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Study of Piled Raft Foundation on Layered Soil of Guwahati

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Abstract - *Piled-raft foundations, known also as piled rafts, are a combination of a shallow foundation (raft) and a deep foundation (pile group). Study of the influence of different parameters of piled raft foundation is the objective of this research work. To analyze piled-raft foundations on layered soil., a numerical model has been developed using the software PLAXIS 3D. Parametric study of piled raft foundation has been carried out at geological province of Alluvium (Phanerozoics) of India such as Guwahati (Assam, India). As the pile length increases in individual piled raft foundation in layered soil of Guwahati, the settlement decreases. Introduction of 4 nos. of piles, 9 nos. of piles to raft placed directly below the column position, 16 nos. of piles to raft placed at one-third of bay in between the column positions and 24 nos. of piles to raft placed at column center line in addition to one third of bay can reduce the total settlement in layered soil of Guwahati. Increasing the number of piles up to 16 numbers in piled raft foundation has considerable effect in reducing settlement in layered soil. However, increasing the number of piles to 24 does not significantly reduce the settlement of the piled raft foundation. The thickness of raft has nominal effect on the settlement of piled raft foundation. In case of pile groups, position of piles has much effect to the reduction of settlement of piled raft foundation.*

Key Words: Foundation, piled-raft, settlement, layered soil,

1.INTRODUCTION

A piled raft is a foundation that is made up of three load-bearing components: piles, raft, and subsoil. Piled-raft foundations, known also as piled rafts, 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. Generally, the raft by itself can provide the necessary bearing capacity but it cannot regulate the settlement. As a result, the piles are essential to reduce the raft settlement. Pile-raft foundations are considered extremely complex systems since they combine piles and rafts into a single structure.

2.LITERATURE REVIEW

The method by Poulos and Davis is a convenient method of hand calculations that can be used as preliminary design tool. Poulos modeled piled raft foundation as a spring-loaded strip where the strip represents the raft in one direction and the springs represent the piles. Anbazhagan P. et. al. in 2014 while development of any earthquake resistant design, presented the soil classification for different geological provinces of India as per National Disaster Management Authority.

3.PARAMETRIC STUDY

Using a software finite element package for soil and foundation analysis, a 16 m x 16 m raft with massive circular piles of varied diameters was analyzed. To model the piled raft foundation a plane strain finite element model was used. It was assumed that piles and rafts were linearly elastic. The Mohr-Coulomb yield criterion was used to represent the soil type as elastic-perfectly plastic material. Here total vertical displacement was calculated using plastic calculations and a drained condition was assumed. A 15-noded triangular soil element was discretized. Plate elements were used to model the piles and raft. The side skin friction in piles was taken into account by applying interface reduction factor R_{inter}. The piled raft is subjected to a non-uniform vertical loading in the form of concentrated column loads.

Generally, India can be naturally divided into three geological provinces, namely, the Himalayas, the Indo-Gangetic Plain and the Indian Shield. India's geology may be split into 20 provinces, and the Geological Survey of India (GSI) publishes comprehensive geological publications complete with maps. In India, sixteen major types of soils have been recognized. Parametric study of piled raft foundation has been carried out at geological province of Alluvium (Phanerozoics) of India such as Guwahati (Assam). Altogether, 147 nos. of models have been developed to carry out the parametric study.

The properties of different layers soil being used in the study are tabulated in Table 1.

Table -1: Properties of the soil being used in the study

Particulars	Layer 1 (0-2) m depth	Layer 2 (2-4) m depth	Layer 3 (4-4.8) m depth
Soil type	Silty Clay	Sandy Clay	Silty Clay
Material model	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
Angle of friction (ϕ_u)	8^0	10^0	8^0
Stiffness (E_{ref})	4750 kN/m^2	7500 kN/m^2	6250 kN/m^2
Cohesion (C_u)	24 kN/m^2	96 kN/m^2	20 kN/m^2
Poisson's ratio (υ)	0.45	0.3	0.4
Dilatancy angle (Ψ)	0^0	0^0	0^0
Saturated unit weight (Υ_{sat})	20.45 kN/m^3	20 kN/m^3	20.4 kN/m^3
Unsaturated unit weight (Υ_d)	17.25 kN/m^3	17.5 kN/m^3	18.5 kN/m^3
Drainage condition	Drained	Drained	Drained
Permeability $(k_x=k_y=k_z)$	0.000864 m/day	0.00864 m/day	0.000864 m/day
Void Ratio (e_o)	0.75	0.8	0.76
R_{inter}	0.75	0.79	0.77

Particulars	Layer 4 (4.8-16.5) m depth	Layer 5 (16.5-17.8) m depth	Layer 6 (17.8-30.0) m depth
Soil type	Sandy Clay	Silty Clay	Sandy Clay
Material model	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
Angle of friction (ϕ_u)	8^0	10^0	8^0
Stiffness (E_{ref})	4750 kN/m^2	7500 kN/m^2	6250 kN/m^2
Cohesion (C_u)	24 kN/m^2	96 kN/m^2	20 kN/m^2
Poisson's ratio (υ)	0.45	0.3	0.4
Dilatancy angle (Ψ)	0^0	0^0	0^0
Saturated unit weight (Υ_{sat})	20.45 kN/m^3	20 kN/m^3	20.4 kN/m^3
Unsaturated unit weight (Υ_d)	17.25 kN/m^3	17.5 kN/m^3	18.5 kN/m^3
Drainage condition	Drained	Drained	Drained
Permeability $(k_x=k_y=k_z)$	0.000864 m/day	0.00864 m/day	0.000864 m/day
Void Ratio (e_o)	0.75	0.8	0.76
R_{inter}	0.75	0.79	0.77

Figures 1 to 5 below shows the position of piles in the models of piled raft foundation

