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Evaluation of Static Methods for Predicting Axial Bearing Capacity of Minipiles Using PDA Test Results

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ABSTRACT

Accurate prediction of the axial bearing capacity of pile foundations is essential for ensuring structural safety and optimizing foundation design. Although static prediction methods based on Cone Penetration Test (CPT) data are widely used because of their simplicity and cost-effectiveness, their predictive accuracy varies depending on the adopted analytical approach. This study evaluates the performance of three commonly used static methods (Meyerhof, Schmertmann, and Terzaghi) in predicting the axial bearing capacity of precast concrete minipiles using Pile Driving Analyzer (PDA) test results as the field reference. The analysis was conducted using CPT data collected from six sounding locations at a two-story residential building project in Pekanbaru, Indonesia. The predicted bearing capacities obtained from each method were compared with the ultimate capacity derived from PDA and CAPWAP analyses using absolute and relative differences as evaluation indicators. The results show that all three static methods overestimated the measured pile capacity, although the magnitude of deviation varied considerably. The Schmertmann method produced the highest average predicted capacity (50.35 tons), followed by the Meyerhof method (37.08 tons), while the Terzaghi method yielded the lowest prediction (33.54 tons). Compared with the PDA-derived ultimate capacity of 30.10 tons, the Terzaghi method exhibited the smallest relative difference (11.43%), indicating the closest agreement with field measurements. CAPWAP analysis further revealed that approximately 90.7% of the pile capacity was mobilized through shaft resistance, confirming the predominance of frictional load transfer at the study site. These findings demonstrate that the Terzaghi method provides the most representative prediction of minipile axial bearing capacity under the investigated soil conditions and may serve as a practical alternative for preliminary foundation design when field load testing is unavailable.

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1. INTRODUCTION

Accurate prediction of the axial bearing capacity of pile foundations is a fundamental requirement for ensuring structural safety and achieving economical foundation design. An inaccurate estimation may lead to either excessive settlement due to insufficient capacity or unnecessarily conservative designs that increase construction costs. Although full-scale static load testing is widely recognized as the most reliable method for evaluating pile capacity, its implementation is often constrained by time, cost, and field conditions. Consequently, static prediction methods based on cone penetration test (CPT) data remain widely adopted during the preliminary design stage because they provide a practical and economical alternative for estimating pile bearing capacity [1], [2].

Among the available static approaches, the Meyerhof, Schmertmann, and Terzaghi methods are frequently employed in engineering practice to estimate the axial bearing capacity of driven piles. These methods are developed from different theoretical assumptions and empirical correlations, resulting in varying predictions even under identical subsurface conditions [3], [4]. Such discrepancies may influence engineering decisions, particularly in selecting an appropriate pile design method. To verify analytical predictions, dynamic testing using the Pile Driving Analyzer (PDA) has become increasingly accepted because it enables rapid field evaluation of pile performance immediately after installation. PDA test results therefore provide valuable reference data for assessing the reliability of conventional static prediction methods [5], [6].

Numerous studies have evaluated the performance of static prediction methods by comparing analytical results with field measurements obtained from static load tests, PDA testing, or CAPWAP analyses [3], [5], [7]. Previous research has also compared empirical prediction methods with the bearing capacity measured during installation using the Hydraulic Static Pile Driver (HSPD), demonstrating that different empirical approaches may produce significantly different capacity estimates depending on the adopted calculation method and field conditions [11]. Recent developments have introduced numerical simulations and machine-learning-based approaches to improve pile capacity prediction [8]. Nevertheless, conventional static methods continue to be extensively applied in routine engineering design because of their simplicity and practical implementation. Existing studies generally focus on conventional driven piles, evaluate only a limited number of prediction methods, or employ different validation references, making direct comparison among commonly used static methods difficult. Furthermore, studies specifically investigating the predictive performance of the Meyerhof, Schmertmann, and Terzaghi methods for estimating the axial bearing capacity of minipiles using PDA test results under identical site conditions remain limited [7], [9]. Consequently, the selection of the most representative static prediction method for minipile foundation design under similar ground conditions remains an important practical issue.

