase in moment remains same with the corresponding increase in pile diameter. Similarly, for 14 m long pile, the corresponding increase in moment is 1.6%. Moreover, it can also be observed that as the pile length increases from 8m to 14 m, the moment of the raft is found to increase by 1% to 2%.

The deflection of raft corresponding to various values of the embedment depth (L/D) ratio is indicated in Table III. Similarly, Fig. 8 presents the effect of L/D ratio on deflection of the raft.

From this, it is observed that for a given diameter increase in length results in decrease in the deflection of raft, the decrease being in the range of 3% to 8%. Hence, it can be said that the increase in length to diameter ratio results in decrease in deflection of raft.

The settlement of raft in respect of the various diameters in L/D ratio is indicated in Table IV. The schematic of the variation is indicated in Figure 8. It is evident that for a given length, the increase in pile diameter results in decrease in the settlement of raft; the decrease being in the range of 12% to 19%. Hence, the decrease in length to diameter ratio results in decrease in the settlement of raft.

TABLE II. EFFECT OF VARING DIAMETER OF 8 M PILE RAFT ON MAXIMUM MOMENTS AND SETTLEMENT

Pile diameter (m)	Positive moment (kN-m)	Negative Moment (kN-m)	Settlement (mm)
8 m long pile			
1.0	18971.8	-860	10.7
1.2	19260	-971	9.4
1.5	19554	-1180	7.9
11 m long pile			
1.0	19133	-857	10
1.2	19436	-943	8.7
1.5	19470	-1097	7.2
14 m long pile			
1	19181	-848	9.9
1.2	19502	-924	8.4
1.5	19824	1047	6.9