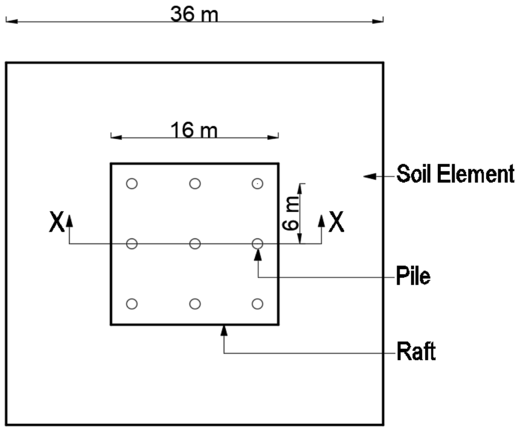

Fig -1: Position of Piles in Piled Raft Foundation-Type A-Raft only (No pile)

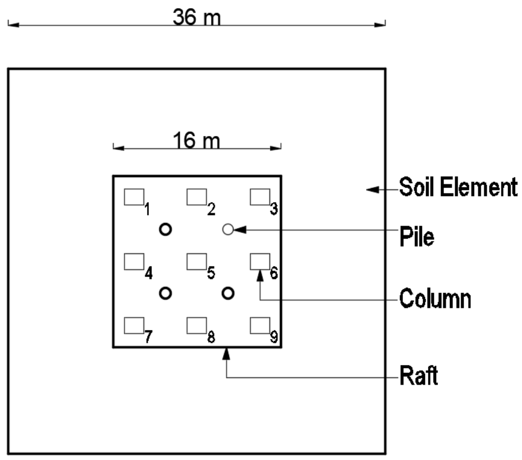

Fig -2: Position of Piles in Piled Raft Foundation-Type B-Pile at half of bay (4 nos. of piles)

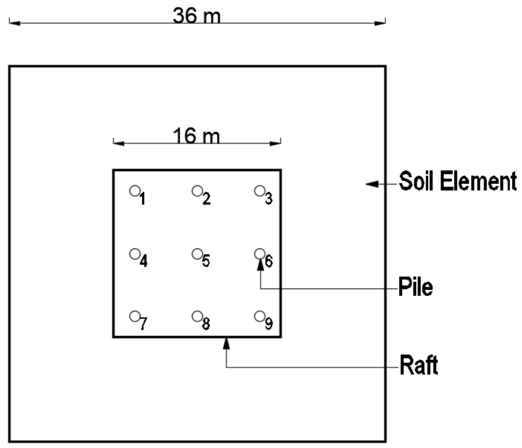

Fig -3: Position of Piles in Piled Raft Foundation-Type C-Pile directly below the column (9 nos. of piles)

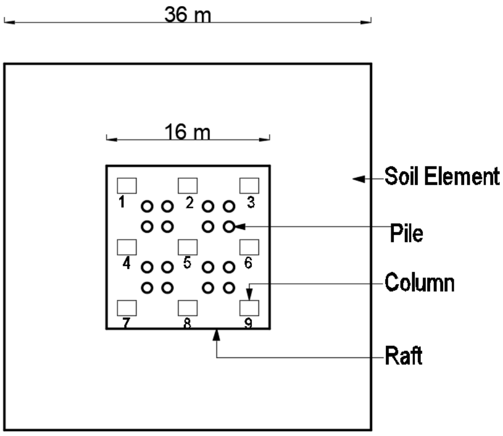

Fig -4: Position of Piles in Piled Raft Foundation-Type D-Pile at one-third of bay (16 nos. of piles)

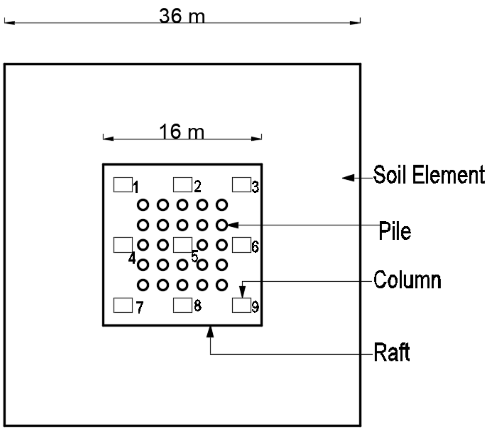

Fig -5: Position of Piles in Piled Raft Foundation-Type E-Pile at one-third of bay + pile at column center-line (24 Nos. of Piles)

The typical 3D model of Piled raft are shown in figure 6 to 10:

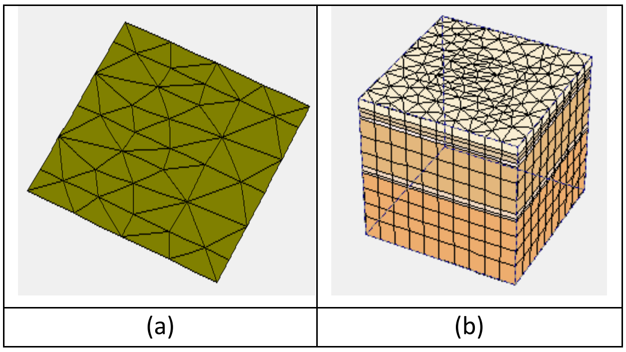

Fig -6: (a)Typical model of Raft only (without piles); (b) generated 3D mesh for Guwahati

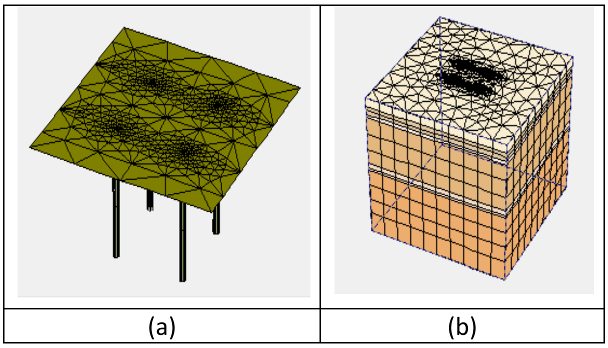

Fig -7: (a) Typical model of Piled Raft with 4 piles; (b) generated 3D mesh for Guwahati