Therefore, this study evaluates the performance of the Meyerhof, Schmertmann, and Terzaghi methods in predicting the axial bearing capacity of minipiles using PDA test results as the reference. Unlike previous studies that compared empirical predictions with HSPD measurements or evaluated only individual prediction methods, the present study systematically compares three widely used static methods against PDA-derived capacities under identical site conditions. The comparison is conducted using the same CPT dataset, pile geometry, and field-testing results obtained from a residential building construction project, thereby minimizing the influence of external variables. The novelty of this study lies in identifying the static prediction method that provides the closest agreement with PDA measurements through a consistent comparative framework. The findings are expected to provide practical guidance for selecting an appropriate static prediction method during the preliminary design of minipile foundations, particularly for low-rise building projects where full-scale static load testing is unavailable or economically impractical [10].

2. METHOD

2.1. Location, Materials, and Data Collection

This study was conducted using field data obtained from the construction of a two-story residential building in Cluster Mahakam, West Park, Pekanbaru, Indonesia. The project adopted precast reinforced concrete minipiles as the foundation system due to the presence of relatively weak near-surface soil layers. Based on the geotechnical investigation, the competent bearing layer was encountered at depths ranging from approximately 6.0 to 8.8 m. The minipiles used in the project had a square cross-section of 200 mm × 200 mm as shown in Figure 1 and were designed to transfer structural loads to the underlying competent soil layer. The piles were fabricated using concrete with a specified compressive strength of 37.35 MPa and reinforced with four D10 longitudinal reinforcing bars combined with Ø5 transverse stirrups. Based on the manufacturer's design specifications, each minipile possesses an allowable axial bearing capacity ranging from 15 to 20 tons. These characteristics make the selected foundation system appropriate for transferring structural loads through the relatively weak upper soil strata to the underlying competent bearing layer encountered at the project site.

This study employed a quantitative comparative approach using secondary data collected from the construction project. The dataset consisted of Cone Penetration Test (CPT) results obtained from six sounding locations (Fig.2), structural design drawings, minipile specifications, installation depths, and Pile Driving Analyzer (PDA) test results. The CPT data were utilized to estimate the axial bearing capacity of the minipiles using three conventional static prediction methods, whereas the PDA test results were used as the reference for evaluating the accuracy of the predicted bearing capacities. All data were obtained from the same project site to ensure consistency in soil conditions, pile geometry, and construction procedures throughout the analysis.

Figure 1. Precast reinforced concrete minipile 200 mm × 200 mm
(*Source: Project documentation, Mahakam West Park Residential Development, Pekanbaru*)

Figure 2. Cone Penetration Test (CPT) locations
(*Source: Project documentation, Mahakam West Park Residential Development, Pekanbaru*)

Six Cone Penetration Test (CPT) soundings were conducted across the project site to characterize the subsurface conditions. Based on the project layout, CPT-5 was selected as the representative sounding location for the PDA-tested pile (Pile F5) because it represents the geotechnical conditions of the investigated foundation area.

2.2. Static Bearing Capacity Analysis

The axial bearing capacity of the minipiles was determined using three widely adopted static prediction methods, namely the Meyerhof, Schmertmann, and Terzaghi methods. These methods estimate pile capacity based on the contribution of end-bearing resistance and shaft resistance derived from CPT data [12], [13]. For each sounding location, the ultimate pile capacity was calculated according to the corresponding equations and design assumptions of each method. Subsequently, the allowable bearing capacity was determined by applying the recommended factor of safety. The calculations were performed for all six CPT locations to evaluate the variation in predicted pile capacities under different subsurface conditions.

