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CUBIC REGRESSION-BASED ANALYSIS OF BORED PILE BEARING CAPACITY IN SANDY SOILS: AN EVALUATION APPROACH

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ABSTRACT: The paper investigates the load-bearing capacity of bored piles in uneven sandy soil conditions, an important issue in the design of deep foundations for large construction projects. The research aims to analyze the relationship between load and vertical displacement of the bored piles while determining the maximum bearing capacity of the pile in a sandy environment with uneven characteristics. The methodology includes numerical simulation using PLAXIS 3D software combined with field tests to analyze the displacement changes of the piles under different load levels. The results indicate that the displacement does not follow a linear relationship but increases rapidly once the load exceeds 17000 kN, with significant settlement observed as the load increases. The cubic regression model applied in this study shows high accuracy, with an R^2 value of 0.997, meaning that 99.7% of the displacement variation can be explained by the load change. The maximum bearing capacity of the bored pile is determined to be 13495.73 kN, indicating the load limit that the pile can withstand before significant settlement occurs. The research contributes to improving deep foundation design in uneven sandy soil conditions and provides useful tools for engineers and designers to assess the load-bearing capacity of bored piles, thereby optimizing foundation construction solutions for real-world construction projects.

Keywords: Bored pile bearing capacity, Cubic regression analysis, Finite element method (FEM), Sandy soil settlement

1. INTRODUCTION

In infrastructure construction, the design of deep foundations plays a crucial role in ensuring the stability and safety of structures, particularly in large-scale projects such as high-rise buildings, bridges, and other civil engineering works. Bored piles, a common type of deep foundation, have been widely used in construction due to their high load-bearing capacity and adaptability to various geological conditions. Bored piles are typically applied when the surface soil layers have low stiffness and insufficient load-bearing capacity, making them an effective solution for transferring the load of the structure to deeper, more stable soil layers [1-3]. However, calculating and analyzing the load-bearing capacity of bored piles in different soil conditions remains a challenging issue, especially in sandy soil environments, which are heterogeneous and prone to fluctuation [4-8].

In recent years, numerous studies have been conducted to assess the load-bearing capacity of bored piles in sandy soils through experimental testing, field trials, and numerical analysis. These studies have shown that the load-bearing capacity of piles is influenced by various factors such as soil density, moisture saturation, loading conditions, and construction methods [9-14]. However, most studies have focused on clay or hard rock soils, while sandy soils, with their highly variable properties, have not been fully investigated. The application of finite element models in predicting pile settlement in sandy soil environments still has many gaps, particularly in defining the nonlinear relationship between load and settlement [15-18]. Therefore, expanding research to accurately analyze the load-bearing behavior of bored piles in uneven sandy soil conditions is necessary to improve the reliability of foundation design. Analytical methods such as field testing (Standard Penetration Test - SPT, Static Compression Tests - SCT), finite element analysis (FEA) using software like PLAXIS 3D, and load simulations have been applied to predict the load-bearing capacity and behavior of piles in real-world construction conditions [19-22]. These studies have provided an overview of the factors influencing pile load-bearing capacity, ranging from the physical properties of the soil to specific load conditions. However, many factors remain under-researched, particularly in sandy soil conditions, where the soil's homogeneity and load distribution are not always easily predictable.

The research problem addressed in this paper is to fill the gap in modeling and analyzing the load-bearing capacity of bored piles in sandy soil conditions. While many studies have analyzed bored piles under various soil conditions, most of these studies have focused primarily on clay or hard rock soils, while sandy soils – which have unique mechanical properties and significant variability – have not received sufficient attention. Therefore, applying finite element modeling to accurately simulate the load-bearing behavior of bored piles in sandy soils is essential in practice.

The objective of this study is to use PLAXIS 3D software to model and analyze the load-bearing capacity of bored piles in sandy soil, to assess the impact of geological factors and load on pile behavior. The study will focus on simulating three different loading cycles, from low to high loads, to determine the maximum load-bearing capacity of the pile. The analysis model will be calibrated based on field test results such as SPT and SCT to ensure the accuracy of the simulation predictions.

2. RESEARCH SIGNIFICANCE

The significance of this study is crucial for improving the design of bored piles, especially in construction projects with uneven sandy soil conditions, such as variability in density, moisture saturation, compressibility, and stress distribution. The cubic regression model not only helps to accurately predict the change in displacement of the bored pile under different load levels but also provides a useful tool for engineers and designers in determining the load-bearing capacity of bored piles in complex soil environments. Using this model will enhance the accuracy of design calculations and optimize deep foundation solutions in construction projects.

