

## Bearing Capacity Analysis of Pile Foundations Using CPT and SPT Data: A Comparative Study of Meyerhof and Schmertmann Methods

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**Abstract**— Accurate estimation of pile foundation bearing capacity is essential for ensuring the safety, serviceability, and cost-effectiveness of geotechnical structures. Cone Penetration Test (CPT) and Standard Penetration Test (SPT) data are widely used for evaluating pile performance; however, differences among empirical prediction methods may lead to variations in design capacity. This study aims to compare the bearing capacity of single and group pile foundations estimated using the Meyerhof and Schmertmann methods based on CPT and SPT datasets. The analysis was conducted on reinforced concrete piles with a diameter of 0.80 m and an embedded depth of 16 m. Single-pile capacities were calculated using both methods, while group pile performance was evaluated using the Converse–Labarre efficiency approach. The results indicate that the Meyerhof method consistently produced higher allowable pile capacities than the Schmertmann method. For CPT-based analysis, allowable capacities ranged from 261.26 to 318.10 tons, whereas SPT-based analysis yielded capacities between 445.94 and 458.20 tons. Group pile capacities were estimated at 792.12 tons and 1352.09 tons based on CPT and SPT data, respectively. The findings suggest that the Meyerhof approach provides more conservative design flexibility for large-diameter piles. The study highlights the importance of selecting appropriate interpretation methods and integrating multiple site investigation techniques to improve the reliability of pile foundation design.

*Keywords: Pile Foundation, Bearing Capacity, CPT, SPT.*

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### 1. Introduction

Pile foundations are widely used in civil engineering projects to transfer structural loads to deeper and more competent soil layers when near-surface soils exhibit insufficient bearing capacity or excessive settlement. The performance of pile foundations directly influences the safety, stability, and serviceability of buildings, bridges, transportation infrastructure, and other geotechnical systems. Consequently, accurate estimation of pile bearing capacity remains one of the most important aspects of foundation design and geotechnical engineering practice [1]–[5]. Among the available site investigation techniques, the Cone Penetration Test (CPT) and Standard Penetration Test (SPT) are the most frequently used methods for evaluating subsurface conditions and predicting pile foundation performance. CPT provides continuous measurements of cone resistance and sleeve friction, enabling detailed assessment of soil stratigraphy and pile resistance mechanisms. In contrast, SPT offers a practical and cost-effective approach for estimating soil strength through penetration resistance measurements. Numerous studies

have demonstrated the applicability of CPT- and SPT-based methods for estimating axial pile capacity under various soil conditions [6]–[10].

Recent research has focused on evaluating the reliability, uncertainty, and predictive performance of different pile-capacity estimation methods. Reliability-based and probabilistic investigations have shown that significant variability may exist among pile-capacity prediction approaches, particularly when CPT- and SPT-based methods are compared with static analysis procedures [1], [2], [11], [12]. Statistical evaluations have further revealed that prediction accuracy depends on soil characteristics, pile type, and the empirical correlations adopted during analysis [4], [6], [13]. Several researchers have compared the performance of CPT- and SPT-based methods for driven piles, bored piles, displacement piles, and prestressed concrete piles. Comparative studies have reported varying levels of agreement between calculated capacities and field load-test results, indicating that no single method can be universally applied under all geotechnical conditions [7], [8], [14]–[17]. Investigations incorporating pile load tests, PDA tests, and CAPWAP analyses have further emphasized the need for careful selection and validation of empirical design approaches [18]–[20].

Advances in data-driven and computational techniques have also contributed to the development of alternative approaches for pile-capacity prediction. Artificial neural networks, reliability-based safety factors, and enhanced empirical formulations have been proposed to improve the accuracy of bearing-capacity estimation and reduce uncertainties associated with conventional methods [12], [21], [22]. Nevertheless, traditional methods such as Meyerhof and Schmertmann remain among the most widely adopted approaches in engineering practice because of their simplicity, practicality, and extensive use in design standards. In addition to single-pile capacity, the performance of pile groups plays a crucial role in foundation design. Most structural systems rely on pile groups rather than individual piles, making it necessary to evaluate pile group efficiency and interaction effects. Although numerous studies have investigated pile bearing capacity using CPT or SPT data separately, fewer studies have simultaneously compared multiple analytical methods using both CPT and SPT datasets while also examining pile-group performance within a unified framework [3], [5], [9], [23], [24].

