INVESTIGATING LOAD TRANSFER BEHAVIOUR OF BORED PILES IN LAYERED SOIL

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Abstract- Piles foundation is considered as an appropriate foundation system for structures subjected to higher axial or lateral loading. In general, piles are constructed in a group to enhance their efficiency and capacity to resist loads. This study investigates the effect of pile configuration and diameter on the pile group efficiency factor, ultimately affecting the overall pile group capacity. Additionally, pile load transfer behavior was also examined to enhance understanding on the pile group response constructed in layered soil. A total of three pile group configurations i.e., 2 x 1, 2 x 2 and 3 x 3 along with three pile diameters of 0.76m, 1.0m and 2.0m with a constant length of 55m, were used for the present study. The results highlight the group efficiency factor reduces with piles. Furthermore, it was observed that major percentage of the load is transfer to the soil around the pile length instead of pile tip in bored piles.

Keywords- Load Transfer Behavior, Bored Piles, Axial Load Capacity

1 Introduction

Piles are defined as slender members, whose primary function is to resist axial load coming from the superstructure. Pile offered resistance to axial loading in two ways i.e. (i) resistance offered along the length of the pile, termed as skin/shaft/frictional resistance; and (ii) resistance offered at the base of the pile, called as base/tip/end resistance. The pile capacity subjected to axial loading is generally obtained in two ways; (i) by adopting well documented procedures in various codes; and (ii) by performing static pile load [1,2]. In both the aforementioned methods, the axial load carrying capacity of the pile along with its settlement is obtained with precision. However, no information related to resistance offered by a particular soil layer is obtained in either of the aforementioned methods.

Researchers over the past few decades had proposed various equations to anticipate load transfer mechanism of piles. The transfer of compressive loads using helical piles was investigated using 3D FEM by varying diameter [3]. In another study, a correlation was proposed to evaluate behavior of screw piles subjected to compression [4]. The load transfer response of driven piles installed in soft soil was studied and the results were compared with the results of static pile load to enhance the understanding of load transfer response of driven piles [5]. Another study concluded that, load displacement at the pile head is direct outcome of reaction forces and their corresponding displacement around the pile head. Based on this conclusion, a mathematical formulation was proposed to anticipate the load transfer response of piles for various soil conditions [7-9]. Based on various research work, it was noticed that load transfer response correlations provides reasonable accuracy during loading phase of the pile. However, load tests had confirmed that unloading of pile does not result into zero settlement resulting into inaccurate estimation during unloading phase of the pile. A modification in the earlier correlation was then proposed to further enhance accuracy of load transfer mechanism of piles [10].

The subsoil of Lahore, the second largest city of Pakistan mainly composed of layered with alternate layers of clay and sandy soil [11]. Whenever the layered soil is encountered, it is vital to know the contribution of each layer in the overall resistance offered by the pile. This information becomes even more crucial when pile groups are considered as group interaction can affect soil degradation and ultimately the capacity of the piles. In the present study, an effort is made to determine the load transfer mechanism of bored piles constructed in-group. To enhance our understanding various scenarios were created by varying pile diameter and pile configuration. Three configurations i.e. 2x1, 2x2 and 3x3 of pile group were considered in the present study. Furthermore, three pile diameters of 0.76m, 1m and 2m with a constant pile length of 55m that worked aspect ratios of 72.5, 55 and 27.5 respectively were considered for the present study. Pile capacity and load transfer behavior is obtained from numerical modeling in PLAXIS 3D.

2 Research Methodology

The research methodology adopted for the present study is shown in Figure 1.

