Assessment Of Non-Uniform Length Of Piles In Piled Raft Foundation Subjected To Non-Uniform Loading

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Abstract - The three dimensional numerical analysis was performed to analyze the piled raft foundation of a considered configuration having non-uniform length of piles. The piled raft foundation has been found very effective to reduce the maximum settlement and differential settlement of a high rise building under the non-uniform load. The central area of piled raft foundation was analyzed for a higher load comparison to other rest area of building due to presence of stiff elements such as lifts, elevators, shear walls and others at the center. The piled raft foundation subjected to undistributed load can be economized with the non-uniform length of piles under the constant thickness of raft satisfying all the settlement criteria of foundation. The different parameters such as maximum settlement and differential settlement of the foundation, maximum positive moment on raft and maximum axial load on piles have been analyzed for a considered configuration.

Index terms: Pile, Raft, Settlement, Differential settlement, Maximum bending moment on raft, Pile axial load.

I. Introduction

A piled raft foundation has been analyzed with the group of identical piles having similar pile length with a constant spacing by different authors [1,3,4,7]. The different length of identical cross-section of piles in a piled raft foundation with proper arrangement can be able to withstand the non-uniform loading of a typical high rise building. At another hand the unused piles of different length can be used at another ongoing site under the serviceability conditions. The difference in pile length of a piled raft foundation is also adoptedin the sloping ground condition [2]. The piled raft foundation optimization assuming the different design parameters have been studied by different authors [2,7,8,11,12]. The existence of lifts, elevators and shear walls of a high rise building imparts higher load on central raft area and under this non-uniform loading a pile group only on the central raft area of 16-25% can present satisfactory optimum design [8]. The few authors suggested to use the non-uniformity in length of piles in a piled raft foundation to get the most economical piled raft arrangement under the raft subjected to non-uniform loading [9,10,11].

The simplified methods for the analysis of piled raft foundation have been performed by the authors [1,3,5,13]. To overcome the limitations of simplified methods, a *finite difference method* was proposed base on the interacting behavior of piled raft foundation with soil [6,12]. On the account of *more rigorous computer–based methods*, the authors proposed the numerical analysis to study the behavior of piled raft system, which includes finite difference or finite element techniques [6, 7, 12].The present numerical analysis has been performed with the finite element tool Plaxis3D to analyze a configuration of piled raft foundation having different lengths of piles.

Ii. Validation Of The Numerical Models

The validation of the three dimensional finite element models were examined by a comparison with a field measurement for vertically loaded piled rafts on the Frankfurt clay, which was carried out by the author [6]. A total number of 84 bored piles with a length of 20 m and diameter of 0.9m were located under two 17.5 m x 24.5 m large rafts with 2.5 m thickness. The subsoil comprises quaternary sand up to 2.5m below the bottom of the raft, followed by the Frankfurt clay. The material properties of the soil and piled raft, which were adopted from the values as reported [13], are shown in Table 1. Constant values of the drained Young's modulus and drained shear strength parameters were adopted to simplify the analysis for the soil layer. The comparison of predicted load-settlement curve is represented by the figure 1.

Table 1: Material properties used for 3D finite element analysis

	Clay	Sand	Raft	Piles
Young's modulus (Mpa)	47	75	34000	23500
Poission's ratio (ϑ)	0.15	0.25	0.2	0.2
Total unit weight (KN/m^2)	19	18	15	15
Angle of internal friction (φ) in degree	20	32.5	-	-
Cohesion (kPa)	20	0	-	-

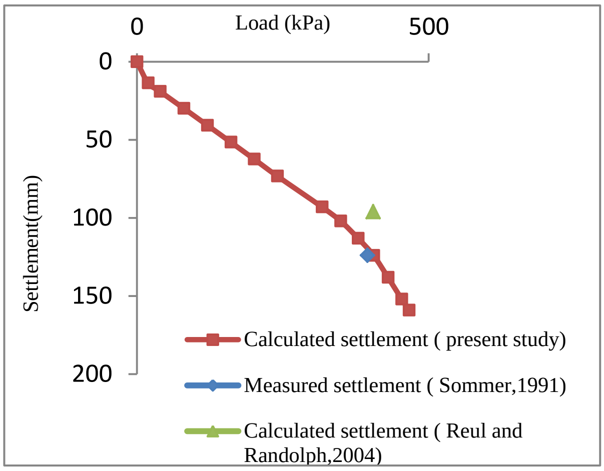


Fig. 1: Load-settlementcurve

Iii. Numerical Analysis

The present study is based on the numerical analysis of the piled raft configurations of 5x5 pile group with a constant spacing of 4.5 times diameter of a pile with PLAXIS 3D finite element tool as shown in figure 1. The arrangement of piles of non-uniform lengths is shown in figure 2c and figure 3. A soil investigation report has been adopted for the analysis and its properties are shown in table 3. The embedded piles were taken as 0.6m in diameter and 3 to 18m in length. The square raft with width, B of 20m and thickness, 0.5m to 1m was considered for the analysis. The summary of the piles and raft properties are shown in table 2. The piles were connected rigidly to the raft in the finite element analysis.

