Comparison of direct SPT method for calculating axial capacity of piles in Jakarta Area

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Abstract. Estimating axial capacity of piles using Direct Method are still considered as challenges these days. Estimation mainly achieved after construction is done and field method such as static load test or PDA are used for calculating axial capacity of piles in real field conditions. This paper discussed estimation from 8 building project cases from Jakarta and Depok that have complete standard penetration test data and field calculations (static load test & PDA). The main objectives are to observe and correlate the results between every Direct Methods and field methods and to obtain which Direct Method is the most efficient to use for estimating axial capacity of piles in Jakarta area. Direct Methods that are used are Meyerhoff, Shariatmadari, Decourt, Aoki, and Robert. Calculation results showed that the most efficient standard penetration test method is that proposed by Decourt with average result of comparison between estimated axial capacity of piles and field calculation is roughly 1.03. The most underpredicted between every standard penetration test method is the one proposed by Aoki de Alencar with roughly 92% underprediction ratios and the largest overpredicted method is proposed by Shariatmadari with roughly ratios of 56%.

1. Introduction
Estimating axial capacity of piles are still considered as challenges from the early development of geotechnical engineering. Estimation of piles capacity often achieved after piles foundation has already been built and the estimated capacity obtained by doing a field method such as static load test or PDA Test. Nowadays, many field tests or in-situ tests are being used for field investigation of the soil, so geotechnical engineer could design according to field conditions. Field test such as cone penetration test (CPT) and standard penetration test (SPT) are common used for calculating axial capacity of piles foundation. Standard penetration test (SPT) often used because of the relatively inexpensive cost and fast process. This paper hopefully can be used for a faster method to estimate axial capacity of piles foundation in Jakarta area.

2. Axial Capacity of Piles
Even though pile foundation commonly used as a group but it is needed to calculate the allowable load a single pile could bear. Allowable load could be determined from the load that caused shear failure or the amount of load reached allowable settlement, the smaller value will be used as the allowable load of the foundation. Indirect method used soil data from lab test whereas direct method doesn’t need any soil data from laboratory, it only needed field data from cone penetration test (CPT) or standard penetration test (SPT). This paper only discussed direct methods from standard penetration test data or N-SPT.
2.1. Direct method

In development of geotechnical engineering, it is more common to use in-situ test for the sake of geotechnical design. This is mainly because of there are an increasing amount of research for in-situ testing, development of soil characteristics knowledge, and realized that conventional laboratory test has many limitations. Based on this research title, direct method that used is only from standard penetration test (SPT). Table below is the explanation of every direct SPT method that is used in this paper.

**Table 1.** Direct SPT methods for estimating piles axial capacity.

| Method          | Method expression | Remarks |
|-----------------|-------------------|---------|
| Meyerhof (1956) | Driven: $40N(L/d)$ | $q_b = 40N(L/d) \leq 400N$ |
|                 | Bored: $133N$     | (N/A)   |
|                 | Driven: $2\bar{N}$|         |
|                 | Bored: $0.67\bar{N}$|         |
| Shariatmadari   | $385N_b$          | $\alpha = 1$; driven piles |
|                 | $3.65N_s$         | $\alpha = 1$; bored piles in clay |
|                 | $\alpha = 0.5-0.6$; bored in granular soil |
| Decourt (1995)  | $k_bN_b$          | $k_b = 0.325$; driven & bored piles in granular |
|                 | $\alpha (2.8N_s + 10)$ | $k_b = 0.1$; driven piles in clay |
|                 | $\alpha = 0.5-0.6$; bored in granular soil |
| Robert          | Driven: $N_b190$  | (N/A)   |
|                 | Bored: $N_b115$   |         |
| Aoki Velosso    | $(k/1.75)N_b$     | $a = 14$; for clay |
|                 | $(ak/3.5)N_s$     | $a = 60$; for sand |
|                 |                    | $k = 1$; for clay |
|                 |                    | $k = 0.2$; for sand |

2.1.1. Influence or failure zone. Based on Table 1, there are two notations, $N_b$ and $N_s$ that are obtained from the N-SPT Data. $N_s$ is the average N-SPT value that is used to calculate the shaft resistance of pile ($q_s$). $N_s$ value is calculated by the average of N-value from top to bottom of the pile. Every method uses this average of N-value along the piles to calculate the $N_s$ value. It is not the same case for $N_b$, where $N_b$ is the average of N-SPT value that correlates to the end bearing value and the depth of $N_b$ influence zone is achieved based on the assumption of every proposed method.

2.2. Axial Compression load test and PDA

Axial loading test and PDA test are used for checking the quality of piles foundation in field, 2 categories are need to be checked which are axial capacity of piles and piles settlement. Axial capacity value from every pile based on loading test or PDA test are needed for comparing with axial capacity result from direct SPT method. Axial loading test results are interpreted with 2 methods which are Chin Method and Decourt Method. Both of them are extrapolation method to achieve ultimate axial capacity of pile based on load and settlement data of each load test.

