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Research Paper

ANALYSIS OF PILED RAFT FOUNDATION USING FINITE ELEMENT METHOD

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Raft foundation covers the entire area of the structure, transmitting the entire structural load and reduces differential settlements whereas piles are relatively long, slender members that transmit foundation loads through soil strata of low bearing capacity to deeper soil or rock strata having a high bearing capacity. In recent years, a piled-raft foundation which is a composite structure consisting pile and raft has been proved to be an appropriate alternative instead of conventional pile or mat foundations. In this paper, analysis of piled raft foundation has been carried out by using finite element software ANSYS. For understanding the behavior of piled raft foundation, parametric studies has been carried out in medium sand by varying pile diameters and pile lengths in different combinations. It has been found out that Pile diameter has significant influence on the ultimate capacity of piled raft foundation whereas the pile length has not of much significance. It is concluded that an optimum combination of pile diameter of 0.5 m at the center of the raft with 0.4 m at the edges of the raft is giving ultimate load of 4.45 MN with settlement of 26.76 mm which is in acceptable limits.

Keywords: Raft, Pile, Piled raft foundation, Finite element method, Sand, ANSYS

INTRODUCTION

In this study, piled-raft foundation has been considered which is a combination of advantages of both raft and pile foundation. Piles are provided along with the Raft so that the total load acting is shared partly by the raft and partly by piles. Piled raft foundations utilize piled support for control of settlements with piles providing most of the stiffness at serviceability loads, and the raft element provides additional capacity at the ultimate load.

To study the behavior of piled rafts, numerical method is a reliable and suitable method due to complex soil-structure interaction. Finite Element Method is one of the numerical methods which is a powerful tool to model this complex geometry of piled-raft foundation. ANSYS V11 is one of the sophisticated finite element software which is well

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suited for foundation analysis because of its flexibility in modeling, meshing and also the field conditions can be incorporated effectively.

In previous literature, it is inferred that the behavior of foundation can be analyzed using methods like finite element method with the help of different software. In some of the studies different diameters of piles and lengths of piles has been considered which affect the performance of the foundation. OH *et al*. (2008) have carried out analysis on unpiled and piled raft foundation in sandy soil using PLAXIS software. . They have varied raft thickness which does not affect significantly the load carrying capacity of the foundation. Rajendra Singh *et al*. (2012) suggested that pile spacing has much effect on the maximum and differential settlement. Poulos *et al.* (2011) carried out 3D analysis of piled raft foundation of Incheon tower in South Korea subjected to horizontal and vertical loading using PLAXIS and the same is compared with pile group foundation system. They suggested that piled raft behaves safely in high raised buildings. Luca De Sanctis and Alessandro Mandolini (2006) concluded that piled rafts provide an economical foundation option when an unpiled raft does not satisfy design requirements. Hence, they suggested that addition of limited number of piles will improve the ultimate load capacity and settlement performance of the foundation. They have concluded from their work is that the piled raft foundation is a good option for the future projects.

There are different variables which influence the load carrying capacity of piled raft foundation. Initially, the effectiveness of ANSYS is validated with static formula of bearing capacity of unpiled raft and also with existing data on piled raft foundation from available literature before proceeding with parametric study. Then, the parametric study is carried out by considering variables like uniform diameter of piles and uniform length of piles and different diameter of piles and different length of piles under the raft. This parametric study is carried on piled raft foundation in medium sand.

METHODOLOGY

Two dimensional plane strain non linear analysis under vertical load is carried out using finite element software ANSYS to determine ultimate load carrying capacity and settlement of foundation. Here, pile and raft are treated as linear, soil-raft and soil-pile interface as non-linear and Drucker-Prager constitute model is used for soil.

Here, pile and raft were modeled as linear isotropic and the properties considered for analysis are Young's modulus (E), Poisson's ratio(μ) and density for pile and raft. Soil is modeled as an elasto plastic and in addition to linear material properties, properties like material cohesion strength (c), friction angle (ϕ) and flow angle (ψ) is given. For pile, raft and soil, PLANE82 was used as an element type and the element behavior is specified as plane strain. The interface behavior is non linear. Contact elements CONTA172 (for soil) and TARGET169 (for pile and raft) at soil-pile and soil-raft interface are considered. Regarding boundary conditions, nodes constituting bottom of the soil zone is fixed against both vertical and horizontal directions whereas the zone away from pile raft, i.e., the vertical surface of soil at the boundary is restricted against horizontal movements. The horizontal boundary (H) was placed at 5 times the piled raft cluster diameter (5D) and the vertical boundary (V) is placed at 3 times the piled raft cluster diameter (3D) as shown in Figure 1.