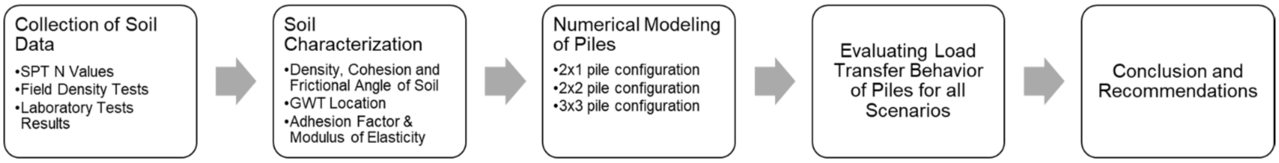


Figure 1: Research Methodology

2.1 Data Collection

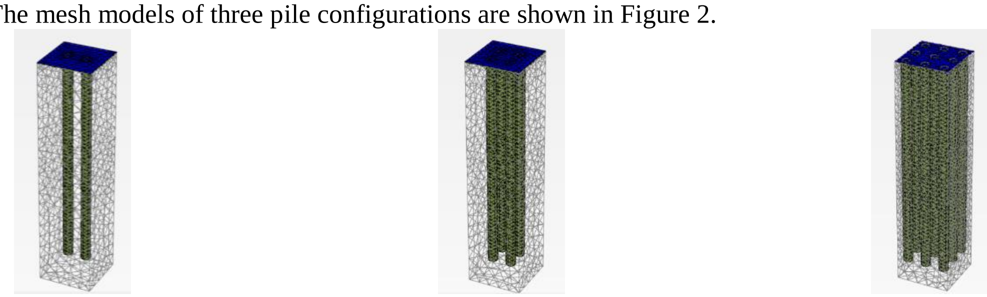
The data of sixteen boreholes, drilled up to the depth of 60m, were collected. The collected data included corrected SPT N values and soil index properties such as bulk and dry densities, NMC, OMC and MDD. Soil characterization was performed based on the collected soil data, the generalized profile of layered soil, composed of layers of alternate layers of clay and sand, was compiled. The strength properties, (cohesion, frictional angle and elastic modulus) were estimated on the basis corrected SPT N values and presented in Table 1.

Table 1: Soil Properties Used in Numerical Simulation

Layer No.	**Soil Type**	**Thickness (m)**	**Bulk Density (tons/m^3)**	**Elastic Modulus (MPa)**	**Cohesion (tons/m^2)**	**Friction Angle**
01	Silty Clay (ML)	3	1.84	10	07	-
02	Silty Sand (SM)	27	1.70	15	-	30
03	Lean Clay (CL)	5	1.90	20	15	-
04	Clayey Sand (SC)	25	1.95	20	-	33

2.2 Numerical Modelling

The numerical simulations were performed in PLAXIS 3D connect version using finite element method. Layered soil is modelled using Mohr-Coulomb failure criteria. Cohesion, friction angle, bulk density, saturated density and soil modulus are used are input parameters to model the soil. Piles are modelled as volume element, using section designer option. Pile cap is modelled using plate element. Medium mesh size was used in accordance with guidelines incorporated in PLAXIS 3D manual. The mesh models of three pile configurations are shown in Figure 2.



(a) *(b)* *(c)*

Figure 2: Mesh of Pile Models (a) 2 x 1 (b) 2 x 2 (c) 3 x 3

3 Results

3.1 Capacity of Pile Group

The capacity of piles group obtained from numerical simulation is presented in Figure 3. The pile group efficiency factor was calculated using Converse-Labarre equation. The capacity of pile group configuration of 2x1, having diameter of 0.76m, 1.0m and 2.0m were found to be 216 tons, 713 tons and 5805 tons respectively. Whereas the capacity of pile group configuration of 2x2, having diameter of 0.76m, 1.0m and 2.0m were found to be 205.5 tons, 665 tons and 5000 tons respectively. Furthermore, the capacity of pile group configuration of 3x3, having diameter of 0.76m, 1.0m and 2.0m were found to be 198 tons, 633 tons and 4472 tons respectively. From Figure 3, it can be observed that axial load carrying capacity of piles increase with an increase in diameter and number of piles This is primarily to increase stiffness of overall soil pile system due to increase in pile size and numbers. Stiffness of the structure is major factor that governs the overall capacity of the structure. This observation is consistent with the results and recommendations published by another researcher [11].

From Figure 4, it can be noticed that attained group efficiency decrease with an increase in piles. The obtained values of pile group efficiency factor for 2x1 pile group were found to be 0.95, 0.94 and 0.88 for pile measuring dia. of 0.76m, 1.0m and 2.0m respectively. The pile group efficiency factor for 2x2 pile group were found to be 0.90, 0.88 and 0.76 for pile measuring dia. of 0.76m, 1.0m and 2.0m respectively. Whereas group efficiency factor for 3x3 pile group were found to be 0.88, 0.83and 0.67 for pile measuring dia. of 0.76m, 1.0m and 2.0m respectively. It is important to note that spacing between the two piles were kept at 2.5 of pile diameter. Due to this close spacing, the increase in the number of piles resulted into block failure which leads to reduction into overall pile group efficiency factor. Another reason for reduction in the pile group efficiency factor is the formation of pressure bulb. Due to the close spacing, the pressure bulb of the pile overlaps, leading to soil degradation, ultimately affecting pile group capacity. These observations are in agreement with the already published research study [12].