The existing literature indicates that variations in investigation techniques and analytical approaches can lead to substantial differences in estimated pile capacities. Such differences may influence foundation dimensions, construction costs, and structural safety. Therefore, a comprehensive comparison of commonly used pile-capacity prediction methods remains essential for improving the reliability of geotechnical design. The novelty of this study lies in the integrated evaluation of pile bearing capacity using both CPT and SPT investigation data through the Meyerhof and Schmertmann methods, combined with pile-group assessment using the Converse–Labarre approach. Unlike many previous studies that focus solely on either CPT or SPT data, this research provides a direct comparison of both investigation techniques within the same analytical framework and examines their implications for both single-pile and pile-group design.

Accordingly, this study aims to compare the allowable bearing capacity of single piles estimated using the Meyerhof and Schmertmann methods based on CPT and SPT data and to evaluate pile-group capacity using the Converse–Labarre method. The findings are expected to contribute to a better understanding of the influence of investigation methods and analytical procedures on pile foundation design and to provide practical guidance for geotechnical engineering applications.

## **2. Method**

This study employed a quantitative analytical approach to evaluate the bearing capacity of pile foundations using data obtained from in-situ geotechnical investigations. The analysis was conducted using secondary data collected from a multi-story building construction site. The available geotechnical dataset consisted of five Cone Penetration Test (CPT) sounding points and two Standard Penetration Test (SPT) boreholes, which were used to characterize subsurface conditions and estimate pile foundation

capacity. The foundation system analyzed in this study consisted of reinforced concrete driven piles with a diameter of 0.80 m and an embedded length of 16 m. The design load considered in the analysis was 750 tons. Additional foundation parameters, including pile geometry and material properties, are summarized in Table 1. The geotechnical investigation data obtained from the CPT and SPT tests are presented in Table 2 and Table 3, respectively.

The bearing capacity of single piles was evaluated using the Meyerhof and Schmertmann methods. These methods were selected because they are widely applied in geotechnical engineering practice for estimating pile capacity from field investigation data. The analysis considered both end-bearing resistance and shaft resistance derived from the CPT and SPT results. The allowable capacities obtained from each method were subsequently compared to assess differences in prediction outcomes and identify the most suitable approach for pile foundation design.

In addition to single-pile analysis, pile group behavior was evaluated to determine the allowable capacity of pile groups under the applied structural load. The pile group capacity was assessed using the Converse-Labarre approach, which accounts for the interaction effects among adjacent piles through pile group efficiency. The allowable capacity of the pile group was then determined based on the efficiency factor and the allowable capacity of an individual pile.

The analytical procedure adopted in this study is illustrated in Figure 1. As shown in the figure, the study began with the collection and review of CPT and SPT investigation data, followed by the determination of pile geometry and loading parameters. Single-pile capacities were subsequently calculated using the Meyerhof and Schmertmann methods. The pile group capacity was then evaluated using the Converse-Labarre approach. Finally, the results obtained from CPT-based and SPT-based analyses were compared and interpreted to examine the influence of different investigation techniques and analytical methods on the estimated bearing capacity of pile foundations.