3. MATERIALS AND METHODS

The study area consists of an 80m thick sandy soil layer with a groundwater level at a depth of -1.5m. The subject of the study is a bored pile with a diameter of 1m, made of B25 concrete, with a depth of 45.3m and a design load of 8500 kN [23]. B25 concrete, produced according to international standards, has high compressive strength, making it suitable for deep foundations in infrastructure construction [24, 25]. Soil samples have been collected and processed to analyze physical and mechanical properties, such as density, moisture content, elasticity modulus, and shear strength (Table 1).

Field tests such as the SPT and SCT were conducted to evaluate the geological properties and compressibility of the soil at different depths (Table 2) [26]. The obtained data were used to construct and calibrate the numerical analysis model, ensuring an accurate simulation of the actual conditions of the soil layer and the pile.

The numerical simulation used Finite Element Analysis (FEA) software, specifically PLAXIS 3D, to simulate real-world conditions and predict the load-bearing capacity of the bored pile [27]. The model accurately represents the geological structure and soil layers of the study area, with the piles simulated according to their actual size and depth (Fig. 1). In the numerical analysis, the study assumes the soil to be elastic, homogeneous, and isotropic, without considering the variation in moisture content and the effects of the pile installation process.

Table 1. Descriptive Parameters of Soil Layers

Property	Symbol	Unit	Layer 8
Soil Type			Sandy Clay
Natural Void Ratio	e		0.585
Density	γ_w	g/cm^3	2.024
Saturated Density	γ_{sat}		2.056
Direct Shear Test	C	kN/m^2	5.39
	φ	0	31°1'
Average SPT			48

Table 2. SCT Results

Load Level (% Design Load)	Load (Tons)	Load Holding Time (Minutes)	Settlement (mm)
Cycle 1			
0	0	0	0
25	212.5	60	1.68
50	425	60	3.37
75	637.5	60	5.55
100	850	360	7.99
50	425	30	6.38
0	0	60	2.58
Cycle 2			
25	212.5	30	4.16
50	425	30	6.28
75	637.5	30	7.95
100	850	30	9.66
120	1020	60	11.34
140	1190	60	13.46
160	1360	60	16.09
170	1445	60	18.86
180	1530	60	22.41
190	1615	180	36.94
185	1572.5	1440	38.62
160	1360	30	38.55
120	1020	30	37.31
100	850	30	35.27
50	425	30	30.87
0	0	60	25.13

Vertical load levels were applied in three cycles: Cycle 1 from 0 to 100% of the design load (0 to 8500 kN), Cycle 2 from 0 to 190% of the design load (0 to 16150 kN), and Cycle 3 from 0 to 300% of the design load (0 to 25500 kN). Cycles 1 and 2 simulate conditions similar to the field SCT tests, while Cycle 3 is used to determine the maximum load-bearing capacity. The simulation results from Cycles 1 and 2 are compared with SCT data (test load of 16150 kN) to validate the accuracy of the model.

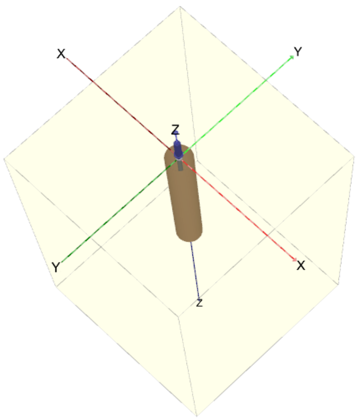

Fig. 1 Model of the Bored Pile

A cubic regression analysis was applied to the FEM data to study the relationship between the applied load and the vertical displacement of the pile [28-30]. The regression equation is formulated as Eq. (1).

$$Uy = aP^3 + bP^2 + cP + d \quad (1)$$

where Uy represents the vertical displacement, and P is the load. To determine the maximum load-bearing capacity of the pile during loading, the tangent equations are calculated at the corresponding load points of 100% and 200% of the design load. These tangent lines are determined through the derivative of the regression equation as Eq. (2).

$$m = 3aP_0^2 + 2bP_0 + c \quad (2)$$

The maximum bearing capacity of the pile is calculated by solving the intersection equation of the two tangent lines using the formula Eq . (3).

$$P_{max} = \frac{m_2P_2 - m_1P_1 + Uy_2 - Uy_1}{m_1 - m_2} \quad (3)$$

where P_{max} is the intersection point's abscissa, P_1 and P_2 are the abscissas of the tangent points, and Uy_1 and Uy_2 are the corresponding displacement values at these points.