Figure 1: Piled Raft Foundation

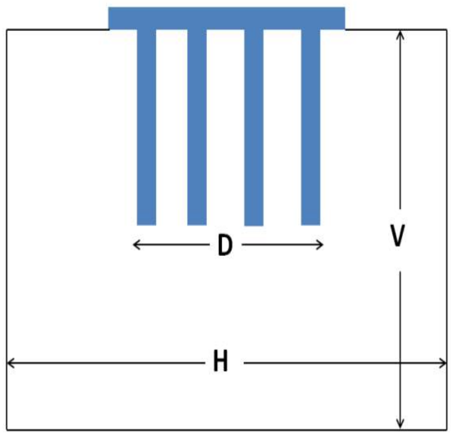
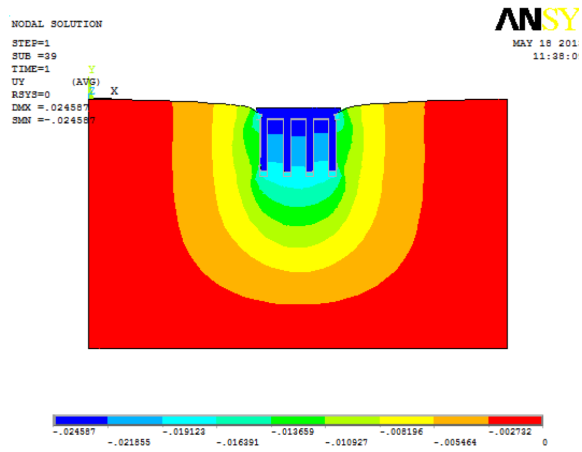
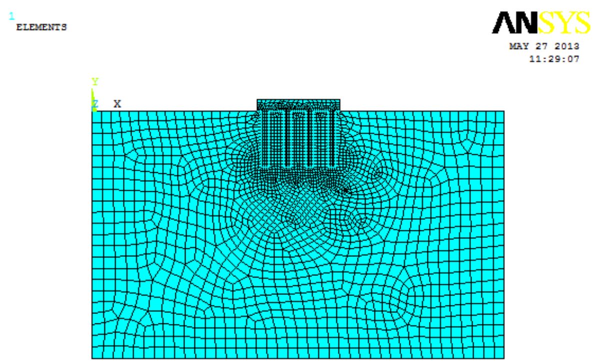


Figure 3: Displacement Contours Along y-Direction



For validation of ANSYS, immediate settlement in medium sand is calculated using static formula [3, 5, 6, 11, 16] and the same is compared with the results obtained from ANSYS. Here, the results obtained from ANSYS are compatible with the calculated theoretical results. Similarly, validation is done using literature [3] is compared with the results obtained from ANSYS. The outcome of this analysis is that the results obtained from ANSYS are compatible with the literature. The model meshed is shown in Figure 2. The resultant model from the analysis showing displacement contours is shown in Figure 3.

Figure 2: Meshed Model



RESULTS AND DISCUSSION

Effect of Pile Diameter

Initially, the influence of pile diameter on the behavior of piled raft foundation is analyzed. The number of piles (16 in no.), pile length (all are of 3 m), thickness of raft (0.6 m), spacing of piles (3 d) are kept constant. The material properties considered are shown in Table 1.

Table 1: Material Properties [3,5,6,11,16]

Properties	Piled Raft	Soil (Medium Sand)
E	$2.5*10^7$ kPa	$4*10^4$ kPa
μ	0.15	0.3
ρ	2500 kg/m^3	1900 kg/m^3
C	-	5kPa
Φ	-	35^o
ψ	-	10.5^o

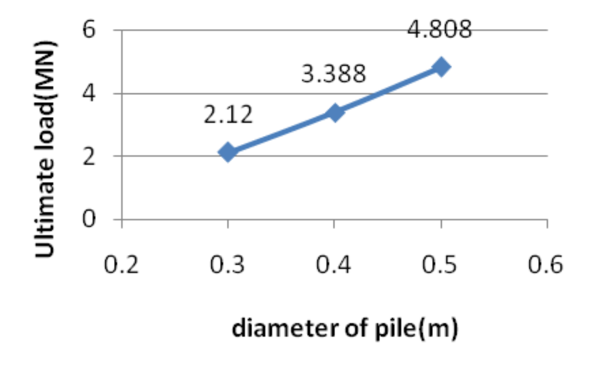
From the analysis, the ultimate load capacity and corresponding settlement is obtained for all the combinations are given in Table 2.

The ultimate load carrying capacity increases significantly with the increase in pile diameter (Figure 4).