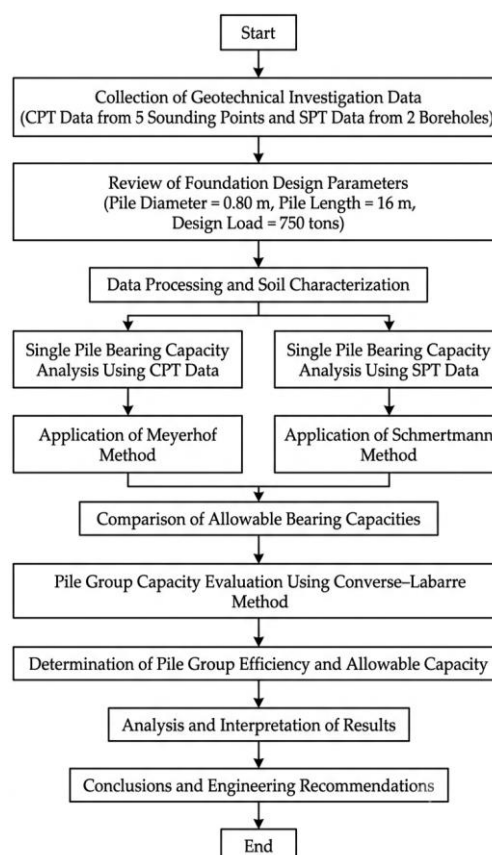


Figure 1. Research Flowchart

Table 1. Design Parameters of the Analyzed Pile Foundation

| Parameter                           | Value                    |
|-------------------------------------|--------------------------|
| Design load (Pu)                    | 750 ton                  |
| Foundation type                     | Driven concrete pile     |
| Pile length                         | 16 m                     |
| Pile diameter                       | 0.80 m                   |
| Pile spacing (center-to-center)     | 2.0 m                    |
| Number of piles in group            | 4                        |
| Pile perimeter                      | 2.512 m                  |
| Cross-sectional area                | 0.502 m <sup>2</sup>     |
| Concrete compressive strength (f'c) | 52 MPa                   |
| Unit weight of reinforced concrete  | 24 kN/m <sup>3</sup>     |
| Groundwater table depth             | 2.5 m below ground level |

Table 2. Summary of CPT Investigation Data

| CPT Point | Maximum Cone Resistance, qc (MPa) | Average Cone Resistance, qc (MPa) | Sleeve Friction, fs (kPa) | Estimated Soil Type     |
|-----------|-----------------------------------|-----------------------------------|---------------------------|-------------------------|
| S-1       | 24.8                              | 18.5                              | 132                       | Dense silty sand        |
| S-2       | 21.6                              | 16.8                              | 125                       | Medium dense silty sand |
| S-3       | 22.4                              | 17.2                              | 128                       | Medium dense silty sand |
| S-4       | 23.1                              | 17.9                              | 130                       | Dense silty sand        |
| S-5       | 24.6                              | 18.3                              | 134                       | Dense silty sand        |

Table 3. Summary of SPT Investigation Data

| Depth (m) | N-SPT-1 | N-SPT-2 | Soil Description |
|-----------|---------|---------|------------------|
| 2         | 10      | 11      | Silty clay       |
| 4         | 15      | 16      | Clayey silt      |
| 6         | 21      | 22      | Sandy silt       |
| 8         | 28      | 30      | Silty sand       |
| 10        | 34      | 35      | Dense silty sand |
| 12        | 39      | 41      | Dense sand       |
| 14        | 45      | 46      | Very dense sand  |
| 16        | 50      | 52      | Very dense sand  |

### 3. Results and Discussion

The bearing capacity analysis was performed using CPT and SPT investigation data for a reinforced concrete pile with a diameter of 0.80 m and an embedded length of 16 m. The allowable bearing capacities of single piles were first evaluated using the Meyerhof method. The results obtained from the five CPT sounding points are presented in Table 4. As shown in Table 4, the allowable bearing capacities derived from CPT data varied between 261.26 and 318.10 tons. The highest capacity was obtained at point S-1, while the lowest capacity occurred at point S-2. These variations reflect differences in subsurface soil resistance and stratigraphic conditions across the investigated area. Higher cone resistance values generally resulted in greater pile capacities due to increased end-bearing and shaft resistance contributions. The allowable bearing capacities calculated from SPT data using the Meyerhof method are presented in Table 5.

Table 4. Allowable Bearing Capacity of Single Piles Based on CPT Data Using the Meyerhof Method

| CPT Point | Allowable Capacity, Qi (ton) |
|-----------|------------------------------|
| S-1       | 318.1                        |

| CPT Point | Allowable Capacity, $Q_i$ (ton) |
|-----------|---------------------------------|
| S-2       | 261.26                          |
| S-3       | 265.96                          |
| S-4       | 283.49                          |
| S-5       | 317.07                          |

Table 5. Allowable Bearing Capacity of Single Piles Based on SPT Data Using the Meyerhof Method

| SPT Point | Allowable Capacity, $Q_i$ (ton) |
|-----------|---------------------------------|
| N-SPT-1   | 445.94                          |
| N-SPT-2   | 458.2                           |

Table 5 indicates that the capacities estimated from SPT data were considerably higher than those obtained from CPT data. The allowable capacities ranged from 445.94 to 458.20 tons, suggesting the presence of dense to very dense soil layers at the pile tip elevation. The relatively high penetration resistance recorded in the SPT investigation contributed to the larger predicted bearing capacities. To examine the influence of the analytical method, the allowable capacities obtained using the Meyerhof and Schmertmann approaches were compared. The comparison based on CPT data is presented in Table 6.

