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Lateral Behaviour of Pile in Sand

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Abstract

Pile foundation used to support structures like bridges and slender tower are subjected to considerable lateral loads. Pile behavior as an individual and piles in group under lateral load are complex because of soil structure interaction and shadowing effects. The interaction between piles depends on parameters like type of soil, spacing, length of pile and presence of water table. This paper presents the analysis of models with single and a row of piles (1x3) under varying parameters. The soil is modeled to be sand using Mohr-Coulomb Constitutive model in PLAXIS 2D. The deflection characteristics and stresses developed in piles under different conditions is compared with past studies. Pile as single and group show insignificant changes in deformation and stress values for change in vertical loading. When water table in introduced, pile shows increased deflection and stresses with increased value of vertical loading. Leading pile in a row show more stresses compared to trailing piles. The trailing pile farthest from leading pile shows minimum value of stress.

Keywords

Soil Structure Interaction, PLAXIS 2D, Lateral Loading, Combined Loading, Leading Pile

1. Introduction

Piles are structural components supporting different civil engineering structures such as transmission towers, earth retaining structures, and foundation of bridges. These piles and the structures supported by them are frequently subjected to lateral loads like wind loads and wave impact loads. Therefore, adequate design of piles is crucial from the perspective of safety and design standards [1]. Mostly, piles are adopted in a single or a group form which are directly influenced by vertical loads; meanwhile, their deflection must be within the permissible limit for their proper functioning [1]. In addition, they can also be grouped as long and short piles, and their behavior varies with their type, surrounding soil, spacing, and water table [1].

Investigating the Soil Structure Interaction (SSI) between a soil subjected to lateral load and a pile is a challenge in itself. Exact behavior of such interaction is very difficult to predict because of the transition of soil from elastic to plastic phase during its deformation[2]. The behavior of pile can be broadly grouped into two categories: Short and Long Piles under different load transfer mechanisms. When Lateral load is applied to pile with unrestrained head, load is directly transferred to the top soil where the deformation of the soil is elastic. Meanwhile, certain amount of load is transferred to greater depths. As load increases, deformation becomes plastic and significant amount of load is transferred to further depths. For a short pile, when a load is applied on restrained and unrestrained ones at the top, it fails by translation and rotation, respectively [3]. On the other hand, the failure mechanism of an infinitely long pile is different. The passive resistance to yielding provided by the soil below the yield point can be considered infinite and rotation of the pile cannot occur. Failure occurs when the pile yields at the point of maximum bending moment. A plastic hinge is supposed at this point for calculation purposes[3].

To date, there are several papers for vertically loaded pile, laterally loaded pile and pile groups showing analysis in different case scenario. Analysis is limited to a particular set of conditions. There is no universal method for analysis of pile bored in soil. A range of data has been published by various authors[1, 3, 4, 5, 6]for conditions of soil type, pile diameter, pile spacing and others.

This paper presents numerical modeling of single and a row of piles bored in sand with different conditions of water table. To study the effect of pile spacing, multiple model have been used to perform analysis.

2. Model and Research methodology

A model consisting of a single pile bored in sand is prepared in a finite element software PLAXIS 2D. The dimension of the model is set by criteria as 16B for width from centre of pile and L+6B for depth. Soil is modelled as an elastic-perfectly plastic model using predefined Mohr-Coulomb constitutive model in PLAXIS 2D[7]. Soil material is cohesionless sand. Unit weight of sand is 18.1 KN/m^3. Young's modulus of elasticity of soil is 364 N/mm^2. Friction angle is obtained from corrected SPT value as 29.3. Piles are modelled using plate elements. Piles are defined as elastic structures with pile caps on their top, and the material is assigned as M40 concrete. The diameter of pile 1 m and and Young's modulus of elasticity is 2.97e4 N/mm^2. Poisson's ratio is 0.15. Load is assigned on pile head in two perpendicular directions, and meshing is performed with medium coarseness. For the study of row of piles, other models are prepared with three piles in a row, which are connected using a pile cap. Here, the node connections are assigned rotation fixities. Furthermore, the soil material is defined as in previous models with same properties, and load is applied on the middle pile for the research purpose.

Lateral Deflection profile is obtained for single pile with combined loading and lateral loading separately and compared. Lateral Deformation profile is obtained by introducing water table 2 m above ground surface and applying the aforementioned loading.