Table 2: Values of Ultimate Load and Settlement

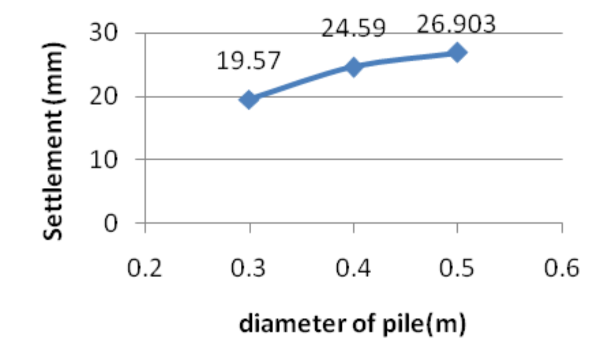
Pile Diameter(m)		Ultimate load	Settlement
Centre of the raft	Edges of raft	P (MN)	δ (mm)
0.3	0.3	2.12	19.57
0.4	0.4	3.388	24.59
0.5	0.5	4.808	26.903

Figure 4: Variation of Ultimate Load with Diameter of Pile



The corresponding settlement also increases significantly with the increase in pile diameter (Figure 5).

Figure 5: Variation of Settlement with Diameter of Pile



The ultimate load carrying capacity and corresponding settlement is obtained for piles of different diameters in different combinations are discussed in the following (Table 3).

Table 3: Values of Ultimate Load and Settlement

Pile Diameter(m)		Ultimate load	Settlement
Centre of the raft (Inner)	Edges of raft (Outer)	P (MN)	δ (mm)
0.4	0.3	3.616	28.16
0.5	0.3	3.926	25.97
0.3	0.4	3.850	30.85
0.3	0.5	3.486	24.55
0.5	0.4	4.45	26.76
0.4	0.5	3.581	22.15

From Table 3, as either of inner and outer pile diameters is increased from 0.3 to 0.4 m and 0.5 m, the ultimate load increases around 81% and 85% whereas the settlement increases around 50% to 30%. An interesting observation from this study is that the combination of 0.3 m at the centre and 0.4 m at the edge of the raft is giving reliably higher value of ultimate load which is economic also.

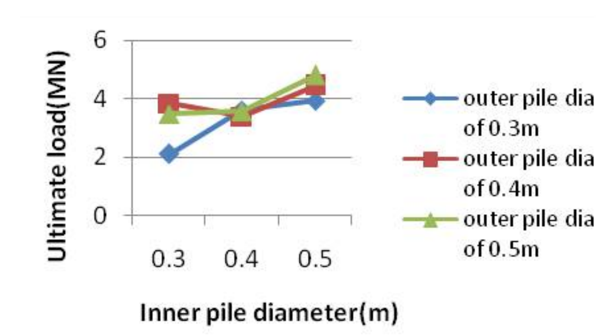
Similarly, when comparing with uniform diameter of 0.4 m, the combination of 0.5 m along centre with 0.4 m along edge of the raft is giving higher value of ultimate load.

From this study, it can be concluded that even though relatively it is difficult for casting different diameters, but it is giving relatively higher values of ultimate load which is cost effective also.

Variation of ultimate load with different pile diameter combination is plotted as shown in Figure 6.

From Figure 6 also it can be seen clearly that there is a good amount of increase in ultimate load from 0.3 m diameter combination to 0.3 and 0.4 m diameter combination.

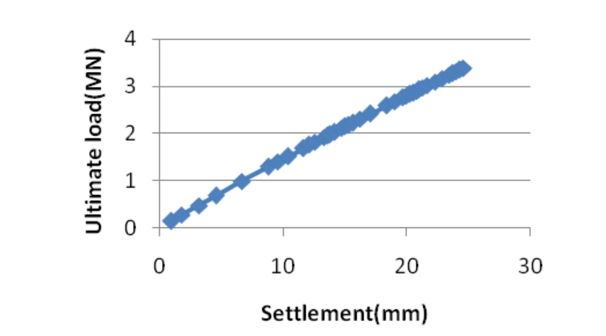
Figure 6: Variation of Ultimate Load With Inner and Outer Pile Diameters in Combinations



From the above results, a pile diameter combination of 0.5 m at the centre of the raft with 0.4 m at the edge of the raft is showing credible results.

From the results obtained from ANSYS, a plot on ultimate load vs settlement is shown in Figure 7.

Figure 7: Ultimate Load Vs Settlement Plot for the Case of Uniform Pile Diameter of 0.4m



Since, the load carried in case of piled raft foundation is more at the centre of the raft, there is a need to provide larger pile diameter in the central portion of the piled raft. Also, the above two combinations of 0.5 along the centre portion of the raft with 0.3 along the edge of the raft and 0.5 along the centre portion of the raft with 0.4 along the edge of the raft is preferred. Hence, it is concluded that greater the pile diameter at the center of raft, greater is the ultimate load carrying capacity of the foundation system.

