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EXAMINING IMPACT OF GROUP CONFIGURATION ON PILE RESPONSE USING NUMERICAL METHOD

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Abstract- The anticipation of load transfer mechanism of piles has been topic of interest in the domain of geotechnical engineering. Many researchers have proposed various methods to anticipate load transfer mechanism and effect of pile spacing on the load deformation characteristics of piles. However, understanding the effect of pile configuration on bending moment and shear force distribution, when installed in groups remains area to be further explored, particularly in layered soil conditions. This study aims to investigate how the arrangement of piles in groups affects the bending moment and shear force experienced at the pile heads in layered soil. Numerical simulations using the finite element method were conducted, varying the configurations of pile groups to gain a comprehensive insight into the changes in bending moment and shear force. The findings indicate that both bending moment and shear force increase as the number of piles in a group is increased

Keywords- Pile Configuration, PLAXIS 3D, Bending Moment, Shear Force

1 Introduction

Piles are slender structural elements designed to transfer loads to deeper layers, ideally to rock or firm soil. Typically, piles are installed in clusters. As urbanization continues to grow, there is a rising demand for constructing tall buildings, industrial facilities, and bridges. These structures must support substantial loads and often necessitate deep foundations, typically using piles. Many megacities around the world feature complex ground profiles comprising layers of various soil types. Lahore, the second largest city in Pakistan, serves as an example, where the soil profile consists of alternating layers of clayey and sandy soils.

The design of piles may be categorized into two groups i.e. (i) Traditional design approaches; and (ii) Load Deformation Analysis using advanced tools. Traditional design approaches involve use of numerical calculations based on SPT N values, closed form solutions and code-based equations such as NAVFAC DM7.02, AASHTO LRFD Design Specification etc. [1, 2]. Many researchers proposed various equations to anticipate the load – settlement and load transfer mechanisms of piles constructed in layered soil [3-8]. Traditional approach of pile design has some obvious limitations mainly (i) Ignore load deformation of bored piles, (ii) Mandatory vertical movement up to 0.5 % of pile diameter and 10 % of pile diameter to invoke skin and base resistance respectively; and (iii) Underestimation of skin resistance [3]. One of the most commonly employed method to understand pile performance is load transfer approach. The aforementioned method provides realistic estimates even considering soil as nonlinear material. In this approach, pile is discretized into nonlinear elements whereas soil is modelled as nonlinear springs. The spring stiffness determines the resistant of the soil. The springs defined and modelled at pile tip level is referred as Q-Z spring whereas spring used to represent soil around pile is termed as T-Z springs. [4-9].

With an advancement in the computation, the researchers shifted to adopt load deformation analysis instead of traditional methods using advanced tools. Among them finite element method had gained significant popularity among researchers. A comprehensive review on use of finite element method to anticipate pile performance subjected to axial and lateral loading is already well documented in literature [10].

The effect of pile configuration and pile spacing on the load deformation characteristics of helical pile group are well understood and documented in the literature [11]. However, very limited number of studies were available that focused effect of pile configuration on the bending moment and shear force of bored pile group embedded in layered soil subjected to axial loading. In this study, an effort was made to determine effect of pile configuration installed in groups on the bending moment and shear force constructed in layered soil profile of Lahore. The relationship between aspect ratio with bending moment and with shear forces was obtained by varying number of piles in group. A total of three pile group configurations i.e., 2 x 1, 2 x 2 and 3 x 3 with a constant pile diameter and length of 2.0m and 55m respectively, are used for the present study,