3. Data base

A data base of 52 piles case histories, combination of 23 bored piles and 29 driven piles that also included with static load test or PDA test data. Figure 1 below is the map plot of the location of every project that is being used. The case histories are collected from 8 projects based on Jakarta and Depok.
The piles generally located in clayey soil or sandy soil and the depth of piles ranging from 17 m to 53.2 m and the diameter of the piles started from 0.4 m until 1.2 m. All of the piles are made of concrete and the cross-section shape are mainly square or circle.

Figure 1. Locations of piles data projects. Green dots represent the project locations.

4. Results
Every pile from data base is calculated with all of direct SPT method that have been introduced in Table 1. Also every axial capacity result is compared and divided with the measured result from interpretation of loading test or PDA test. Rank Index method is used to decides whether the proposed method is reliable to be used in Jakarta or not and which method is the best from 5 proposed methods, its main purpose is to sort the result from every proposed method and ranks it from the best to worst. Rank index have 3 criteria on evaluating every method.

The first criterion (R1) is based on the best fit line or the data distribution from the graph, every result from all method is made into plot graph which the x-axis is the measured axial capacity ($Q_m$) that obtained from interpretation of loading test or PDA test and the y-axis is the predicted axial capacity ($Q_p$) that achieved from every direct SPT method. This criterion ranks every method based on the result of predicted axial capacity per measured axial capacity ($Q_p/Q_m$) or the $r$ squared of the regression linear graph. The value of predicted axial capacity per measured axial capacity ($Q_p/Q_m$) is also obtained by dividing the linear equation ($y/x$) and $r$ squared value obtained from the linear regression. The best predicted per measured value ($Q_p/Q_m$) is when the value indicating that the predicted is not far off the measured from field, this means it is best when $Q_p/Q_m$ value is come near to or the same as

The second criteria (R2) is based on the rank of mean and standard deviation results from every method. The third criteria (R3) is using log-normal distribution which the probability prediction could be obtained by this distribution, the probability prediction used error tolerance of 25% that means the upper and lower bounds of $Q_p/Q_m$ value that included are 1.25 and 0.75. This rank index method is used to evaluate 3 dataset, which are: all piles (bored & driven), only bored piles and only driven piles. Figure 2 below is the result of best fit line and Figure 3 is the log-normal distribution of the first dataset or all data.
Figure 2. Best fit line plot graph of all piles.
Based on Figure 3 below, probability prediction of every method could be obtained by using this equation (e.g. Shariatmadari et.al, 2006)

\[ P_p(\%) = 100 \times \int_{0.75}^{1.25} f(x) \, dx \]  

(1)

![Figure 3. Log-normal distribution of all piles.](image)

Rank Index of of every criterion is made and combined with 2 others to obtain the overall rank of every direct SPT method. Table 2 below is the result of combined rank index table. As can be seen from Table 2 from best-fit line criterion, the best method is Decourt with \( Q_p/Q_m \) result of 1.28 and 0.60 \( R^2 \) squared. Second criterion based on mean and standard deviation, the best method is also Decourt with mean and standard deviation results of 1.03 and 0.55. The third criterion is based on the probability prediction which obtained from log-normal distribution, the best method as can be seen from the table is also Decourt. The rank total and overall rank based on three criterions could be seen at second and first column from the right. As can be seen from the last column, the overall best method after evaluating with 3 criterions is method proposed by Decourt and the last rank is method proposed by Robert. If Shariatmadari method results compared with Decourt, both of them gave similar result but Shariatmadari tends to overpredict based on the \( Q_p/Q_m \) and mean results.

| Method     | Best-Fit Line | Mean & Standard Deviation | Log-Normal Distribution Probability | Rank Index (RI) | Rank |
|------------|---------------|---------------------------|-------------------------------------|-----------------|------|
|            | \( Q_p/Q_m \) | (R1) Mean, S.D (\( \sigma \)) | Rank R2 Probability (\( \pm 25\% \) Error) | Rank R3          |      |
| Meyerhoff  | 0.48          | 0.32                      | 5 0.79, 0.66 2 23.88 3 | 10              | 3    |
| Shariatmadari | 1.28          | 0.60                      | 2 1.30, 0.61 3 72.13 2 | 7               | 2    |
| Decourt    | 0.80          | 0.60                      | 1 1.03, 0.55 1 85.19 1 | 3               | 1    |
| Aoki       | 0.68          | 0.53                      | 3 0.65, 0.28 4 19.02 4 | 11              | 4    |
| Robert     | 0.56          | 0.61                      | 4 0.65, 0.31 5 18.32 5 | 14              | 5    |

4.1. Bored piles

On this section bored piles data is separated from driven piles data for evaluating with rank index criterion. The steps and method are same as section before, using three criterions to evaluate the best method for bored piles in Jakarta area. Figure 4 below is the best-fit line plot of all methods and Figure 5 is the log-normal distribution curve result. Table 3 below is the summary result of rank index criterion that have been calculated from bored piles data. As can be seen from the table, the best result of three criterion is still method proposed by Decourt. Eventhough the probability prediction of Decourt is not as high from earlier section but the end result shows that it is still the best method to use. The second
best result is the method proposed by Shariatmadari, from probability prediction it got a higher percentage compared than Decourt but from the log-normal distribution can be seen that the result is more dispersed than Decourt.

