Analysis of Ultimate Bearing Capacity of Bore Pile Foundation in High-Rise Building at Pulomas, East Jakarta

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Abstract

Soil condition at the Pulomas tower project site with a water level of 17 m below the ground and the hard soil at ground depth of 18 – 22 m, as well as the project location surrounded by houses and office buildings made the choice of bore pile as the foundation in this project. This condition is the background to the need for a bore pile capacity analysis in this tower project. The objective of this study is to analyze the bore pile capacity which is based on Standard Penetration Test (SPT) and Cone Penetration Test (CPT) and to be compared to the interpretation result of static loading test at a tower project location in East Jakarta. The ultimate bearing capacity of bore pile foundation was calculated using Meyerhof method and Reese & Wright method, and static loading test using Chin method. This study indicated that the ultimate bearing capacity using Reese & Wright method is closer to the interpretation result of static loading test from Chin method compared to Meyerhof method.

Keywords: bore pile, CPT, SPT, bearing capacity, static loading test

1. Introduction

Foundation is very important for building as foundation is the lowest part of the building that transmits the building load to the soil or rock that is on the ground underneath. Shape and type of foundations varies, and the usage of which foundations depends on type of soil and its structure. Generally, there are two types of foundation which are shallow foundation and deep foundation. Shallow foundations are located less than 2 m below the lowest finished floor of a structure. Deep foundations are structural elements that are used to transfer loads from weak and compressible soils to a stronger layer, usually located at a significant depth below the ground.

Before the casting of foundations, it is a must to conduct tests of soils on site. The most common tests used are Standard Penetration Test (SPT) and Cone Penetration Test (CPT). The results of soil tests will be used to design the foundation suitable to the building design. The design needed to have capacity suitable for the intended buildings and to know the capacity of the intended bore pile, there are 2 ways which are theoretical way and empirical way. Theoretical way is estimating the bearing capacity according to soil test, whereas empirical way is estimating the bearing capacity with CPT and SPT.

Based on the soil test conducted on location of a tower project at Pulomas in East Jakarta, hard soil was found at the ground depth 18 – 22 m, and the ground water level is approximately at depth of 17 m. Due to this ground water level, it was decided that the foundation of the building will be the pile foundation. The surrounding of the project which in city and near settlements, as well as office buildings, the bore piles were selected as the foundation of the building specifically because installation does not cause sound and vibration disturbances that endanger the surrounding buildings.

The objective of this study is to analyze the bore pile capacity which is based on CPT & SPT. The data of CPT, SPT, and

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result from interpretation of Static Loading Test (SLT) at a tower project in East Jakarta will be compared in order to investigate the differences between the result from analysis and actual test. This analysis will only calculate the capacity of single bore pile. The benefit of this study is as a reference to calculate the bore pile foundation capacity and as a consideration in choosing empirical methods in designing bored pile foundation in areas with the typical soil characteristics as Pulomas, East Jakarta.

2. Literature Review

The selection of the type of foundation depends on the condition of the foundation soil which can be known by doing soil investigation. Soil investigations can be divided into 2 types which are field investigation and laboratory investigation. Field investigation consist of drilling, CPT, SPT, Sand Cone Test and Dynamic Cone Penetration. Types of investigation in the laboratory consist of soil index tests and soil engineering properties. CPT is a test for determining the soil layers based on the resistance of the cone tip and the adhesion of the soil at each depth on the sondir tool [1-2]. The parameters measured are cone resistance (q_c), friction resistance (f_s), shear ratio (R_f), total soil shear (T_f). The result of CPT test will be described in graph which states the relationship between the depth of each soil layers and the resistance of soil to the cone penetration expressed in force per unit length. SPT is a test method carried out concurrently with drilling to know both the dynamic resistance of the soil and disturbed sampling with the impact technique [3, 4]. SPT is done to obtain parameters of soil penetration resistance in the field in which can be used to identify the soil layers under the surface level. Soil with the same level of density but at different depths gives higher $Nspt$ numbers at greater depths. The correction value (C_N) in Table 1 is needed find the exact $Nspt$ value [3, 5]. The correction value equation is as follows.

$$C_N = 2.2/(1.2 + ((\sigma'_{vo})/Pa)) \quad (1)$$

$$\sigma'_{vo} = (\gamma - \gamma_w)\ x\ h \quad (2)$$

where σ'_{vo} is the effective vertical stress, Pa is 100 kPa, γ is the soil specific weight (saturated), γ_w is the water specific weight, and h is the height.