2 Research Methodology

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

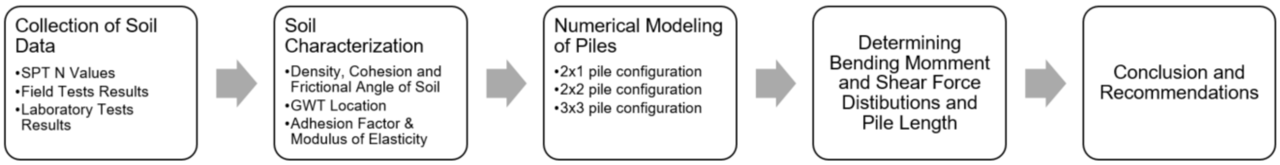


Figure 1: Research Methodology

2.1 Data Collection

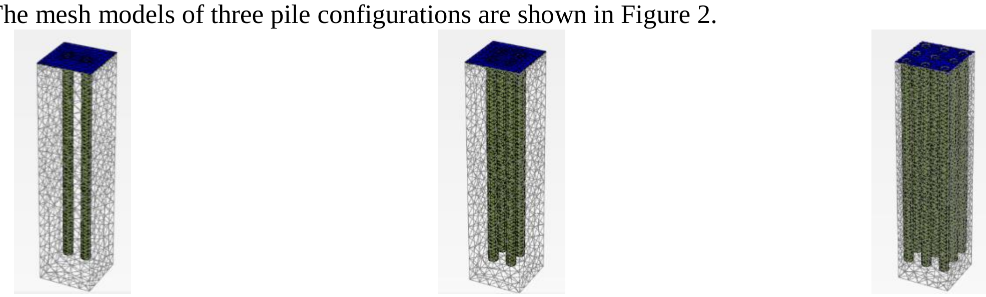
The data of sixteen boreholes, drilled up to the depth of 60m, were collected. The collected data included corrected SPT N values and soil index properties such as bulk and dry densities, NMC, OMC and MDD. Soil characterization was performed on the basis of the collected soil data, the generalized profile of layered soil was compiled. The strength properties 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	3	1.84	10	07	-
02	Silty Sand	27	1.70	15	-	30
03	Sandy Clay	5	1.90	20	15	-
04	Clayey Sand	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.



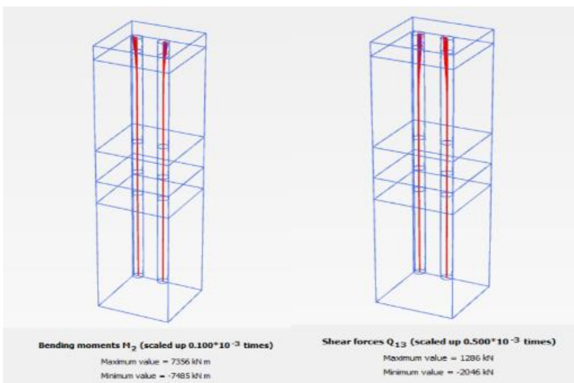
(a) (b) (c)

