Proceedings of Indian Geotechnical Conference 2020
December 17-19, 2020, Andhra University, Visakhapatnam

Visakhapatnam Chapter

Optimization of Piled Raft on Sand for Plaza-Type Structures

B. Sharmila[1], V. Balakumar[2], and S.S. Chandrasekaran[3].

[1] Former Student, MTech Structural Engineering, School of Civil Engineering, Vellore Institute of Technology, Vellore, India, sharmilabaskaran2552@gmail.com.
[2]Simplex Infrastructures Limited, Chennai, India, vb_kumar2012@yahoo.com.
[3]Professor, School of Civil Engineering, Vellore Institute of Technology, Vellore, India, chandrasekaran.ss@vit.ac.in.

Abstract. Tall and super-tall structures have in general two parts namely tower portion and shallow portion. Here the loading is different for every portions of the structures. Hence, providing the same parameter of pile for that structures becomes uneconomical. The present work tries to study the effect of the piled raft with varying pile length and varying pile diameter considering two different types of loading relating to shallow portion and tower area, then provide the shorter length of piles for the shallow structures and longer length of piles for the tower area. The present study adopts a plane strain analysis to see the effect of shorter and longer piles interacting with each other. E-Tabs 16.2.1 2016 and Plaxis 8.2 have been used for the analysis and this study presents observations and discussions are relating to the possibility of using–different length of the piles or piles of different diameters.

Keywords: Piled Raft, E-tabs, Plaxis.

1 Introduction

The Exponential Growth in the demand of occupational spaces has resulted in the increase of tall and super tall structures. The geotechnical site conditions are no more a constraint and so the foundation designers face the challenge of designing an economical foundation system that will satisfy safety and serviceability requirements. Optimization of pile length, pile diameter and layout along with an appropriate raft thickness form the major features in the economics of foundation design. In this combined foundation system, the total load coming from the superstructure is transferred by means of a complicated three-dimensional interaction among the constituent elements namely raft, soil and the pile group. Zeavert (1957) was perhaps the earliest researcher to introduce the concept of using piles with the raft as a settlement reducer. The observational study had indicated that the pile group taking a major portion of the load. In general, large pile groups are designed with piles of uniform length and diameter having uniform spacing which may result in an uneconomical raft design. The uniform pile length is used to maximize the overall stiffness or minimizing the differential settlement. The intensity of loading and the settlement requirement decides an optimum pile layout keeping the economy in the design of raft and the pile.

Most of the structure have been supported on piles of the uniform length and same diameter. The pile groups were capped with a raft of uniform thickness. Till now to the best of our knowledge optimized design of pile group, depending on the column loads appears to the scarce. Although extensive studies had been carried out on the behavior and performance of piled raft through analytical and numerical modeling (Clancy 1993; Russo,1998), 1g model tests (Balakumar, 2008) centrifuge modelling (Horikoshi 1995) and observational studies (Katzenbach etal.,2000). Very little work had been done on the optimization work with the use of piles in the case of structures with varying stiffness (Cunha et al. 2001, Leung et al. 2009, EI Sawwaf 2010). In the present study, Plaza-type structure have been analyzed in E-tabs and the obtained support reactions are taken for the pile group design. According to the column load, the length of pile is varied. Therefore, it becomes necessary to study the performance of raft-soil foundation system reinforced with piles and the behavior of raft contact pressure distribution by introduction of different length of piles in the combined foundation system.

2 Numerical Modelling

Finite element modelling is a method for dividing up a very complicated problem into a small element. It is due to ease in modelling and arranging the elements in the desired shape and pattern. The interface idealization is the essential aspects to be considered for the numerical study of soil-structure interaction.

Any numerical analysis needs a certain level of dilution to reduce the computational efforts. Therefore, the analytical model must be chosen amendable in the sense that the level of the result is not sacrificed. Hence the plane strain model is chosen as a key equipment for analyzing the present study. Prakoso and Kulhway (2001) performed a piled raft problem by assuming plane strain conditions. The plane strain condition involves a fundamental simplification wherein a finite-sized piled raft is simplified into a strip piled raft provided by Desai et al (1974) and established that this type of model can provide good results and can be used to analyze a relatively large piled raft without any excessive modeling and computing time. The piles in the plane are converted into plain strain wall and its equivalent pile young's modulus can be calculated by using the below equation 3.1 which is given by (Prokoso,1991).

$$E_{eq} = \frac{n_{p-row} A_p E_p}{L_r B} \qquad (1)$$

where, n_{p-row}: *Number of piles in a row*

A_p : *Area of each pile*

E_p : Young's modulus

L_r : length of the raft

B : Width/Diameter of pile.

