EFFECT OF ASPECT RATIO ON BENDING MOMENT AND SHEAR FORCE DISTRIBUTION OF AXIALLY LOADED PILES

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Abstract- Piles are categorized as a type of deep foundation and are generally adopted as an appropriate foundation system for high-rise structures, bridges, offshore structures etc. Generally, piles are constructed in a group to enhance their efficiency and capacity to resist loads. The procedure to evaluate the axial load-carrying capacity of piles is well documented in various codes adopted around the globe, however, determination of the variation in moment and shear with pile length is not explicitly incorporated in codes. In this study, an attempt is made to determine the bending moment and shear force distribution along the length of piles constructed in group of 2x2 pile configuration, in layered soil for different aspect ratios. Numerical simulations based on the finite element method were performed by considering three pile diameters to obtain a comprehensive understanding on the effect of aspect ratios on bending moment and shear along pile lengths. The results showed higher moments and shear at the top of the pile. Furthermore, bending moment and shear force decrease with an increased aspect ratio.

Keywords- Aspect Ratio, Layered Soil, Finite Element Method, Bending Moment, Shear Force

1 Introduction

Piles are defined as slender members, used to transfer load to deeper layers preferably rock or hard soil. In general, piles are always constructed in groups. With an increase in urbanization, the construction of high-rise structures, industrial buildings and bridges is in abundance. These structures withstand higher loads and are required to be supported on deep foundations preferably piles. There are numerous megacities in the world where ground profiles consist of layers of different soil types. One such example is Lahore, the second largest city in Pakistan, where the soil profile is composed of layers of clayey and sandy soil.

The procedure to evaluate the vertical load-carrying capacity is well documented in codes and standards such as NAVFAC DM7.02, AASHTO LRFD Design Specification etc. [1, 2]. Furthermore, many correlations are available based on SPT N values to obtain the vertical load-carrying capacity of the piles. Over the past few decades, many researchers had proposed methods to obtain pile load transfer mechanisms. Vijayvergia proposed T-Z curves for sandy and silty soils [3]. Later Kraft et. al presented a displacement-resistance relationship by considering soil as a continuum material [4]. Another study proposed a set of equations to anticipate the displacement of driven pipe piles by analyzing the results of pile load tests. These earlier studies set the tone for researchers and the subject of soil-pile interaction became a topic of interest in the field of geotechnical engineering. The load-displacement response of bored piles was investigated by considering modulus degradation [5]. A study was published that appraised simplified nonlinear prediction models for pile groups under axial loading, offering insights into the limitations and potential of various analytical methods. Their work contributes to the ongoing efforts to establish well-defined analysis methods considering all influencing parameters [6]. Zhao et al. explored the pile response subjected to repeated axial loads through numerical simulation, provided useful insights on the performance of piles [7]. The load transfer mechanism of single piles embedded in layered soil was investigated and correlations were developed to anticipate pile skin resistance using SPT N values [8].

Very limited number of studies were available that focused on the determination of bending moment and shear force distribution of group piles embedded in layered soil, considering the effect of aspect ratios on the bending moment and shear force distribution. In this study, an effort is made to determine the bending moment and shear force distribution of the pile group constructed in layered soil by varying pile diameters. A configuration of 2x2 pile group along with three pile diameters such as; (i) 0.76m; (ii) 1m and (iii) 2m with a constant pile length of 55m, that worked aspect ratios of 72.5, 55 and 27.5 respectively were considered for this study.

2 Research Methodology

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

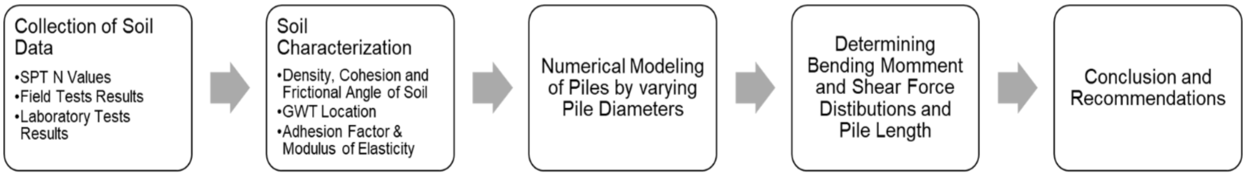


Figure 1: Research Methodology

2.1 Data Collection

The data of sixteen boreholes, drilled up to the depth of 60m, were collected. The collected data included SPT N values and soil index properties such as bulk and dry densities, NMC, OMC and MDD. Soil characterization was then performed on the collected soil data and the generalized layered subsoil profile soil was compiled. The strength properties were then estimated using corrected SPT N values and are presented in Table 1.