![Figure 4. Best fit line method of bored piles.](image)

![Figure 5. Log-normal distribution of bored piles.](image)

**Table 3. Rank index of bored piles.**

| Method  | Best-Fit Line | Mean & Standard Deviation | Log-Normal Distribution Probability | Rank Index (RI) | Rank |
|---------|---------------|---------------------------|-------------------------------------|-----------------|------|
|         | $Q_p/Q_m$     | $R^2$ Rank R1 Mean S.D. Rank R2 Probability (±25% Error) Rank R3 |
| Meyerhoff | 0.35 0.55 | 5 0.34 0.11 5 9.14 5 15 5 |
| Shariatmadari | 1.30 0.46 | 2 1.26 0.42 2 74.53 1 5 2 |
| Decourt | 0.78 0.44 | 1 0.80 0.25 1 47.85 2 4 1 |
| Aoki | 0.71 0.32 | 3 0.73 0.24 3 26.74 3 9 3 |
| Robert | 0.57 0.50 | 4 0.58 0.18 4 11.63 4 12 4 |
4.2. Driven piles

On this section driven piles data is separated from bored piles data for evaluating with rank index criterion. The steps and method are same as section before, using three criterions to evaluate the best method for driven piles in Jakarta area. Figure 6 below is the log-normal distribution curve result and Figure 7 is the best-fit line plot of all methods. Table 4 below is the summary result of rank index criterion that have been calculated from driven piles data. As can be seen from the table, the best result of three criterion is still the method proposed by Decourt. The second and third best result is the method proposed by Meyerhoff and Shariatmadari with similar results but Shariatmadari results show it is tend to overpredicting the axial capacity.

![Figure 6. Log-normal distribution of driven piles.](image)

![Figure 7. Best fit line of driven piles.](image)
Table 4. Rank index results of driven piles.

| Method            | Best-Fit Line | Mean & Standard Deviation | Log-Normal Distribution Probability | Rank Index (RI) | Rank |
|-------------------|---------------|----------------------------|-------------------------------------|----------------|------|
|                   | $Q_p/Q_m$     | $R^2$                      | Rank R1                            | Mean           | S.D (σ) | Rank R2 | Probability ±25% Error | Rank R3 |
| Meyerhoff         | 0.91          | -0.10                      | 3                                  | 1.14           | 0.71    | 1       | 72.07                        | 2      | 6    | 2 |
| Shariatmadari     | 1.01          | -0.03                      | 1                                  | 1.32           | 0.73    | 3       | 69.5                         | 3      | 7    | 3 |
| Decourt           | 0.92          | -0.01                      | 2                                  | 1.22           | 0.65    | 2       | 81.74                        | 1      | 5    | 1 |
| Aoki              | 0.46          | -0.04                      | 5                                  | 0.59           | 0.30    | 5       | 16                           | 5      | 15   | 5 |
| Robert            | 0.52          | -0.06                      | 4                                  | 0.71           | 0.38    | 4       | 23.89                        | 4      | 12   | 4 |

5. Conclusion

Database of 52 piles data consist of bored and driven piles, located on Jakarta and surrounding area with complete data of field test method which either from static loading test or PDA test. There are 5 different direct SPT method are being used for calculation, Meyerhoff (1956), Decourt (1995), Shariatmadari et al (2008), Aoki-Vellso (1975) and Robert (1997). Based on three rank index criterion results from all data, it is obtained that the best and efficient direct SPT method is the one proposed by Decourt. Results showed that Decourt always ranked first overall from the three criteria discussed before and almost always got probability of prediction percentage above 50%. It is indicating that method proposed by Decourt is suitable for both bored piles and driven piles. Decourt calculation shows a little drawback that tends to underpredict the axial capacity but the results are always consistent.

The second best method from three analyses of rank index is method proposed by Shariatmadari. Probability predictions of Shariatmadari show relatively good percentage but tends to overpredict axial capacity of piles. It is important to note that Shariatmadari only proposed this method only for granular soil, because commonly driven pile is used for granular soil and bored piles for fine grained soil. It shows that this method normally fits better for driven piles. Method proposed by Meyerhoff also gave good result from the probability prediction but only for driven piles data.

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