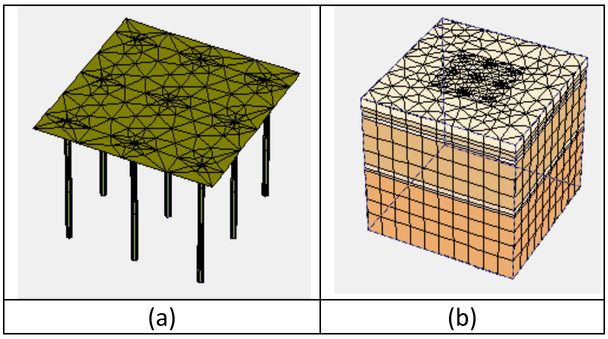

Fig -8: (a) Typical model of Piled Raft with 9 piles; (b) generated 3D mesh for Guwahati

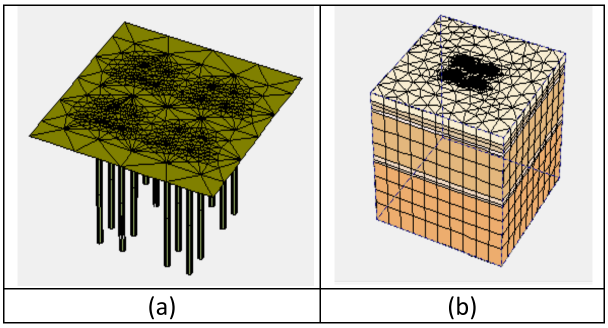

Fig -9: (a) Typical model of Piled Raft with 16 piles; (b) generated 3D mesh for Guwahati

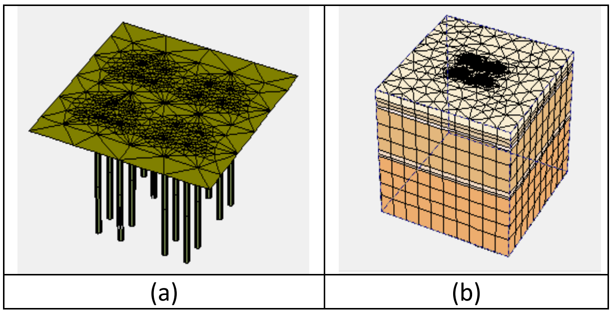

Fig -10: (a) Typical model of Piled Raft with 24 piles; (b) generated 3D mesh for Guwahati

4.RESULTS AND DISCUSSION

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 center column. This distribution of vertical load is based on the general pattern of load distribution in different columns of a building.

Here (i) A represents N_p=0 (ii) B represents N_p=4 & P_p= Pile at half of bay (iii) C represents N_p=9 & P_p= Pile directly below the column (iv) D represents N_p=16 & P_p= Pile at one-third of bay (16 no. of piles) (v) E represents N_p=24 & P_p= Pile at one-third of bay + pile at column center-line (24 no. of piles)

Chart -1 shows the variation of total settlement of piled raft foundation after loading at varied number of piles at pile diameter of 300 mm, pile length of 10m for varied raft thickness of from 300 to 400 mm.

The maximum settlement of the piled raft foundation decreases as the number of piles increases. For raft thickness of 300mm, introduction of 4-piles, shows a decrease in total settlement up-to 4.23 %. Increasing the pile number to 9 (nine), total settlement decrease up-to 12.60 % with respect to 4 (four) number of piles. Further increasing the pile number to 16 (sixteen), shows as decrease in total settlement up-to 17.48 % with respect to 9 (nine) number of piles. Again, increasing the pile number to 24 (twenty-four), there is a decrease in total settlement up-to 6.34 % with respect to 16 (sixteen) number of piles. Also, the total settlement reduces upto 35.30 % with introduction of 24 (twenty-four) numbers in comparison to unpiled raft of 300mm thickness.

For raft thickness of 350mm, introduction of 4-piles, shows a decrease in total settlement up-to 6.00 %. Increasing the pile number to 9 (nine), total settlement decrease up-to 9.00 % with respect to 4 (four) number of piles. Further increasing the pile number to 16 (sixteen), shows as decrease in total settlement up-to 20.36 % with respect to 9 (nine) number of piles. Again, increasing the pile number to 24 (twenty-four), there is a decrease in total settlement up-to 6.20 % with respect to 16 (sixteen) number of piles. Also, the total settlement reduces upto 36.14 % with introduction of 24 (twenty-four) numbers in comparison to unpiled raft of 350mm thickness.

For raft thickness of 400mm, introduction of 4-piles, shows a decrease in total settlement up-to 6.81 %. Increasing the pile number to 9 (nine), total settlement decrease up-to 11.64 % with respect to 4 (four) number of piles. Further increasing the pile number to 16 (sixteen), shows as decrease in total settlement up-to 19.67 % with respect to 9 (nine) number of piles. Again, increasing the pile number to 24 (twenty-four), there is a decrease in total settlement up-to 6.27 % with respect to 16 (sixteen) number of piles. Also, the total settlement reduces upto 38.01 % with introduction of 24 (twenty-four) numbers in comparison to unpiled raft of 400mm thickness.

