Study of Piled Raft Foundation on Layered Soil

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Abstract. Piled-raft foundations are a combination of a shallow foundation (raft) and a deep foundation (pile group). In this type of foundations, the role of the raft is to provide the required bearing capacity and the piles are used mainly as settlement reducers but can also contribute to the bearing capacity. In this paper a numerical model was developed using the software PLAXIS 3D to analyze piled-raft foundations on layered soil. Layered soil i.e. clay layer underlain by silty sand and then dense sand at lower layer with water table at a constant depth was assumed for the study. Here a drained condition was assumed and total vertical displacement was calculated using plastic calculations. The piles and raft were modeled using a plate element. A non-uniform vertical loading in the form of concentrated column loads has been imposed on the piled raft. The effect of some important design parameters on the performance of piled-raft foundations such as pile length, pile diameter, pile spacing and raft thickness with varied number of piles on layered soil are studied. The effect of these parameters was studied in terms of their influence on the deformation of the piled raft foundation.

Keywords: Piled-raft, Settlement, Layered Soil, Finite element.

1 Introduction

A piled raft is a foundation consisting of three load bearing elements: piles, raft and subsoil, which acts as a composite construction According to its stiffness, the raft distributes the total load of the structures as contact pressure and over the piles in the ground. In this type of foundations, the role of the raft is to provide the required bearing capacity and the piles are used mainly as settlement reducers but can also contribute to the bearing capacity.

2 Parametric Study

In this study a 16 m x 16 m raft with massive circular piles of varied diameter were analysed using a software finite element package for soil and foundation. A plane strain finite element model was used to model the piled raft foundation. The piles and raft were assumed to be linearly elastic. The Mohr-Coulomb yield criterion was used to represent the soil type as elastic-perfectly plastic material. Layered soil with water table at a 4m depth ground level was assumed for the study. Here a drained condition was assumed and total vertical displacement was calculated using plastic calculations. The layered soil segment was discretized as 15 noded triangular elements. The piles and raft were modeled using a plate element. The side skin friction in piles was taken into account by applying R_{inter} i.e. interface reduction factor. Sub-soil thickness is considered up-to a depth of 30m from ground surface for all soil types. A non-uniform vertical loading has been imposed on the piled raft in the form of concentrated column loads.

The table below describes the type and properties of materials being used in the study.

Table 1. Properties of the materials being used in the study

Material	Bored Pile	Raft (Floor)
Material model	Linear elastic	Linear isotropic
Material type	Non-porous	Non-porous
Stiffness (E_{ref})	2.920E+07 kN/m^2	1.000E+07 kN/m^2
Poisson's ratio (υ)	0.30	0.20
Unit weight (Υ_{sat})	24 kN/m^3	24 kN/m^3
Permeability	0 m/day	0 m/day

The table below discusses the type and properties of soil that is used in the study.

Table 2. Properties of the soil being used in the study

Particulars	**Layer 1 (0-6)m depth**	**Layer 2 (6-15)m depth**	**Layer 3 (15-30)m depth**
Soil type	Silty Clay	Clayey Sand	Dense Sand
Material model	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
Angle of friction (ϕ_u)	8^0	28^0	37^0
Stiffness (E_{ref})	5000 kN/m^2	9600 kN/m^2	11250 kN/m^2
Cohesion (C_u)	20 kN/m^2	35 kN/m^2	0 kN/m^2
Poisson's ratio (υ)	0.45	0.4	0.3
Dilatancy angle (Ψ)	0^0	0^0	7^0
Saturated unit weight (Υ_{sat})	20.45 kN/m^3	18.85 kN/m^3	19.6 kN/m^3
Unsaturated unit weight (Υ_d)	17.25 kN/m^3	15.7 kN/m^3	15.7 kN/m^3
Drainage condition	Drained	Drained	Drained
Permeability(k_x=k_y=k_z)	0.000864 m/day	0.0864 m/day	0.864 m/day
Void Ratio (e_o)	0.85	0.75	0.55

The table below describes the properties of soil-pile interface and soil-raft interface.

