The Comparison of Pile Bearing Capacity using 8 Direct Method based on CPT data in Surabaya Area

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Abstract. This research focuses on comparing the pile bearing capacity resulting from eight different methods that have been developed and are widely used in design. The methods used are the Schmertmann (1978), LCPC (Bustamante & Gianeselli 1982 – Laboratoire Central des Ponts et Chausses), De Ruiter and Beringen (1979), Tumay and Fakhroo (1982), Price and Wardle (1982), Philipponnat (1980), Aoki and De Alencar (1975), and the Penpile methods (Clisby et al 1978). CPT data is used in this study because it is considered easier, faster and fast and relatively economical, and supplies continuous records with depth. Twenty different CPT data variations in the Surabaya area were used in this study. The piles used in this study are concrete piles with a diameter of 60 cm. The result of this research is that the bearing capacity using the Schmertmann method tends to be greater when compared to other methods while the Penpile method produces the lowest carrying capacity. The ratio of the minimum and maximum carrying capacity of the 8 methods used is up to 20%.

1. Introduction
Pile are relatively long material and generally a type of structural foundation. It is suitable for subgrade conditions that have a deep soft soil layer. Piles usually serve as a foundation that transmits the upper structure load to deep sub-soil layers. The ultimate axial load carrying capacity or bearing capacity (Qu) of piles is composed of end bearing capacity of the pile (Qt) and shaft friction capacity (Qs). Established the piles bearing capacity is a challenge especially in various natural conditions. The engineering practice and researchers have developed several methods to cope with the uncertainty in the design and analysis. However, due to simplification assumptions regarding the soil characteristic, shaft resistance along with a pile and soil-pile structure interaction the methods provide qualitative results rather than truly quantitative values directly useful in the pile design [1]. In addition to soil data, the bearing capacity of a pile is also influenced by the shape and size of the pile. From soil data parameters and the dimensions of the piles used, different bearing capacity values will be generated.

An overview of soil conditions can be obtained from the results of soil investigations in the form of laboratory tests, SPT (Standard Penetration Test), Cone Penetration Test, CPT). The cone penetration test (CPT) is a preferred measurement for site characterization and soil properties evaluation. It has been widely used by engineers practice especially for geo-technician to evaluate soil stratigraphy and soil properties for engineering purposes such as soil classification, soil strength, and soil deformation characteristics. Different devices can be added to the cone penetrometer, making it possible to use the test in a variety of geotechnical applications [2]. Moreover, several researchers [2,3-7] argued that CPT method is simple, fast and relatively economical, and supplies continuous records with depth.
The CPT results are interpreted easily on an empirical and analytical basis. Because of the similarity of the cone and the pile, the prediction of pile capacity using the CPT data is considered among the earliest applications of the CPT [2]. Besides that, when compared to the standard penetration test (SPT) method, its method is more popular owing to the many problems and limitations associated with the performance and interpretation of the results obtained from the SPT [3-4].

There are two main approaches for pile design using CPT data: Indirect methods and direct methods. Indirect methods is evaluated the pile bearing capacity using soil parameters such as undrained shear strength and internal friction angle derived from CPT data, while direct methods use directly the CPT data to assess the end bearing capacity and shaft friction bearing capacity [7-8]. Direct methods are preferred due to the considering inherently the influences of several soil and pile behavior such as effective stress, soil compressibility and soil stress–strain behavior on bearing capacity in both CPT and pile [9]. There are several direct methods in the literature which have a difference between them such as the types of CPT measurements (corrected/uncorrected cone tip resistance, sleeve friction and pore water pressure) used by each method).

During the 1980s, there were several methods developed for piles bearing capacity calculation. These included the Schmertmann [10], the Aoki and de Alencar method [11], the Penpile method [12], the de Ruiter and Beringen method [13], the Philipponnat method [14], the Bustamante and Gianeselli method [15], the Price and Wardle method [16], the Tumay and Fakhroo method [17], and many more. Most of these were proposed by compared the predictions from various CPT data with the load test results within relatively small local areas. Hence the best methods that are matched with the field pile loading test from the previous study generated a different trend. Many researchers have compared the piles bearing capacity with the formulas that have developed from the 1980s. The results are different depending on several things, one of which is the different soil conditions in each study area. In addition, the number of areas tested, and the type of pile used can also be one of the factors affecting the difference in results.

Obeta [3] in his study resulted that LCPC and Philipponnat methods are best suited for cohesionless soils, while the LCPC, Tumay and Fakhroo and De Ruiter and Beringen methods are recommended for cohesive soils. However, [18] stated that The Nottingham & Schmertman method is a good method in estimating the axial bearing capacity of the pile foundation with an error deviation less than 10% of the reference loading-test results. Moreover, [2] in his study found another result that the Schmertmann, de Ruiter and Beringen, and Tumay and Fakhroo methods predicted the ultimate compression capacities of piles installed in soft Louisiana soils with a reasonable accuracy. The LCPC method underpredicted the measured capacities of these piles. The Philipponnat method and the Begemann method are quite good when used on clay soil (not silt soil). Murad and Titi [19] with his study resulted the best performing CPT methods are the LCPC method for by Bustamante and Gianeselly as well as the De Ruiter and Beringen Method. There are many more similar researches such as [4-8,20-21] but produced different conclusions related with finding the best and suitable method for pile bearing capacity calculation. Based on these differences in results, this study was conducted to study the trend differences, especially those related to the bearing capacity of the pile.