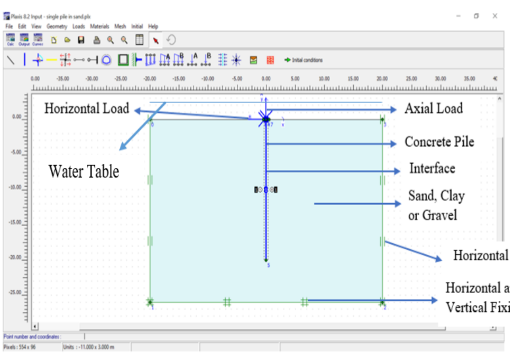

Figure 1: Representation of single pile in sand

Bending moment and Shear Stress profile is obtained in all above conditions. Similarly, the row of pile is introduced to loading of same magnitude and same conditions of water table. Deformation profile, Bending Moment Diagram and Shear Force Diagram is obtained for all conditions.

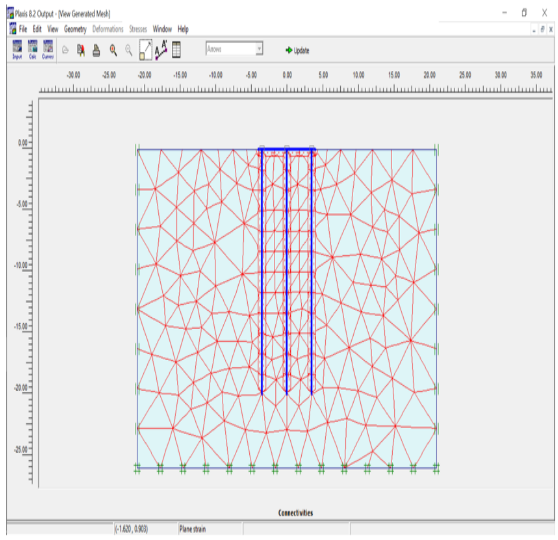

Figure 2: Representation of group pile in sand with meshing of medium coarseness

3. Results and Discussion

Results are obtained from Single and group piles loaded with vertical and horizontal loads under different conditions. Deformation profile, Bending Moment and Shear Force diagram are obtained and compared with past results. Lateral deformation of single pile form model and theoretical method showed less than 5% variation. Lateral deformation showed very less change for presence of vertical load[4]. Its value increased significantly under water table. The increase is more for pile under both vertical and lateral loading than the case where only horizontal load is applied. In case of Bending moment, the results from model and theoretical approach illustrates a good convergence. Also the presence and absence of vertical load does not show much difference. When water table is introduced, there is increase in bending moment. The increase in bending moment is higher during application of both vertical and lateral load.

Deformation profile, Bending Moment and Shear Force diagram was obtained and compared with previously published results. The result obtained from this study has been presented in the form Lateral deformation, Bending Moment and Shear Force.

3.1 Lateral deformation of single pile in sand

The deflection profile of single pile embedded in sand from model and theoretical approach are similar. The deflection value at pile head shows a deviation of 5% from two approaches. The influence of vertical load is not significant [2] as shown in Figure 3. The variation is less than 2%. The same model when combined with water table showed increased deflections in two cases. The increase is more in case of pile subjected to combined loading as seen in Figure 4. The deflection values shows nearly double value for combined loading while 1.5 times the value when subjected to lateral load only.

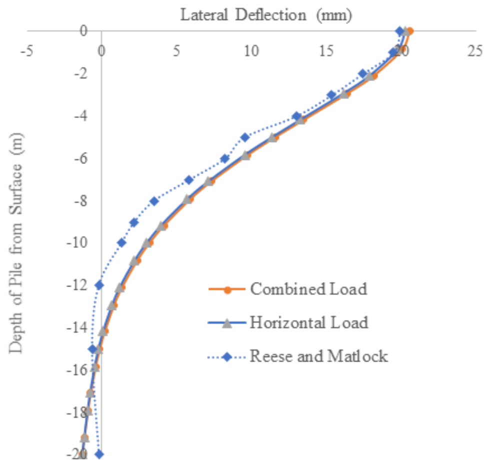

Figure 3: Lateral Deflection of Pile bored in sand by numerical and theoretical approach