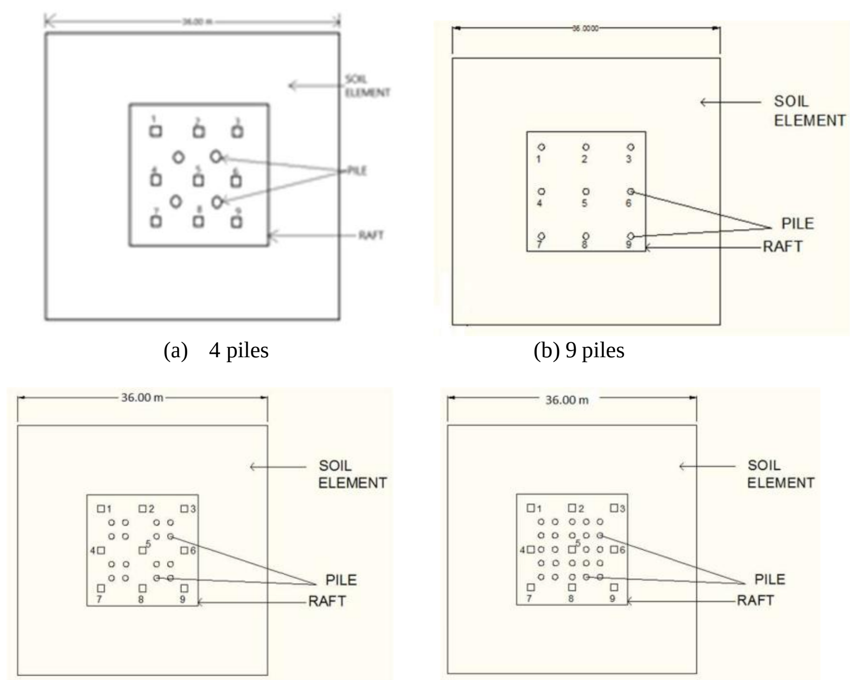
Table 3: Properties of the soil-pile and soil-raft interface

	Layer 1	**Layer 2**	**Layer 3**
Soil type	Silty Clay	Clayey Sand	Dense Sand
$\mathbf{R_{inter}}$	0.75	0.8	0.9

The table below describes the dimensions of the materials being used in the study.

Table 4: Dimensions of the materials being used in the study

Material	Pile	Raft
Diameter, D	300mm, 400mm, 500mm	-
Thickness, d	-	300mm, 350mm, 400mm
Length, L	10m, 12,m, 15m, 18m	-
Number, N	4, 9, 16, 24	-



(a) 4 piles (b) 9 piles

(c) 16 piles (d) 24 piles

Fig. 1. Position of Piles in Piled Raft Foundation

The images of different models of piled raft foundation with varied parameters along with their generated mesh are shown below. Total 153 nos. of models have been created to check the effect of raft and piled raft on settlement criteria.

