Reliability of Estimation Pile Load Capacity Methods

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Abstract. None of numerous previous methods for predicting pile capacity is known how accurate any of them are when compared with the actual ultimate capacity of piles tested to failure. The author's of the present paper have conducted such an analysis, based on 130 data sets of field loading tests. Out of these 130 data sets, only 44 could be analysed, of which 15 were conducted until the piles actually reached failure. The pile prediction methods used were: Brinch Hansen's method (1963), Chin's method (1970), Decourt's Extrapolation Method (1999), Mazurkiewicz's method (1972), Van der Veen's method (1953), and the Quadratic Hyperbolic Method proposed by Lastiasih, *et al.* (2012). It was obtained that all the above methods were sufficiently reliable when applied to data from pile loading tests that loaded to reach failure. However, when applied to data from pile loading tests that loaded without reaching failure, the methods that yielded lower values for correction factor N are more recommended. Finally, the empirical method of Reese and O'Neill (1988) was found to be reliable enough to be used to estimate the Q_{ult} of a pile foundation based on soil data only.

Keywords: *COV; standard deviation; load settlement curve; pile loading test; quadratic hyperbolic.*

1 Introduction

Estimation of the ultimate axial capacity of pile foundations always involves many uncertainties. This is because the soil parameters used also contain uncertainties, starting from the time of taking the soil samples in the field to testing the samples in the laboratory. Contributing factors are for example: inaccuracies in testing equipment readings, lack of expertise of the operators, and inappropriate handling of the soil samples. Furthermore, the soil parameters usually involve assumptions that can vary considerably from one designer to the

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next, so that the estimated ultimate pile capacity, Q_{ult}, will also vary accordingly, even for the same soil data. These inacuracies and the discrepancy between the estimated capacity and the actual loading test results usually become more pronounced in case of larger pile diameters and bored pile foundations.

With all the uncertainties involved in estimating pile bearing capacity, especially for bored piles and large-diameter piles, designers of pile foundations tend to specify pile loading tests conducted directly in the field in addition to the soil investigation report. This is to gain more assurance that their method for estimating pile capacity is sufficiently reliable when compared to the results of the pile loading tests. The pile loading test most commonly performed is the static loading test that is instrumented with an Osterberg Cell, as shown in Figure 1. Yet, the results of a pile loading test still need interpretation to yield the "actual" ultimate pile bearing capacity. Some of the methods used to interpret field loading tests are: 1. Brinch Hansen's method [1], 2. Chin's method [2], 3. Decourt's Extrapolation Method [3], 4. Mazurkiewicz's method [4], 5. Van der Veen's method [5], and 6. The latest method, proposed by Lastiasih, *et al.* [6], also known as the Quadratic Hyperbolic Method.

Figure 1 Types of pile loading tests.

All the above six methods for interpreting results from field loading tests have their own usefulness, but it has never been attempted before to investigate how reliable any of those six methods are when applied to relatively large pile loading tests data. In this research, the authors have attempted to investigate the reliability of the above methods, using data from loading tests of relatively large piles, a total of 45 data sets, mostly of bored piles in several Indonesian cities, i.e. Medan, Jakarta, Bandung, Cirebon, Jogyakarta, Semarang, Surabaya, Pacitan, and cities in Kalimantan and Manado. The data sets are listed in Table 1. In most cases, the bored piles were not loaded to reach failure but to a recommended load of about 200% of the designed working load. Only 15 data sets were for piles loaded to reach actual failure.

Table 1 List of Pile Loading Tests Used.