After increasing the raft thickness from 300 to 400 mm at a pile diameter of 300 mm, the pile length increased from 10 to 18 m, along with increase in the number of piles from 4 (four) to 24 (Twenty-four) shows a decrease in the settlement up to 29.36 % for pile length of 10 m, 30.22 % for pile length of 12 m, 34.41 % for pile length of 15 m and 36.84 % for pile length of 18 m respectively in comparison to un-piled raft. (Chart -1, Chart -2, Chart -3 & Chart -4)

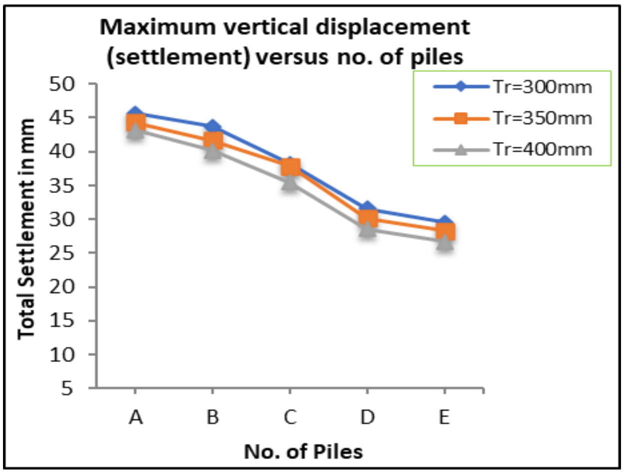

Chart -1: Variation of Total Settlement for Pile Dia. = 300 mm and Pile length = 10 m

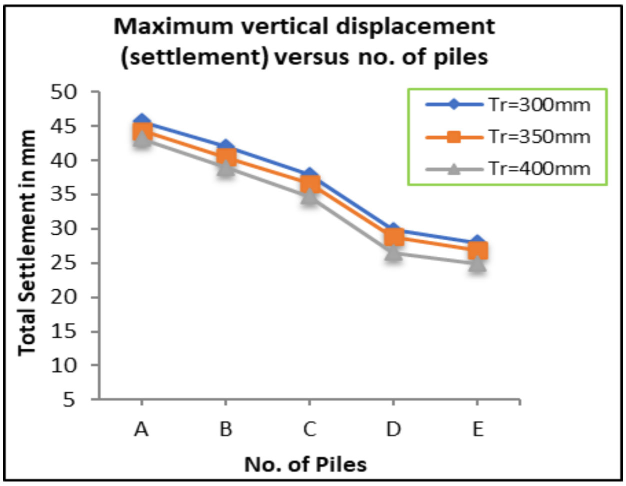

Chart -2: Variation of Total Settlement for Pile Dia. = 300 mm and Pile length = 12 m

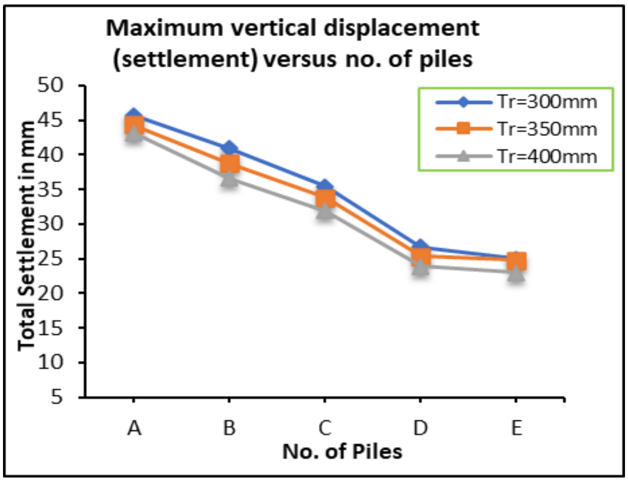

Chart -3: Variation of Total Settlement for Pile Dia. = 300 mm and Pile length = 15 m

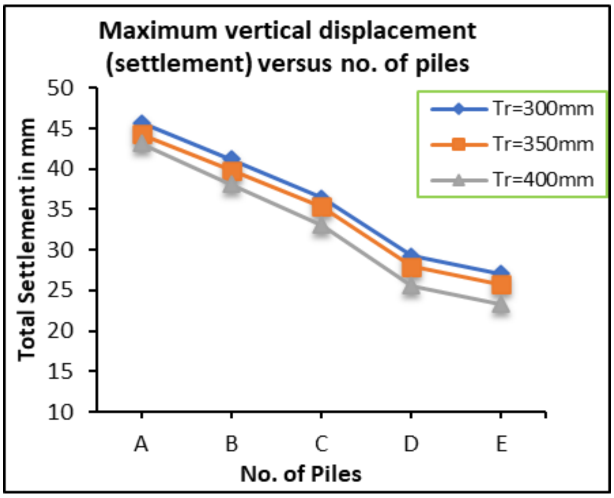

Chart -4: Variation of Total Settlement for Pile Dia. = 300 mm and Pile length = 18 m

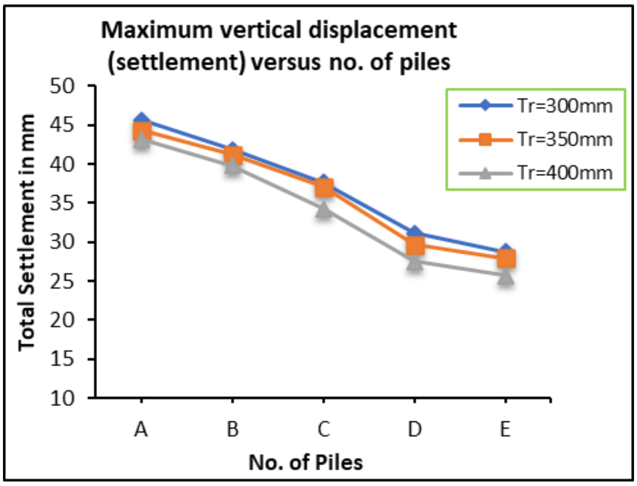

Chart -5: Variation of Total Settlement for Pile Dia. = 400 mm and Pile length = 10 m