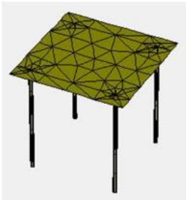


Fig. 2 (a). Model of Piled Raft with 4 piles

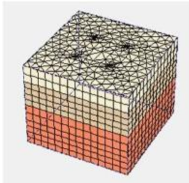


Fig. 2(b). Generated 3D Mesh

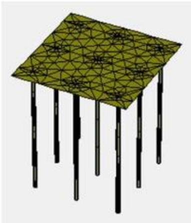


Fig. 3 (a). Model of Piled Raft with 9 piles

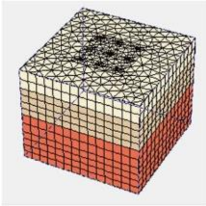


Fig. 3(b). Generated 3D Mesh

Fig. 4(a). Model of Piled Raft with 16 piles

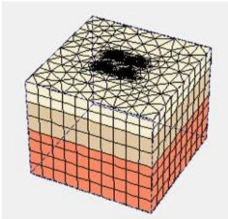


Fig. 4(b). Generated 3D Mesh

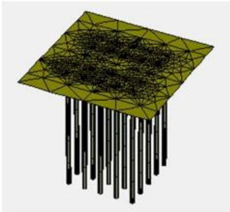


Fig. 5 (a). Model of Piled Raft with 24 piles

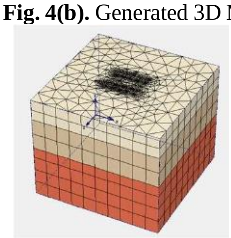


Fig. 5(b). Generated 3D Mesh

The total vertical load applied is 2470kN which is unequally distributed on nine equally spaced columns with 250kN vertical load each on 4 nos. of corner columns, 280kN on each 4 nos. of intermediate and 350kN on a single centre column. Figure 6 shows the variation of total settlement of the superstructure as well as foundation before introduction of pile (i.e. only raft) and after introduction of pile (i.e. piled raft) on layered soil

3 Results and Discussion

Here (i) A represents N_p=0 (ii) B represents N_p=4 & P_p=1,3,7,9, (iii) C represents N_p=9 & P_p=1,2,3,4,5,6,7,8,9 (iv) D represents N_p=16 & P_p= Type A1-Pile at one-third of bay (16 no. of piles) (v) E represents N_p=24 & P_p= Type B1- Pile at one-third of bay+ pile at column centre line (24 no. of piles)

Figures below shows the variation of total settlement of piled raft foundation after loading with increase in the number of piles at varied thickness of raft.

[Here Dp= Diameter of pile, Lp= Length of pile, Tr=Thickness of raft]

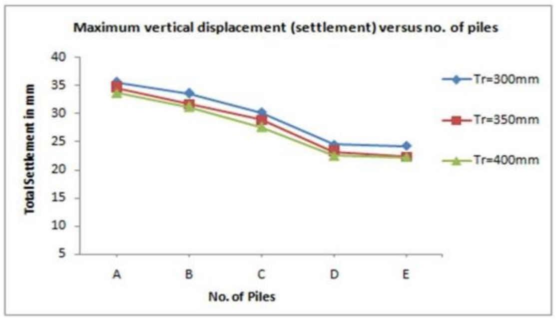


Fig. 6. Variation of Total Settlement with No. of Piles (Dp= 300mm, L p= 10m)

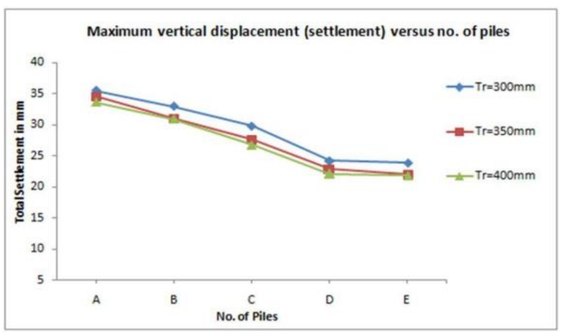


Fig. 7. Variation of Total Settlement with No. of Piles (Dp= 300mm, L p= 12m)

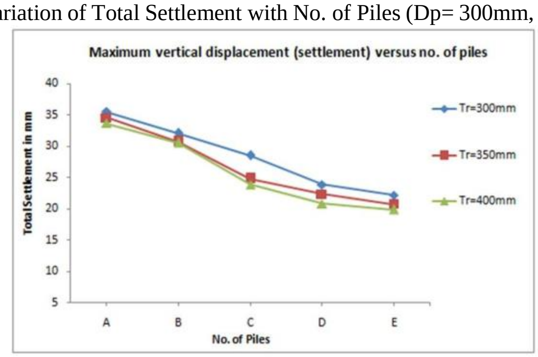


Fig. 8. Variation of Total Settlement with No. of Piles (Dp= 300mm, L p= 15m)

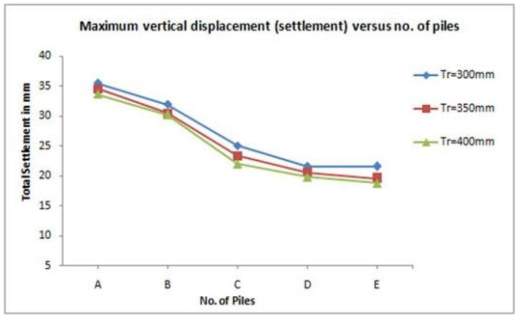


Fig. 9. Variation of Total Settlement with No. of Piles (Dp= 300mm, L p= 18m)