4. RESULTS

The FEM analysis and Static Compression Test (SCT) of the bored pile at the pile head under different load levels in Cycle 1 (Fig. 2) and Cycle 2 (Fig. 3) highlight the vertical displacement (Uy) behavior (Table 3).

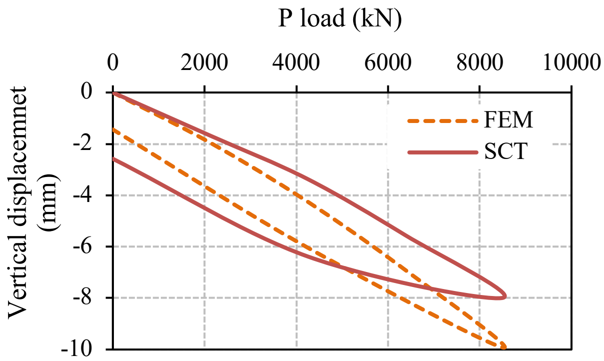

Fig. 2 Vertical displacement in Cycle 1

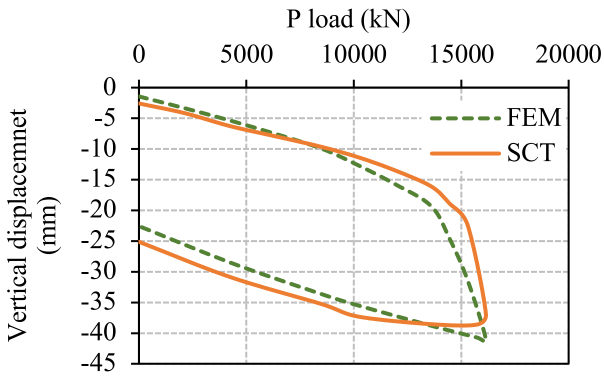

Fig. 3 Vertical displacement in Cycle 2

In the first cycle, both methods show an increase in settlement as the load increases. However, FEM data shows greater settlement and a more linear trend, indicating that FEM responds more quickly and sensitively to load changes compared to SCT. In the second cycle, the settlement rate for both methods is relatively similar across the low to high load levels. The displacement of the pile is influenced by the load level P, with settlement increasing rapidly when the load exceeds a threshold, reflecting a decrease in load-bearing capacity.

The comparison between SCT and FEM shows a correlation coefficient of 0.97 in both Cycle 1 and Cycle 2, indicating that both methods provide similar results regarding settlement under different load levels, confirming the consistency between SCT and FEM. The study also shows that FEM more sensitively reflects the factors affecting vertical displacement, possibly due to its ability to more accurately simulate structural and environmental factors. However, the differences between the two methods indicate that assumptions and input parameters play a crucial role in influencing the research results. The discrepancies between numerical simulation and field testing primarily stem from the soil parameters used in the FEM model, particularly the elastic modulus, internal friction angle, and applied boundary conditions.

Table 3. Description of Load Levels with Corresponding Time and Settlement

Load Level (% Design Load)	Load (kN)	Load Holding Time (Minutes)	Vertical Displacement (mm) - SCT	Vertical Displacement (mm) - FEM
0	0	0	0	0
25	2125	60	-1.68	-1.96
50	4250	60	-3.37	-4.25
75	6375	60	-5.55	-6.9
100	8500	360	-7.99	-9.92
50	4250	30	-6.38	-6.04
0	0	60	-2.58	-1.44
25	2125	30	-4.16	-3.35
50	4250	30	-6.28	-5.37
75	6375	30	-7.95	-7.56
100	8500	30	-9.66	-9.94
120	10200	60	-11.34	-12.64
140	11900	60	-13.46	-15.69
160	13600	60	-16.09	-19.29
170	14450	60	-18.86	-24.55
180	15300	60	-22.41	-31.41
190	16150	180	-36.94	-41.09
185	15725	1440	-38.62	-40.72
160	13600	30	-38.55	-38.8
120	10200	30	-37.31	-35.5
100	8500	30	-35.27	-33.65
50	4250	30	-30.87	-28.51
0	0	60	-25.13	-22.57