The Meyerhof method is one of the most widely used empirical approaches for estimating the axial bearing capacity of pile foundations based on Cone Penetration Test (CPT) data. This method assumes that the ultimate pile capacity consists of the sum of the end-bearing resistance and the shaft resistance mobilized along the pile length. The ultimate axial bearing capacity is expressed as:

$$Q_{ult} = Q_p + Q_s \tag{1}$$

where the end-bearing resistance is calculated as:

$$Q_p = A_p \times q_p \tag{2}$$

and the shaft resistance is determined by:

$$Q_s = \sum(A_s \times f_s) \tag{3}$$

where:

Q_{ult} = ultimate axial bearing capacity of the pile (tons)
Q_p = end-bearing resistance (tons)
Q_s = shaft resistance (tons)
A_p = cross-sectional area of the pile toe (cm²)
q_p = cone tip resistance obtained from the CPT (kg/cm²)
A_s = surface area of the pile shaft for each soil layer (cm²)
f_s = unit shaft resistance (kg/cm²) = α . q_c
α = reduction factor relating shaft resistance to cone resistance, commonly taken as $0.8q_c$ for sandy soils and $0.5q_c$ for clayey soils.

The Schmertmann method estimates the axial bearing capacity of pile foundations using Cone Penetration Test (CPT) data by considering both the cone tip resistance and the shaft resistance mobilized along the pile. The ultimate axial bearing capacity is calculated as the sum of the end-bearing and shaft resistance components:

$$Q_{ult} = Q_p + Q_s \tag{4}$$

The end-bearing resistance is expressed as:

$$Q_p = A_p \times q_p \tag{5}$$

where q_p is obtained from the average cone tip resistance within a specified influence zone around the pile toe in accordance with Schmertmann's CPT interpretation procedure:

$$Q_s = \sum(A_s \times f_s) \tag{6}$$

where the unit shaft resistance f_s is estimated from CPT data using Schmertmann's empirical correlation
where:

Q_{ult} = ultimate axial bearing capacity of the pile (tons)
Q_p = end-bearing resistance (tons)
Q_s = shaft resistance (tons)
A_p = cross-sectional area of the pile toe (cm²)
q_p = cone tip resistance obtained from the CPT (kg/cm²)
A_s = surface area of the pile shaft for each soil layer (cm²)
f_s = unit shaft resistance (kg/cm²) = α . q_c

The Terzaghi method estimates the axial bearing capacity of pile foundations based on the classical bearing capacity theory. The ultimate pile capacity is determined by combining the end-bearing resistance at the pile toe with the shaft resistance developed along the embedded pile length:

$$Q_{ult} = Q_p + Q_s \tag{7}$$

The end-bearing resistance is calculated as:

$$Q_p = A_p \times q_p \tag{8}$$

Where:

$$q_p = cN_c + \sigma'_v N_q + \frac{1}{2}\gamma B N_\gamma \tag{9}$$

The shaft resistance is expressed as:

$$Q_s = \sum(A_s \times f_s) \tag{10}$$

2.3. Pile Driving Analyzer (PDA) Testing

Dynamic pile testing was conducted using the Pile Driving Analyzer (PDA) after pile installation to determine the in-situ bearing capacity of the minipiles. The PDA system records force and velocity signals generated during hammer impact through sensors attached near the pile head. These wave signals were subsequently processed using CAPWAP analysis to determine the ultimate pile capacity, shaft resistance, end-bearing resistance, and pile settlement. Because the PDA test directly evaluates the pile response under field conditions, the measured bearing capacity was adopted as the reference value for assessing the reliability of the static prediction methods [14].

2.4. Methodological Framework

The research was conducted through several sequential stages. First, geotechnical investigation data, structural drawings, minipile specifications, and PDA test results were collected from the construction project. Subsequently, the axial bearing capacity of the minipiles was calculated using the Meyerhof, Schmertmann, and Terzaghi methods based on the CPT data. The predicted capacities obtained from each method were then compared with the PDA test results to evaluate their agreement. Finally, the comparative results were analyzed to identify the static prediction method that most accurately represented the measured pile capacity under the investigated soil conditions.