Table 2**:** Raft and Pile properties for present numerical analysis

Sr. no.	**Material**	**Dia./Thickness**	**γ (KN/m^3)**	**ν**	**E (KN/m^2)**	**Modeling Behavior**
01	Raft (20m x 20m)	0.5m, 0.8m, 1m	15	0.2	$25x10^6$	Linear-elastic
02	Pile (3m to 18m)	0.6 m diameter	15	0.2	$25x10^6$	Linear-elastic

Soil was modeled as Mohr's-Coulomb model in the present Plaxis 3D finite element analysis. The embedded piles and the raft were modelled as linear elastic model. The allowable bearing capacities of the piles were computed by finite element modeling with Plaxis 3D software based on the methods recommended in Plaxis 3D manual and shown in table 4.

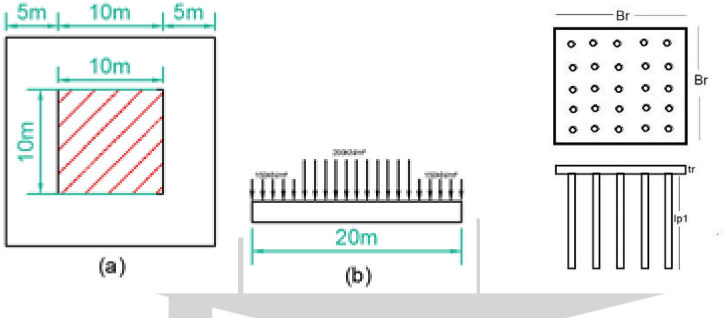
Table 3**:** Soil properties of Bore log for numerical analysis

Soil layer	**Soil type**	**Layer thickness (m)**	**Nav.(SPT)**	**γ(KN/m^3)**	**ν**	**Cohesion (c, KN/m^2)**	**Angle of internal friction (degree)**	**Young's modulus, E (KN/m^2)**
01	Very soft clay	0-4.5	1	15	0.3	6	0.3	1200
02	Medium stiff clay	4.5-14	7	16	0.3	13.5	6	12150
03	Clayey sand	14-20	45	18	0.3	72	22	19200

Table 4: Pile details for the numerical analysis

Pile type	Length	Pile allowable loading capacity
P1	18m	1832KN
P2	12m	898KN
P3	6m	486KN
P4	3m	272KN

A typical high rise building generally imparts heavier load on central area due to the existence of shear walls, elevators and others. In the present study, 200KN/m^2 load was applied on the central core area (10m x10m) of raft, whereas the other rest area of raft 150N/m^2 was applied in the considered configuration of piled raft foundation.



(c)

Fig. 2: Loading Pattern on the raft a) Plan of the raft & b) Loading patterns under central core area (200KN/m^2) and edge area (150 KN/m^2) on the raft of a considered thickness c) Pile raft of configuration 5x5 with uniform length of piles, PR1

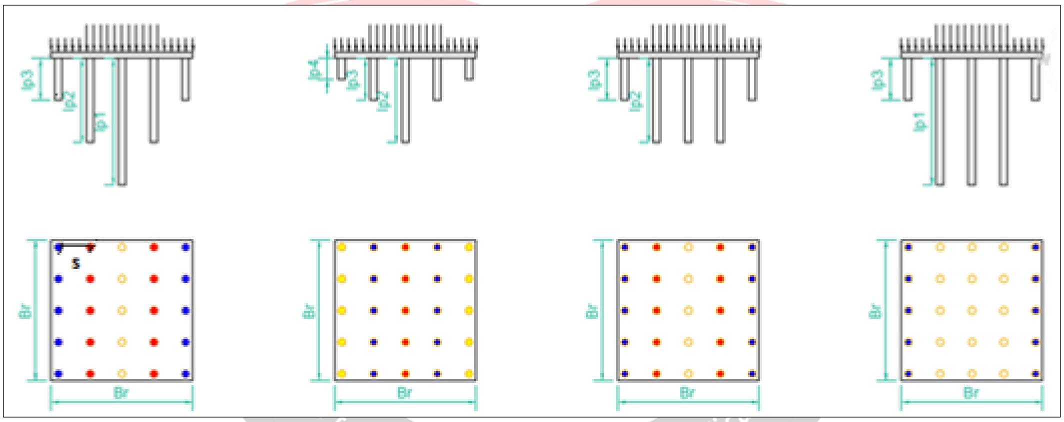


Fig.3: The piled raft configuration with different arrangements in sequence PR2, PR3, PR4 and PR5

Iv. Results And Discussions

The raft thickness is dependent on the bending moment on raft of a piled raft foundation in design. The maximum bending moment on raft was found unchanged during increasing the thickness from 0.8m to 1m of the raft in the piled raft foundation. So, the raft of constant thickness 0.8m was adopted in the analysis. The total length of each piled raft configuration has been presented in the bar diagram of figure 4. The permissible maximum settlement of the piled raft was considered 50mm and the differential settlement was adopted 15mm [9,11]. The piled raft configuration PR3 was found failed in both permissible maximum settlement criteria and differential settlement criteria. But configurations PR1, PR2, PR4 and PR5 were found safe to serve the settlement criteria as shown in figure 5 and figure 6.