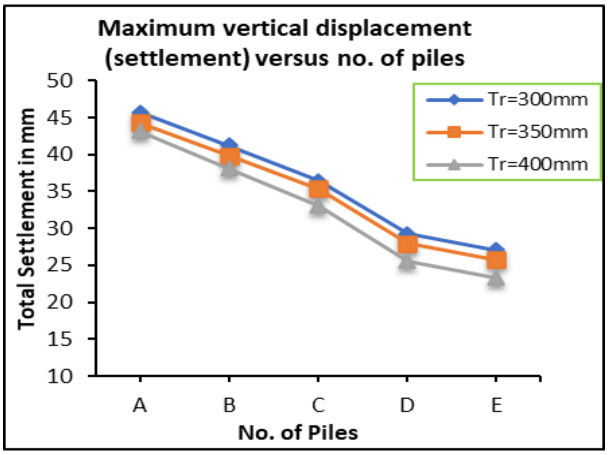

Chart -6: Variation of Total Settlement for Pile Dia. = 400 mm and Pile length = 12 m

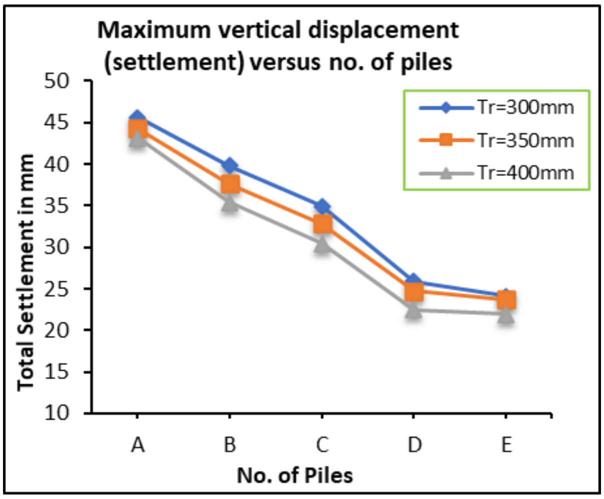

Chart -7: Variation of Total Settlement for Pile Dia. = 400 mm and Pile length = 15 m

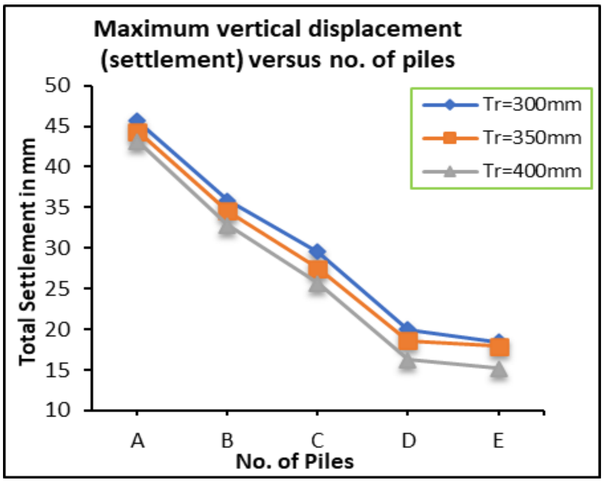

Chart -8: Variation of Total Settlement for Pile Dia. = 400 mm and Pile length = 18 m

At pile diameter 400 mm, with increase in raft thickness from 300 to 400 mm and subsequently increase in pile length from 10 m to 18 m along with increase in the number of piles from 4 (four) to 24 (Twenty-four) shows a decrease in the settlement up to 32.81 % for pile length of 10 m, 35.79 % for pile length of 12 m, 40.93 % for pile length of 15 m and 42.58 % for pile length of 18 m respectively in comparison to un-piled raft. (Chart -5, Chart -6, Chart -7, Chart -8)

At pile diameter 500 mm, with increase in raft thickness from 300 to 400 mm and subsequently increase in pile length from 10 m to 18 m along with increase in the number of piles from 4 (four) to 24 (Twenty-four) shows a decrease in the settlement up to 35.52 % for pile length of 10 m, 37.21 % for pile length of 12 m, 44.74 % for pile length of 15 m and 49.17 % for pile length of 18 m respectively in comparison to un-piled raft. (Chart -9, Chart -10, Chart -11, Chart -12)

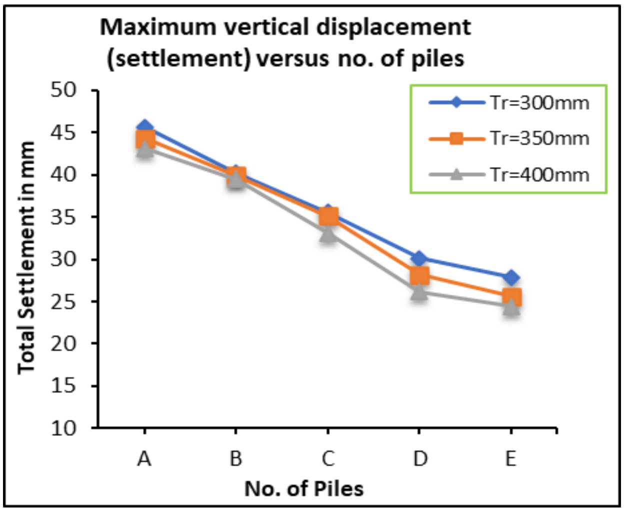

Chart -9: Variation of Total Settlement for Pile Dia. = 500 mm and Pile length = 10 m

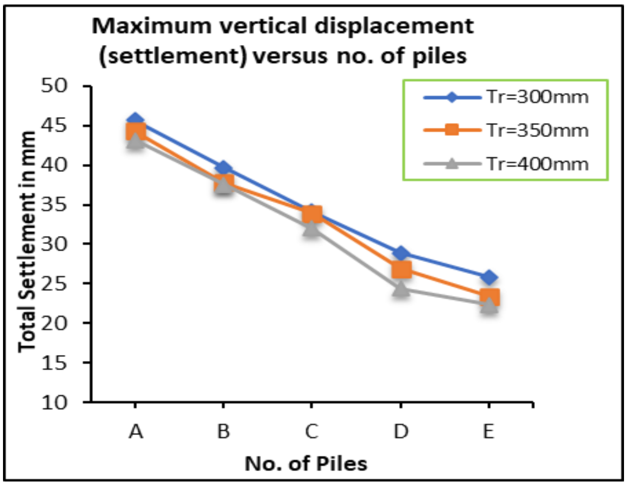

Chart -10: Variation of Total Settlement for Pile Dia. = 500 mm and Pile length = 12 m