3 Super-Structure Modelling

The commercial building adapted in this study carries twelve stories at the center of the building and the rest of the sides carries four stories as shown in figure 3.1. the shape of the building is irregular. The width of the building is 32m and the length of the building is 96m along the largest span. The building is designed for a flat-slab system. The building lies on a raft soil foundation system reinforced with piles. The piles are placed exactly below the column.

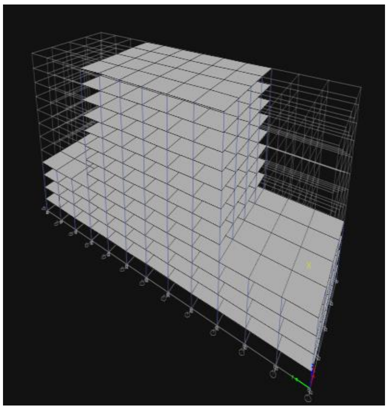

Fig.1. Modeled Structures

The commercial building was modeled using E-tabs for the physical properties. The spacing of the column provided as 8m and the outer wall were modeled as reinforced concrete walls. M_{35} Grade of concrete and Fe_{500} Grade of steel has been assigned for the structure. The structure has been modeled using E-tabs. The material and section properties are defined for all the structural elements. All the columns are fixed to the base. The static and dynamic loadings are calculated based on IS 875 part 1 and 2 1987 and IS 1893-2002. The self-weight of the building is calculated automatically by E-tabs with their loading combination. After modeling the building, the structure is analyzed. The shear force, bending moment, Storey drift and displacement values have been extracted from E-Tabs after analyzing. The support reaction i.e. column load obtained from the analysis is used for the further design of foundation elements.

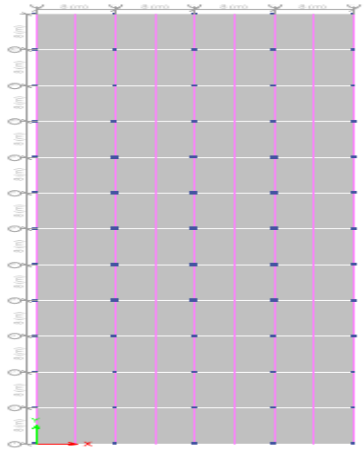

Fig.2.(a). Column Layout

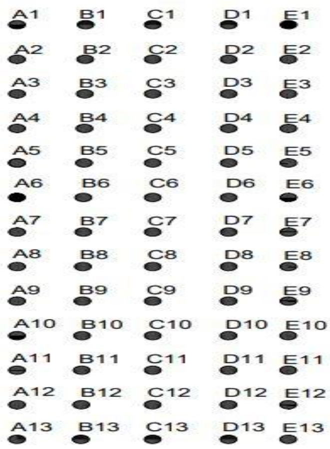

Fig.2(b). Pile Layout

4 The Foundation System

The Raft, soil and pile are modeled as solid components under material and geometry properties are mentioned in Table 1 Circular piles were modeled are introduced beneath the raft in the combined foundation system.

Table 1. Properties of Foundational Element:

Property	raft	Pile	Sandy soil
Material	concrete	concrete	Medium dense sand
shape	Rectangle	Circle	Rectangle
Elastic Modulus (kN/m^2)	3.1×10^{10}	3.1×10^{10}	4.4×10^{7}
Density (Kg/m^3)	2400	2400	1442
Poisson ratio	0.2	0.2	0.25
Shear angle	-	-	33^0
Size	Thickness=900mm Width =50m	Depth =20m, 16m, 10m Diameter=0.7m,0.8m,0.9m	Depth=50m Width=100m

The piled acted as reinforcement in the raft-soil system. In the piled raft foundation system, piles were located below the column under the raft. The total number of columns in the structural frame was 65 as in fig 2(a). Since the structure is symmetric to each other, so the pile naming in fig 2(b) C1 to C7 has been taken for the analyses and the properties of the pile are tabulated in Table 1. Fig 2(a) and fig 2(b) are to be read in configuration with each other. The length of the long pile is 20m and provided under the tower area simultaneously for shallow area provide the shorter pile of length 16m. The same procedure is repeated by keeping the longer length pile constant by changing the shorter length of the pile has 10m.