Table 6. Comparison of Single-Pile Allowable Capacities Based on CPT Data

| CPT Point | Schmertmann (ton) | Meyerhof (ton) |
|-----------|-------------------|----------------|
| S-1       | 276.84            | 318.1          |
| S-2       | 228.53            | 261.26         |
| S-3       | 233.72            | 265.96         |
| S-4       | 248.11            | 283.49         |
| S-5       | 275.2             | 317.07         |

The comparison in Table 6 demonstrates that the Meyerhof method consistently predicted higher allowable capacities than the Schmertmann method at all CPT investigation points. The increase ranged from approximately 13% to 15%, indicating that the choice of analytical approach can significantly affect pile foundation design. Although both methods followed similar trends, the Meyerhof method yielded more favorable capacity estimates for the investigated soil conditions. The variation in allowable capacities predicted by both methods is further illustrated in Figure 2.

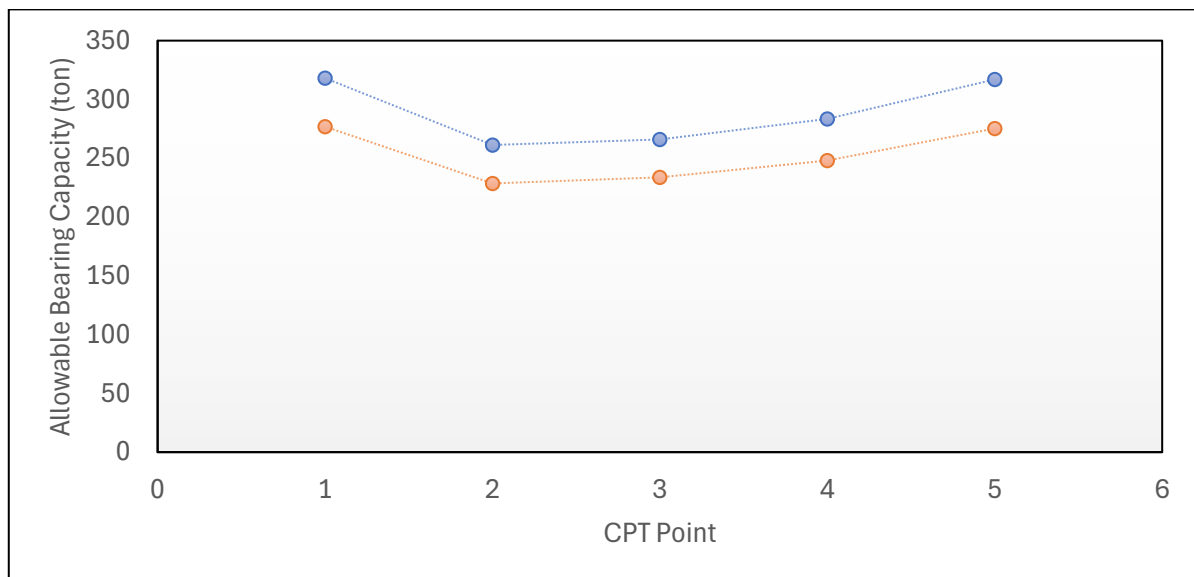


Figure 2. Comparison of Single-Pile Allowable Capacities Obtained from CPT Data Using the Meyerhof and Schmertmann Methods

As illustrated in Figure 2, both methods identified similar patterns of soil behavior across the investigation points. Locations with higher CPT resistance values produced greater allowable capacities regardless of the method used. However, the Meyerhof method consistently generated larger capacity values than the Schmertmann method. A similar comparison was conducted using SPT data, and the results are presented in Table 7.