Table 1 Correction Value in SPT

Factor	Type of Equipment	Parameter	Correction Value
Effective Vertical Stress		C_N	$2.2/(1.2 + (\frac{\sigma'_{vo}}{Pa}))$
Energy Ratio	Automatic Hammer	C_E	$0.8 - 1.3$
Drill Diameter	$6.5\ mm - 115\ mm$	C_B	1.0
Rod Length	$10\ m - 30\ m$	C_R	1.0
Sampler	Standard Tube	C_S	1.0

While the equation for correcting $Nspt$ value is as follows,

$$(N_1)_{60} = N_M\ x\ C_N\ x\ C_E\ x\ C_B\ x\ C_R\ x\ C_S \quad (3)$$

where $(N_1)_{60}$ is SPT value corrected for the effect of 60% power efficiency, N_M is SPT test results in the field, C_N is correction factor for effective vertical stress (value ≤ 1.70), C_E is correction factor to hammer force ratio, C_B is correction factor for drill diameter, C_R is correction factor for SPT rod length, C_R is correction factor for SPT rod length liners.

The correction factors C_E, C_B, C_R, C_s depends on the judgement of the soil investigator as it is about the equipment used on site. Standard equipment normally has value of 1.0 and may be less or more depends on the situations on site. Bore pile functions to transfer the load from the superstructure to the soil below through the end bearing capacity of the pile and also the bearing capacity of the pile blanket. The end bearing capacity is determine by the bearing capacity of the hard soil layer under the end of the pile. Friction resistance is determined frictional resistance between pile wall and the surrounding soil. Generally, the ultimate bearing capacity can be found by summing up the end bearing and friction resistance.

SLT is a test which is used to determine the load that can be supported by deep foundation. The result will be in graph of the relationship between the magnitude of the load given and the settlement that occurred and needed to be interpreted to know the ultimate capacity of the said foundation. SLT can be interpreted using Chin method (Fig. 1 and 2) that proposed an application to piles of the general work by Kondner [6]. To find the ultimate bearing capacity of foundation using Chin method is by drawing a curve between the ratio of settlement to load (S/Q) and settlement [7]. The Chin method is based on the assumption that when the pile fails, the load-settlement curve pattern will be hyperbolic. Because of this, the formula in this method uses the failure load value of the Kodner hyperbolic equation model to draw the straight lines representing the points that have been drawn [8]. Kodner's equation for finding the ultimate bearing capacity is:

$$Q = \frac{S}{a + c\ x\ S} \tag{4}$$

$$Q_{ult} = \frac{1}{c} \tag{5}$$

where S is settlement, Q is load, and a, c are constants.

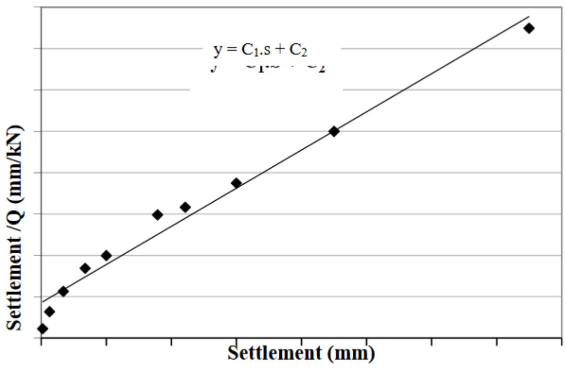

Fig. 1 Chin Method

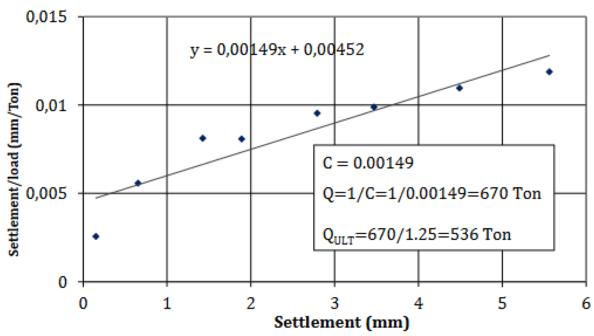

Fig. 2 Interpretation of SLT using Chin Method

3. Data and Method

Soil test data carried out at the tower project site in Pulomas, East Jakarta are as follows. The cone used is a biconus with a cross-sectional area of 10 cm^2, a blanket area of 150 cm^2. The CPT is carried out at intervals of 20 cm depth until it shows a cone resistance (tip) and a maximum shear resistance of 250 kg/cm^2, or up to a maximum depth of 20 m. The CPT is done at 4 bore point (S1-S4) until reach the hard soil at 8.20 m − 10.20 m (Fig. 3).

