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Database-based Evaluation of Various Capacity Interpretation Criteria for Micropiles in Drained and Undrained Soils

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ABSTRACT

This study seeks to assess the correlation between theoretical and actual micropile capacities in both drained and undrained soils, considering the limited understanding of micropile behavior in diverse soil types. A comprehensive database of pile load tests was compiled from various global case histories. Theoretical capacities of micropiles in fine-grained soils were determined using Alpha and Meyerhof's methods, while Coyle's & Castello, and Meyerhof's methods were applied for coarse-grained soils. Actual micropile capacities were derived from load-displacement curves, employing interpretation methods such as the Davisson Offset, Chin, Terzaghi & Peck, and L_1-L_2 Methods. Subsequent regression analyses were conducted to establish the correlation between theoretical and actual capacities in the two soil types, accompanied by significance testing. Upon confirming a significant relationship between actual and theoretical capacities, corresponding linear regression models were recommended. These models serve as valuable guides for designers, indicating which interpretation methods are applicable at various displacement ranges required by the design.

1. INTRODUCTION

Various methods have historically been employed to determine the bearing capacity of pile foundations in geotechnical engineering. Notable methods included those proposed by Brinch-Hansen (1963), Chin-Hondner (1970), Modified Chin (1980), Decourt (1999), and a semi-empirical approach using correlations of Standard Penetration Test (SPT) and Cone Penetration Test (CPT) results (Yousif & Ali, 2021). These methods were complemented by both theoretical or calculated approaches and

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actual test results to identify pile bearing capacity. Analytical and numerical techniques were employed to estimate bearing capacity and settlement (Cecen & Sivrikaya, 2003). A significant discrepancy was observed when comparing values derived from actual tests to those obtained through theoretical calculations for the bearing capacity of sand (Leong et al., 2016). Differences also arose when piles, particularly micropiles, were utilized as foundations in varying soil types, such as fine-grained and coarse-grained soils. According to the journal article "Micro-Piles," micropiles were effectively used in various ground improvement applications, particularly for strengthening existing foundations, thereby increasing bearing capacity and reducing settlement. The bearing capacity varied between coarse-grained and fine-grained soils, with the skin friction of the pile primarily affecting the former and the point bearing of the pile tip being significant for the latter.

Despite numerous studies on the bearing capacity of piles in soil, there remains a limited scope of research focusing on the relationship between actual and theoretical methods in determining the bearing capacity of micropiles in coarse-grained and fine-grained soils. According to theoretical understanding and previous experimental confirmations, the majority of load distribution through piles occurred at the soil-grout interface. Although micropiles possess an end-bearing capacity, it is generally considered negligible due to their smaller diameter (Galicia, 2020). This study aimed to provide results that would assist the engineering industry in selecting appropriate methods for serviceability and understanding the correlation between theoretical and actual approaches. Leong et al. (2016) highlighted differences between theoretical and actual pile capacities, underscoring the importance of this study in determining the relationship between these capacities for micropiles in coarse-grained and fine-grained soils.

2. METHOD OF ASSESSMENT

A comparative analysis design was utilized in this study to compare two distinct variables. Specifically, this research design analyzed the comparison of micropile bearing capacity between fine-grained soil and coarse-grained soil, based on results gathered from pile load tests.

After gathering all necessary data, the researchers employed the statistical treatment of comparative analysis to derive results for the comparison of the corresponding data. The researchers subsequently interpreted and analyzed these results. Given the study's objective to compare the theoretical and actual bearing capacities of micropiles in drained and undrained soils, a comparative analysis supported by statistical treatment was identified as the most suitable approach.

The procedure for achieving the results was based on standard comparative study methodologies, along with existing methodologies gathered from related studies (Topacio et al., 2021; Chen et al., 2021; Hsiao et al., 2020). Data were primarily sourced from journal articles, conference proceedings, and case studies, including load-displacement curves, soil profiles/parameters, and pile load test results. Upon collection, all values underwent classification, with the database divided into sections based on usage in coarse-grained and fine-grained soil contexts. Categorized values were analyzed for suitability with the chosen methods and other available methods before proceeding with computations. If required values were absent from the data, correlation and interpolation were utilized.