The objective of this study is to seek to appraise the eight methods performance for piles bearing capacity calculation from CPT logs. The results will be compared with the previous research and can also be used as a guide for designing the needs of piles in the real field construction. 20 variations of soil CPT data were used in this analysis consisting of 10 CPT data with dominant clay soil, 10 sand dominant soil data and 10 heterogeneous soil data. The piles in this study are PPC piles with dimensions 60 cm. This study aims to see the pattern of bearing capacity analysis results for each method with different soil conditions.

2. Data and Method
Based on the introduction that has been described, the data and methods are described below:

2.1 Data
Soil data used is data carried out by the soil and rock mechanics laboratory of the ITS Civil Engineering Department. The number of investigation points used was 10 scattered in several
locations in Surabaya. From the obtained soil data, it can be illustrated in the graph in Figure 1. From the results of the CPT test a total of 20 used the assumption of two types of soil, 10 of those are dominant clay and the other 10 data are sand dominancy. The pile foundation used is a circle, the size of the piles used in the calculation of the allowable axial bearing capacity is 60 mm. The dimensions and shape of the piles were chosen because they are mostly used in application.

![Figure 1. Relationship between depth and qc value on 10 CPT data in Surabaya.](image)

From the 10 data obtained, it shows that the average depth of soil investigation is 10-20 m with the largest qc value is 25000 KN/m². The minimum qc value is at almost 10 points of soil investigation range 0 - 1000 KN / m² it means a little bearing capacity. Except for data 7 where the depth of the investigation was carried out to a depth of 28.2 m but the average qc value obtained was 500 KN / m² at the minimum value and 4300 KN/m² for the maximum qc value.

2.2 Method
The method used in calculating allowable axial capacity based on CPT uses 8 methods. The calculation principle used is a direct calculation of the qc value obtained. 8 methods of calculating bearing capacity of the pile, namely: Schmertmann [10], LCPC [15], De Ruiter and Beringen [13], Tumay and Fakhroo [17], Price and Wardle [16], Philipponnat [14], Aoki and De Alencar [11], and the Penpile methods [12]. The formula for calculate the bearing capacity of pile with those eight methods described in Table 1.
Table 1. Formula for calculate the bearing capacity based on CPT Data

| CPT pile prediction method | \( q_b \) (unit end bearing capacity) | \( f \) (unit shaft friction) |
|---------------------------|--------------------------------------|-----------------------------|
| Schmertmann [10]          | \( q_b = \frac{q_{cl1} + q_{cl2}}{2} \leq 15 \text{ MPa} \) | \( f = k_c f_s \leq 120 \text{ KPa}; \ k_c = 0.2-1.25 \) In clay: \( f = k_c f_s \leq 120 \text{ KPa}; \ k_c = 0.2-1.25 \) In sand: \( Q_s = k \left( \sum_{d=0}^{\delta D} \frac{d}{\delta D} f_s A_s + \sum_{d=0}^{\delta D} f_s A_s \right) \) Where \( K \) depends on \( d/D \) ratio |
| De Ruiter and Beringen [13] | In clay: \( q_b = N_c S_u \leq 15 \text{ MPa} \) \( S_u = \frac{q_{ca}}{N_k}, N_c = 9, N_k = 15 \) to 20 | In sand: \( f = \min \left\{ \frac{q_{ca}}{300} \right\} (\text{compression}) \) \( f = \min \left\{ \frac{q_{ca}}{400} \right\} (\text{tension}) \) 120 KPa Depending on soil type, pile type and installation procedure |
| LCPC (Bustamante and Gianaselli [15]) | \( q_b = k_{b1} q_{eq}(tip) \) | \( f = \frac{q_{eq}(side)}{K_{s1}} \leq \max k_{s1} = 30 - 150 \) |
| Tumay and Fakhroo [17] | Similar to Schmertmann [10] | \( f = m f_{ca} \leq 72 \text{ KPa} \) \( m = 0.5 + 0.9 e^{-0.009 f_{ca}} \) where \( f_{ca} \) is average friction in KPa |
| Aoki and De Alencar [11] | \( q_b = \frac{q_{ca}(tip)}{F_b} \leq 15 \text{ MPa} \) \( F_b \) depends on pile type = 1.75 for PPC driven piles | \( f = \frac{q_{ca}(side) \alpha_1}{F_{s2}} \leq 120 \text{KPa} \) \( \alpha_1 = 1.4-6 \) depends on soil type while \( F_{s2} \) depends on pile type = 3.5 for PPC driven piles |
| Price and Wardle [16] | \( q_b = k_{b2} q_{ca}(tip) \) where \( k_{b2} \) depends on pile type = 0.35 for driven piles | \( f = \alpha_2 f_s \) where \( \alpha_2 = 0.53 \) for driven piles |
| Philipponnat [14] | \( q_b = k_{b3} q_{ca}(tip) \) where \( k_{b3} \) depends on soil type = 0.4 for sand, 0.45 for silt and 0.45 for clay | \( f = \frac{q_{ca}(side) \alpha_3}{F_{s2}} \) \( \alpha_3 \) depends on soil type = 1.25 for PPC driven piles and \( F_{s2} = 50-200 \) depending on soil type |
| Pendle Clisby et al [12] | \( q_b = \begin{cases} 0.25 q_{ca}(tip) \text{ for pile tip in clay} \\ 0.125 q_{ca}(tip) \text{ for pile tip in sand} \end{cases} \) | \( f = \frac{f_s}{1.5 + 14.47 f_s} \) where \( f_s \) and \( f_s \) are in MPa |