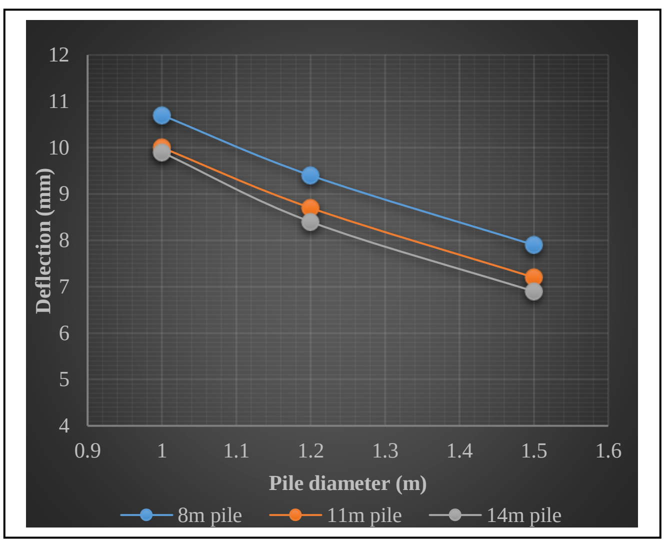

Fig. 6. Effect on deflection of piles for different pile diameter

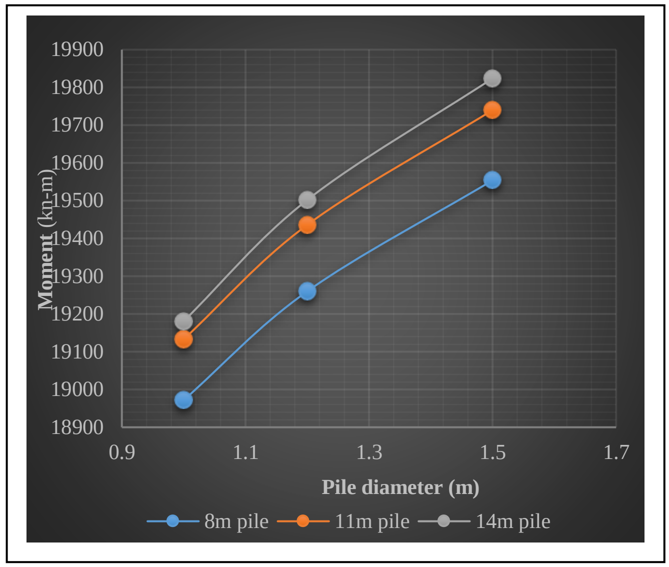

Fig. 7. Effect in moment of piles for different pile diameter

TABLE III. EFFECT OF EMBEDDMENT DEPTH (L/D) RATIO ON SETTLEMENT OF RAFT

L/D Ratio	Settlement of raft (mm)
6.67	9.4
9.17	8.7
11.67	8.4

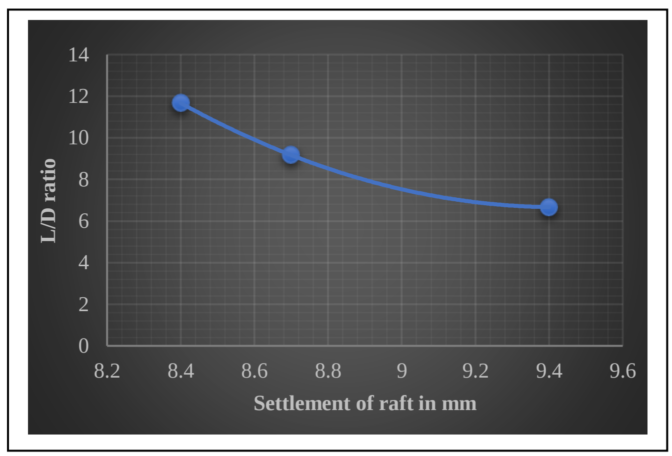

Fig. 8. Effect of pile length on settlement of raft in piled raft

TABLE IV. EFFECT OF EMBEDDMENT DEPTH (L/D) RATIO ON SETTLEMNT OF RAFT

L/D Ratio	Settlement of raft (mm)
8	10.7
6.67	9.4
5.33	7.9

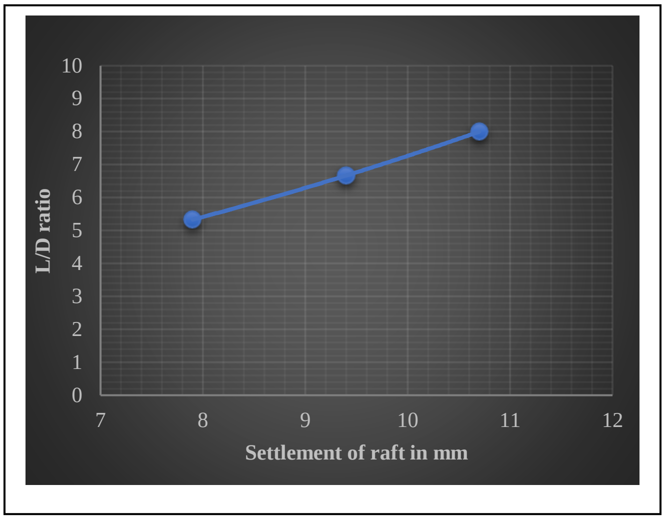

Fig. 9. Effect of varying diameter in L/D ratio on settlement of raft in piled raft

VII. Conclusions

Some of the significant conclusions deduced from the present parametric study are:

- The increase in the pile diameter as well as that in the length of the pile results in decrease in the settlement of raft. This may be attributed to the fact that the increased diameter or increased pile length improves the passive resistance of the foundation as a result of which the settlement of raft decreases.
- With the increase in pile diameter and increase in pile length, moments in raft also increases.
- For a given pile diameter increase in length results in decrease in the settlement of raft; the decrease being in the range of 3% to 8%. Subsequently, increase in embedment depth ratio (i.e., L/D ratio) results in decrease in settlement of raft.
- For a given pile length increase in diameter results in decrease in settlement of raft, the decrease being in the range of 12% to 19%. This implies that decrease in embedment depth ratio (L/D) results in decrease in the settlement of raft.

References

[1] Butterfield, R. and Banerjee, P. K. (1971), “The problem of pile group - pile cap interaction”, Geotechnique, 21(2), 135-142.

[2] Ottaviani, M. (1975), “Three-dimensional finite element analysis of vertically loaded pile groups”, Geotechnique, 25 (2), 159-174.

[3] Chow, Y. K. (1987), “Axial and lateral response of pile groups embedded in non-homogeneous soil”, Int. Jl. Num. Analyt. Meth. Geomech., (11) 6, 621-638.

[4] Liu, W, and Novak, M. (1991), “Soil-pile-cap static interaction analysis by finite and infinite elements”, Canadian Geotech. Jl., 28, 771-783.

[5] Chen, K. S., Karasudhi, P. and Lee, S. L. (1974), “Force at a point in the interior of layered elastic half-space”, Int. Jl. Solids Struct., 10(11), 1179-1199.

[6] Randolph, M. F. (1983), “Design of piled raft foundations”, Proc. Int. Symposium on Recent Developments in Laboratory and Field Tests and Analysis of Geotechnical Problems, Bangkok, 525—537.

[7] Clancy, P. and Randolph, M. F. (1993), “An approximate analysis procedure for piled raft foundations”, Int. Jl. Num. and Analyt. Meth. in Geomech., 17(12), 849–869.