The researchers computed the theoretical bearing capacities based on the corresponding soil profiles of the actual pile load tests. For the computation of point bearing capacity of micropiles, Meyerhof's Method for clays was used for fine-grained soils, and Meyerhof's Method for sands was used for coarse-grained soils. For determining friction resistance, the α-Method was used for fine-grained soils, and Coyle and Castello's Method was used for coarse-grained soils. After obtaining the end bearing and frictional capacities of the micropiles, the bearing capacity was determined using Theoretical Pile Capacity.

This study focused on four methods: Chin (1970), Davisson Offset (1972), Terzaghi & Peck (1967), and the L_1-L_2 method (1988). By adhering to the prescribed procedures of each method, an interpreted actual ultimate load of the micropile was produced. Using the appropriate statistical tools, the theoretical and actual bearing capacities determined were analyzed and subjected to correlational and regression analyses. In this study, pairwise correlations were conducted between theoretical and actual pile capacities.

3. DATABASE AND RESULTS OF ANALYSIS

Table 1 presents the theoretical ultimate bearing capacities of micropiles in drained and undrained soils. For micropiles MP-01 to MP-10 (drained), frictional resistance (Q_s) was higher than point bearing capacity (Q_p), significantly influencing the ultimate load capacity (Q_u).

Table 1. Theoretical bearing capacity of the database

PILE REFERENCE NUMBER	THEORETICAL CAPACITY (KN)		
	Q_s	Q_p	Q_u
MP-01	212.16	18.29	230.45
MP-02	818.55	26.07	502.25
MP-03	863.29	65.99	519.10
MP-04	88.00	14.90	321.06
MP-05	1.88	0.34	2.21
MP-06	2.50	0.34	2.84
MP-07	3.13	0.34	3.46
MP-08	0.47	0.08	0.55
MP-09	0.63	0.08	0.71
MP-10	0.78	0.08	0.87
MP-11	236.42	1529.98	1766.40
MP-12	708.18	2226.15	2934.33
MP-13	104.35	457.18	563.53
MP-14	171.48	2186.73	2358.21
MP-15	78.84	506.19	585.03
MP-16	396.96	937.03	1343.36
MP-17	0.66	2.93	3.59
MP-18	30.27	95.47	125.74
MP-19	59.11	1303.63	1362.73
MP-20	0.05	0.18	0.23

Conversely, for MP-11 to MP-20 (undrained), the end capacity exceeded the side, indicating a greater impact on ultimate capacity from the tip. The ultimate capacity in drained and undrained soils was determined by summing the friction resistance and end bearing capacity.

Table 2 compares theoretical and actual pile capacities. Among interpretation methods, the L_1 load was closest to theoretical values in fine-grained soils, followed by Davisson Offset, while L_2, Terzaghi & Peck, and Chin produced higher values. For coarse-grained soils, Terzaghi & Peck's values were nearest to the theoretical calculations. Pearson correlation coefficients demonstrated a strong relationship between theoretical capacities in fine-grained soils and various interpretation methods: Davisson (0.926), Chin (0.931), L_2 (0.931), and Terzaghi & Peck (0.934). All correlations were significant ($p < 0.05$).

Table 2. Theoretical and actual bearing capacity

PILE REFERENCE NUMBER	THEORETICAL (KN)	ACTUAL (KN)			
		Davisson Offset	Chin	Terzaghi & Peck	L_2
MP-01	230.45	349.85	510.02	460.25	400.16
MP-02	502.25	565.43	816.66	716.40	617.21
MP-03	519.10	803.25	1001.30	881.71	823.89
MP-04	321.06	120.15	156.43	149.27	135.86
MP-05	2.21	2.70	5.09	2.88	3.16
MP-06	2.84	2.71	5.72	4.53	3.43
MP-07	3.46	4.12	6.13	5.59	4.76
MP-08	0.55	0.59	0.96	0.82	0.51
MP-09	0.71	0.64	1.13	0.95	0.61
MP-10	0.87	0.95	1.34	1.21	1.01
MP-11	1766.40	1347.86	1347.86	1891.80	1727.15
MP-12	2934.33	1347.86	1891.80	1727.15	1409.59
MP-13	563.53	2190.13	3619.25	2970.58	2355.74
MP-14	2358.21	614.96	697.23	802.51	699.18
MP-15	585.03	1873.67	3049.71	2494.85	1982.91
MP-16	1343.36	463.61	617.09	565.50	541.09
MP-17	3.59	948.03	1646.36	1208.33	1032.82
MP-18	125.74	2.90	4.58	3.80	3.24
MP-19	1362.73	213.51	429.40	285.19	229.83
MP-20	0.23	0.23	0.25	0.25	0.23