Project	Test Method(s)	Maximum Load (ton)	Number/Diameter
Ambassade Residences (2008)	Static C	1250	1 D 800 mm
BPK (2008)	Static C	700	1 D 1000 mm
Cervino Village (2008)	Static C, Ins	1250	1 D 1000 mm
Cyber 2 Tower (2007)	Static C	1150	1 D 1000 mm
DPRD Kebon Sirih (2009)	Static C	750	1 D 1000 mm
Dept. Kelautan & Perikanan (2005)	Static C	900	1 D 1000 mm
Eightrium (2009)	Static C		1 D 500 mm, 2 D 800 mm, 2 D 1000 mm
Essence of Darmawangsa (2006)	Static C & T	800	6 D 1000 mm
Gedung Baru PPM (2009)	Static C	625	1 D 1000 mm
Grand Indonesia (1994 & 2005)	Static C & T, Ins (2)	1320	1 D 800 mm, 11 D 1000 mm
Green Bay (2010)	Static C	600	1 D 1000 mm
Life Tower (2007)	Static C, Ins	1250	1 D 600 mm, 1 D 1000 mm
Menara Jakarta (1996)	Static C	1,741,658	1 D 1000 mm
Moritz, St, (2005, 2009)	Static C & T, Ins (2)	1250; 1500	4 D 1000 mm , 2 D 1200 mm
Multivision Tower (2009)	Static C	1060	1D 800mm, 1 D 1000 mm
Kebagusan City (2010)	Static C	1225	1 D 1000 mm
Kejaksaan Agung (2008)	Static C	420	1 D 800 mm
Kemang Village Residence (2007)	Static C, Ins	1050; 2100	1 D 1000 mm, 1 D 1200 mm
Plaza Indonesia Extension (2006)	Static C – Osterberg		3 D 1800 mm
Private Residence (2008)	Static C	1000	1 D 1000 mm
Prodia (2007)	Static C	500	1 D 800 mm
Senopati Suites (2008)	Static C	800	1 D 1000 mm
Sudirman Test (before 1992)	Static C	800	1 D 1000 mm
Tanah Abang Timur (before 1992)	Static C	800	1 D 1000 mm
Teluk Gong (before 1992)	Static C	800	1 D 1000 mm
TMTC (2008)	Static C	800	1 D 800 mm 1 D 1000 mm

Table 1 ***Continued.*** List of Pile Loading Tests Used.

Project	Test Method(s)	Maximum Load (ton)	Number/Diameter
TV 7 Office & Studio (2005)	Static C & T		2 D 1200 mm
Tempo Scan Tower (2009)	Static C	1050	1 D 1000 mm
Tempo Tower (2009)	Static C	1050	1 D 1000 mm
Pakubowono residence	Osterberg C	1500	D 1800 mm
Wisma Pondok Indah 3 (2010)	Static C & T	640	5 D1000 mm
			3 D1200 mm
OT Office Puri Krembangan (2010)	Static C	220	2 D 800 mm
GP Plaza Gatot Subroto	Static C	32	1 D 1000 mm
Southern Lake Residence (2011)	Static C	220	1 D 1000 mm
			1 D 1200 mm
Icon Residence	Static C	131,25; 1417,5	2 D 1000 mm
Cirebon	Static C	1600	1D1500 mm
Jogjakarta	Static C	230	1D1000 mm
Medan	Static C	1100	1D1000 mm
Menado	Static C	755	1D1500 mm
Semarang	Static C	800	1D1000 mm
Surabaya	Osterberg C	2019, 2553, 2990, 3400, 4160	5D2400 mm
Pacitan	Static C	800	1D1000 mm
Kalimatan	Static C	400	1D1000 mm

The main purpose of this study was to investigate the reliability of the above six methods of pile loading test interpretation. Furthermore, since a large percentage of the collected pile loading test data sets from Indonesia also include the initial prediction of the pile load capacity, mostly calculated using the theoretical-empirical method of Reese and O'Neill [7], it was possible to compare the predicted load capacity from this method with the interpreted ultimate pile capacity using the six methods above. Hopefully, the results of this study can encourage people to be more confident in selecting bored piles as their choice of pile foundation. In big cities with densely spaced buildings such as in Figure 2, the use of bored piles for a pile foundation is often the only choice available.

Figure 2 Densely spaced buildings.

2 Previous Study

The existing methods for pile loading test interpretation have been established with their own criteria, assumptions, and methods of formulation in such a way that for each of them a curve of load vs. settlement can be drawn.

Chin's method [2] specifies that the ultimate load capacity of a pile will be reached after all the pile's resistant forces have been fully mobilized. The load-displacement curve will approach a hyperbolic curve. This method is also an extrapolation, using a slow or quick maintained load test with a constant time interval of loading increment. Chin used one steel pipe pile with a diameter of 1.94" (4.93 cm) and 3 (three) concrete piles with a diameter of 14" (35.56 cm) to verify his criteria. Then Chin applied his criteria to other pile loading test data. The load increment was applied every 48 hours.

