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REVIEW

Numerical study on vertical bearing behavior of pedestal pile's embedded in fine grained soils

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The aim here is to investigate the behavior of pedestal/belled piles present in soft clay soil through numerical analysis using Plaxis 2D software. The method used here was based on finite element analysis to simulate pile-soil interaction and to analyze the pile's behavior under different loads by varying parameters such as length embedded in the soil and also the diameter of the shaft. The results indicate that increase in length as well as the shaft diameter of the pile enhances the pile's load-bearing capacity. The study also shows that the pedestal/bell pile can improve the pile's performance in soft clay soil by reducing the soil's displacement and increasing the pile's axial capacity in comparison to conventional straight pile. The study concludes that the pedestal/belled pile is a promising option for the foundation of structures in soft clay soil, and the numerical analysis using Plaxis 2D software can provide quick and reliable predictions of the pile's behavior. The study's findings can be useful for optimizing the design of pedestal/belled piles in soft clay soil and improving the efficiency and safety of foundation systems in similar geotechnical conditions.

Keywords: PLAXIS 2D, settlement, belled pile, pedestal pile, mohr-coulomb

Introduction

The of a structure is critical for its reliability and stiffness. The foundation and the superstructure are interdependent - without a strong foundation, the superstructure cannot exist. However, historically, more attention has been paid to the superstructure, while the importance of a solid foundation has been overlooked. Foundation engineering is a vast field of study because soils are unpredictable and can vary greatly depending on geological conditions. It is essential for engineers to solve real-world problems to ensure a reliable superstructure.

In recent years, software advancements have enabled researchers to model and analyze various structural elements accurately. This study utilizes PLAXIS 2D, a powerful and user-friendly software package developed by Bentley Systems Incorporated, to perform finite element analysis (FEA). FEA has been a game-changer since the 1960s, allowing for great innovations and discoveries. PLAXIS 2D's exceptional accuracy in solving and providing results has been incorporated into this study.

Belled pile foundations, also known as pedestal piles, are commonly used in the construction of various structures like transmission towers along with ports as well as piers which are prone to massive external actions. These deep foundations have an enlarged base at the bottom, which could make maximum use of the soil's strength in shear and facilitate good holding capacity while resisting the uplifted load and also the bending moment. However, the behavior of belled piles in fine-grained soil is complex and difficult to predict accurately using traditional methods. Therefore, the main aim is to analyze the applicability of belled piles in fine-grained soil, with a particular focus on using numerical analysis techniques to investigate their behavior. Numerical analysis is a powerful tool that allows for a more detailed and accurate understanding of the behavior of belled piles in different soil conditions. Unlike field load tests, which are time-consuming, costly, and can be affected by numerous factors such as weather, numerical analysis can provide quick and reliable results with a high degree of accuracy.

Methodology

Plaxis 2D FEA and interface

In this study, the finite element method program PLAXIS 2D V20 is used to obtain load-bearing ability of belled piles undergoing concentric axial load (point load). The software platform provides a 2-D interface that is similar to CAD tools used for drafting drawings. The bore hole tool is used to create the soil strata followed by inputting the soil and other material data, prescribing the depth of the soil model. After the structure of pile gets modeled, initial conditions are defined, staged the construction of the pile similar to field load test, and staged the loads in increments. The results were extracted as displacements caused by respective static loading, plotted load-displacement graphs, and determined the ultimate loads. PLAXIS-2D offers two types of finite elements, 6-noded and 15-noded triangular elements, the latter is used to discretize the soil model. This decision was made because it is more advantageous due to its better capturing of failure modes and thereby produces robust solutions for geotechnical problems.

Model type

The pile model type used in this study is Axisymmetric because the pile foundation in this analysis is circular in shape with uniform radial cross-section and the loading is applied along its central axis, where deformations are taken to be similar in any direction radially. In an axisymmetric model, the axis(x) is representing the radius and the axis(y) is representing the symmetrical line in the interface.