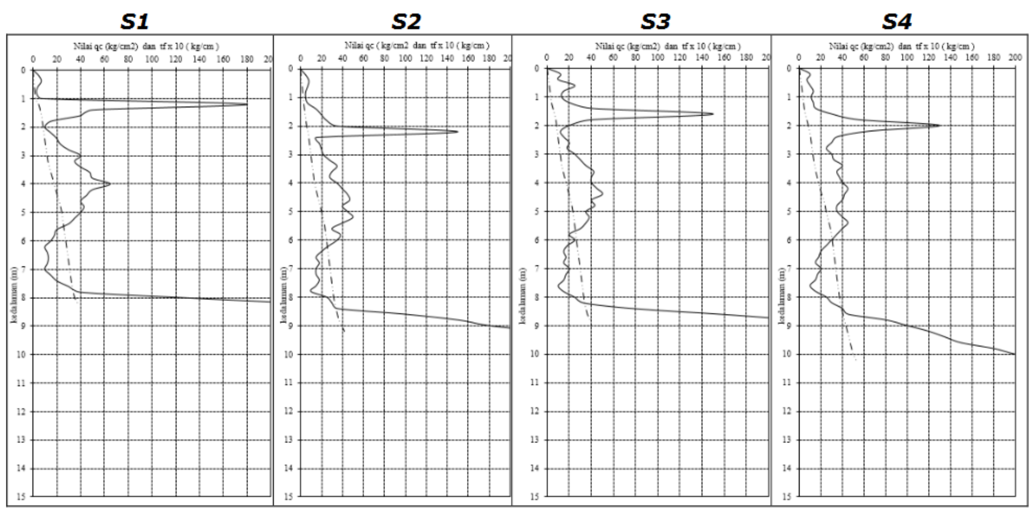

Fig. 3 The CPT results of S1-S4

The SPT is carried out by washing drilling using a drill bit in the form of a 75 cm long tube in stages every 75 cm. The soils sample was taken from 2 points (BH-1 and BH-2) with depth of 50 m each. As the CPT test conducted only until 10 meters depth, the SPT test result will be used as correlation to find q_c value. Correlation between CPT and SPT [5] can be find in Table 2.

Table 2 CPT and SPT Correlation

Acka (2003)	Sand	$n = \left(\frac{q_c}{N}\right) = 0.77$
	Silty sand	$n = \left(\frac{q_c}{N}\right) = 0.7$
	Sandy silt	$n = \left(\frac{q_c}{N}\right) = 0.58$
	Clays	$n = \left(\frac{q_c}{N}\right) = 0.2$
	Silty clay	$n = \left(\frac{q_c}{N}\right) = 0.3$
Danziger & De Valleso (1995)	Silt, sandy silt, silt-sand	$n = \left(\frac{q_c + f_s}{N}\right) = 0.2$

where n is the correlation value of SPT and CPT, q_c is resistance of cone, f_s is friction resistance, and N is SPT blow count or $Nspt$.

The value of $Nspt$ from the SPT and CPT correlation for BH-1 and BH-2 with the soil layers from surface to the end is shown in Table 3 and 4, respectively.