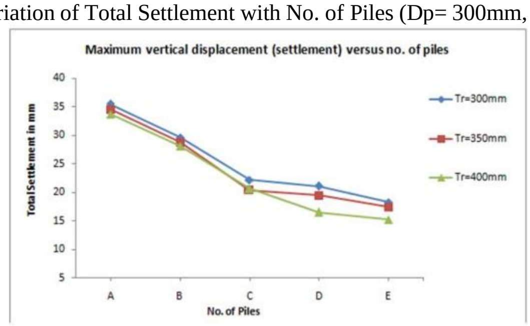


Fig. 10. Variation of Total Settlement with No. of Piles (Dp= 400mm, L p= 10m)

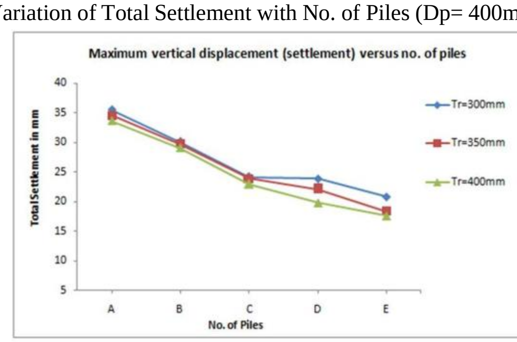


Fig. 11. Variation of Total Settlement with No. of Piles (Dp= 400mm, L p= 12m)

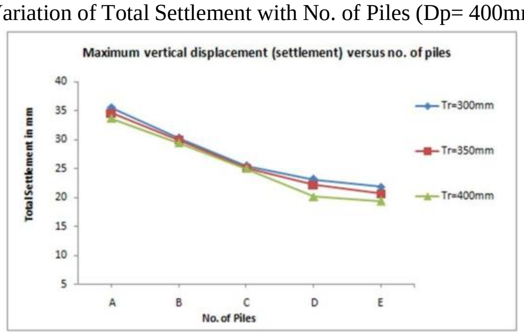


Fig. 12. Variation of Total Settlement with No. of Piles (Dp= 400mm, L p= 15m)

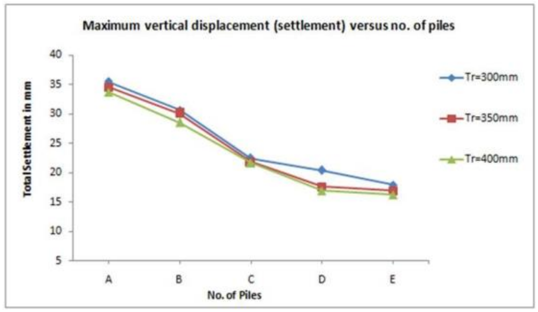


Fig. 13. Variation of Total Settlement with No. of Piles(Dp= 400mm, L p= 18m)

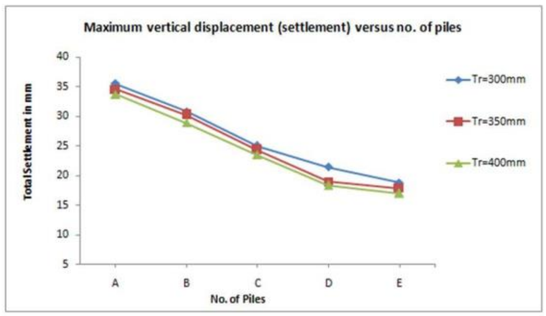


Fig. 14. Variation of Total Settlement with No. of Piles (Dp= 500mm, L p= 10m)

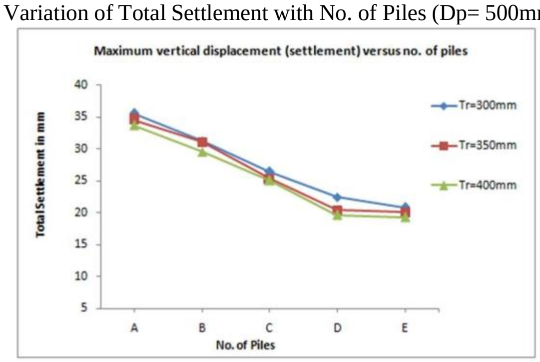


Fig. 15. Variation of Total Settlement with No. of Piles (Dp= 500mm, L p= 12m)