Hence, it can be concluded that it is ideal to provide a combination of different diameter piles rather than equal diameter piles throughout where different pile diameters lead for better function of foundation.

Effect of Pile Length

Here, the influence of pile length on the behavior of piled raft foundation is analyzed. The number of piles (16 in no.), pile diameter (all are of 0.4 m), thickness of raft (0.6 m), spacing of piles (3 d) are kept constant. The material properties are given in Table 1.

From the analysis, the ultimate load capacity and corresponding settlement is obtained for all the combinations are given in Table 4.

From Table 4, as pile length increases uniformly, the ultimate load carrying capacity is decreasing, thereby the settlement decreases slightly. The reason may be is because of more interference with the increase in length, capacity is reducing. Here, the variation in pile length does not affect on the spacing of piles thereby causing pressure between piles. Thus, the pile length has less significance on the performance of the foundation.

Similarly, the ultimate load capacity and corresponding settlement is obtained for piles lengths in different combinations are given in Table 5.

From Table 5, for a equal pile length combination of 3 m as the inner pile length increases to 4 m, the ultimate load decreases slightly by 3% and settlement decreases by 7%. Similarly, for the equal pile length combination of

Table 4: Values of Ultimate Load and Settlement

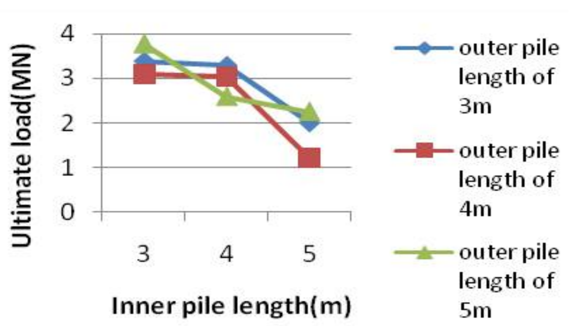
Pile Diameter(m)		Ultimate load	Settlement
Centre of the raft (Inner)	Edges of raft (Outer)	P (MN)	δ (mm)
3	3	3.388	24.59
4	4	3.037	20.99
5	5	2.251	15.12

Table 5: Values of Ultimate Load and Settlement

Pile Diameter(m)		Ultimate load	Settlement
Centre of the raft (Inner)	Edges of raft (Outer)	P (MN)	δ (mm)
4	3	3.29	22.84
5	3	2.00	12.86
3	4	3.099	22.306
3	5	3.78	27.65
5	4	1.22	7.34
4	5	2.59	17.93

4 m, as the inner pile length decreases to 3 m, the ultimate load increases by 2%, thereby settlement increases by 6%. Here, the pile length combination of 4 m along the center portion of the raft with 3 m along the edge of the raft shows credible results.

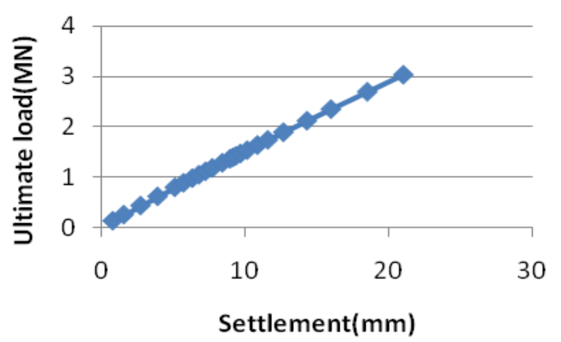
Figure 8: Variation of Ultimate Load with Inner and Outer Pile Lengths in Combinations



The variation of ultimate load for different pile length combinations is plotted as shown in Figure 8.

From the results obtained from ANSYS, a plot on ultimate load vs settlement is shown in Figure 9.

Figure 9: Ultimate Load Vs Settlement Plot for the Case of Uniform Pile Length of 4m



CONCLUSION

From the above studies, the following points can be concluded as follows.

- As the pile diameter increases, the ultimate load increases significantly.
- From the results obtained, it is useful to provide piles with different diameter than with equal diameter.
- A pile diameter combination of 0.5 m along the central portion of the raft with 0.3 m along the edge of the raft is best suggested based on its ultimate load and settlement results. From this it is clear that, providing larger inner pile diameter with smaller outer pile diameter leads to good results.
- Pile length has not much significance on the ultimate load carrying capacity of the foundation.

Hence, the piled raft foundation has a better scope for both research and applications in the field. This paper will give an idea for designers and practitioners about benefits of using different diameters under raft.

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