Table 3 Distribution of $Nspt$ and soil layers of BH-1

Depth (m)	N1	N2	N3	N	Description	qc	qc	Method
0	0	0	0	0	Clay, brownish-gray	0	0	Acka
2	3	5	8	13		3	31	
4	4	6	9	15		3	31	
6	6	8	12	20		4	41	
8	7	8	13	21	Silt, brownish-gray	4	41	Danziger & De Valleso
10	25	30	30/10	60		12	122	
12	60/13	>	>	60		12	122	
14	8	12	25	37		7	71	
16	12	20	30	50	Sandy silt, blackish	35	357	Acka
18	25	40	20/5	60	black sand	46	469	
20	22	30	35	65	Silt, gray yellow blackish brown	13	133	Danziger & De Valleso
22	11	22	30	52		10	102	
24	13	19	25	44		9	92	
26	13	17	18	35		7	71	
28	11	14	17	31		6	61	
30	12	16	16	32		6	61	
32	13	17	20	37		7	71	
34	10	16	22	38		8	82	
36	12	20	24	44		9	92	
38	15	19	27	46		9	92	
40	11	16	20	36		7	71	
42	15	17	22	39	Clay silt, blackish gray	12	122	Acka
44	13	16	21	37		11	112	
46	14	19	27	46		14	143	
48	12	17	25	42		13	133	
50	18	20	24	44		13	133	

Table 4 Distribution of $Nspt$ and soil layers of BH-2

Depth (m)	N1	N2	N3	N	Description	qc	qc	Method
0	-	-	-	0	Landfill	0	0	
2	-	-	-	0		0	0	
4	7	9	13	22	clay, yellowish red	4	45	Acka
6	5	7	12	19		4	39	
8	6	11	16	27	silt, brownish	5	55	Danziger & De Valleso
10	14	20	35	55		11	112	
12	13	21	40/10	60	silty sand, brown	42	428	Acka
14	12	23	36	59	silt, blackish gray	12	120	Danziger & De Valleso
16	60/12	>	>	60		12	122	
18	25	40/5	>	60		12	122	
20	21	30	30/10	60		12	122	
22	19	25	33	58		12	118	
24	17	20	24	44	silty sand, black	31	314	Acka
26	25	30	35	65		46	464	
28	50	40/7	>	60		42	428	
30	60/10	>	>	60		42	428	
32	7	11	15	26	silt, blackish yellow gray	5	53	Danziger & De Valleso
34	10	17	23	40		8	82	
36	9	15	27	42		8	86	
38	12	17	23	40	silty clay, yellow-gray brown	12	122	Acka
40	10	13	16	29		9	89	
42	8	15	21	36		11	110	
44	12	17	25	42		13	128	
46	11	14	23	37		11	113	
48	14	19	29	48		14	147	
50	16	20	27	47		14	144	

The result of Static Loading Test done on bore pile foundation with diameter of 80 cm is shown in Fig. 4 and Table 5 as follows.

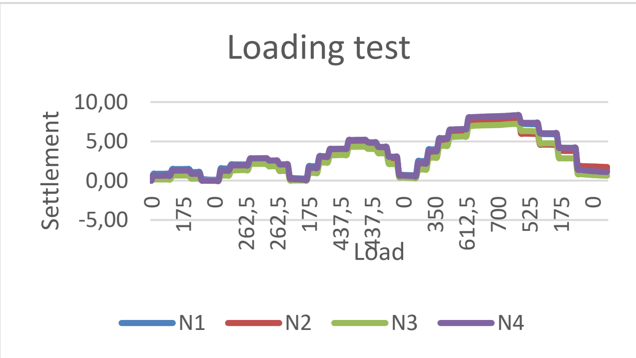

Fig. 4 Static Loading Test result

Table 5 The Value of N_1, N_2, N_3, N_4 and $\bar{N}$

Load	N_1	N_2	N_3	N_4	$\bar{N}$
87.5	0.88	0.45	0.15	0.64	0.53
175.0	1.50	0.96	0.65	1.28	1.10
262.5	2.06	1.54	1.32	1.95	1.72
350.0	2.88	2.40	2.19	2.91	2.59
437.5	4.03	3.57	3.24	4.03	3.72
525.0	5.18	4.75	4.34	5.21	4.87
612.5	6.48	6.12	5.58	6.51	6.17
700.0	7.95	7.59	7.07	8.16	7.69