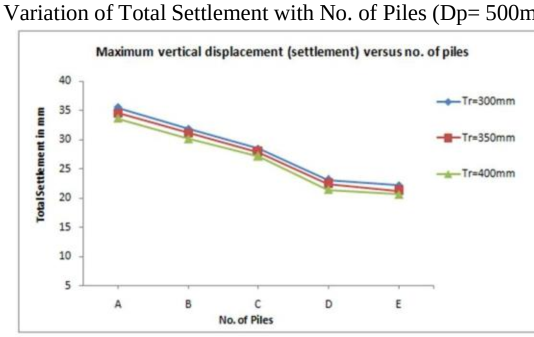


Fig. 16. Variation of Total Settlement with No. of Piles (Dp= 500mm, L p= 15m)

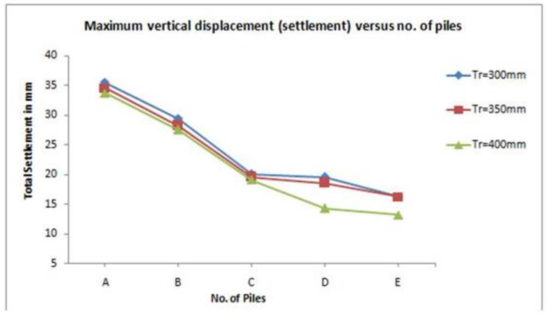


Fig. 17. Variation of Total Settlement with No. of Piles (Dp= 500mm, L p= 18m)

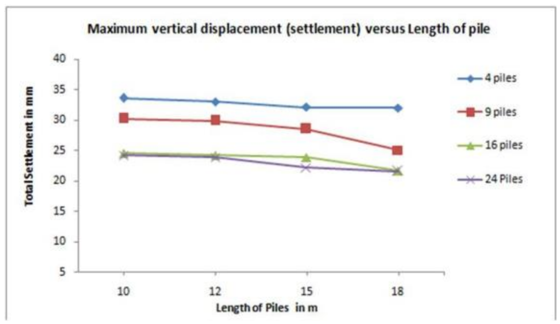


Fig. 18. Variation of Total Settlement with Length of Piles (Dp= 300mm, Tr= 300mm)

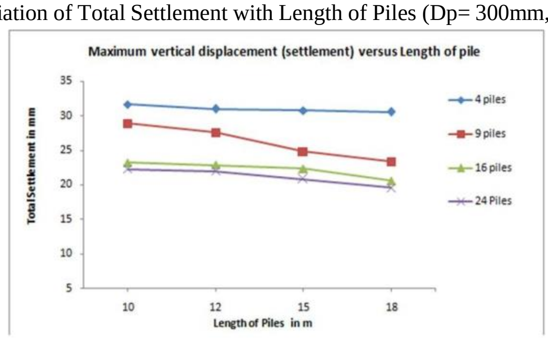


Fig. 19. Variation of Total Settlement with Length of Piles (Dp= 300mm, Tr= 350mm)

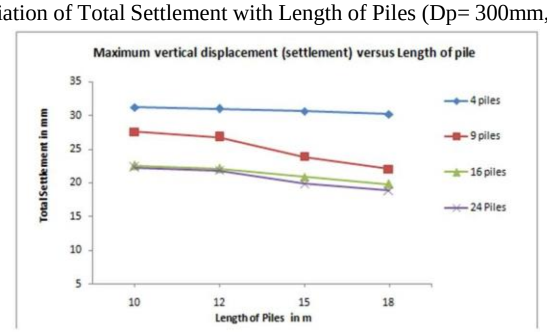


Fig. 20. Variation of Total Settlement with Length of Piles (Dp= 300mm, Tr= 400mm)