Davidson [3] has developed his method for determining ultimate pile load based on the assumption of total deformation of a pile exceeding the assumed bearing capacity displacement in the bottom tip of the pile plus an additional movement of 0.15" (0.38 cm). The pile tip bearing capacity, Q_{tip}, was found to be variable for different types of piles and the loading methods were for static loading of quick maintained loading without cyclic unloading. Davidson verified his method using test piles with a diameter of 1 foot (30.48 cm).

Hansen's 80%-criteria method [1] was developed using the assumption of a parabolic stress-strain correlation based on laboratory measurements. This is an extrapolation method that can be applied for all types of pile loading tests in general and is not limited to a particular pile type. Hansen [1] did not mention how and to what types or dimensions of piles his method was verified; yet, this method can be applied for slow or quick maintained loading, and for constant rate of penetration loading without the need of cyclic unloading.

Introducing his Extrapolation Method, Decourt [8] did not specify the assumptions he had used in developing it. In his method the ultimate pile load is determined by crossing the linear regression lines with the load axis.

Mazurkiewicz [4] suggested his formula based on the assumption of a parabolic load-settlement curve; yet, he did not mention the types, dimensions, or the methods of testing through which his method was verified.

Finally, Van der Veen [5] introduced his method with the asumption of a load-settlement curve approaching an exponential function, but Van der Veen also did not reveal the types and dimensions of piles, nor the pile loading tests used in his investigations.

3 Basic Assumptions Used

3.1 Ultimate Load Criteria (Q_{ult})

According to Thomlinson [9], there are 7 criteria to determine pile failure, but the criteria most commonly used for determining Q_{ult} is the one where settlement keeps increasing without any increment of the load, as shown in Figure 3. This assumption will be used throughout this paper.

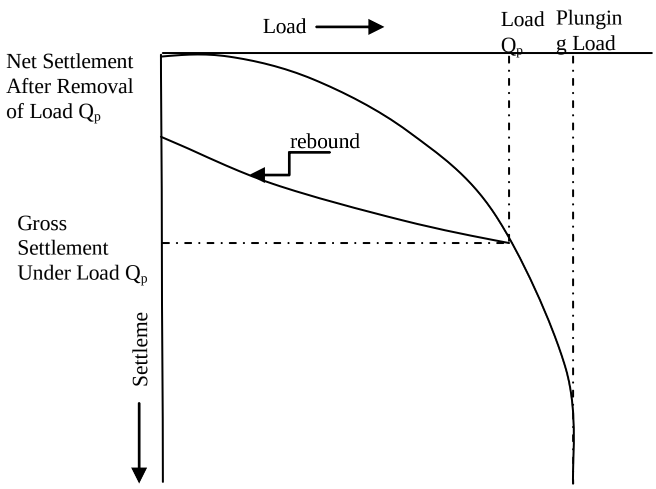

Figure 3 Typical load-settlement curve [8].

3.2 Formulas for Ultimate Load Capacity of Piles

The ultimate load capacity of piles comprises the summation of the pile tip bearing capacity and the pile shaft frictional capacity, as given in Eq. (1) and illustrated in Figure 4.

$$Q_u = Q_p + Q_s \tag{1}$$

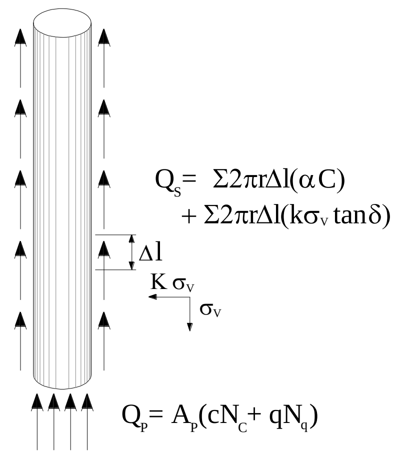

Figure 4 Elements contributing to axial pile load capacity.