The methods which will be covered in this study will be Meyerhoff, and Reese & Wright method [9-10]. Meyerhoff method is using the following equations:

$$Q_u = Q_b + Q_s \tag{6}$$

$$Q_b = A_p \ x \ f_b \tag{7}$$

$$f_b = \omega_1 \ x \ \omega_2 \ x \ q_{ca} \tag{8}$$

where Q_u is the ultimate capacity, Q_b is the end bearing capacity, Q_s is the friction bearing capacity, f_b is the end bearing resistance (bore pile 70%), q_{ca} is the average q_c at $1D$ under and $4D$ above the bottom end of the foundation, ω_1 = $[\frac{(d+0.5)}{2d}]^n$: the scale effect modification coefficient, if $d > 0.5\ m$, $\omega_1 = 1$, A_p = Area of bottom end of bore pile, f_b is the end bearing resistance per unit area, $\omega_2 = L/10d$: modification coefficient for bore pile penetration (when $L < 10d$, if $L > 10d, \omega_2 = 1$), L is the depth of the bore pile foundation, n is the exponential value $\left(n = 1,\ if\ q_c < 5\ ; n = 2, if\ 5 < q_c < 12\ ; n = 3, if\ q_c > 12\ (in\ MPa)\right)$.

To calculate the friction resistance, the formula is $Q_s = A_s\ x\ f_s$, then using $f_s = K_f\ x\ q_f$ with $K_f = 1$ or $f_s = K_c\ x\ q_c$ with $K_c = 0.005$, where Q_s is the friction resistance, A_s is the perimeter of the bore pile, f_s is the friction resistance per unit area, K_f is the coefficient of modification of the cone side friction resistance, K_c is the coefficient of modification of the cone resistance.

Reese & Wright method using the following equation to find the ultimate bearing capacity:

$$Q_u = Q_P + Q_s \tag{9}$$

$$Q_p = A_p\ x\ q_p \tag{10}$$

where Q_u is the ultimate capacity, Q_P is the end bearing, Q_s is the friction bearing capacity, A_p is the area at the end of the bore pile, q_p is the end bearing resistance per unit area.

Reese & Wright distinguish the equation to calculate the end bearing resistance between cohesive soil (Eq. 11) and non-cohesive soil (Eq. 12).

For cohesive soil : $q_p = 9\ x\ C_u\quad ;\quad C_u = Nspt\ x\ \frac{2}{3}\ x\ 10$ (11)

For non-cohesive soil : $Q_p = \frac{40}{3}\ x\ \ Nspt_1\ \ x\ \frac{L_i}{D} \leq \frac{400}{3}\ x\ Nspt_1$ (12)

where $Nspt_1$ is the average value of $Nspt$ from 10D to 4D below the end of the bore pile), and C_u is the undrained shear strength. The friction resistance formula in the Reese & Wright method is also distinguished based on cohesive soil (Eq.13) and non-cohesive soils (Eq. 14).

For cohesive soil : $Q_s = \propto\ x\ C_u\ x\ P\ x\ L$ (13)

For non-cohesive soil : $Q_s = 2\ x\ Nspt\ x\ P\ x\ L$ (14)

where Q_s is the friction resistance per unit area, $\propto$ is the friction coefficient (bore pile = 0.55), P is the perimeter of the bore pile, and L is the depth of bore pile.

4. Results and Discussion

Bore piles have diameter of Ø80 cm with length 22 m underground. Area at the end of the bore pile and perimeter of bore pile can be found using the following equation:

$A_b = \frac{1}{4} x\ \pi\ x\ d^2$ $\qquad P = \pi\ x\ D$

$A_b = \frac{1}{4} x\ \pi\ x\ 80^2 = 5026.55\ cm^2$ $\qquad P = \pi\ x\ 80 = 251.32\ cm$

$A_b = 0.502\ m^2$ $\qquad P = 2.51\ m$

The correction of $Nspt$ needed to be done as the $Nspt$ is affected by overload pressure. The correction values of $Nspt$ at bore point of BH-1 and BH-2 can be seen in Table 5. Where C_{N1} is the correction factor at bore point of $BH - 1$, C_{N2} is the correction factor at bore point of $BH - 2$, N_1 is the original $Nspt$ value at bore point $BH - 1$, N_2 is the original $Nspt$ value at bore point $BH - 2$, N_1' is $Nspt$ value after correction at bore point $BH - 1$, and N_2' is $Nspt$ value after correction at bore point $BH - 2$.