A uniform dense sand block was modeled around the pile-raft system. Since the influence of the imposed structural load on the raft in an unpiled raft, the system is transferred to the soil. The load that is imposed on the foundation is obtained from the structural analysis of the plaza-type structures in E-Tabs. The concentrated loads are converted into equivalent uniformly distributed load. This equivalent UDL was imposed on the raft surface in the combined foundation system in the form of pressure. The fixity condition act as bounding limits to the soil.

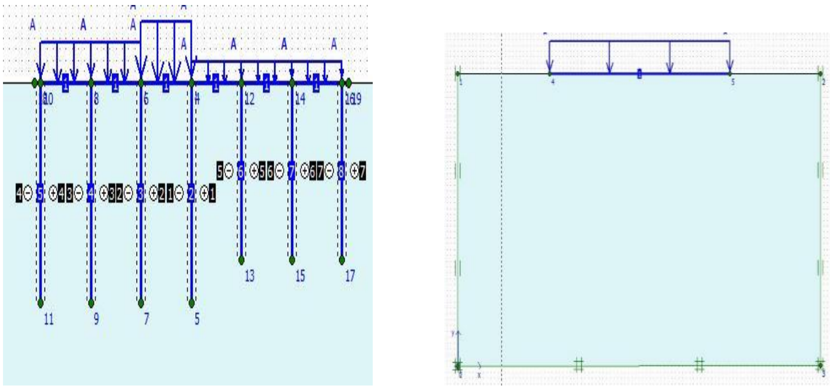

Fig. 3. Modelled of Piled raft and unpiled raft with structural loading

After completing the model and meshing of the structure, analysis is completed assigning each phase of construction and results are obtained and interpolated. Total deformation and equivalent stress are the two output parameters required in the present study. The numerical analysis is performed after the required output is selected. Total deformation and stress contours are obtained as the end results of the analysis. These displacements and stress contours denote the pattern of the displacement and the stress that undergoes in the combined raft, soil and pile foundation system respectively.

5 Discussion

The present study as said earlier examines this behavior of the pile group of piled raft supporting a plaza-type building. In general, such buildings have column loads varying widely. In particular, the shallow portion transits much lesser load when compared to tower on the columns. The present study tries to evaluate the effectiveness of piled raft with varying pile length (keeping the diameter constant) or varying the pile diameter, keeping the length as constant.

5.1 Effect of varying pile length

In the present cases, the numerical analyses are performed on the combined raft, soil and pile foundation system for the *D/t ratios* where,

D – Diameter of the pile

t – thickness of the raft

Two different pile length has been used namely 10m and 16m. the raft thickness has been kept as 900mm. From the below graph images. It clearly explains that

i. When the length of the pile was kept as 20m. it clearly shows that, The load carrying capacity of a pile at **d/t** ratio unity was 15% higher than the **d/t** ratio of 0.8.

ii. When the length was increased to 16m, the load taken by the system having **d/t** ratio of unity was higher only by 25% compared to the system having **d/t** ratio of 0.8.

iii. When the length of the piles was kept at 10m. It is found that **d/t** is ratio, the carrying capacity for the settlement of 50mm was 40% higher than the **d/t** ratio was 0.8.

Table 2..Deflection results:

D/t ratio	Maximum Deflection (mm)		
	Piled Raft		
	L=20m	*L*=10m	*L*=16m
0.8	68.08	65.73	69.14
0.9	65.76	63.73	66.75
1	63.52	60.59	63.52

From the above table, it can be observed the reduction in the settlement with the increase in diameter of the pile for a constant thickness of the raft. It shows that the maximum settlement reduces with the reduction of the pile length of 50%. This reflects the fact that when the pile length increases the enhancement of the confining pressure might not have been effective over the entire length of the pile.