The formulas of the pile load capacity of pile foundations are derived based on the soil type and the type of material used for the piles as given in Eqs. (2) and (3) for cohesive soils and in Table 1 and Table 2 for non-cohesive soils. The formulas to predict pile load capacity can be itemized as follows:

a. Formula for Pile Load Capacity in Cohesive Soils

For bored piles, the ultimate tip bearing resistance is

$$Q_p = 9c_u A_p \tag{2}$$

The ultimate shaft frictional resistance is

$$Q_s = \alpha \times c_u \times L_i \times p \tag{3}$$

where:
α = adhesion coefficient between pile and soil;
c_u = undrained shear strength of soil;
L_i = length of pile section;
p = pile circumference.

b. Formula for Pile Load Capacity in Non-Cohesive Soils

For bored piles or drilled shafts in sand, the formulas are as given in Table 2 and Table 3.

Table 2 Tip Bearing Capacity for Drilled Shafts in Sand.

Reference	Description
Touma and Reese (1974)	Loose ⇒ q_p (tsf) =0 Medium Dense ⇒ $q_p(tsf) = \frac{16}{k}$ Very Dense ⇒ $q_p(tsf) = \frac{40}{k}$ k = 1 for D_p < 1,67ft & k = 0,6D_p for D_p > 1,67 ft
Meyerhof (1976)	$q_p(tsf) = \frac{2 \times N_{corr} \times D_b}{15 \times D_b} < \frac{4}{3} Ncorr$ for sand $q_p(tsf) = \frac{2 \times N_{corr} \times D_b}{15 \times D_b} < Ncorr$ for non-plastic silts
Quiros and Reese (1977)	Same as Touma and Reese (1974)
Reese and Wright (1977)	$q_p(tsf) = \frac{2}{3} N$ for $N \leq 60$ $q_p(tsf) = 40$ for N > 60
Reese and O'Neill (1988)	$q_p(tsf) = 0,6N$ for N < 75 $q_p(tsf) = 45$ for N > 75

where:

N_{corr} = SPT blow count corrected for overburden pressure

= $\left(0.77 \log_{10}\left(20 / \sigma_v'\right)\right) N$

N = uncorrected SPT blow count

D_p = base diameter of drilled shaft in ft

D_b = embedment of drilled shaft in sand bearing layer.

Table 3 Shaft Resistance Capacity of Drilled Shaft in Sand.

Reference	Description
Touma and Reese (1974)	$q_s = k \times \sigma_v' \tan\phi'$ < 2,5 tsf where: k = 0,7 for $D_b \leq$ 25 ft k = 0,6 for 25 ft < D_b < 40 ft k = 0,5 for $D_b \geq$ 40 ft
Meyerhof (1976)	$q_s = \frac{N}{100}$
Quiros and Reese (1977)	$q_s(tsf) = 0,026 \times N$ < 2 tsf

Table 3 ***Continued.*** Shaft Resistance Capacity of Drilled Shaft in Sand.

Reference	Description
Reese and Wright (1977)	$q_s(tsf) = \frac{N}{34}$ for $N < 53$ $q_s(tsf) = \frac{N-53}{450} + 1{,}6$ for $53 < N < 100$
Reese and O'Neill (1988)	$q_s(tsf) = \beta \times \sigma_v'$ $\leq$ 2 tsf for $0{,}25 \leq \beta \leq 1{,}2$ where $\beta = 1{,}5 - 0{,}135\sqrt{z}$

where:

N = uncorrected SPT blow count
σ_v' = vertical effective stress
ϕ' = friction angle of sand
k = load transfer factor
D_b = embedment of drilled shaft in sand bearing layer
β = load transfer coefficient

3.3 Prediction of Ultimate Load Capacity of Piles Commonly Used in Indonesia

For most of the pile loading test data collected from various cities throughout Indonesia, the method used for predicting the ultimate load capacity of piles is the formula used by Reese and O'Neill [7], as follows:

Ultimate Pile Tip Bearing Capacity (Q_p) for cohesive soils:

$$Q_p = 9 \times c_u \times A_p (ton) \tag{4}$$

Ultimate Pile Tip Bearing Capacity (Q_p) for non-cohesive soils:

$$Q_p = \frac{45}{0.3048^2} \times A_p (ton) \text{ for } N_{SPT} > 75 \tag{5}$$

$$Q_p = \frac{0.6}{0.3048^2} \times N \times A_p (ton) \text{ for } N_{SPT} \leq 75 \tag{6}$$