Meshing technique

Meshing is a crucial step in any finite element program as the accuracy of the results depends on the model's fineness or coarseness. However, adopting finer meshing techniques often results in higher computational time. Therefore, this study has used a medium meshing technique for reasonable computing time and accurate results.

Constitutive model

Soil modeling is a complex and critical part of geotechnical analysis, and constitutive soil model is used to simulate the soil character as a unit element subjected to loading and how the soil material responds. To solve practical engineering problems, it is important to consider complex constitutive models. Various soil models, such as Mohr-Coulomb, Hardening soil, HS small, and more, are available, and in this study, the soil modeling is done using the Mohr-Coulomb

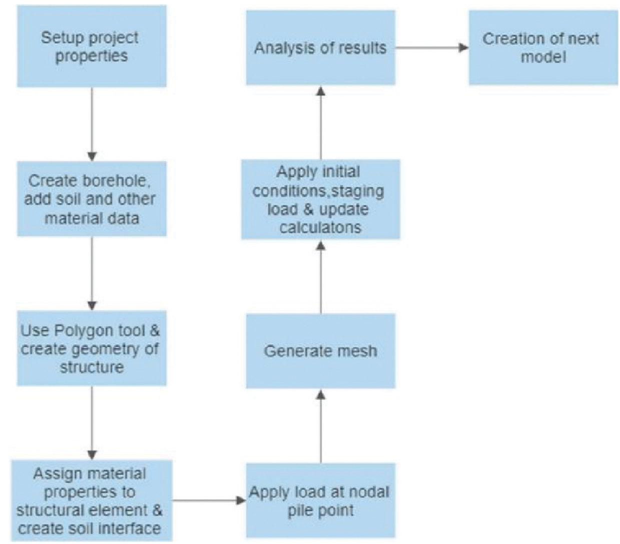

FIGURE 1 | Flowchart of simulation process.

type, one of the most widely used constitutive soil models to simulate soil behavior. It is the simplest model that requires few parameters such as cohesion c, angle of internal friction φ, Elastic modulus E, Poisons ratio ν, bulk density γ and Saturated density γ_{sat} and the accuracy is reasonably good for preliminary analysis and studies.

Procedure used for simulation of analysis

Figure 1 Following flow chart expresses the procedure adopted for simulation of pile model.

Parametric studies

This study has considered two parameters i.e., Embedded length (L) and Diameter od Shaft (D_S). Both the pile types were subjected to point loads along their centroidal axis and the consequent settlements observed for each load were recorded and a load vs. settlement graph was prepared.

The first parameter is the embedded length (L), the length of the belled pile was varied from 4 m, 5 m, 6 m and 7 m, and the diameter of the pile shaft (D_s) is taken as 0.5 m, the D_b/D_s is 2.5 and an optimum bell angle of 45° is adopted, these categories of piles have been classified as B-Piles as shown in **Table 1** along with the schematic model diagram in **Figure 2**.

The second parameter is the diameter of shaft (D_s), the length of the pile was fixed at 5 m, and the shaft diameter (D_s) is varied from 0.3 m, 0.4 m, 0.5 m, and 0.6 m diameter keeping D_b/D_s of 2.5 and an optimum bell angle of 45°, these categories of piles have been classified as C-Piles as shown in **Table 2** along with the schematic model diagram in **Figure 3**.

Similar analysis was followed to compare the performance for conventional straight pile foundations by varying its length and shaft diameter. The (table) provides summary

TABLE 1 | Classification of B Piles.