\( q_{ca} \) = average \( q_c \) values over a specified zone that depends on the method
3. Result and Discussion

The analysis is carried out by comparing the bearing capacity of the pile using 8 methods on 20 variations of soil data. The result is that each method produces different bearing capacity values, both on the dominant clay soil and the sand dominant one. Most of the carrying capacity values generated by the Schermatmann method have the highest values compared to others. Conversely, the lowest bearing capacity value is obtained using the Penpile method. Score bearing capacity based on the highest value in each method can be seen in Figure 2a for clay soil and Figure 2b for sand soil. Based on Figure 2a, it can be seen that the sequence of the dominant scores for the bearing capacity of the pile from highest to lowest is Schermatmann, Tumay and Fakhroo, Philipponnat, Aoki and De Alencar, Price and Wardle, De reuter, LCPC and Penpile; respectively. The sequence that tends to be different is obtained for sand dominant soils in Figure 2b. De Ruiter has a pile bearing capacity that tends to be high, while Philipponnat has a pile bearing capacity value that tends to be small in sand-dominant soil types. This condition is caused by a significant difference in coefficient between sand and clay soils with those formulations. There is also a difference in the score of the bearing capacity value at each location due to the difference in the CPT result obtained at each location as well as the fluctuation of the CPT result at each depth. Similar results were also obtained by [3] in most of the locations reviewed in this study. The difference in carrying capacity values in each method at each review location in this study can be seen in Figures 3a and 3b.

The results study by [18] which has the same study location, namely in Indonesia, states that The Nottingham & Schermertman method is a good method in estimating the axial bearing capacity of the pile foundation with an error deviation less than 10% of the reference loading-test results. If these results are used as a comparison in this study, the carrying capacity value when using the other 7 methods tends to be stronger when used in the design but becomes very uneconomical. In contrast to the results of a study conducted by [19], states that the best performing are the LCPC method by Bustamante and Gianeselly as well as the De Ruiter and Beringen Method. In addition, [3] stated that LCPC is a good method to use on cohesive and non-cohesive soils. If these results are used as a reference, the Schermantmann method which produces high pile bearing capacity is not conservative and is not strong in planning. In fact, the results of previous research [2] states the opposite regarding the results of the LCPC method where The LCPC method underpredicted the measured capacities of these piles. Other research results also obtained different conclusions, especially in determining the best method to use as a design reference.

The bearing capacity value generated in this study resulted in a significant difference. The ratio of the lowest and highest carrying capacity values reached 20% in both clay dominance and sand dominance. The ratio of the bearing capacity values of the 7 methods to the Schermartmann method on clay dominant soils can be seen in Figure 4a and on sandy soils can be seen in Figure 4b. The very low ratio is caused by the small value of the bearing capacity generated by the Penpile method. This result is supported by a study conducted by [2] who obtained the results of The worst prediction method was the penpile, which is very conservative (underpredicted pile capacities) which was carried out on soil in Louisiana.
Figure 3. The bearing capacity value of each method in the dominant clay soil (a) and dominant sand soil (b).

Figure 4. The ratio of the bearing capacity values of 7 methods to the method on dominant clay soil (a) and dominant sand (b).
4. Conclusion
There are many formulations developed to calculate the bearing capacity of the pile. The bearing
capacity produced by these methods is different from one method to another. This is caused by several
factors, namely differences in soil types which cause differences in coefficients in each formulation. In
addition, the fluctuating of $q_u$ value obtained from CPT test results also causes differences in the
maximum and minimum bearing capacity values when a comparison is made between methods at
different locations. In this study, the bearing capacity value generated by Schmertmann tends to be the
highest when compared to other methods. The results of the bearing capacity with this method are
almost close to the Tumay and Fakhroo and Aoki and de Alencar methods. In addition, the Pen incorporated
method produces the lowest carrying capacity for all data variations in this study. These results also
support the results of previous studies. The ratio of the smallest and largest bearing capacity values
produced by each method is up to 20%, which means that the pile bearing capacity in one method can
be more than four times greater than the other methods. These results may be different when using
other data considering that the data in this study are limited to only 20 variations.

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