The comparison was carried out to evaluate the predictive performance of each static method under identical site conditions. The analysis focused on the differences between the predicted capacities and the PDA-derived capacity, as well as the consistency of each prediction method across all CPT locations. The static method exhibiting the smallest deviation from the PDA test result was considered the most representative method for estimating the axial bearing capacity of minipiles at the study site.

$$\text{Absolute difference} = |Q_{STATIC} - Q_{PDA}| \tag{11}$$

$$\text{Relative difference (\%)} = \frac{|Q_{STATIC} - Q_{PDA}|}{Q_{PDA}} \times 100 \tag{12}$$

3. RESULTS AND DISCUSSION

3.1. Subsurface Conditions

Cone Penetration Test (CPT) investigations were conducted at six sounding locations to characterize the subsurface conditions at the project site. The final penetration depth, cone tip resistance (qc), and total sleeve friction (Tf) obtained from each sounding are summarized in Table 1.

The CPT results indicate relatively consistent cone tip resistance values ranging from 195 to 202 kg/cm², while the total sleeve friction varied between 266 and 498 kg/cm². The competent bearing layer was encountered at depths ranging from 6.0 to 8.8 m, indicating spatial variability in the subsurface profile across the site. The measured cone tip resistance values at the final penetration depth indicate a relatively stiff to dense bearing layer suitable for supporting the installed minipiles. These CPT parameters were subsequently used as the primary input for estimating the axial bearing capacity using the Meyerhof, Schmertmann, and Terzaghi methods.

Table 1. Summary of Cone Penetration Test (CPT) Results

CPT Point	Final Depth (m)	Cone Tip Resistance, *qc* (kg/cm²)	Total Sleeve Friction, *Tf* (kg/cm²)
CPT-1	7.0	200	390
CPT-2	6.6	195	338
CPT-3	8.8	200	442
CPT-4	6.0	202	266
CPT-5	8.8	200	498
CPT-6	6.8	200	322

Table 2. Statistical Summary of CPT Parameters

Parameter	Minimum	Maximum	Average
Final Depth (m)	6.0	8.8	7.33
Cone Tip Resistance, *qc* (kg/cm²)	195	202	199.5
Total Sleeve Friction, *Tf* (kg/cm²)	266	498	376.0

Table 2 presents the statistical summary of the CPT parameters obtained from the six sounding locations. The final penetration depth varied between 6.0 and 8.8 m, with an average depth of 7.33 m, indicating moderate spatial variability in the depth of the competent bearing layer across the project site. Despite these variations, the measured cone tip resistance (qc) exhibited a relatively narrow range, varying from 195 to 202 kg/cm², with an average value of 199.5 kg/cm². This finding suggests that the bearing layer encountered at the termination depth possessed relatively uniform strength characteristics.

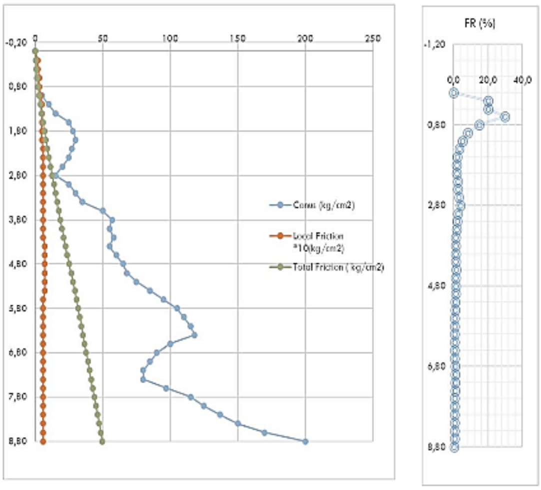

Figure 3. CPT-5 profile graph showing Depth vs. Cone Tip Resistance and Friction Ratio
(*Source: Project documentation, Mahakam West Park Residential Development, Pekanbaru*)