5.2 Effect of variation in Pile Diameter

The parametric study was further continued to study the effect of variation in the pile length for three different diameters namely 700mm, 800mm and 900mm. The pile naming from C1 to C3 has been taken from the Shallow portion and the remaining C4 to C7 pile taken from the tower area for the further analyses. The tower area pile length is kept as constant of 20m and the shallow area pile length is changed as three aspects such as 20m, 16m and 10m. For the result discussion, the maximum stress for the pile C1(Shallow portion pile), C4(Intermediate Pile) and C7(Tower area Pile) has been taken to plot the graph.

Pile Diameter 700mm

The interaction between the soil and pile remains the same by using the same length of the pile. It can be seen that the trend in the shaft stress distribution remains the same irrespective of pile location. Further in all three cases, considered the shaft stress falls rapidly beyond the pile length of 0.6l to 0.7l namely 14m in the case of 20m long pile and 6m in the case of 10m long pile In the same manner, in the case of 16m long pile this value corresponds to 0.65l to 0.75l (where l is the overall length of the pile considered).

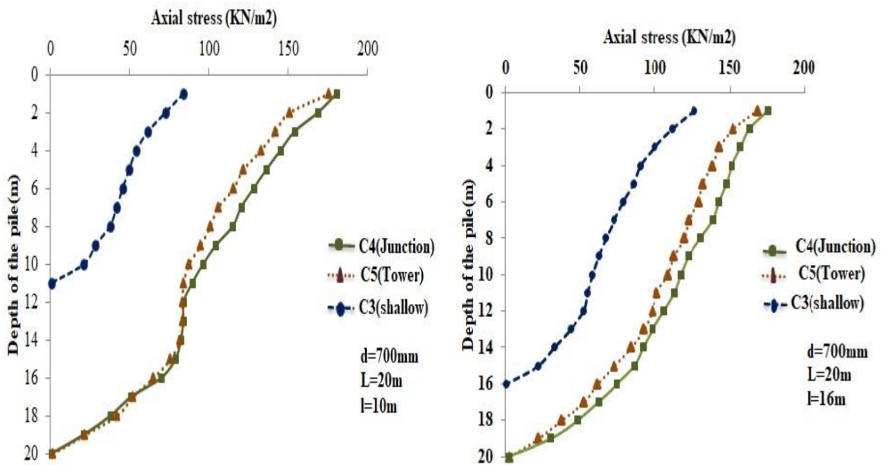

Fig. 3. Shaft Stress (d=700mm and l=10m &16m)

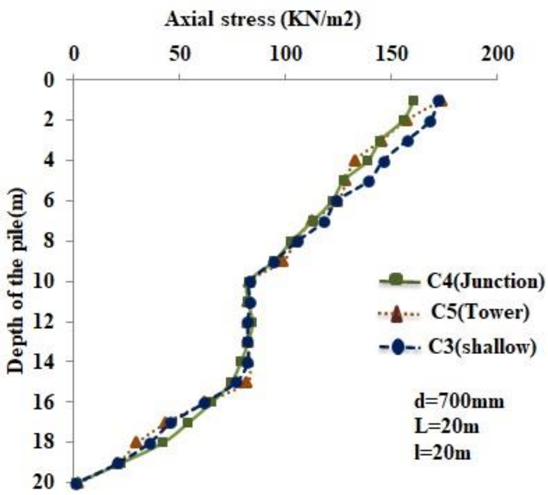

Fig.4. Stress Curve of equal length of Piled raft

Pile diameter 800mm

while the trend remains the same, the rate of fall of shaft stress appears to be more rapid from the beginning. At the point corresponding to 50% of the pile length, the shaft stress falls by 40% but at 0.8l it is 60%. Therefore, it can be said that the rate of fall of shaft stress between 0.5l to 0.8l is more gradual. Some at higher diameter, the effective pile length increases to 0.8l.