Table 4. Results of Vertical Displacement Analysis using FEM (Cycle 3)

Time (min)	P load (kN/m2)	Vertical Displacement (Uy) (mm)
30	2125	-2.025
30	4250	-4.319
30	6375	-6.972
30	8500	-9.990
60	10200	-12.713
60	11900	-15.761
60	13600	-19.395
60	14450	-24.406
60	15300	-31.461
180	16150	-41.217
60	17000	-53.096
60	19125	-90.300
60	21250	-135.431
60	23375	-186.834
60	25500	-244.066

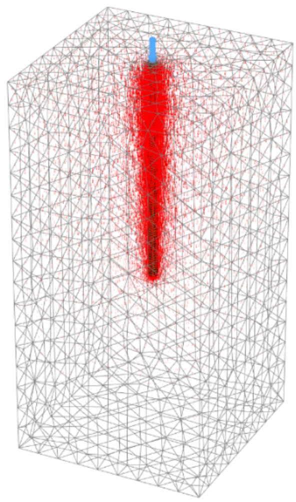

Fig. 4 Vertical displacement (25% design load)

The FEM analysis in Cycle 3, with loads ranging from 0 to 25500 kN (Table 4), shows a continuous and significant increase in settlement as the load increases (Fig. 4). This growth is not only linear but also tends to increase exponentially as pressure exceeds a certain threshold. Specifically, at high load levels, settlement increases sharply when the pressure exceeds 17000 kN (Fig. 5), indicating significant vertical settlement of the bored pile under high loads.

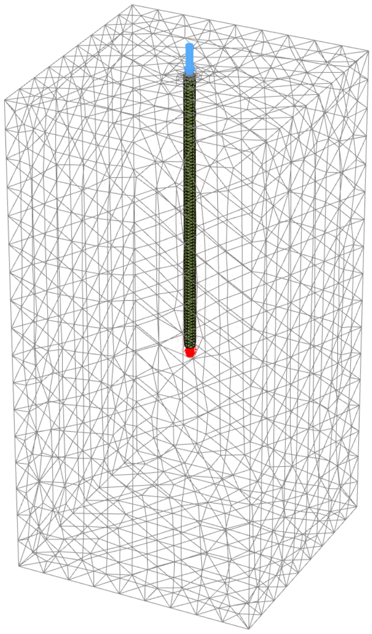

Fig. 5 Vertical displacement (200% design load)

Table 5. ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	76376.505	3	25458.835	1059.423	0.000
Residual	264.339	11	24.031		
Total	76640.844	14			
The independent variable is P.					

Table 6. Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.998	0.997	0.996	4.902
The independent variable is P.			

The ANOVA analysis results show that the P-value (Sig.) is $0 < 0.05$ (Table 5), indicating a statistically significant relationship between load and vertical displacement. The high F-value of 1059.423 further confirms the statistical significance of the model in explaining the variation in vertical displacement. The statistical analysis model indicates an almost perfect relationship between the independent variable (load) and the vertical displacement variable, with an R-value of 0.998, R^2 of 0.997, and adjusted R^2 of 0.996, showing an almost perfect fit of the regression model to the collected data (Table 6). This means that 99.7% of the variation in vertical displacement can be entirely explained by the change in load, with no data dispersion around the regression line. Eq. (4) describes the cubic regression model used to represent the relationship between load and vertical displacement of the bored pile.

$$\boldsymbol{Uy = -2.74 \times 10^{-11} x^3 - 3.85 \times 10^{-07} x^2 - 1.71 \times 10^{-3} x - 2.26} \quad (4)$$

The tangent line equation at the 100% design load is $y^{tl}_{100\%} = -0.0011x + 3.622$ and the tangent line equation at the point with the 200% design load is $y^{tl}_{200\%} = -0.0124x + 156.015$ as shown in Fig. 6.