As the load sharing behavior concern, the bending moment reflects the actual load sharing behavior of piled raft foundation. As the stiffness of raft is constant, the variation of stiffness of pile group produces different positive bending moment in each configuration. The bar diagram figure 7 presents the maximum positive bending moment of each piled raft configuration system. It is also important to check the maximum individual pile axial load P1, P2, P3 and P4 for the different configurations selected for the optimized design of piled raft foundation. In this study the axial load on each type of pile was found less than its allowable loading capacity for each configuration adopted in the numerical analysis.

For the configurations which serving the settlement criteria, the total length of piles of the configuration PR4 was found minimum and so it can be considered for the most economical arrangement of piled raft foundation for the considered soil conditions in the analysis as referring the assumption that the optimization of foundation is directly proportional to the pile length. Using PR4 configuration, the excess consumption of pile materials during the piling can be saved where pile length variation ration was lp1/lp2 = 1.5 and lp2/lp3 = 2, adopted in the study.

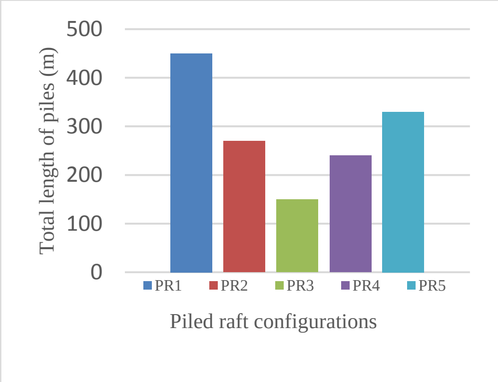


Fig. 4: Total length of piles in the configurations

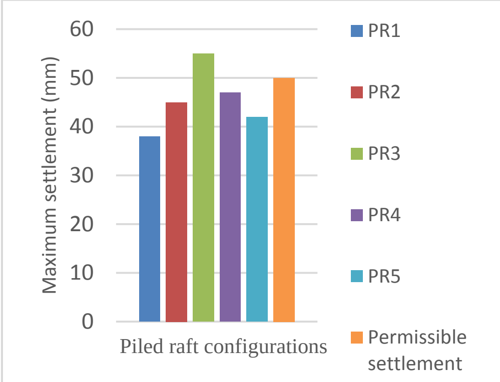


Fig. 5: Maximum settlement of the piled raft foundation in the configurations

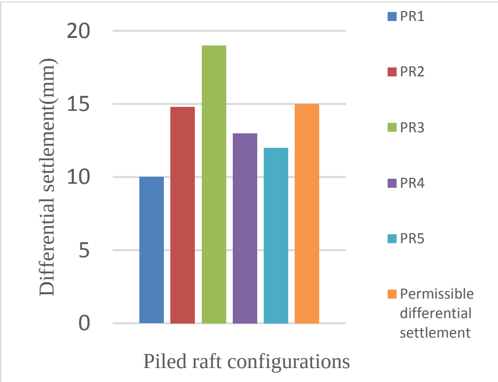


Fig. 6: Differential settlement of the piled raft foundation in the configurations

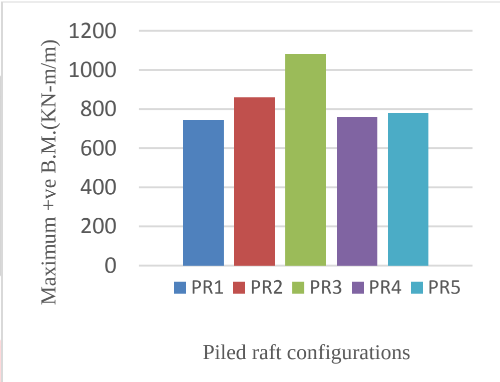


Fig. 7: Maximum +ve moment on the raft in the configurations

V. Conclusion

In the present study, it was observed that the non-uniform length of piles in a piled raft foundation can perform well, serving all the settlement criteria. The proper arrangement of piles in a piled raft configuration was also required under the application of non-uniform loading of a typical high rise building. So, the variation of pile length i.e. using non-uniform pile length in the proper arrangement in a piled raft configuration can satisfy the design aspects of the foundation and able to reduce the overall cost of the foundation.

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