In contrast, the total sleeve friction (*Tf*) showed greater variability, ranging from 266 to 498 kg/cm², with an average value of 376.0 kg/cm². The wider variation in sleeve friction may reflect differences in local soil stratification and interface friction along the pile shaft. The relatively consistent cone tip resistance values across the six CPT locations indicate that variations in the predicted pile capacities are more likely to be associated with the assumptions of the selected static prediction methods than with substantial differences in subsurface conditions. Therefore, the site provides an appropriate basis for evaluating the predictive performance of the Meyerhof, Schmertmann, and Terzaghi methods against the PDA test results.

3.2. PDA Test Results

The axial bearing capacity of the installed minipile was evaluated through a Pile Driving Analyzer (PDA) test followed by Case Pile Wave Analysis Program (CAPWAP) interpretation. The PDA test was performed after pile installation using the restrike method to assess the in-situ performance of the pile under dynamic loading conditions. The interpreted results obtained from the CAPWAP analysis are summarized in Table 3.

Table 3. Summary of PDA and CAPWAP Analysis Results

Pile ID	PDA Blow Count	Ultimate Capacity, *Qu* (ton)	Shaft Resistance, *Rs* (ton)	Toe Resistance, *Rb* (ton)	Permanent Settlement (mm)	Remarks
F5	30	30.1	27.3	2.8	15	*Restrike Test

Source: PDA and CAPWAP test report

The CAPWAP analysis indicated an ultimate axial bearing capacity of 30.1 tons for the tested minipile (Pile F5). Of this capacity, 27.3 tons were mobilized through shaft resistance, whereas only 2.8 tons were contributed by toe resistance. This distribution demonstrates that approximately 90.7% of the pile capacity was derived from shaft resistance, while the remaining 9.3% originated from end-bearing resistance. The predominance of shaft resistance suggests that the installed minipile primarily behaved as a friction pile under the investigated ground conditions.

The recorded permanent settlement after restrike testing was 15 mm, indicating stable pile performance during dynamic loading. Because the PDA test directly evaluates the response of the installed pile under actual field conditions, the CAPWAP-derived ultimate bearing capacity was adopted as the reference value for evaluating the predictive performance of the Meyerhof, Schmertmann, and Terzaghi static methods presented in the subsequent section.

3.3 Static Bearing Capacity Prediction

The allowable axial bearing capacity of the minipiles was estimated using the Meyerhof, Schmertmann, and Terzaghi methods based on the CPT data obtained from the six sounding locations. The predicted bearing capacities are summarized in Table 4.

Table 4. Predicted Axial Bearing Capacity of Minipiles Using Static Methods

CPT Point	Depth (m)	Meyerhof (ton)	Schmertmann (ton)	Terzaghi (ton)
CPT-1	7.0	35.95	41.44	18.29
CPT-2	6.6	34.25	49.45	32.17
CPT-3	8.8	39.28	55.50	44.55
CPT-4	6.0	37.68	48.70	28.32
CPT-5	8.8	44.55	56.30	38.37
CPT-6	6.8	36.90	50.74	33.33
Average	7.33	38.10	50.35	32.51

Among the three prediction methods, the Schmertmann method consistently produced the highest estimated bearing capacity, whereas the Terzaghi method yielded the lowest predictions across all CPT locations. The Meyerhof method generally provided intermediate values. This trend reflects the different empirical assumptions adopted by each method in evaluating shaft and toe resistance from CPT data.

The results indicate noticeable differences among the three prediction methods despite being applied to the same subsurface conditions. The Schmertmann method consistently produced the highest predicted allowable bearing capacities, ranging from 41.44 to 56.30 tons, with an average value of 50.35 tons. In contrast, the Terzaghi method yielded the lowest predictions, with capacities varying between 18.29 and 44.55 tons and an average of 32.51 tons. The Meyerhof method produced intermediate values, ranging from 34.25 to 44.55 tons, with an average predicted capacity of 38.10 tons.