Ultimate Shaft Resistance Capacity (Q_s) for cohesive soils:

$$Q_s = c_u \times \alpha \times p \times \Delta l (ton) \tag{7}$$

Ultimate Shaft Resistance Capacity (Q_s) for cohesive soils:

$$Q_s = \beta \times \sigma_v ' \times p \times \Delta l (ton) \quad (8)$$

$$\beta = 1.5 - 0.315\sqrt{z} \quad (9)$$

where:
Q_p = end bearing capacity
Q_s = friction bearing capacity
Q_u = ultimate pile load capacity
A_p = pile crossectional area (m^2)
p = pile circumference
α = correction factor
σ_v' = vertical effective stress
β = load transfer coefficient

3.4 Method of Quadratic Hyperbolic Curve

Based on personal communication, Toha [10] suggested to research a new method for interpreting pile loading test results to obtain ultimate bearing capacity. A new method using a quadratic hyperbolic curve has recently been introduced by Lastiasih, *et al*. [6]. In this method, the interpretation is performed on the basis of a large number of pile loading test data that are available in Indonesia. The assumption also uses a hyperbolic approach, but with a higher-order one, i.e. the quadratic hyperbolic, which has the following equation:

$$y = \frac{a\left(x^2 + bx\right)}{\left(x^2 + cx + d\right)} \quad (10)$$

This method was developed based on the results of static pile loading tests using an Osterberg Cell for measuring the loads on various diameters of piles, ranging between 80 cm and 240 cm. This method also merely plots the results of the load vs. settlement curve as given in Figure 5, from which the drawn curve can be estimated to approach a quadratic hyperbolic such as the one given in Eq. (10). The coefficients of parameters *a*, *b*, *c*, and *d* can be obtained using the help of the mathematical program MATLAB by means of trial-and-error in order to obtain the final curve with value $R^2 \approx 1$.

The value of *a* represents the load when settlement approaches infinity (very large); the value of *b* represents the slope of the straight line tangent to the curve after reaching its peak; the value of *c* represents the parameter of the parabolic curve at its peak; and the value of d represents the slope of the straight line tangent to the curve at the beginning of the curve.

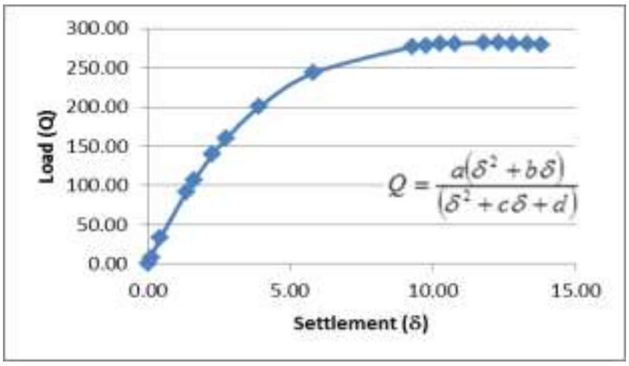

Figure 5 Ultimate load estimation using the Quadratic Hyperbolic Method [6].

4 Methodology for Comparing the Accuracy of the Interpretation Methods

To obtain the accuracy of the above interpretation methods prior to conducting interpretation, a relatively large number of pile loading test data have been collected from cities throughout Indonesia. A total of 130 data sets from pile loading tests have been collected. 15 (fifteen) of these loading tests were data of pile loading tests that loaded to reach failure, while the rest of the data were for pile loading tests that loaded to reach 200% of the working load, as commonly specified, without having to reach the failure load.

The first trials performed were to compare the results of each of the interpretation methods with the results of the field loading tests when the piles were loaded to reach failure (from 15 test data sets). The results of the field loading tests were usually drawn as load vs. settlement curves. The six interpretation methods mentioned above use similar load-and-settlement correlations. Therefore, by using the field settlement data as reference, one can perform a curve-fitting procedure to match the results of each of the interpretation methods with the field loading test results.

The next step was to investigate the accuracy of each of the interpretation methods when applied to the data of the field loading tests that loaded without reaching failure. The data of the 15 pile loading tests that loaded to reach failure were compared with the same data of the interpretation methods, where the field data were truncated to a value of only 175% of the predetermined working load. The reason for taking the 175% limit was because some of the piles already reached failure during the loading test at 200% of the working load, while none of them reached the failure point at 175% of the working load. Therefore, when referring to data of pile loading tests that loaded without reaching failure, each of the interpretation methods would be able to predict their failure load, Q_{ult}, and comparison with the actual failure load would reveal their accuracy of prediction.