2.2 Numerical Modelling

The numerical simulations were performed in PLAXIS 3D connect version employing finite element method. Layered soil was modelled using Mohr-Coulomb failure criteria. Cohesion, friction angle, bulk density, saturated density and soil modulus were used are input parameters to model the soil. Piles were modelled as volume element, using section designer option. Pile cap was modelled using plate element. Medium mesh size was used in accordance with guidelines incorporated in PLAXIS 3D manual. A configuration of 2x2 pile group along with three pile diameters such as; (i) 0.76m; (ii) 1m and (iii) 2m with a constant pile length of 55m that worked aspect ratios of 72.5, 55 and 27.5 respectively were considered for this study. The pile diameters are selected to represent piles having small, medium and large diameter piles. All the three diameters are commonly used in various project in Lahore, Pakistan. The mesh of 2x2 pile configuration is shown in Figure 2. The spacing between the piles are kept at 2.5 times of pile diameter, in line with recommendations proposed by various codes.

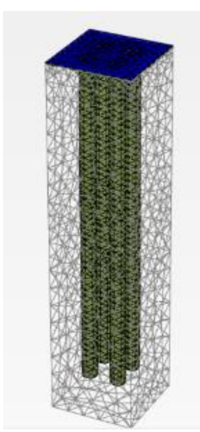


Figure 2: Mesh of Pile Models

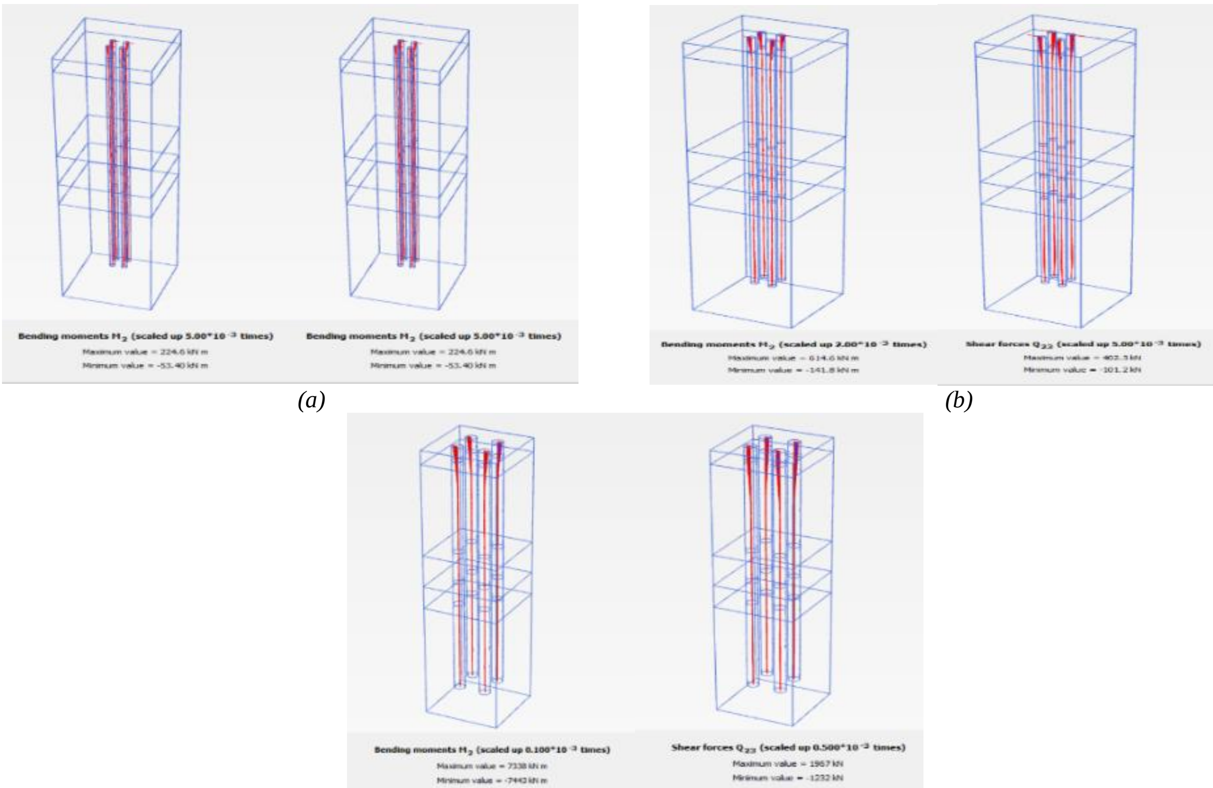
Table 1: Soil Properties Used in Numerical Simulation