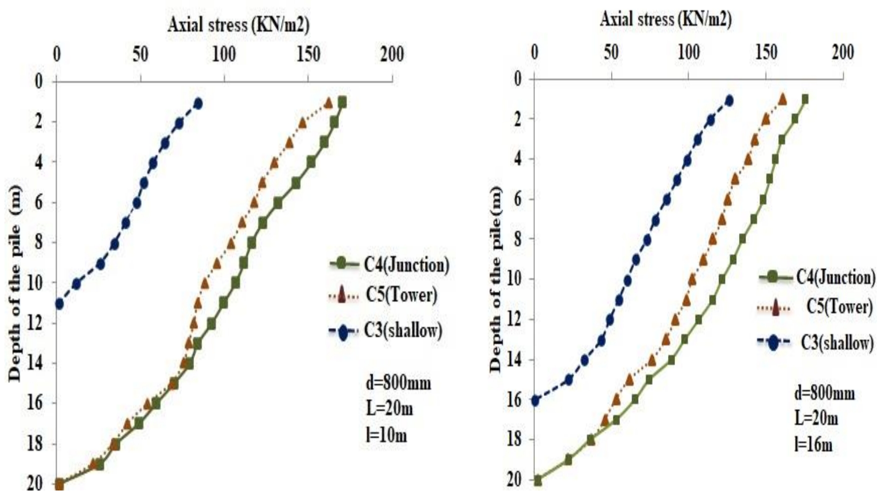

Fig. 5. Shaft Stress (d=800mm and l=10m&16m)

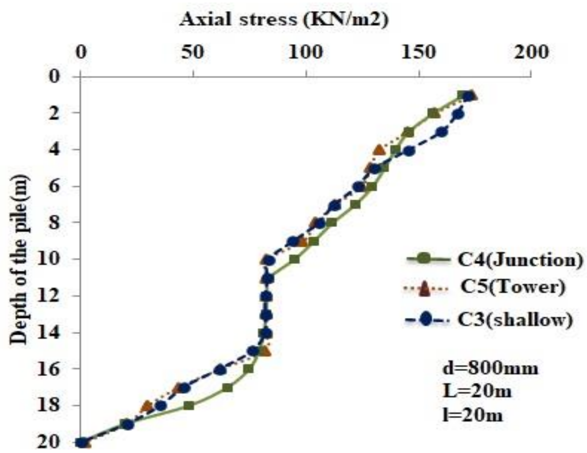

Fig. 6. Stress Curve of equal length of Piled raft

Pile diameter 900mm

It is shown that the shaft stress curve remains unique. The C4(intermediate Pile) pile stress is maximum because the loading is high due to the combination of Tower area loading and Shallow portion loading. But the stress remains equal when we use the equal length of pile for both the area portion. At the point corresponding to 0.5l, the shaft stress falls by 0.65l to 0.7l. Similarly, at 0.8l the shaft stress falls by 0.65l to 0.75l. The shaft stress is more gradual at a point of 0.65l to 0.75l for a greater diameter.

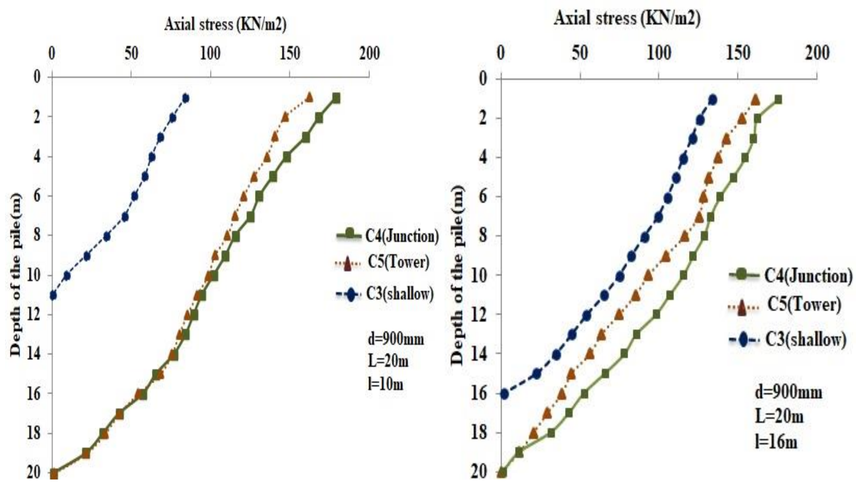

Fig.7. shaft stress (d=900mm and l=10m&16m)