For coarse-grained soils, the correlations between theoretical capacities and actual methods were low and not significant ($p > 0.05$). However, significant relationships existed among all interpretation methods themselves.

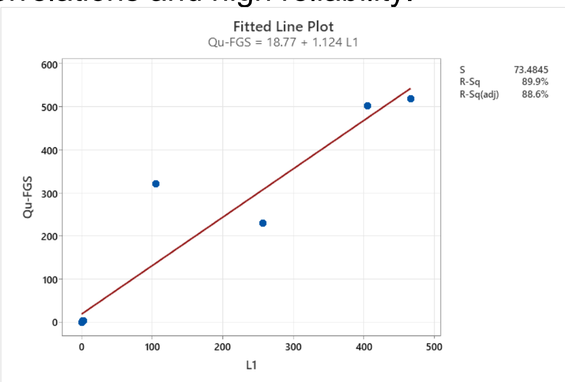
Regression analysis showed high reliability for the correlation between theoretical and actual capacities in drained soils: L_1 ($R^2 = 88.6\%$), Davisson ($R^2 = 83.9\%$), L_2 ($R^2 = 85\%$), and Terzaghi & Peck ($R^2 = 87.2\%$). These results indicate that theoretical and actual measures in fine-grained soils are significantly correlated and can be used to calculate ultimate bearing capacity.

However, for undrained soils, the lack of significant correlation suggests theoretical and empirical measures are unrelated. This discrepancy may arise from assumptions in theoretical computations and the behavior of micropiles in coarse-grained soils, which are often installed in groups and exhibit different stability characteristics.

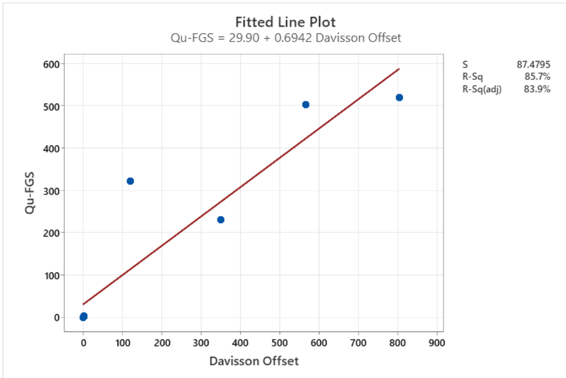
Overall, the study revealed significant correlations between theoretical and actual measures in fine-grained soils but not in undrained soils, highlighting the need for careful consideration of soil type in pile capacity assessments.

4. REGRESSION RESULTS FOR DRAINED SOILS

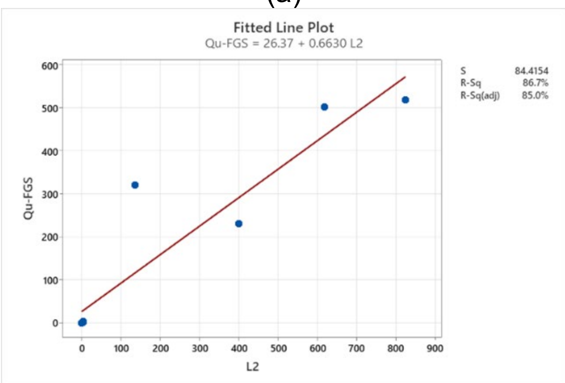
Regression analysis was done for drained soils because of the high correlation results for this dataset. Results for the theoretical ultimate bearing capacity of micropiles in drained soils ($Q_{drained}$) against various actual interpretation methods showed strong correlations and high reliability.