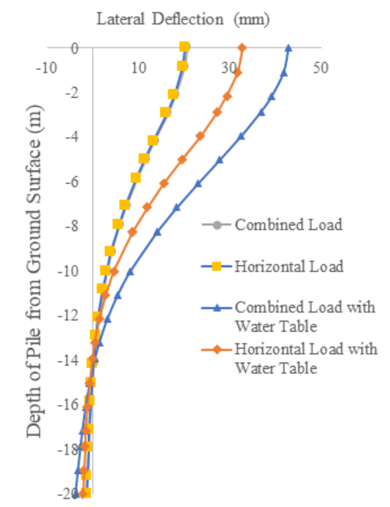

Figure 4: Lateral Deflection of Pile bored in sand with and without water table from numerical model

3.2 Bending Moment along pile in sand.

The bending moment diagram of single pile obtained from model and theoretical approach are similar as seen in Figure 5[2][4]. The bending moment at head shows a deviation of less than 1% from two approaches. In case of water table, the values are increased. For pile subjected to combined loading, the increase is more as shown in Figure 6. The increase in nearly 38% for pile with combined loading while 27% for pile subjected to lateral loading only.

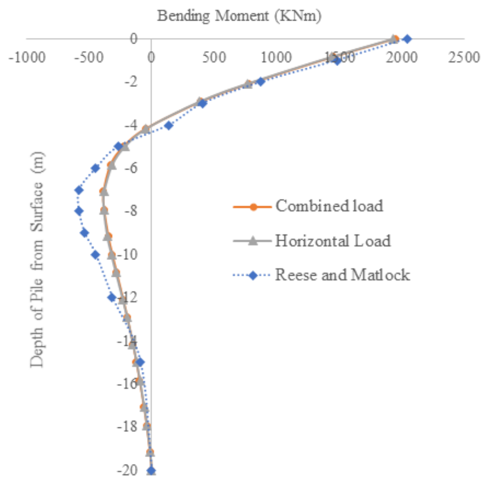

Figure 5: Bending Moment along Pile bored in sand by numerical and theoretical approach

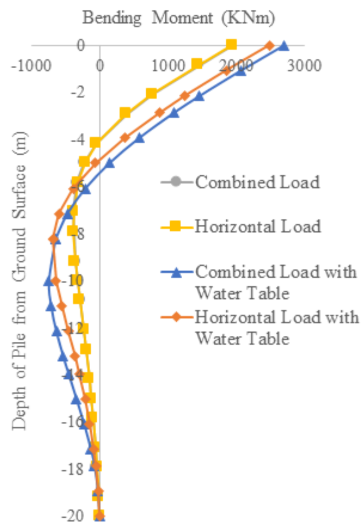

Figure 6: Bending moment along pile bored in sand with and without water table from numerical model

3.3 Shear force for single pile bored in sand

The shear force diagram is obtained from the models. Maximum value is obtained at top which is equal to load applied [1]. The depth of zone of passive resistance shows nature similar to bending moment diagram. The output curves have been obtained from validated model (Figure 7).

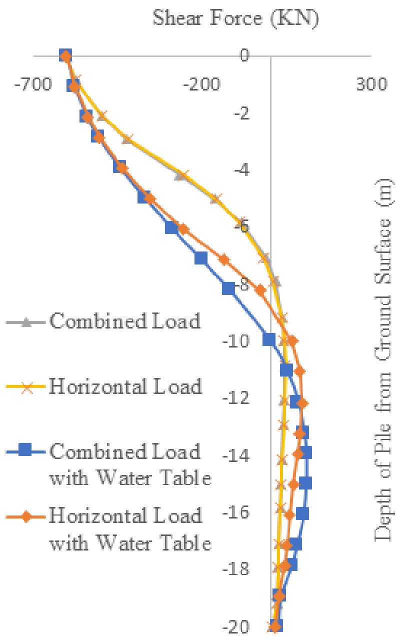

Figure 7: Shear Force along pile bored in sand with and without water table from numerical model

3.4 Behaviour of group piles in sand

Models with pile spacing 2.5d and 3.5d were prepared as shown in figure 2. Bending moment and shear force diagram are obtained. Shear force has been normalized against horizontal load for single pile producing same deflection as shown in Figure 8 and Figure 10[5, 6]. For pile spacing 2.5d, the ratio of shear force of leading pile to normalizing shear force of single pile is 0.67 and the ratio for pile spacing 3.5d is 0.77. The result is similar to data from past studies[5]. Shear force diagram obtained from respective models are shown in Figure 9 and Figure 11. For first trailing and second trailing pile, the reduction ratio are 0.49 and 0.33 respectively for pile spacing 2.5d. For pile spacing 3.5d, the ratio are 0.42 and 0.21 respectively.