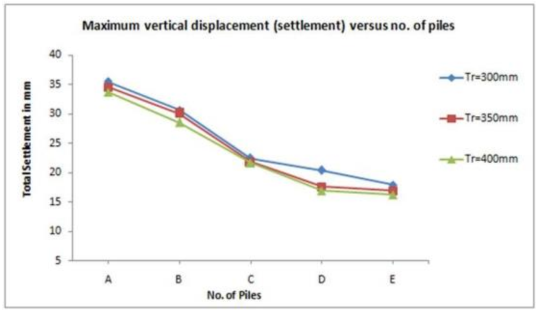


Fig. 21. Variation of Total Settlement with Length of Piles (Dp= 400mm, Tr= 300mm)

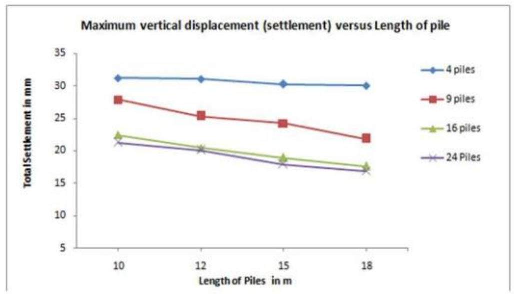


Fig. 22. Variation of Total Settlement with Length of Piles (Dp= 400mm, Tr= 350mm)

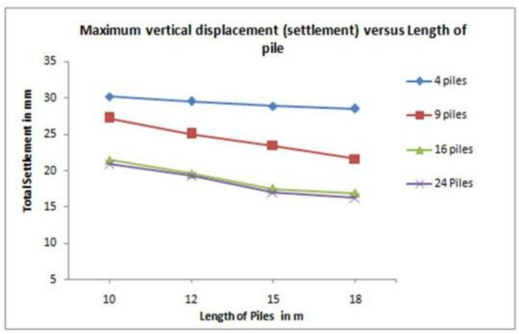


Fig. 23. Variation of Total Settlement with Length of Piles (Dp= 400mm, Tr= 400mm)

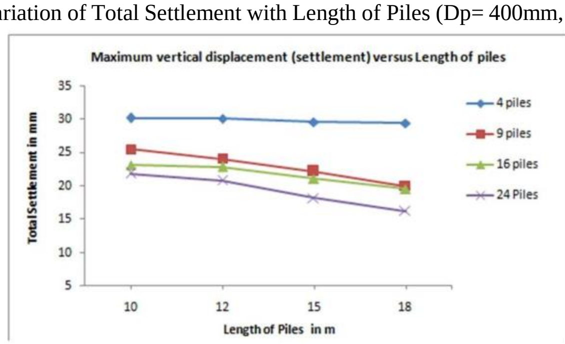


Fig. 24. Variation of Total Settlement with Length of Piles (Dp= 500mm, Tr= 300mm)

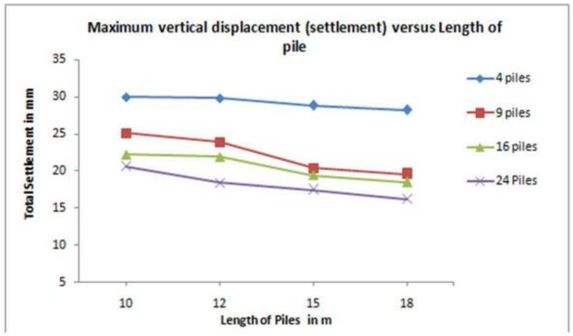


Fig. 25. Variation of Total Settlement with Length of Piles (Dp= 500mm, Tr= 350mm)

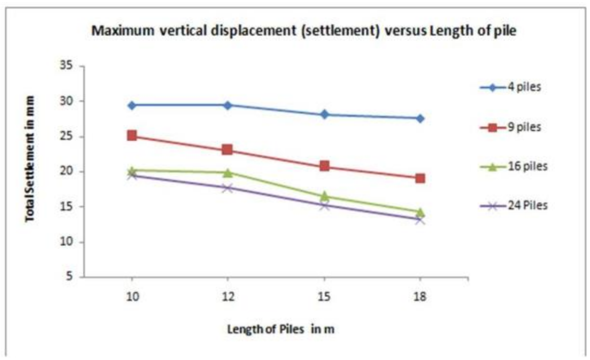


Fig. 26. Variation of Total Settlement with Length of Piles (Dp= 500mm, Tr= 400mm)