Table 7. Comparison of Single-Pile Allowable Capacities Based on SPT Data

| SPT Point | Schmertmann (ton) | Meyerhof (ton) |
|-----------|-------------------|----------------|
| N-SPT-1   | 392.18            | 445.94         |
| N-SPT-2   | 404.63            | 458.2          |

Table 7 confirms the trend observed in the CPT-based analysis. The Meyerhof method produced higher allowable capacities than the Schmertmann method at both SPT locations. The difference between the two methods remained relatively consistent, suggesting that the Meyerhof approach provides less conservative capacity estimates for the analyzed pile configuration.

Following the single-pile analysis, the allowable capacity of pile groups was evaluated using the Converse–Labarre method. The minimum allowable capacity obtained from the CPT analysis was 261.26 tons at point S-2. Based on the design load of 750 tons, a pile group consisting of four piles arranged in a 2 × 2 configuration was selected. The calculated pile group efficiency was 0.758, resulting in an allowable group capacity of 792.12 tons.

For the SPT-based analysis, the minimum allowable single-pile capacity was 445.94 tons at point N-SPT-1. Using the same pile arrangement and efficiency factor, the allowable group capacity was calculated as 1352.09 tons. A summary of the pile group analysis is presented in Table 8.

Table 8. Summary of Pile Group Capacity Analysis

| Data Source | Minimum Single-Pile Capacity (ton) | Number of Piles | Group Efficiency | Allowable Group Capacity (ton) |
|-------------|------------------------------------|-----------------|------------------|--------------------------------|
| CPT         | 261.26                             | 4               | 0.758            | 792.12                         |
| SPT         | 445.94                             | 4               | 0.758            | 1352.09                        |

As shown in Table 8, both pile group configurations provided capacities exceeding the required design load of 750 tons. The CPT-based pile group capacity exceeded the design load by approximately 5.6%, while the SPT-based capacity exceeded it by approximately 80.3%. These results indicate that both designs satisfy the load-bearing requirements; however, the SPT-based analysis provides a substantially larger margin of safety.

Overall, the findings demonstrate that the estimated pile bearing capacity is influenced by both the field investigation method and the analytical approach adopted. The Meyerhof method consistently produced higher allowable capacities than the Schmertmann method for both CPT and SPT datasets. Furthermore, SPT-based analyses yielded larger capacity values than CPT-based analyses. These differences highlight the importance of carefully selecting and validating empirical design methods during foundation engineering practice. Integrating multiple site investigation techniques and comparing alternative analytical approaches can improve the reliability of pile foundation design and reduce uncertainties associated with bearing-capacity estimation.

#### 4. Conclusion

This study evaluated the bearing capacity of pile foundations using CPT and SPT investigation data and compared the prediction results obtained from the Meyerhof and Schmertmann methods. Based on the analyses performed, several conclusions can be drawn. The results indicate that the Meyerhof method consistently produced higher allowable bearing capacities than the Schmertmann method for all

investigated locations. For the CPT-based analysis, the allowable capacities obtained using the Meyerhof method ranged from 261.26 to 318.10 tons, whereas the Schmertmann method yielded capacities ranging from 228.53 to 276.84 tons. Similarly, for the SPT-based analysis, the Meyerhof method produced allowable capacities between 445.94 and 458.20 tons, which were higher than the values predicted by the Schmertmann method, ranging from 392.18 to 404.63 tons.

The comparison between CPT- and SPT-based analyses revealed that SPT data resulted in substantially higher pile bearing capacities than CPT data for the investigated soil conditions. This finding highlights the influence of field investigation techniques and interpretation methods on the estimated foundation performance. The pile group analysis using the Converse–Labarre approach showed that a four-pile configuration with a group efficiency of 0.758 provided allowable capacities of 792.12 tons and 1352.09 tons based on CPT and SPT data, respectively. Both capacities exceeded the required design load of 750 tons, indicating that the proposed pile group configuration satisfies the structural loading requirements.

Overall, the findings demonstrate that the selection of analytical methods and geotechnical investigation data can significantly affect pile foundation design outcomes. Therefore, the combined use of CPT and SPT investigations, together with comparative evaluation of alternative bearing-capacity prediction methods, is recommended to improve the reliability and safety of pile foundation design in engineering practice. Future studies are encouraged to validate the analytical results using pile load test data and to investigate the applicability of additional empirical and numerical approaches under different soil conditions.

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