[8] Poulos H.G. (1994), “An approximate numerical analysis of piled raft interaction” Int. Jl. Num. and Analyt. Meth. in Geomech., 18 (2), 73–92.

[9] Katzenbach, R. and Reul, 0. (1997), “Design and performance of piled rafts”, Proc. XIV” Int. Conf. Soil Mech. and Foundation Engg., 97, Hamburg, 4, 2253-2256.

[10] Prakoso, W. A. and Kulhawy, F. H. (2001), “Contribution to piled raft foundation design”, Jl. Geotech. and Geoenv. Engg., ASCE, 127(1), 17-24.

[11] Kitiyodom, P. and Matsumoto, T. (2003), “A simplified analysis method for piled raft foundations in non-homogeneous Soils”, Int. Jl. Num. Analyt. Meth. in Geomech., 27(2), 88-109.

[12] Hooper, J. A. (1973), “Observations on the behaviour of a piled-raft foundation on London Clay”, Proc. Int, Jl. Civ. Eng., 55 (2), 855-877.

[13] Madhav, M.R. and Karmarkar, R.S. (1982), “Elasto-plastic settlement of rigid footings”, Journal Geotechnical Engineering Division, ASCE, 108 (GT-3), 483-488.

[14] Kakurai, M., Yamashita, K. and Tomono, M. (1987), “Settlement behaviour of piled raft foundation on soft ground”, Proc. 8th Asian Regional Conf. Soil Mech. and Foundation Engg., Kyoto, Japan, 1, 373-376.

[15] Chow, Y. K. and Teh, C. I. (1991), “Pile-cap-pile-group interaction in non- homogeneous soil”, Jl. Geotech. Engg., ASCE,, 117 (11), 1655-1667.

[16] Wiesner, T. J. (1991). “Various applications of piled raft analysis”, Proc. Int. Conf. on Comp. Meth. and Advances in Geomech., (Ed.:Beer, Booker and Carter), Balkema, Rotterdam, 1035-1039.

[17] Gandhi, S.R. and Maharaj, D.K. (1996), “Analysis of piled raft foundation”, Proc. Sixth Int. Conf. on Piling and Deep Foundations, Mumbai, India, 1.11, 1-7.

[18] Smith I. M. and A. Wang (1998), “Analysis of piled rafts”, Int. Jl. Num. and Analyt. Meth. Geomech., 22 (10), 777–790.

[19] Franke, E., El-Mossallamy, Y. and Wittmann, P. (2000), “Calculation methods for raft foundation in Germany”, Design Applications of Raft Foundation, Thomas Telford, 283-322.

[20] Katzenbach, R., Arslan, U. and Moormann, C. (2000), “Piled raft foundation projects in Germany”, Design Applications of Raft Foundation, Thomas Telford, 323-391.

[21] Reul, O. and Randolph, M. F. (2003), “Piled rafts in over consolidated clay: Comparison of in- situ measurements and numerical analyses”, Geotechnique, 53(3), 301-315.

[22] Maharaj, D. K. and Gandhi, S. R. (2004), “Non-linear Finite Element Analysis of Piled Raft Foundations”, Proc. Inst. Civ. Eng., Geotech. Engg., 157, 107-113.

[23] Poulos, H.G., Badelow, F., Small, J.C., Moyes, P. (2006), “Economic foundation design for tall buildings”. Proc. 10th Int. Conf. on Piling and Deep Foundations, Amsterdam, 200-209.

[24] Thoiba Singh, N. and Baleshwar Singh (2008), “Interaction analysis for piled rafts in cohesive soils” The 12th Int. Conf. Int. Association for Comp. Meth. and Advances in Geomechanics (IACMAG), Goa, India.

[25] Noh, E. Y., Huang, M., Surarak, C., Adamec, R. and Balasurbamaniam, A. S. (2008), "Finite element modeling for piled-raft in sand", Proc. of Eleventh East Asia-Pacific Conf. Structural, Engineering and Construction (EASEC-11), Taipei, Taiwan.

[26] Cheng, Z. (2011), “Prediction and measurement of settlement of a piled raft foundation over thick soft ground”, E- Jl. Geot. Engg. (EJGE), 16(A), 125-136.

[27] Xie X., Shou M. and Huang J. (2012), “Application Study of Long-short-piled Raft Foundation”, Applied Mechanics and Materials, 70, 242-245.

[28] Sawant,V. A., Ladhane, K. and Pawar, S. (2012), “Parametric study of piled raft for three load-patterns”, Coupled System Mech.: An Int. Jl., 1(2), 115-131.