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

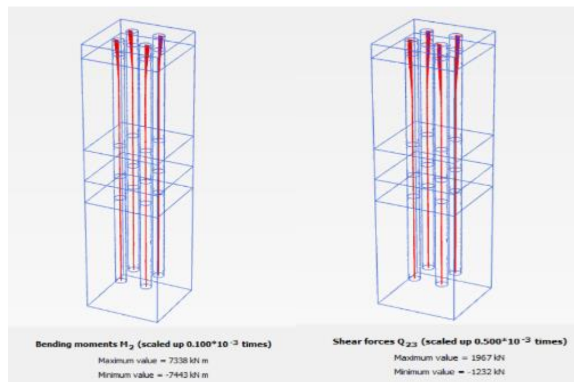
3 Results

3.1 Bending Moment and Shear Force Variation along the Pile

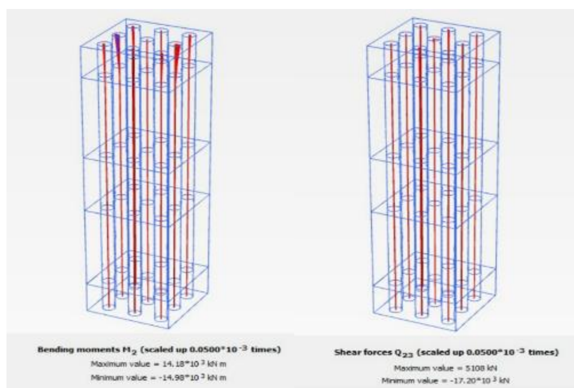
The variation of moment and shear along pile length is presented in Figure 3 for all three configurations of piles measuring 2.0m in diameter and length of 55m. It can be observed from Figure 3, that the maximum bending moment are obtained at the pile head level. A similar trend is observed for shear forces as the maximum shear force values are at the pile head level. There are two primary reasons for the higher maximum bending moment and shear forces at the pile head level. The first reason is the accumulation of axial load at the top of the pile. This axial loading originates from the pile cap where the pile is embedded, resulting in a concentrated axial load at the pile head. The second major reason for higher bending moment and shear forces at the pile head is the higher stiffness at the pile head level due to joint of pile cap and pile. The stiffness of a structural member influences the distribution and accumulation of loads, as well as other dynamic parameters of the structure. Due to the connection between the pile and pile cap at the top, the overall system stiffness is highest at the pile head and diminishes with increasing pile length. This decrease in stiffness along the length reduces the bending moment and shear force along the pile. This also result in decrease in the intensity of moment and shear with embedded depth of the pile, and becoming almost negligible at the pile tip. This observation supports the recommendation in building codes for the critical depth concept of piles, typically ranging between 12D to 18D in widely adopted codes globally. These results of the present study are in agreement with the results published in the literature [11].



(a)



(b)



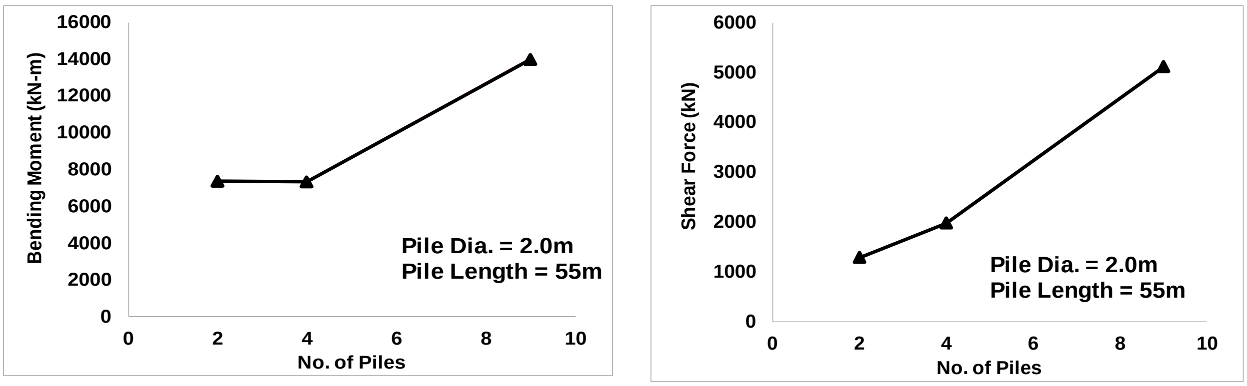
(c)

Fig 3: Bending Moment and Shear Force Distribution of Piles (a) Configuration 2 x 1(b) Configuration 2 x 2, (c) Configuration 3 x 3

3.2 Effect of Pile Configuration on Maximum Bending Moment and Shear Forces

A total of three (03) pile configurations i.e. 2x1, 2x2 and 3x3 were used in this study. The corresponding number of piles are 2, 4 and 9 respectively. Figure 4 shows the relationship between the obtained maximum bending moment and shear forces with a number of piles in each configuration. From the obtained results, it is observed that bending moment and shear increase with an increase in no, of piles. Thus, it can be concluded that bending moment and shear force will be directly proportional to the number of piles. As the increase in the no. of piles increases the stiffness of the overall system, the higher bending moment and shear forces are resulted. Another reason for increased bending moment and shear forces with an increase in number of piles is attributed to degradation of the soil between the two piles. As more soil in pile group configuration of 3x3 was degraded as compared to pile group configuration of 2x2, due to development of transfer of the load to the surrounding soil and the pile tip level, this load transfer affects the distribution of shear forces and bending moment. These observations are consistent with the other results documented in literature [12].