Finally, from the rest of the 115 field pile tests, which loaded without reaching failure, a large percentage were reported with complete soil data and with an estimated value of Q_{ult} using the empirical method of Reese and O'Neill [8]. Assuming the estimated empirical Q_{ult} by Reese and O'Neill as the empirical ultimate load, one can compare the empirical values with the ultimate values obtained from the six interpretation methods. Most of the results showed that the interpretation methods would give much higher values than the empirical values, so that a correction factor *N* should be applied, as follows:

$$\left(N = \frac{Q_{ult.\mathrm{int}erpretation\_method}}{Q_{ult.empiric}} \right) . \tag{11}$$

5 Results and Analysis

5.1 Accuracy of Load-Settlement Curve From Data of Pile Loading Tests That Loaded To Reach Failure

Using only the data of the pile loading tests that were performed to reach failure, the resulted load-settlement curves will produce an average correction value, *N*, by comparing points obtained directly from the loading test data with points defined by each of the interpretation formulas, in alphabetical order: Brinch Hansen's 80% method [1], Chin's method [2], Decourt's Extrapolation Method [8], Mazurkiewicz's method [4], the Quadratic Hyperbolic Method by Lastiasih, *et al.*[6], and Van der Veen's method [5]. The comparison results can be seen in Table 4.

It is apparent from Table 4 that correction factor *N* for the piles that were loaded to reach failure is relatively similar from one method to the other. The correction factor varied slightly within a maximum variation of only 6%, which is quite acceptable. Also the coefficient of variation, COV, is very similar for each method. Therefore, it can be concluded that if the the pile loading test includes loading to reach failure, any of the interpretation methods mentioned above can be used confidently.

Table 4 Statistical Analysis of Various Methods when Used to Interpret Pile Loading Tests that Loaded To Reach Failure.

Fitting Curve Analysis	Chin	Decourt	Hansen	Mazurkiewizc	Quadratic Hyperbolic	Van der Veen
Avarage Correction Factor	0.99	1.00	1.06	1.01	0.96	1.02
Variance	0.01	0.01	0.01	0.01	0.01	0.01
Standard Deviation	0.10	0.10	0.10	0.10	0.10	0.10
COV	10.3%	10.2%	9.9%	10.1%	10.4%	10.1%

5.2 Accuracy of Load-Settlement Curves From Pile Loading Tests That Loaded Without Reaching Failure

A large number of data from pile load tests were obtained from tests that loaded to reach a maximum load of 200% of the working load without reaching failure. To investigate the accuracy of the proposed methods, the results of the pile loading tests from Section 5.1. were used again, but now only the load-settlement data to a maximum of 175% of the working load. Each of the above methods, Chin's method [2], Decourt's Extrapolation Method [8], Hansen's 80% method [1], Mazurkiewicz's method [4], the Quadratic Hyperbolic Method by Lastiasih, *et al.*[6], and Van der Veen's method [5], were applied again to the same data.

The input data were retained to a maximum of 175% of the working load and the estimated Q_{ult} obtained from each method was compared with the actual Q_{ult} of the results in Section 5.1. The analysis results are given in Table 5.

Table 5 Statistical Analysis of Various Methods When Used to Interpret Pile Loading Tests That Loaded To 175% of the Working Load.

Data 175% Working Load	Chin	Decourt	Hansen	Mazurkiewizc	Quadratic Hyperbolic	Van der Veen
Avarage Correction Factor	1.18	1.52	0.95	0.97	0.93	0.97
Var	0.10	0.21	0.05	0.07	0.02	0.04
SD	0.31	0.46	0.23	0.27	0.14	0.20
COV	56%	68%	48%	52%	38%	44%

From the results in Table 5 it is apparent that the results with the highest accuracy were the ones produced by the Quadratic Hyperbolic Method by Lastiasih, *et al.* [6], it is shown by the values of COV (38%) and σ(0,14) .They are lower than the others. Decourt's Extrapolation Method provided the lowest accuracy.