Pile	L (m)	Ds (m)	Db (m)	Db/Ds
B1	4 m	0.5 m	1.25	2.5
B2	5 m	0.5 m	1.25	2.5
B3	6 m	0.5 m	1.25	2.5
B4	7 m	0.5 m	1.25	2.5

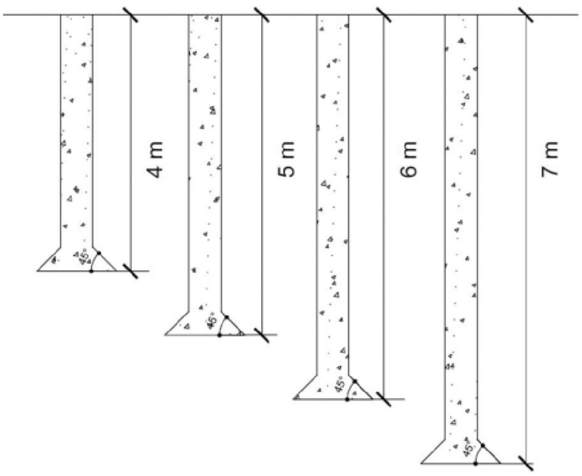

FIGURE 2 | Schematic section for B belled piles.

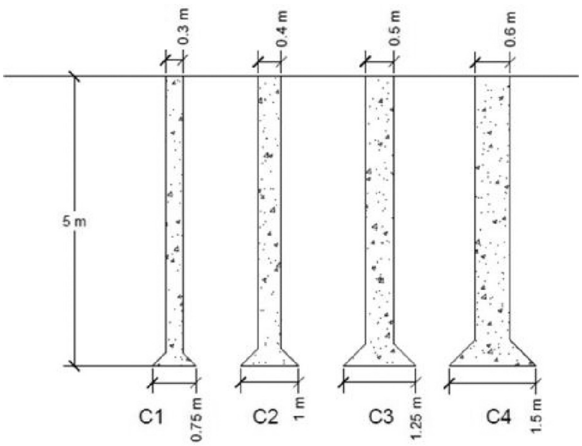

FIGURE 3 | Schematic section for C belled piles.

of selected cases of straight piles. The pedestal pile and soil properties used in the analysis are shown in Table 3.

Results and discussions

The analysis was conducted on pedestal piles with varying embedded lengths (L) and shaft diameters (D_s), as well as straight piles. The results of the study revealed that the embedded length and shaft diameter of pedestal piles significantly affect their load-bearing capacity. As the embedded length of the pedestal pile increased, the load bearing capacity also increased. This is because longer embedded lengths allow the pile to interact with deeper and more stable soil layers, thereby increasing its capacity to resist loads. Similarly, as diameter of the shaft increased, the load-bearing capacity of the pedestal pile also increased. This is because a larger diameter shaft provides more lateral resistance to the soil, which in turn increases the pile's load-bearing capacity. Moreover, the study also found that straight piles exhibited a lower load-bearing capacity compared to pedestal piles. This is because pedestal piles are designed with a wider base or footing, which distributes the load more evenly across the soil, resulting in a greater load-bearing capacity.

The findings of this study have significant implications for the construction and the design of foundation systems. Specifically, engineers and designers should consider the embedded length and shaft diameter of pedestal piles to ensure optimal load-bearing capacity. Additionally, pedestal piles should be preferred over straight piles when designing foundation systems that need to support heavier loads. However, it is important to note that the results of this study are specific to the soil conditions and pile configurations used in the experiment. Therefore, further research is needed to determine the applicability of these findings to other soil conditions and pile configurations. Nonetheless, the present study provides a valuable contribution to the understanding of the behavior of pedestal piles and their load-bearing capacity.

Figure 4 compares the load displacement/settlement curves of the belled pile's having different embedded length (L) (B1, B2, B3, and B4 respectively). B1 pile for 40 mm settlement the load is approx 190kN whereas the embedded length is increased the settlement is reduced subsequently for the same 190kN.

Figure 5 compares the load displacement/settlement curves of the belled pile's having different Diameter of Shaft(Ds) (C1, C2, C3, and C4 respectively). C1 pile for 40mm settlement the load is approx. 80kN whereas the diameter of the shaft is increased the settlement is reduced subsequently for the same 80kN. But the load carrying capacity increased drastically when compared to C1 and C2 Piles.