The present study provides an effect of pile group configuration on the bending moment and shear forces, subjected axial loading, constructed in layered soil. Understanding the accumulation of bending moment and shear forces along with relationship between number of piles in particular configuration and its corresponding internal actions (bending moment and shear force) is vital for design optimization. The outputs of the study will help practice engineers gain insights while dealing with piles installed in layered soil strata. The outcomes of the study can be used for optimizing pile design encountering layered soil, mitigate risks and also enhance significance of soil conditions. For academicians and researchers, the present study provides a framework to simulate the response of pile groups subjected to axial loading and determine moment and shear force distribution along the pile length.



(a) (b)

Figure 4: Effect of Pile Configurations (a) Relationship between Bending Moment and no. of Piles (b) Relationship between Shear Force and no. of Piles

4 Conclusion

The following conclusions can be drawn from the present study:

- The result concludes the bending moment and shear concentrate at the connection between the pile and pile cap due to higher stiffness.
- The bending moment and shear forces will increase with an increase in the number of piles.
- The increase in the number of piles enhances the soil degradation between the piles as higher load will be transferred to the soil in case of higher pile configuration.

References

[1] Foundations and Earth Structures: NAVFAC DM 7.02

[2] AASHTO LRFD bridge design specifications. (2019). Washington, D.C. :American Association of State Highway and Transportation Officials.

[3] Burland, J. B., & Twine, D. (1988, June). The shaft friction of bored piles in terms of effective strength. In Proceeding of 1st international conference on deep foundations, bored and Augered piles (pp. 411-420).

[4] Vijayvergiya, V. N. (1977). Load Settlement Characteristics of Pile. Proceedings of Port 77 Conference, Loong Beach California, 269-284

[5] Kraft, L. M., Kagawa, T., & Ray, R. P. (1981). Theoretical tz curves. Journal of the Geotechnical Engineering Division, 107(11), 1543-1561.

[6] Zhu, H., & Chang, M. F. (2002). Load transfer curves along bored piles considering modulus degradation. Journal of geotechnical and geoenvironmental engineering, 128(9), 764-774

[7] Zhao, M. H., Liu, D. P., Zhang, L., & Jiang, C. (2008). 3D finite element analysis on pile soil interaction of passive pile group. Journal of Central South University of Technology, 15, 75-80

[8] Zhang, Q. Q., Zhang, Z. M., & He, J. Y. (2010). A simplified approach for settlement analysis of single pile and pile groups considering interaction between identical piles in multilayered soils. Computers and Geotechnics,37(7), 969-976

[9] Suhail, S. A., & Thammarak, P. (2021). Evaluation of dynamic behavior of single floating piles embedded in soft clay layer under lateral harmonic and impulse loading. Innovative Infrastructure Solutions, 6(3), 172.

[10] P. E. Kavitha, K. S. Beena, and K. P. Narayanan, "A review on soil–structure interaction analysis of laterally loaded piles," Innov. Infrastruct. Solut., vol. 1, no. 1, pp. 1–15, 2016

[11] Venkatesan, V., Mayakrishnan, M., & Shukla, S. K. (2024). Effect of pile spacing in helical pile groups in soft clays under combined loading. Marine Georesources & Geotechnology, 42(4), 432-452.

[12] Suhail, S. A., & Thammarak, P. (2021). Evaluation of dynamic behavior of single floating piles embedded in soft clay layer under lateral harmonic and impulse loading. Innovative Infrastructure Solutions, 6(3), 172.