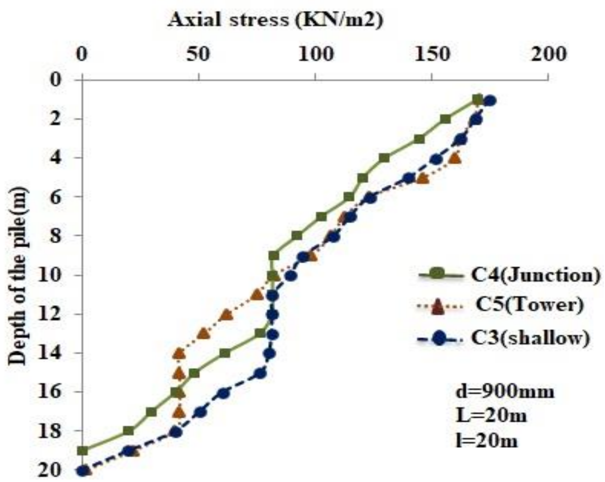

Fig.8. Stress Curve of equal length of Piled raft

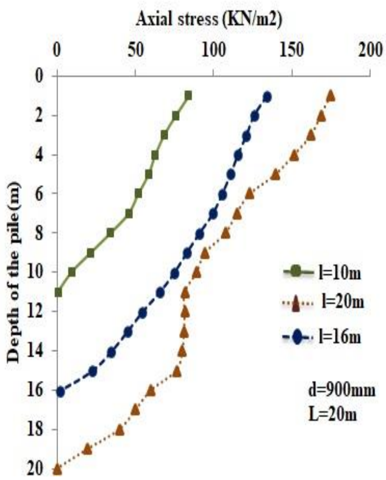

Fig. 9.Effect of changing pile length

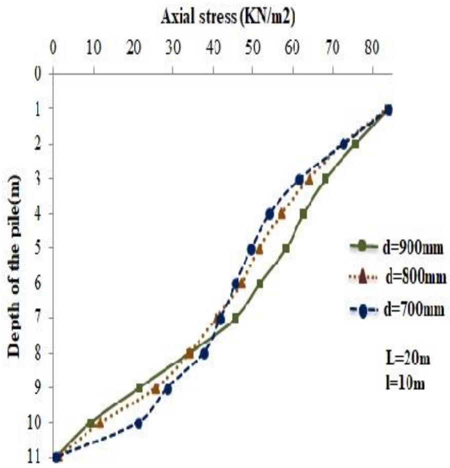

Fig.10. Effect of changing pile diameter

Fig 9 shows that the shaft stress decreases with the decrease of pile length even the loading is the same. The diameter and length of central area pile are kept as a constant of 900mm and 20m. the maximum interaction occurs at the shorter pile length when compared with using 60% and equal length of the pile. The interaction varies 68-85% with the pile length decreases. Fig 11 shows that when the pile diameter increases, the shaft stress remains same at the tip of the pile but gradually decreases at certain point of 8m, after that certain point the shaft stress value increases gradually.

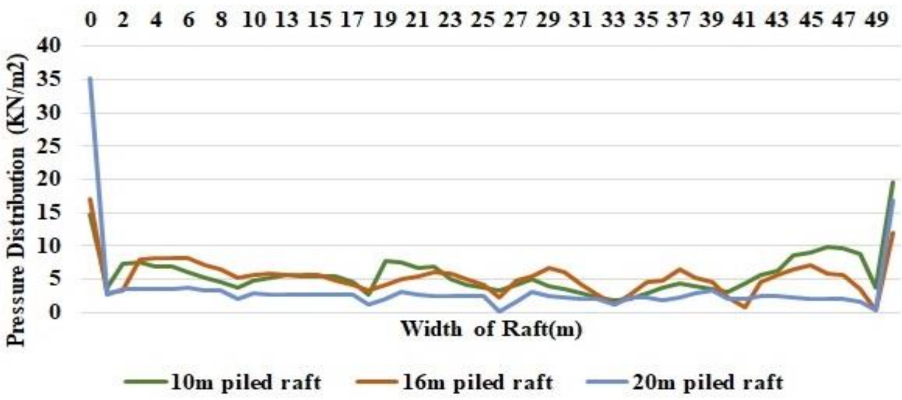

Fig. 11. Contact Pressure distribution of Piled Raft

The load carrying capacity of raft increases with usage of a small length of the pile. Then the more settlement is observed for a small length of piles. By using the different length of pile, the contact pressure distribution of raft carries 70% of load when compared to the same length of the pile.