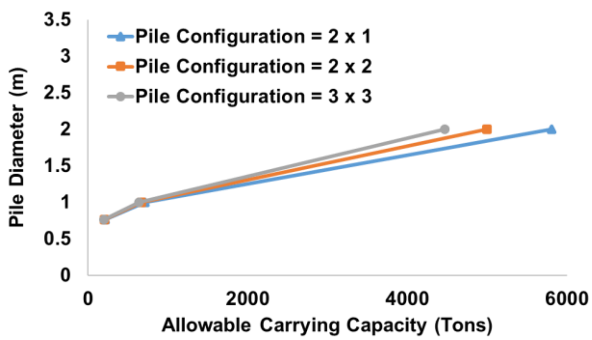


Figure 3: Allowable Load Carrying Capacity

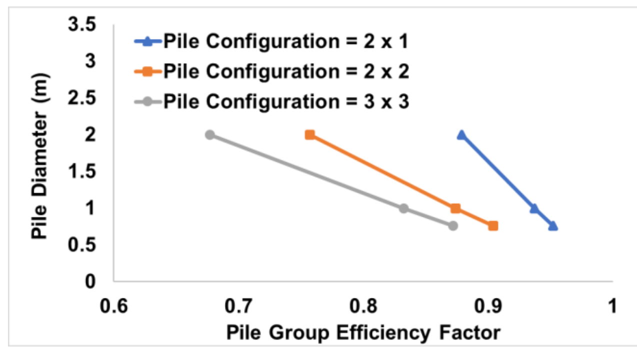
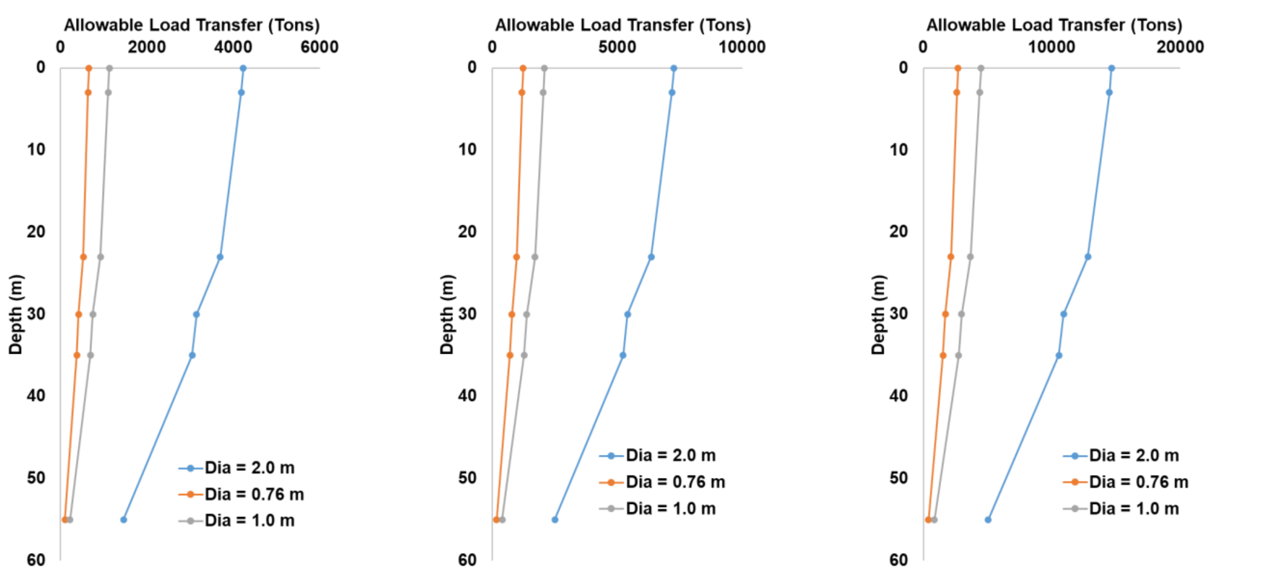


Figure 4: Pile Group Efficiency Factor

3.2 *Load Transfer Behaviour of Piles Groups*

The load transfer performance of the pile is presented in Fig 5 for all the three pile group configurations and pile diameters. It can be observed. The load transfer behavior is primarily governed by two important parameters i.e., strength characteristics of the soil and the pile construction method. In case of bored piles that pile resistance is mainly composed of shaft resistance. This can be seen in the Figure 5, that major portion of the load is transfer to the soil around the pile shaft and minor portion of the overall load is resisted at the pile tip for all three pile configurations and pile diameter. In the present study the obtained percentage of load transfer through shaft resistance for piles measuring diameter of 0.76m, 1.0m and 2.0m were found to be 85%, 80% and 65% respectively. The trend will be entirely opposite in case of driven piles where load is primarily transferred to the soil at the pile tip level instead of pile shaft. It is noteworthy that with an increase in the diameter of the pile, the contribution of base resistance is increasing in the overall resistance of piles.



(a) *(b)* *(c)*

Figure 5: Load Transfer Mechanism of Piles (a) Pile Configuration 2x1 (b) Pile Configuration 2x2 (c) Pile Configuration 3x3

4 Conclusion

The following conclusions can be drawn from the present study:

- It can be concluded from the obtained results that pile configuration have significant impact on the axial load carrying capacity and load transfer response of piles groups due to variation of pile-soil system's stiffness .
- From the results, it can be concluded that group efficiency factor reduces with more piles due to overlapping of pressure bulb and formation of block failure.
- The load transfer performance of the pile obtained in this study substantiate that major portion of load in bored piles will be resisted through shaft resistant.
- From the results of load transfer behavior of piles, it is concluded that contribution of pile end bearing in the overall resistance of piles to axial load enhances with an increase in the pile diameter.

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