These differences significantly influence the calculated allowable bearing capacities, even though the analyses were performed using identical pile dimensions and geotechnical data. To determine the most reliable prediction approach, the bearing capacities calculated from the representative CPT sounding (CPT-5) were subsequently compared with the PDA-derived bearing capacity.

3.4 Comparative Evaluation

To provide a direct comparison with the PDA test, the static bearing capacities (the Meyerhof, Schmertmann, and Terzaghi methods) calculated from CPT-5, which represents the investigated pile location (Pile F5), were used for comparison. The remaining CPT soundings were utilized to describe the overall spatial variability of the subsurface conditions across the project site. The comparative results are presented in Table 5.

Table 5. Comparison and Deviation Indicators Between Static Predictions (Pile F5) and PDA Results

Method	Predicted Capacity (CPT-5) (ton)	PDA Capacity (ton)	Absolute Difference (ton)	Relative Difference (%)
Meyerhof	44.55	30.10	14.45	48.01
Schmertmann	56.30	30.10	26.20	87.04
Terzaghi	38.37	30.10	8.27	27.48

The comparative evaluation indicates that all three static methods overestimated the axial bearing capacity relative to the PDA measurement, although the magnitude of overestimation differed substantially among the methods. The Terzaghi method produced the closest prediction to the PDA-derived capacity, with an absolute difference of 8.27 tons (27.48%), whereas the Schmertmann method showed the largest deviation, overestimating the measured capacity by 26.20 tons (87.04%). The Meyerhof method also overestimated the pile capacity, yielding an absolute difference of 14.45 tons (48.01%). These results demonstrate that the choice of static prediction method has a significant influence on the estimated bearing capacity and highlight the importance of validating analytical predictions using field measurements.

The relatively large deviation observed for the Schmertmann method suggests that its empirical correlations may predict higher shaft resistance under the investigated site conditions, leading to a more conservative estimation of pile capacity. Conversely, the Terzaghi method provided predictions that were more consistent with the measured field capacity, despite employing a simpler analytical framework. The Meyerhof method produced intermediate results between these two approaches.

Overall, the comparative evaluation indicates that the Terzaghi method demonstrated the best agreement with the PDA test results for the investigated minipile foundation. Under the soil conditions encountered at the study site, the Terzaghi method appears to provide the most representative estimate of the axial bearing capacity and may therefore be considered a practical alternative when PDA testing is unavailable.

3.5 Discussion

The comparative evaluation demonstrated that the three static prediction methods produced different levels of agreement with the PDA-derived bearing capacity, despite being applied to the same CPT dataset. Among the evaluated methods, the Terzaghi method provided the closest prediction to the measured pile capacity, with a relative difference of 11.43%, whereas the Meyerhof and Schmertmann methods overestimated the pile capacity by 23.19% and 67.28%, respectively. These findings indicate that the choice of prediction method has a considerable influence on the estimated axial bearing capacity of minipiles and, consequently, on foundation design decisions.

The differences in prediction accuracy can be explained by the theoretical assumptions underlying each method. The Meyerhof and Schmertmann methods estimate pile capacity using empirical relationships derived from CPT parameters, with substantial contributions from both shaft resistance and end-bearing resistance. In contrast, the Terzaghi method is based on the classical bearing capacity theory and adopts a more conservative representation of pile resistance. Under the subsurface conditions encountered at the study site, this conservative approach resulted in predictions that were more consistent with the PDA measurements.

The CAPWAP analysis further showed that approximately 90.7% of the measured pile capacity was mobilized through shaft resistance, while only 9.3% originated from toe resistance. This finding indicates that the installed minipiles primarily behaved as friction piles, with load transfer dominated by shaft friction rather than end-bearing resistance. Such a mechanism is reasonable considering that the pile lengths ranged from approximately 6.0 to 8.8 m, where sufficient shaft resistance could be mobilized before substantial toe resistance developed. Consequently, prediction methods that assume greater contributions from end-bearing resistance may produce higher capacity estimates than those observed under actual field conditions.