(a)



(b)



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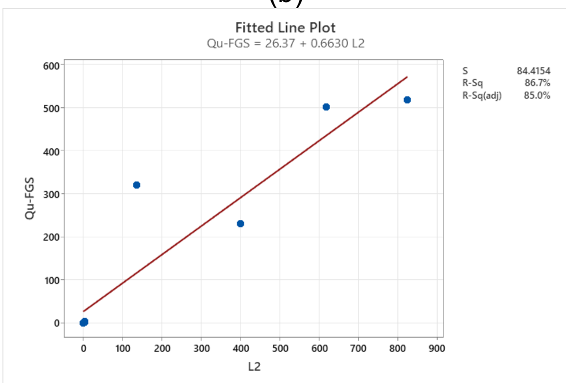

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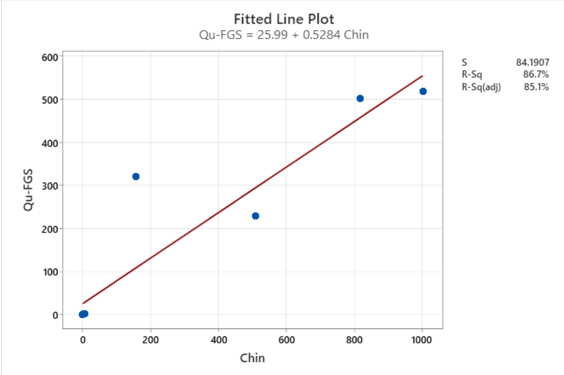

(e)

Fig. 1 Regression Results for Drained Soils

Figure 1(a) displayed the regression between $Q_{drained}$ and the L_1 interpretation, with data points closely aligning with the regression line (Eq. 1). The R-squared value of 88.6% indicated a reliable model for predicting theoretical bearing capacity using the L_1 method. Figure 1(b) illustrated the $Q_{drained}$ versus Davisson Offset regression, showing an R-squared value of 83.9%. This high reliability confirmed the suitability of the regression equation for theoretical bearing capacity calculations using the Davisson Offset method. Figure 1(c) presented the regression between $Q_{drained}$ and the L_2 interpretation, with an R-squared value of 85%. The strong alignment of data points with the regression line (Eq. 3) indicated the reliability of this method for predicting theoretical bearing capacity. Figure 1(d) showed the $Q_{drained}$ versus Terzaghi & Peck regression, yielding an R-squared value of 87.2%. This high reliability suggested that the regression model was trustworthy for predicting theoretical bearing capacity using the Terzaghi & Peck method. Figure 1(e) depicted the regression between $Q_{drained}$ and the Chin interpretation, with an R-squared value of 85.1%. The strong correlation indicated that this method was reliable for theoretical bearing capacity predictions.

$$Q_{drained} = 18.77 + 1.124\, Q_{L1} \quad (1)$$
$$Q_{drained} = 29.90 + 0.6942\, Q_{DAV} \quad (2)$$
$$Q_{drained} = 26.37 + 0.6630\, Q_{L2} \quad (3)$$
$$Q_{drained} = 24.67 + 0.6012\, Q_{T\&P} \quad (4)$$
$$Q_{drained} = 25.99 + 0.5284\, Q_{CHIN} \quad (5)$$

5. CONCLUSIONS AND RECOMMENDATIONS

From the results and analyses from this study, the researchers conclude the following:

1. The actual interpretation methods used in this study provide relevant precision in terms of determining the actual load capacities of micropiles from load displacement curves. The methods of interpretation, which were Davisson Offset, Chin, Terzaghi & Peck, and L_1-L_2, were defined and expounded in the article provided by Hirany and Kulhawy (2002).

2. The theoretical pile capacity in undrained soils using the appropriate methods was reliable but using correlations to achieve a certain parameter in computations introduces uncertainties in the models created.
3. There is a significant relationship between the theoretical and actual capacities of micropiles in drained soils and the regression equations 1-5 can be used to determine the theoretical pile capacity from the actual load test results. However, in undrained soils, no significant relationship was established, and therefore, no regression equations were determined.
4. Additional load test database will make the results of the regression more reliable and accurate to actual test results.

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