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

3 Results

3.1 Bending Moment and Shear Force Variation along the Pile Length

The variation of obtained bending moments and shear forces along pile length is presented in Figure 3(a), (b) and (c) for piles measuring 0.76m, 1.0m and 2.0m in dia. respectively. It can be observed from Figure 3, that the maximum bending moment is obtained at the pile head level. A similar trend is observed for shear forces. There are two primary reasons of the higher values at the pile top. The first reason is the accumulation of axial load at the top of pile. Since axial loading is applied at the pile cap, in which pile is embedded, as a result higher concentration of axial load is at the pile head level. The second major reason, is because of higher stiffness at the pile head. The stiffness of the structural member governs the load distribution, accumulation and other important dynamic parameters of the structure. Due to the joint of pile and pile cap at the top, the stiffness of the overall system is higher at the top of the pile and decreases along pile length. The decrease in the stiffness along the length leads to decrease in the moment and shear values. Another interesting observation noted from the obtained results is the nominal moment and shear at the pile tip level. This observation endorses the codes recommendation of the pile critical depth concept which ranged between 12D to 18D in mostly adopted codes around the globe. Both the findings as explained above are consistent with the results published by other researchers [9].



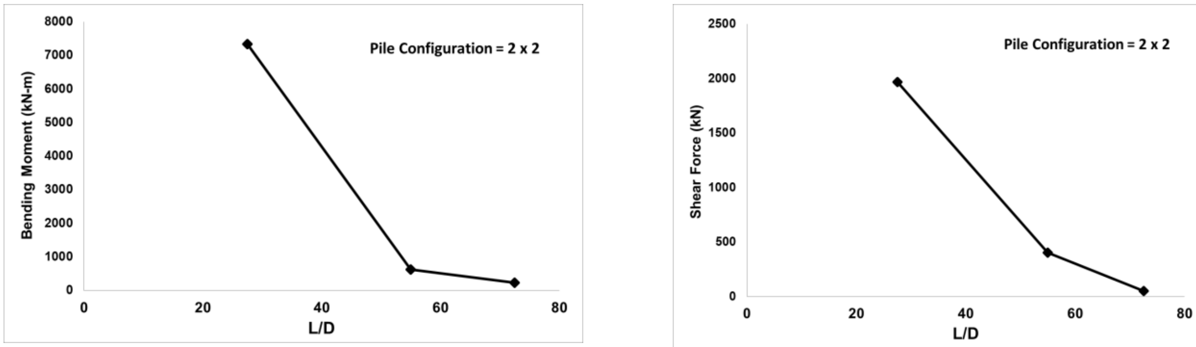
(a) *(b)* *(c)*

Fig 3: Bending Moment and Shear Force Distribution of Piles (a) Dia. = 0.76m, (b) Dia. = 1.0m, (c) Dia. = 2.0m

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

As stated in the introduction of this paper, a total of three (03) pile diameters i.e.; (i) 0.76m; (ii) 1m and; (iii) 2m with a constant pile length of 55m were considered in this study. The corresponding aspect ratios (L/D) are 72.5, 55 and 27.5 respectively. The obtained maximum moment and shear with aspect ratio are shown in Figure 4. Interestingly, the paper posits that the occurrence of higher moment and shear at the minimum aspect ratios of piles i.e. at maximum diameters. Thus, it can be concluded that an increase in diameter leads to increased moment and shear. Furthermore, the relationship between aspect ratio of piles with bending moment and shear is nonlinear in general. The aspect ratio of a pile influences how these internal forces distribute along the pile diameter. The increase in moment and shear with diameter is justified as increase in diameter leads to higher stiffness of the pile. As stated above stiffness plays a major role in accumulating bending moment and shear forces, so higher internal forces will be concentrated with an increase in diameter. Similar results were obtained by Salman and Thammarak in their published research (2021) [9].

The present study provides an overview of pile group response, subjected axial loading, constructed in layered soil. Understanding the accumulation of moment and shear along with relationship between aspect ratio of piles and internal actions (bending moment and shear force) is crucial for optimizing pile design. 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, this study provides a detailed methodology to simulate the response of pile groups subjected to axial loading and determine moment and shear distribution along the pile length.



(a) *(b)*

Figure 4: Effect of Pile Diameter (a) Relationship between Bending Moment and L/D ratio (b) Relationship between Shear Force and L/D ratio

4 Conclusion

- The overall stiffness of the soil-pile systems is vital to anticipate the accumulation of moment and shear in the pile-soil systems.
- From the results, it can be concluded that maximum moment and shear will occur at the top of the pile.
- It is further concluded that moment and shear reduced with the length the pile and become negligible at the pile tip level.
- The moment and shear will increase with an increase in dia. of the pile due to increase stiffness.

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