[29] Chore, H.S. and Siddiqui, M.J. (2013), "Analysis of piled raft for three load patterns", Coupled Systems Mech, 2 (3), 289-302.

[30] Brown, P. T. and Wiesner, T. J. (1975), "The behaviour of uniformly loaded piled strip footings", Soils and Foundations, 15 (4), 13-21.

[31] Kuwabara, F. (1989), "An elastic analysis for piled raft foundations in a homogeneous soil", Soils and Foundations, 29(1), 82-92.

[32] Baziar, M. H., Ghorbani, A., Katzenbach, R. (2009), "Small-scale model test and three dimensional analysis of piled -raft foundation on medium-dense sand", Int. Jl. Civ. Eng., 7 (3), 170-175.

[33] Sales, M.M., Small, J. C. and Poulos, H.G. (2010), "Compensated piled rafts in clayey soils: behaviour, measurements, and predictions", Canadian Geotech. Jl., 47, 327-345.

[34] Basile, F. (2015), "Non-linear analysis of vertically loaded piled rafts", Computers and Geotechnics, 63, 73-82.

[35] Hain, S. J. and Lee, I. K. (1978), "The Analysis of flexible raft-pile systems", Geotechnique, 28 (1), 65-83.

[36] Sinha, J. (1997), "Piled raft foundations subjected to swelling and shrinking soils", Ph.D. Thesis (Unpublished), University of Sydney, Australia.

[37] Mendonca, A. V. and De Paiva, J. B. (2003), "A Boundary element method for the static analysis of raft foundations on piles", Engg Analysis with Boundary Elements, 24, 237-247.

[38] Small, J. C. and Booker, J. R. (1984), "Finite layer analysis of layered elastic materials using flexibility approach, Part I. — Strip Loadings", Int. Jl. Num. Meth. Eng., 20, 1025-1037.

[39] Small, J. C. and Booker, J. R. (1986), "Finite layer analysis of layered elastic materials using flexibility approach, Part II. — Circular and Rectangular Loadings", Int. Jl. Num. Meth. Eng., 23, 959-978.

[40] Tan, Y.C., Chow, C.M. and Gue, S.S. (2005), "Piled raft with different pile length for medium rise buildings ob very soft clay", Proceedings 16th Int. Conf. Soil Mech. And Geot. Engg. (ICSMGE), Osaka, Japan, September 12-16.

[41] Chow, Y.K., Poulos, H.G. and Small, J.C. (2011), "Piled Raft Foundations for Tall Buildings", Geot. Engg. Jl. (South East Asian Geotechnical Society), 42(2).

[42] Shen, W. Y., Chow, Y. K. and Yong, K. Y. (1999), "Variational solution for vertically loaded pile groups in an elastic half-space", Geotechnique, 49 (2),199-213.

[43] Shen, W. Y. and Teh, C. I. (2002), "Analysis of laterally loaded pile groups using a variational approach", Geotechnique, 52 (3), 201-208.

[44] Liang, F. Y. and Chen, L. Z. (2004), "A modified variation approach for the analysis of piled raft Foundation", Mechanics Research Comm., 31, 593-604.

[45] Wulandari, P.S. and Tjandra, D. (2015), "Analysis of piled raft foundation on soft soil using PLAXIS 2D", Procedia Engineering, 125, 363-367.

[46] Ko, J., Cho, J. and Jeong, S. (2017), " Nonlinear 3D interactive analysis of superstructure and piled raft foundation", Engineering Structures, 143, 204-218.

[47] Nasrollahi, S.M. and Hosseininia, S. (2019), "A simplified solution for piled-raft foundation analysis by using the two-phase approach", C. R. Mecanique, 347, 716-733.

[48] Deb, P. and Pal, S. K. (2019), "Numerical analysis of piled raft foundation under combined vertical and lateral loading", Ocean Engineering, 190, 106431.

[49] Chanda, D., Saha, R. and Haldar, S. (2020), "Behaviour of piled raft foundation in sand subjected to combined V-M-H loading", Ocean Engineering, 216, 107596.

[50] Kumar, U. and Vasanwala, S. (2021), "A numerical analysis on the effect of pile head connections on piled raft foundation subjected to vertical and static horizontal load", Materials Today: Proceedings, 42, 3083-3088.

[51] Modak, R. and Singh, B. (2022), "A parametric study of large piled raft foundations on clay soil", Ocean Engineering, 262, 112251.

[52] Deb, P., Debnath, B., Reang, R. B. and Pal, S.K. (2022), " Structural analysis of piled raft foundation in soft soil: An experimental simulation and parametric study with numerical method", Ocean Engineering, 261, 112139.