6 Conclusions

It was observed from the present study that the introduction of the piles reduced settlement in the foundation by about 80-90% for the present layout of piles. Further reduction in settlement can be achieved by changing the length of pile. It was observed that the introduction of piles has not only reduced the raft settlement but also bought out a considerable change in the stress level along the area of the raft. From this study,

1. In the shallow portion, the shaft stress distribution falls rapidly at certain point even the pile diameter increases, and the pile length decreases.
2. The load from the superstructure is directly applied on the piled raft foundation. From the applied load, pile carries nearly 2-3rd of the load applied on the combined foundation system.
3. The behaviour of raft on the piled raft foundation shows that the contact pressure on the raft gradually decreases at the pile location.
4. By using the different length of pile, the contact pressure distribution of raft carries 70% of load when compared to the pile using the same length in all portions of the building.
5. The percentage of load carried by raft increases for a small length of the pile. Also, relatively more settlement is observed for small lengths of piles.

6. The interaction effect remains the same when the length of pile reduces to 80% even the diameter increases. But when the pile length reduced to 50%, the interaction increases with increase of diameter.

The raft contact stresses obtained from the numerical analysis show uniform distribution and gradually decreases at the pile location and the edges. The shaft stress distribution obtained from the analysis indicated that the stress is higher at the pile head and reduces towards the pile tip.

References

1. Balakumar V. and Ilamparuthi K. (2007) Performance Monitoring of a Piled Raft Foundation of Twelve Storied Building and Analytical Validation, Indian geotechnical Journal, Vol. 37, No. 2, pp. 94-115.
2. Balakumar.V (2008) Experimental Studies of Model Piled Raft on Sand and Field Study of Prototype Behavior. PhD. Thesis, Anna University, Chennai.
3. Balakumar, V., and Anirudhan, I.V. (2011). "Piled Raft behavior-model studies and field performance." Proc, Indian Geotechnical Conference, 947-950.
4. Balakumar, V., Oh, E., Bolton, M. and Balasubramaniam, A.S. (2013). "A design method for Piled Raft foundations." Proc. The 18th International conference on soil mechanics and Geotechnical Engineering, Paris, 2671-2674.
5. Burland J.B. (1995), Piles as Settlement Reducer, 18th Italian Congress on Soil Mech., Pavia.
6. EI Sawwaf, M. (2010). "Experimental Study of eccentrically loaded raft with connected and unconnected short piles." J. Geotech. Geoenvi. Eng., 136(10), 1394-1402.
7. Meisam Rabiel, Asskar Janalizadeh Choobbasti. (2019). "Innovative Piled Raft Foundation design using Artificial Neural Network." Frontiers of structural and civil engineering, 14, 138-146.
8. Min Huang, Erwin Oh, Balasubramaniam, A.S and Balakumar, V.(2018). "A Critical and Comparative Study on 2D and 3D Analyses of Raft and Piled Raft Foundations." Geotechnical Engineering Journal of the SEAGS & AGSSEA, Vol. 49, No. 1.
9. Padmanaban, M.S. and Sreerambabu. J.(2017). "Issues on Design of Piled Raft Foundation." Journal of mechanical and civil engineering, 14(2),pp-36-40.
10. Poulos, H.G. "Piled raft foundations: design and applications." Geotechnique, 51(2), 95-113.
11. Vamsi Krishna, B. and SrinivasaReddy Ayuluri. (2017). "Settlement analysis of Piled Raft Foundation System (PRFS) in soft clay." International Journal of Mechanical and Civil Engineering, 14(2), pp-62-68.
12. Yunfei Xie, Shichun Chi (2019). "Optimization method for irregular Piled Raft Foundation on Layered Soil Media." Advances in civil engineering, volume 2019.
13. Zeevaert, L. (1957). "Compensated Friction Piled Foundation to reduce the settlement of building on highly compressible volcanic clay of Mexico city". Proc. 4th international conference of Soil Mechanics and Foundation. Eng., London 2.