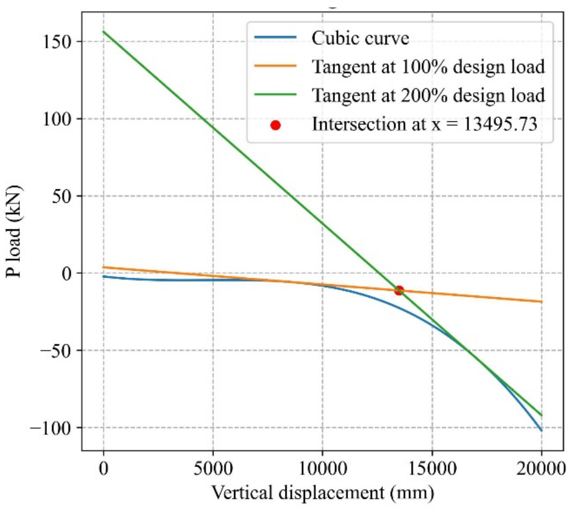

Fig. 6 Tangent line of Cubic curve

The maximum bearing capacity of the pile is determined by the intersection point of the two tangent lines from the cubic regression model at the intersection positions corresponding to 100% and 200% of the design load, where there is a sudden change in slope, indicating the maximum load the pile can withstand before significant settlement occurs. Solving the intersection abscissa equation shows that the maximum bearing capacity is $P_{max} = 13495.73$ kN.

5. DISCUSSION

The research results on the load-bearing capacity of bored piles in uneven sandy soil conditions have revealed several similarities and differences compared to previous studies. While earlier studies generally show that bored piles have good load-bearing capacity in homogeneous sandy soil conditions, the load-bearing capacity of the pile significantly changes when the soil is sandy and uneven. This study has clarified the relationship between load and displacement of the bored pile in uneven sandy soil through numerical analysis using PLAXIS 3D software combined with actual experimental data. Specifically, the displacement of the bored pile does not follow a linear pattern but tends to increase sharply when the load exceeds a certain threshold. Moreover, the phenomenon of rapid settlement when the load exceeds a threshold is not new, but this study emphasizes that this change occurs more significantly and distinctly in uneven sandy soil conditions, which previous studies have not fully addressed. This indicates that bored piles can withstand high loads in stable sandy soil conditions, but this stability rapidly diminishes when the load surpasses a certain limit.

The relationship between Table 3, Table 4, Eq. (4), and Fig. 6 demonstrates consistency in the analysis of the bearing capacity of bored piles. Data from Table 3 and Table 4 provide information on settlement at different load levels, while Equation 4 describes the nonlinear relationship between load and displacement. Fig. 6 illustrates the bearing capacity limit, confirming the trend observed in both numerical simulations and field tests.

The cubic regression model applied in this study to simulate the relationship between load and vertical displacement of the bored pile has demonstrated high accuracy, with an R^2 value of 0.997. This means that 99.7% of the displacement variation can be explained by the change in load. This result is particularly evident when the pressure exceeds 17000 kN, where the change in displacement of the bored pile becomes pronounced, indicating a decrease in the pile's load-bearing capacity.

In terms of practical application, the results of this study can be directly applied in the design and construction of bored pile foundations, especially in projects that require high accuracy regarding load-bearing capacity. Engineers and designers can use the cubic regression model to predict the change in displacement of the bored pile under different load levels. Parameters such as the slope of the regression line will help identify the load limit that the pile can withstand before significant settlement occurs. This is especially important when working with uneven soils, where traditional calculation methods may not be sufficiently accurate. Therefore, in deep foundation projects, combining field testing methods with numerical simulations will help determine the load-bearing capacity more precisely and, thus, provide optimal solutions for construction projects.

6. CONCLUSIONS

This study has clarified the relationship between load and vertical displacement of bored piles in uneven sandy soil conditions and has also determined the maximum load-bearing capacity of the pile. The research results indicate that the displacement of the bored pile does not increase in a linear fashion but tends to rise sharply at higher load levels. The cubic regression model applied in the study demonstrated high accuracy, with an R^2 value of 0.997, indicating that 99.7% of the variation in displacement can be explained by the change in load. As a result, the maximum load-bearing capacity of the bored pile was determined to be 13495.73 kN, corresponding to the intersection point of the two tangent lines from the regression model, indicating the load limit that the pile can withstand before significant settlement occurs.

The cubic regression model developed in the current study, while achieving high accuracy in simulating the relationship between load and displacement of bored piles in uneven sandy soils, still has certain limitations. One of the main limitations of the model is its complexity when applied to soils other than uneven sandy soil. The current model is primarily developed and optimized for sandy soil, so when applied to other types of soil, such as clay or gravel, the results may be inaccurate or unsuitable.