Leading pile is subjected to maximum stress and depth of zone of passive resistance is most as seen from figure 8 and figure 10. The nature of curves for all three piles is influenced by adjacent piles. Thus the nature of curves is different for the three piles in group.

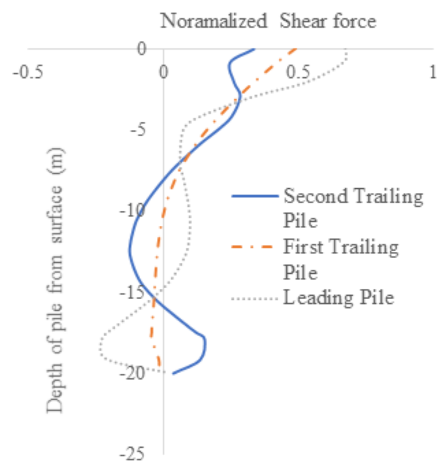

Figure 8: Variation of normalized shear force in a row for pile spacing 2.5d

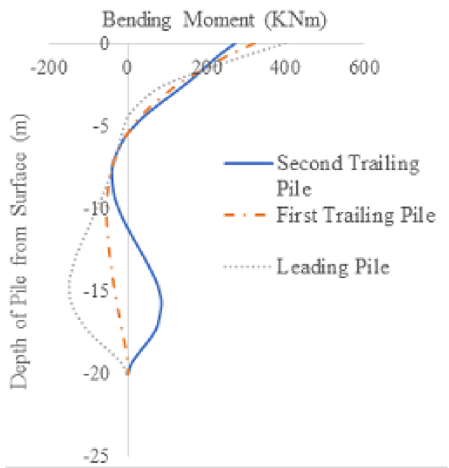

Figure 9: Variation of bending moment in a row for pile spacing 2.5d

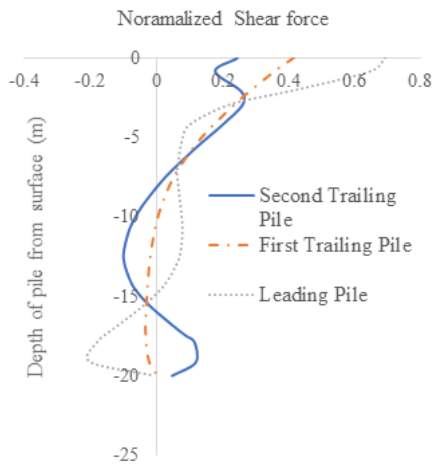

Figure 10: Variation of normalized shear force in a row for pile spacing 3.5d

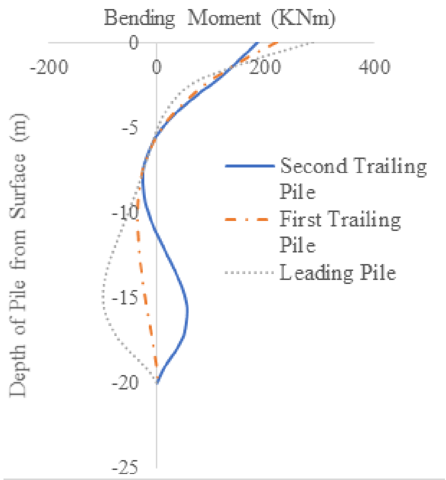

Figure 11: Variation of bending moment in a row for pile spacing 3.5d

4. Conclusion

This paper presents a single and a row of piles subjected to combined loading under different conditions: spacing of pile and water table. The results obtained from various conditions are compared with each other and some valuable conclusions have been derived and presented as follows.

1. Lateral deflection of pile is not significantly affected by the application of vertical load when water table is not present.The variation is less than 2%. However, when the water is present,the pile under the water table shows increased deflection which is higher in case of combined loading compared to the laterally loaded pile. The increase is significant and may increase up to 2 times.

2. Stress on pile under sand without water table is similar for both lateral and combined loading.The variation in values of bending moment and Shear force is less than 1%. When water table is introduced, stress on pile increases significantly, which is higher for the combined loading. In the model, the increase is 37% and 28% for bending moment in case of combined loading and lateral loading respectively.

3. Leading pile is subjected to higher stress compared to trailing piles; and when the trailing pile is farther from the leading pile, the stress on it is relatively lower. The ratio of bending moment of leading to maximum bending moment of single pile is 0.67 and 0.77 for 2.5d and 3.5d respectively.

4. For the better understanding of pile soil interaction, its 3D analysis must be performed.

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