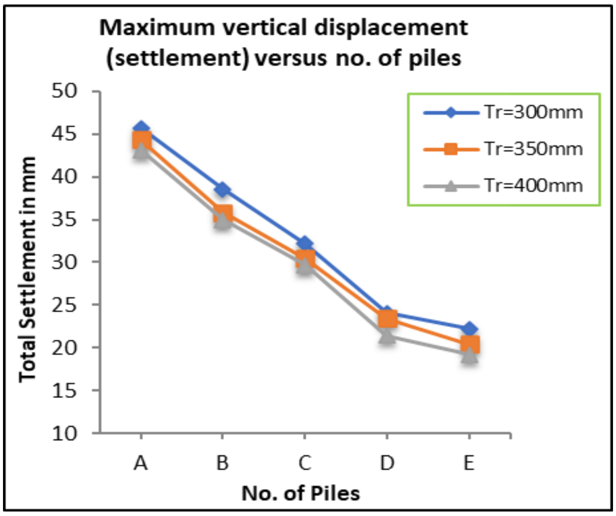

Chart -11: Variation of Total Settlement for Pile Dia. = 500 mm and Pile length = 15 m

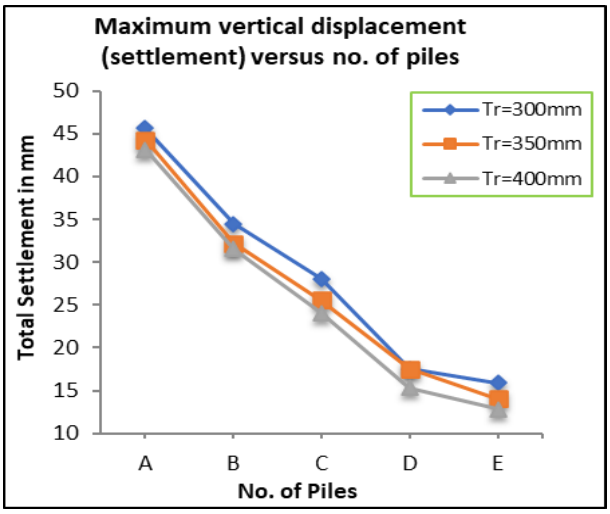

Chart -12: Variation of Total Settlement for Pile Dia. = 500 mm and Pile length = 18 m

Figures below shows the variation of total settlement of piled raft foundation after loading with increase in the length of piles from 10m to 18m at varied number of piles from 4 to 24 numbers at a particular diameter of pile and thickness of raft. From chart-13, 14 & 15, it is significant that as the length of pile increases, total settlement decrease.

At pile diameter of 300 mm, raft thickness of 300 mm with increase of pile length from 10m to 18 m, increase in the number of piles shows a decrease in the total settlement upto 9.24 % for 4 nos. of piles, 17.08 % for 9 nos. of piles, 32.06 % for 16 nos. of piles and 32.52 % for 24 nos. of piles respectively in comparison to unpiled raft. (Chart -13)

At pile diameter of 300 mm, raft thickness of 350 mm with increase of pile length from 10m to 18 m, increase in the number of piles shows a decrease in the total settlement upto 11.19 % for 4 nos. of piles, 26.81 % for 9 nos. of piles, 32.89 % for 16 nos. of piles and 35.15 % for 24 nos. of piles respectively in comparison to unpiled raft. (Chart -14)

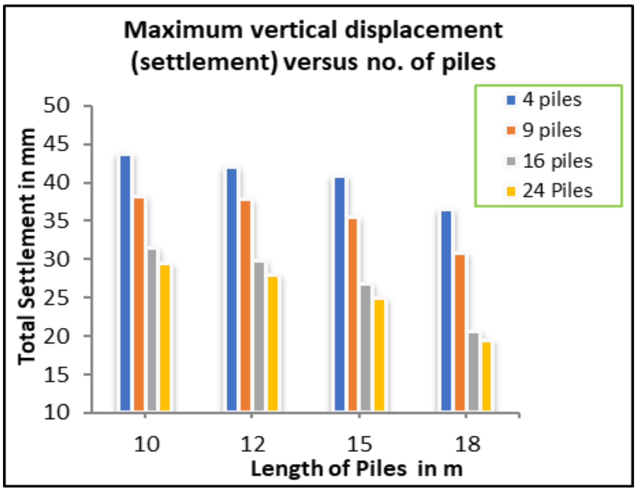

Chart -13: Variation of Total Settlement for Pile Dia. = 300 mm and Raft thickness = 300 mm

At pile diameter of 300 mm, raft thickness of 400 mm with increase of pile length from 10m to 18 m, increase in the number of piles shows a decrease in the total settlement upto 11.87 % for 4 nos. of piles, 29.89 % for 9 nos. of piles, 34.75 % for 16 nos. of piles and 36.84 % for 24 nos. of piles respectively in comparison to unpiled raft. (Chart -15)

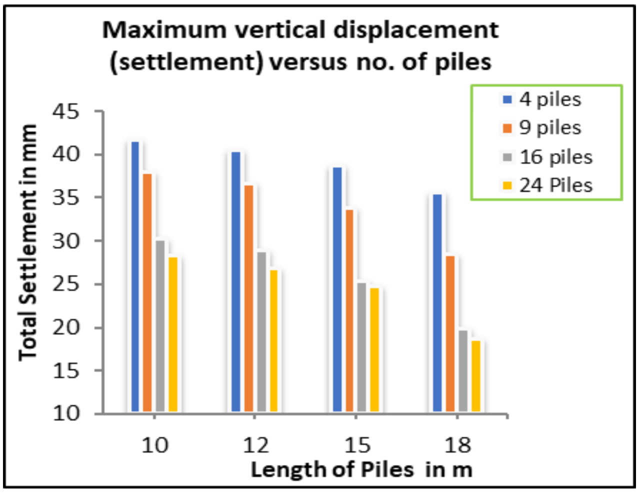

Chart -14: Variation of Total Settlement for Pile Dia. = 300 mm and Raft thickness = 350 mm