At pile diameter 300mm, with increase in raft thickness from 300 to 400mm and subsequently increase in pile length from 10m to 18m alongwith increase in the number of piles from 4(four) to 24(Twenty four) shows a decrease in the settlement up to 33.96% for pile length of 10m, 35.11% for pile length of 12m, 40.93% for pile length of 15m and 44.08% for pile length of 18m respectively in comparison to unpiled raft. (Figure 6-9)

At pile diameter 400mm, with increase in raft thickness from 300 to 400mm and subsequently increase in pile length from 10m to 18m alongwith increase in the number of piles from 4(four) to 24(Twenty four) shows a decrease in the settlement up to 38.62% for pile length of 10m, 42.68% for pile length of 12m, 49.60% for pile length of 15m and 51.83% for pile length of 18m respectively in comparison to unpiled raft. (Figure 10-13)

At pile diameter 500mm, with increase in raft thickness from 300 to 400mm and subsequently increase in pile length from 10m to 18m alongwith increase in the number of piles from 4(four) to 24(Twenty four) shows a decrease in the settlement up to 42.33% for pile length of 10m, 47.55% for pile length of 12m, 54.82% for pile length of 15m and 60.82% for pile length of 18m respectively in comparison to unpiled raft. (Figure 14-17)

At pile diameter of 300mm, raft thickness of 400mm and pile length 18m, increase in the number of piles shows a decrease in the total settlement upto 10.24% for 4 nos. of piles, 34.57% for 9 nos. of piles, 41.22% for 16 nos. of piles and 44.07% for 24 nos. of piles respectively in comparison to unpiled raft. (Figure 18-20)
At pile diameter of 400mm, raft thickness of 400mm and pile length 18m, increase in the number of piles shows a decrease in the total settlement upto 15.25% for 4 nos. of piles, 35.7% for 9 nos. of piles, 49.68% for 16 nos. of piles and 51.82% for 24 nos. of piles respectively in comparison to unpiled raft. (Figure 21-23)
At pile diameter of 500mm, raft thickness of 400mm and pile length 18m, increase in the number of piles shows a decrease in the total settlement upto 18.22% for 4 nos. of piles, 43.39% for 9 nos. of piles, 57.55% for 16 nos. of piles and 60.82% for 24 nos. of piles respectively in comparison to unpiled raft. (Figure 24-26)

4 Conclusion

a) As the pile length increases in piled raft foundation, the settlement decreases. Introduction of 9(nine) nos. of piles to raft in layered soil with varied soil properties can reduce the total settlement upto 43.39% in case of vertical loading. Introduction of 16(sixteen) nos. of piles to raft in layered soil with varied soil properties can reduce the total settlement upto 57.55% in case of vertical loading.
b) Introduction of 24(twenty four) nos. of piles to raft in layered soil with varied soil properties can reduce the total settlement upto 60.82% in case of vertical loading.
c) Increase in the number of piles up to 16 nos. in piled raft foundation has considerable effect in reducing settlement in layered soil. However, further increase in nos. of piles up to 24 nos. does not contribute much for further reduction of settlement of piled raft foundation (Figure 6-17), which justifies the statement made by Poulos. [5]
d) The thickness of raft has nominal effect on the settlement of piled raft foundation. As the thickness of raft increases, the settlement of the piled raft foundation decreases. However, the decrement is very nominal due to the increase in self weight. So,it can be concluded that increasing the thickness of raft does not contribute much to the reduction of settlement.
e) In case of pile groups, position of piles has much effect to the reduction of settlement of piled raft foundation. Introduction of piles below column at a considerable distance from column centre shows good results than piles positioned just below the column.
f) Angle of internal friction of soil plays an important role in the settlement of piled raft foundation. As the angle of internal friction of soil increases in lower layers of soil, the settlement of piled raft foundation decreases drastically in case

of long piles reaching the lower layers. Piled raft foundation can be said to be much effective if angle of internal friction of soil is more than 35^0.

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