5.3 Implications of Comparision Between Ultimate Capacity of Interpretation Methods and Empirical Estimates

In Indonesia a high percentage of engineers use the empirical formula of Reese and O'Neill [7] to predict the ultimate bearing capacity of piles. From the 115 collected data sets of field loading tests that loaded without reaching failure, about 30 were also furnished with an initial estimate of the ultimate pile capacity using the empirical formula of Reese and O'Neill. When the initial empirical estimates afterwards were compared with the calculated Q_{ult} using the respective interpretation methods applied to each of the field loading test data sets, the empirical Q_{ult} using Reese and O'Neill's formula was mostly smaller than the Q_{ult} of the interpretation methods. Therefore, a correction value, N, could be established as folllows: $\left(N = \frac{Q_{ult.\text{interpretation\_method}}}{Q_{ult.empiric}} \right)$. The results of comparing the values of N can be seen in Table 6.

It was apparent that the best results were obtained by the Quadratic Hyperbolic method of Lastiasih, *et al.* [6], by Van der Veen's method [5], and by Mazurkiewicz's method [4], also given their lower standard deviation and COV values. The other methods performed less well, of which Chin's method gave the highest, not very accurate prediction.

Table 6 Average Value of Correction Factor, Variance, Standard Deviation and Coefficient of Variation Comparison between Q_{ult} of Interpretation Methods and Q_{ult} of Reese and O'Neill.

Analysis of Q_{ult} from Reese and O'Neill Method						
	Chin	**Decourt**	**Hansen**	**Mazurkiewizc**	**Quadratic Hyperbolic**	**Van der Veen**
Avarage Correction Factor	2.74	2.13	1.81	1.68	1.52	1.61
Variance	7.45	0.90	2.58	0.36	0.31	0.34
Standard Deviation	2.73	0.95	1.61	0.60	0.56	0.58
COV	100%	45%	89%	36%	37%	36%

The implications of this analysis are the following:

1. It is strongly recommended to use the prediction methods with lower *N* and COV values, such as the Quadratic Hyperbolic Method, Van der Veen's method, and Maturkiewicz's method. This is because the use of the other methods, such as Chin's, will tend to grossly exaggerate Q_{ult}, so that a more dangerous situation may occur.

   For example, a designer might use Chin's method or Decourt's Extrapolation Method and would estimate confidently that Q_{ult} = 274 tons. In this case, he/she may confidently use SF = 2.0, so that he can suggest as allowable working load Q_{all} = 274/2 = 137 tons. In reality, the actual Q_{ult} may merely be approximately 152 ton. Assigning Q_{all} = 137 tons for a pile with a real capacity of Q_{ult} = 152 tons can cause excessive settlement and damage to the structure.

2. The empirical method of Reese and O'Neill [8] for predicting Q_{ult} is conservative and safe enough to be used. For example, from Reese and O'Neill's method a pile designer may obtain Q_{ult} = 100 tons, while the actual Q_{ult} would be at least 152 tons. Should the designer be less conservative and use SF = 2.0, he/she would recommend an allowable maximum working load of around 100/2 = 50 tons; this means the real SF is about 3.04. Edil and Mochtar [9] mention that for pile foundations in soft and cohesive soils, a minimum SF of 3.0 should be used in order to minimize the possibility of excessive pile settlement due to "creep slip". Especially for predominantly friction piles, a SF < 3.0 should not be tolerated. Therefore, Reese and O'Neill's method can be used as intended.

6 Conclusion

The use of prediction methods with lower *N* values in Table 5 is recommended for pile loading test interpretation, since the methods with higher *N* values may give the pile designer misleading information. Higher *N* values can lead a pile design that exceeds the allowable safe bearing capacity and the possibility of excessive pile settlement, especially for friction dominated piles in cohesive soils. From the analysis of the accuracy of the methods of pile loading test interpretation, the Quadratic Hyperbolic method by Lastiasih, *et al.* [6] is considered the most accurate to predict the actual ultimate axial pile capacity, Q_{ult}, especially when the piles are not loaded to reach failure. The use of Reese and O'Neill's [8] formula is considered conservative and safe enough to predict the Q_{ult} and Q_{all} of pile foundations, and is therefore recommended.

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