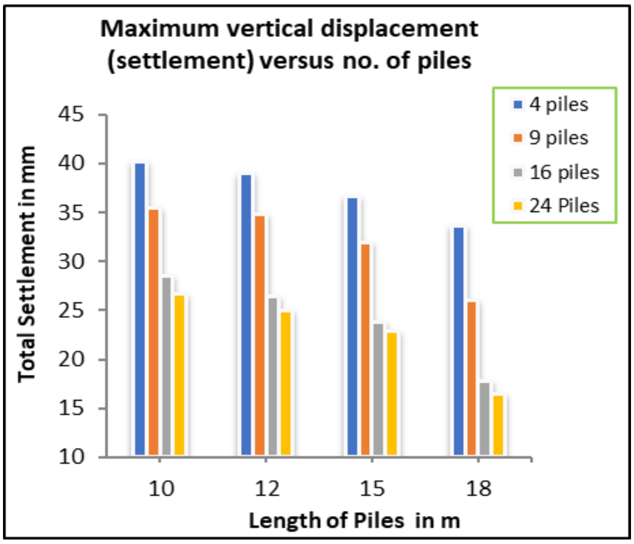

Chart -15: Variation of Total Settlement for Pile Dia. = 300 mm and Raft thickness = 400 mm

At pile diameter of 400 mm, raft thickness of 300 mm with increase of pile length from 10m to 18 m, increase in the number of piles shows a decrease in the total settlement upto 10.97 % for 4 nos. of piles, 28.97 % for 9 nos. of piles, 33.38 % for 16 nos. of piles and 38.81 % for 24 nos. of piles respectively in comparison to unpiled raft. (Chart -16)

At pile diameter of 400 mm, raft thickness of 350 mm with increase of pile length from 10m to 18 m, increase in the number of piles shows a decrease in the total settlement upto 12.19 % for 4 nos. of piles, 30.33 % for 9 nos. of piles, 39.55 % for 16 nos. of piles and 41.02 % for 24 nos. of piles respectively in comparison to unpiled raft. (Chart -17)

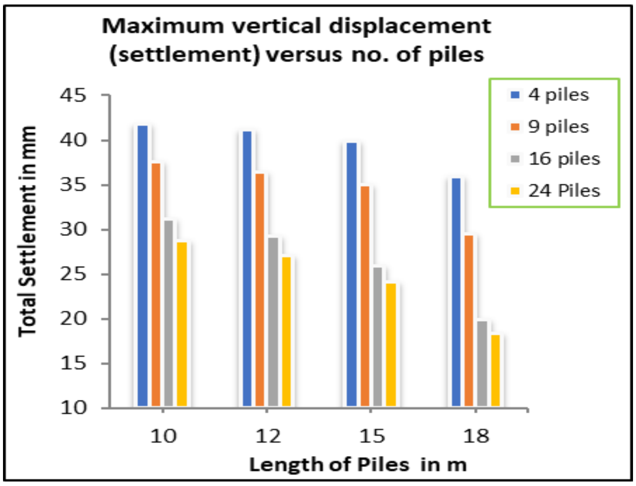

Chart -16: Variation of Total Settlement for Pile Dia. = 400 mm and Raft thickness = 300 mm

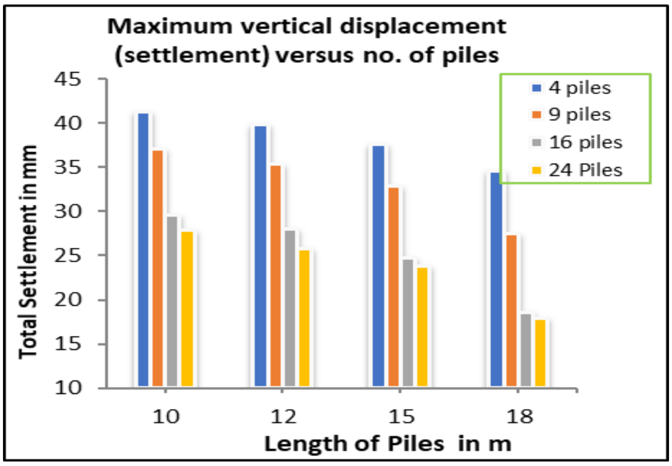

Chart -17: Variation of Total Settlement for Pile Dia. = 400 mm and Raft thickness = 350 mm

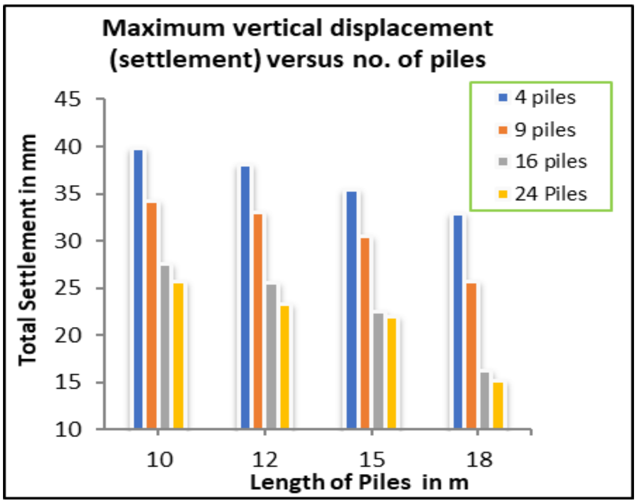

Chart -18: Variation of Total Settlement for Pile Dia. = 400 mm and Raft thickness = 400 mm