The present findings are generally consistent with previous studies reporting that different static prediction methods may produce significantly different pile capacity estimates because of variations in their empirical formulations and assumptions. Several researchers have shown that no single static method consistently provides the most accurate prediction under all soil conditions, and that field verification through PDA or static load testing remains essential for assessing the reliability of analytical predictions. The results of this study further emphasize that the predictive performance of a static method is strongly influenced by local subsurface conditions and the governing load-transfer mechanism.

From an engineering perspective, the findings suggest that the Terzaghi method may provide a more representative preliminary estimate of the axial bearing capacity for precast concrete Mini piles installed under soil conditions similar to those investigated in this study. Nevertheless, the results should not be generalized to all geotechnical conditions because the evaluation was conducted using data from a single construction site and one PDA-tested pile. One limitation of this study is that the exact spatial relationship between the six CPT sounding locations and the PDA-tested pile was unavailable in the original project documentation. Consequently, the comparative evaluation was performed using the CPT sounding considered representative of the investigated foundation area rather than a verified point-to-point correspondence between a single CPT sounding and the tested pile. Therefore, the findings should be interpreted as an evaluation of the predictive performance of the investigated static methods under the site conditions rather than as an exact location-specific comparison. Additional studies involving different soil profiles, pile geometries, and larger datasets are recommended to further validate the applicability of the evaluated prediction methods.

Unlike many previous studies that focused on comparing static prediction methods with load test results, this study specifically evaluated the predictive performance of three widely used CPT-based methods against PDA-derived capacity under identical site conditions. By eliminating the influence of different soil profiles, pile geometries, and construction procedures, the present study provides a more direct comparison of the predictive capability of each method. This contributes practical evidence for selecting an appropriate static prediction method for minipile foundation design when field load testing is limited.

The findings of the present study are also consistent with previous research comparing empirical prediction methods with field measurements obtained from the Hydraulic Static Pile Driver (HSPD). That study reported noticeable variations in the predicted bearing capacities among different empirical methods, highlighting that the selection of the analytical approach substantially influences the estimated pile capacity. However, the previous evaluation was based on HSPD measurements and did not specifically assess the predictive performance of commonly used CPT-based static methods against PDA-derived capacities. The present study extends this line of research by demonstrating that, under identical site conditions, the Terzaghi method provides the closest agreement with the PDA test results, whereas the Meyerhof and Schmertmann methods tend to produce higher capacity estimates. This consistency reinforces the importance of validating analytical predictions with field measurements and emphasizes that the reliability of a prediction method depends not only on its empirical formulation but also on the soil conditions and the field testing approach adopted for verification.

4. CONCLUSION

This study evaluated the predictive performance of three widely used static methods, namely Meyerhof, Schmertmann, and Terzaghi, for estimating the axial bearing capacity of precast concrete minipiles using PDA test results as the field reference. The comparison demonstrated that all three methods overestimated the measured pile capacity to different extents. Among the evaluated methods, the Terzaghi method showed the closest agreement with the PDA-derived capacity, exhibiting the smallest prediction error, whereas the Schmertmann method produced the largest overestimation. These findings indicate that the predictive accuracy of static bearing capacity methods is strongly influenced by their underlying theoretical assumptions and empirical formulations, even when identical CPT data are used.

The results provide practical guidance for selecting an appropriate static prediction method during the preliminary design of minipile foundations, particularly for low-rise building projects where field load testing is limited or unavailable. Under subsurface conditions similar to those investigated in this study, the Terzaghi method may be considered the most representative among the evaluated approaches for estimating axial bearing capacity. Nevertheless, because this study was conducted using data from a single construction site and one PDA-tested pile, further investigations involving different soil profiles, pile geometries, and larger validation datasets are recommended to establish broader applicability of the findings.

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