TABLE 2 | Classification of C Piles.

Pile	L(m)	Ds(m)	Db(m)	Db/Ds
C1	5 m	0.3 m	0.75	2.5
C2	5 m	0.4 m	1	2.5
C3	5 m	0.5 m	1.25	2.5
C4	5 m	0.6 m	1.5	2.5

TABLE 3 | Properties of material's used in simulation.

Type	Material model	Drainage type	γ_{unsat} (kN/m^3)	γ_{sat} (kN/m^3)	E (kN/m^2)	ν	C (kN/m^2)	φ
Pile	Linear Elastic	Non-Porous	28	28	30e6	0.35	–	–
Clay	Mohr- Coulomb	Drained	18	19	9.5e3	0.25	50	20

E, the modulus of elasticity, c the cohesion, φ the angle of internal friction, ν the Poissions ratio, γ_{unsat} the bulk density and γ_{sat} the Saturated unit weight.

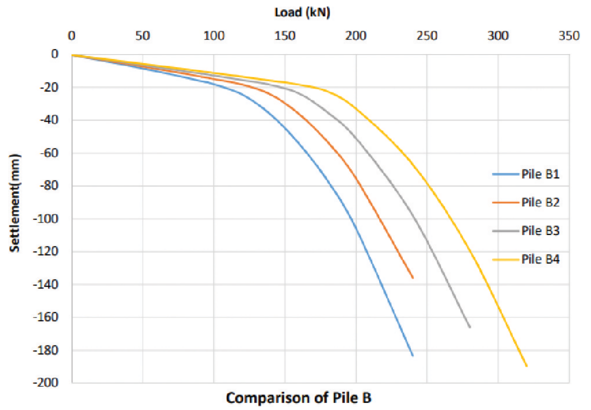

FIGURE 4 | Comparison of B Piles.

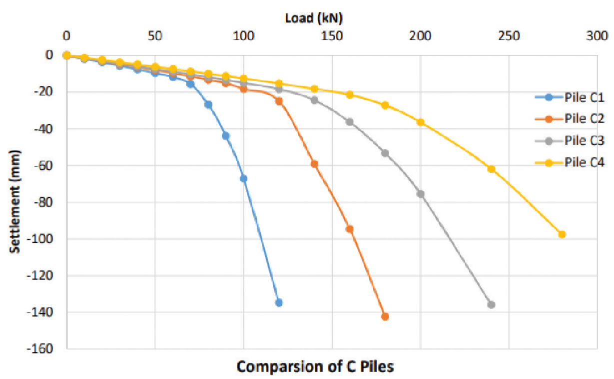

FIGURE 5 | Comparison of C Piles.

Conclusion

After conducting the analysis on pedestal piles and straight piles of varying shaft diameters and embedded lengths, it is evident that pedestal piles outperformed straight piles in all criteria, exhibiting larger load-bearing capacity and minimal settlements for similar loading conditions. The depth of embedding of piles was found to be a crucial factor affecting their load-bearing capacity, as the capacity increased by approximately 20 kN for every meter increase in the depth of embedding.

For a 100 kN load, piles with shaft diameters of 0.3m (C1) yielded the highest settlement of about 68mm, while piles with shaft diameters of 0.4 m (C2), 0.5 m (C3), and 0.6 m (C4) had settlements below 20 mm, indicating that a larger diameter shaft provides greater lateral resistance to the soil, resulting in lower settlements.

Overall, the study has provided significant insights into the behavior of pedestal pile's and their load-bearing capacity, and the findings have practical implications for the construction and the design of foundation systems. It can be concluded that performing numerical-based analysis in software such as PLAXIS is more economical, time-saving, and provides reliable results. Therefore, designers and engineers can rely on the results of such analyses to optimize the design of foundation systems and ensure their safe and efficient construction.

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