At pile diameter of 400 mm, raft thickness of 400 mm with increase of pile length from 10m to 18 m, increase in the number of piles shows a decrease in the total settlement upto 15.55 % for 4 nos. of piles, 30.66 % for 9 nos. of piles, 40.99 % for 16 nos. of piles and 42.57 % for 24 nos. of piles respectively in comparison to unpiled raft. (Chart -18)

At pile diameter of 500 mm, raft thickness of 300 mm with increase of pile length from 10m to 18 m, increase in the number of piles shows a decrease in the total settlement upto 13.53 % for 4 nos. of piles, 34.21 % for 9 nos. of piles, 35.26 % for 16 nos. of piles and 42.51 % for 24 nos. of piles respectively in comparison to unpiled raft. (Chart -19)

At pile diameter of 500 mm, raft thickness of 350 mm with increase of pile length from 10m to 18 m, increase in the number of piles shows a decrease in the total settlement upto 16.32 % for 4 nos. of piles, 35.26 % for 9 nos. of piles, 37.56 % for 16 nos. of piles and 42.55 % for 24 nos. of piles respectively in comparison to unpiled raft. (Chart -20)

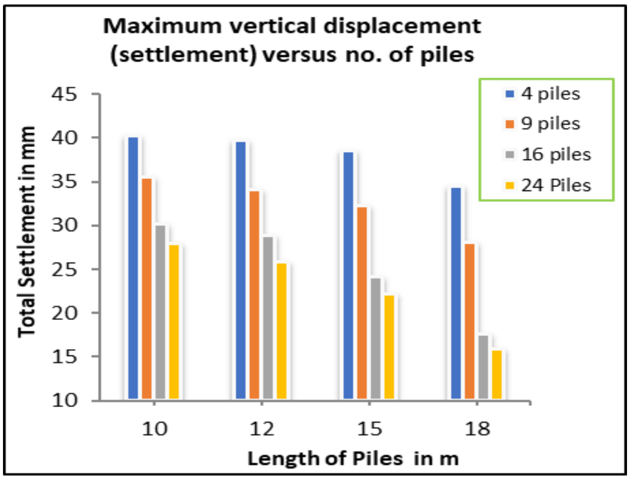

Chart -19: Variation of Total Settlement for Pile Dia. = 500 mm and Raft thickness = 300 mm

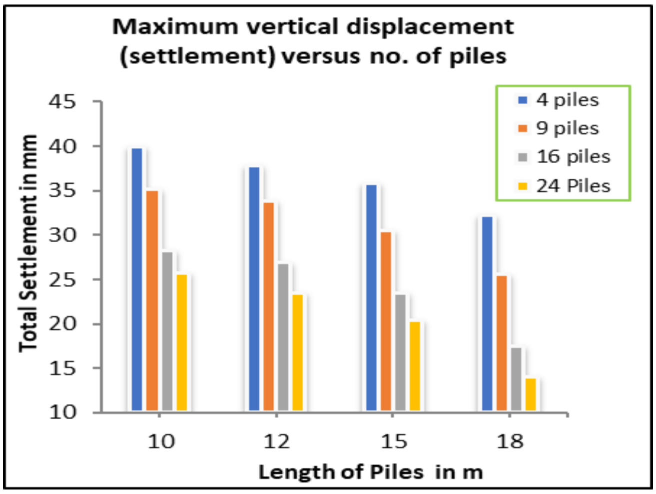

Chart -20: Variation of Total Settlement for Pile Dia. = 500 mm and Raft thickness = 350 mm

At pile diameter of 500 mm, raft thickness of 400 mm with increase of pile length from 10m to 18 m, increase in the number of piles shows a decrease in the total settlement upto 17.76 % for 4 nos. of piles, 38.5 % for 9 nos. of piles, 46.78 % for 16 nos. of piles and 49.17 % for 24 nos. of piles respectively in comparison to unpiled raft. (Chart -21)

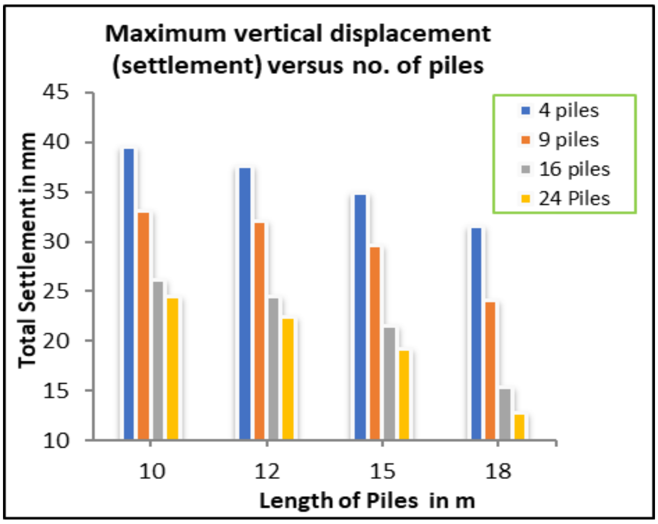

Chart -21: Variation of Total Settlement for Pile Dia. = 500 mm and Raft thickness = 400 mm

5.CONCLUSION

1) As the pile length increases in individual piled raft foundation in layered soil of Guwahati, the settlement decreases. Introduction of 4 (four) piles can reduce the total settlement up-to nearly 17% (seventeen percent) in layered soil. Increasing the number of piles up-to 9 (nine) can reduce the total settlement up-to nearly 38% (thirty eight percent) in layered soil. However, further increase in number of piles up-to 16 (sixteen), can reduce the total settlement up-to nearly 46 (forty six percent). When the number of piles is 24 (twenty-four), settlement reduces up-to 49% (forty nine percent).

2) Increase in the number of piles up-to 16 (sixteen) has considerable contribution in decreasing the settlement of piled raft foundation in layered soil. However, further increase in the number of piles does not contribute much in reducing settlement.

3) 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.

4) 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 center shows good results than piles positioned just below the column.

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