Furthermore, the cubic regression model requires a large amount of experimental data to ensure accuracy, which can be challenging in cases where experimental data is scarce at various locations. Other complex geological factors, such as moisture variation or the effects of climatic conditions, could also reduce the model's accuracy in specific cases.

Compared to other regression models developed for bored piles in sandy soils, the cubic regression model in this study differs in that it not only relies on linear factors or second-degree models but also incorporates nonlinear factors, helping to more accurately reflect the significant change in displacement when the load exceeds a certain threshold. Therefore, future studies should expand the experimental scope to include sandy soils with more variable properties and incorporate environmental factors to refine the model. Moreover, applying advanced analytical methods such as multivariate simulation or machine learning could improve the model's accuracy and broaden its applicability to more complex real-world conditions. These studies will contribute to enhancing the effectiveness of bored pile design in large construction projects, ensuring stability and safety across various geological conditions.

7. REFERENCES

[1] Huynh, V.-H., T. Nguyen, D.-P. Nguyen, T.-S. Nguyen, T.-M.-D. Huynh, and T.-C. Nguyen, A novel direct SPT method to accurately estimate ultimate axial bearing capacity of bored PHC nodular piles with 81 case studies in Vietnam. Soils and Foundations, Vol. 62, Issue 4, 2022, pp. 101163

[2] Mihálik, J., F. Gago, J. Vlček, and M. Drusa Evaluation of Methods Based on CPTu Testing for Prediction of the Bearing Capacity of CFA Piles. Applied Sciences, 2023. 13, DOI: 10.3390/app13052931.

[3] Wei, Y., D. Wang, J. Li, Y. Jie, Z. Ke, J. Li, and T. Wong Evaluation of Ultimate Bearing Capacity of Pre-Stressed High-Strength Concrete Pipe Pile Embedded in Saturated Sandy Soil Based on In-Situ Test. Applied Sciences, 2020. 10, DOI: 10.3390/app10186269.

[4] Kardani, N., A. Zhou, M. Nazem, and S.-L. Shen, Estimation of Bearing Capacity of Piles in Cohesionless Soil Using Optimised Machine Learning Approaches. Geotechnical and Geological Engineering, Vol. 38, Issue 2, 2020, pp. 2271-2291

[5] You, R. and H. Mao, Assessment of ultimate bearing capacity of rock-socketed piles using hybrid approaches. Multiscale and Multidisciplinary Modeling, Experiments and Design, Issue 2024, pp.

[6] Decourt, L. Behavior of foundations under working load conditions. in Proceedings of the 11th Pan-American Conference on Soil Mechanics and Geotechnical Engineering. 1999. International Society for Soil Mechanics and Geotechnical Engineering London, UK.

[7] Hansen, B., A general formula for bearing capacity. (No Title), Issue 1961, pp. 38

[8] Van der Veen, C. The bearing capacity of pile. in Proc. 3rd ICSMFE. 1953.

[9] B. Heidari, S. Yoosefi, and A. A. Garakani, Assessing the effects of horizontal loads on the ultimate vertical bearing capacity of energy piles: A comparative numerical and analytical study, Renew. Energy, Vol. 234, 2024, pp. 121204

[10] V. Ghiasi and S. Eskandari, Comparing a single pile's axial bearing capacity using numerical modeling and analytical techniques, Results Eng., Vol. 17, 2023, pp. 100893

[11] T. N. Anh, T. D. Xuan, P. N. Tuan, and H. T. V. Van, Enhancing the Accuracy in Predicting the Maximum Bearing Capacity of Bored Piles Using Derivative Analysis and FEM Simulation, Transp. Infrastruct. Geotechnol., Vol. 12, Issue. 1, 2025, pp. 77

[12] X. Bai, Y. Zhang, N. Yan, J. Liu, and Y. Zhang, Experimental investigation on bearing capacity of rock-socketed bored piles in silty clay stratum in beach areas, Appl. Ocean Res., Vol. 154, 2025, pp. 104336.

[13] A. Akbari Garakani, B. Heidari, S. Mokhtari Jozani, and O. Ghasemi-Fare, Numerical and Analytical Study on Axial Ultimate Bearing Capacity of Fixed-Head Energy Piles in Different Soils, Int. J. Geomech., Vol. 22, Issue. 1, 2022, pp. 04021258.

[14] Y.-C. Yu, W.-X. Ren, Y.-G. Yin, and X.-G. Luo, Numerical simulation and field tests on vertical load bearing behaviour of bored root piles, Comput. Geotech., Vol. 159, 2023, pp. 105453.

[15] M. Y. Fattah, K. T. Shlash, and M. S. M. Al-Soud, Pile-clayey soil interaction analysis by boundary element method, J. Rock Mech. Geotech. Eng., Vol. 4, Issue. 1, 2012, pp. 28–43

[16] M. Hamderi, Comprehensive group pile settlement formula based on 3D finite element analyses, Soils Found., Vol. 58, Issue. 1, 2018, pp. 1–15.

[17] T. Nguyen, D.-K. Ly, J. Shiau, and P. Nguyen-Dinh, Optimizing load-displacement prediction for bored piles with the 3mSOS algorithm and neural networks, Ocean Eng., Vol. 304, 2024, pp. 117758

[18] S. Alzabeebee and S. Keawsawasvong, Sensitivity of the seismic response of bored pile embedded in cohesionless soil to the soil constitutive model, Innov. Infrastruct. Solut., vol. 8, Issue. 1, 2022, pp. 7.

[19] Dos Santos Oliveira, E.A. and J.R. Garcia, An analysis of static loading tests on short bored pile in tropical soil. Arabian Journal of Geosciences, Vol. 16, Issue 5, 2023, pp. 299

[20] Garakani, A.A., B. Heidari, and M.S. Jozani, Analytical and Numerical Study on the Ultimate Bearing Capacity of Energy Piles in Sandy Soils. Geo-Congress 2020, Issue 2020, pp. 295-304

[21] Zhussupbekov, A., Complex of Static Loading Tests of Bored Piles. International Journal of GEOMATE, Vol. 16, Issue 58, 2019, pp.

[22] Zhou, J., E. Oh, X. Zhang, H. Jiang, M. Bolton, and P. Wang, Compressive and Uplift Static Load Tests of Shaft and Base Grouted Concrete Bored Piles, in The 27th International Ocean and Polar Engineering Conference. 2017. p. ISOPE-I-17-168.

[23] Nguyen, P.T., T.X. Dang, T.A. Nguyen, L.N. Vo, and H. Van Vu Tran, Ultimate Bearing Capacity of Clay Soils Determined Using Finite Element Analysis and Derivative-based Cubic Regression. Transportation Infrastructure Geotechnology, Vol. 12, Issue 1, 2024, pp. 7

[24] Sheinin, V.I., A.M. Dzagov, E.S. Kostenko, A.P. Manzhin, D.I. Blokhin, I.B. Maksimovich, and V.N. Soboleva, Determining the Strength Characteristics of Concrete in Drilled Piles from Tests on Extracted Core Specimens. Soil Mechanics and Foundation Engineering, Vol. 53, Issue 2, 2016, pp. 119-124

[25] Benin, A., A. Konkov, V. Kavkazskiy, A. Novikov, and N. Vatin, Evaluation of Deformations of Foundation Pit Structures and Surrounding Buildings during the Construction of the Second Scene of the State Academic Mariinsky Theatre in Saint-petersburg Considering Stage-by-stage Nature of Construction Process. Procedia Engineering, Vol.

165, Issue 2016, pp. 1483-1489
[26] Farzi, M. and A. Saligheh Zadeh, Determination of relationship between standard penetration test and geotechnical parameters in Ahwaz soil. Geomechanics and Geoengineering, Vol. 16, Issue 6, 2021, pp. 421-433
[27] Cheng, Z. and B. Jeremić, Numerical modeling and simulation of pile in liquefiable soil. Soil Dynamics and Earthquake Engineering, Vol. 29, Issue 11, 2009, pp. 1405-1416
[28] Armaleh, S. and C.S. Desai, Load‐Deformation Response of Axially Loaded Piles. Journal of Geotechnical Engineering, Vol. 113, Issue 12, 1987, pp. 1483-1500
[29] Tra, H.T., Q.T. Huynh, and S. Keawsawasvong, Estimating the Ultimate Load Bearing Capacity Implementing Extrapolation Method of Load-Settlement Relationship and 3D-Finite Element Analysis. Transportation Infrastructure Geotechnology, Issue 2023, pp.
[30] Faraway, J.J., Practical regression and ANOVA using R. Vol. 168. 2002: University of Bath Bath.