Table 5 Correction values of $Nspt$ at BH-1 and BH-2

Depth (m)	C_{N1}	N_1	$(N_1)_{60}$	C_{N2}	N_2	$(N_2)_{60}$
0	1.7	0	0	1.7	0	0
2	1.6	13	19	1.6	0	0
4	1.5	15	20	1.4	22	28
6	1.4	20	25	1.3	19	22
8	1.4	21	27	1.2	27	30
10	1.4	60	73	1.1	55	57
12	1.3	60	70	1.1	60	58
14	1.2	37	41	1.0	59	53
16	1.2	50	53	0.9	60	51
18	1.1	60	61	0.9	60	48
20	1.1	65	63	0.8	60	45
22	1.0	52	49	0.8	58	41
24	1.0	44	39	0.8	44	30
26	1.0	35	30	0.7	65	42
28	0.9	31	26	0.7	60	37
30	0.9	32	26	0.7	60	35

The calculation of the ultimate bearing capacity using the Meyerhoff method is described below. As the diameter, $D = 0.8\ m > 0.5\ m$, then $\omega_1 = 1$, for $10D = 10\ x\ 0.8\ m = 8\ m$, and $L = 22\ m > 8m$ then $\omega_2 = 1$. The detailed calculation of the ultimate bearing capacity for the bore point of BH-1 and the bore point of BH-2 as follows.

$Nspt\ at\ BH - 1$

$q_{ca1} = \frac{469+92}{2} = 281 kg/cm^2$

$f_b = 281\ x\ 70\%\ x\ 10 = 1963\ ton/m^2$

$Q_{b1} = 0.502\ x\ 1963 = 986.9\ ton$

$f_{s1} = 0.005\ x\ 102 = 0.5$

$Q_{s1} = 0.5\ x \frac{251.32}{100} x\ 2 = 2.56\ ton$

$Q_{s1}\ cumm = 38.20\ ton$

$Q_{u1} = 986.9 + 38.2 = 1013.7\ ton$

$Nspt\ at\ BH - 2$

$q_{ca2} = \frac{122+314}{2} = 218\ kg/cm^2$

$f_b = 218\ x\ 70\%\ x\ 10 = 1526\ ton/m^2$

$Q_{b2} = 0.502\ x\ 1526 = 767\ ton$

$f_{s2} = 0.005\ x\ 118 = 0.6$

$Q_{s2} = 0.6\ x \frac{251.32}{100} x\ 2 = 2.97\ ton$

$Q_{s2}\ cumm = 32.25\ ton$

$Q_{u2} = 767 + 32.25 = 789.62\ ton$

The calculation of the ultimate bearing capacity of bore pile foundation using Reese & Wright method is as follows. The $Nspt$ value at 22 m depth is 49 for $BH - 1$ and 41 for $BH - 2$ (after correction according to overload pressure). So, the value of Cu for $BH - 1$ and 41 for $BH - 2$ are,

$C_{u1} = 49\ x \frac{2}{3}\ x\ 10 = 323.5\ kN/m^2$

$C_{u1} = \frac{323.5}{10} = 32.3\ ton/m^2$

$C_{u2} = 41\ x \frac{2}{3}\ x 10 = 275.2\ kN/m^2$

$C_{u2} = \frac{275.2}{10} = 27.5\ ton/m^2$

The detailed calculation of the ultimate bearing capacity using Reese & Wright method for the bore point of BH-1 and BH-2 as follows.

$Nspt\ BH - 1$

$q_{p1} = 9\ x\ 32.3 = 291.1\ ton/m^2$

$Q_{p1} = 291.1\ x\ 0.502 = 146.3\ ton$

$Q_{s1} = 0.55\ x\ 32.3\ x\ 2.51\ x\ 2 = 89.4\ ton$

$Q_{s1}\ cumm = 847.9\ ton$

$Q_u = 146.3 + 847.9 = 994.2\ ton$

$Nspt\ BH - 2$

$q_{p2} = 9\ x\ 27.5 = 247.7\ ton/m^2$

$Q_{p2} = 247.7\ x\ 0.502 = 124.5\ ton$

$Q_{s2} = 0.55\ x\ 27.5\ x\ 2.51\ x\ 2 = 76\ ton$

$Q_{s2}\ cumm = 797.2\ ton$

$Q_u = 124.5 + 797.2 = 921.7\ ton$

The result of interpretation of Static Loading Test (SLT) using Chin method as seen in Fig. 5. Where $Q_{ult} = 1/c$, and $c = 0.0007$, so $Q_{ult} = 1/0.0007 = 1428.57\ ton$ which then divided by 1.5 as the correction factor. The ultimate bearing capacity result from the interpretation using Chin method, the Q_{ult} is $952.38\ ton$.

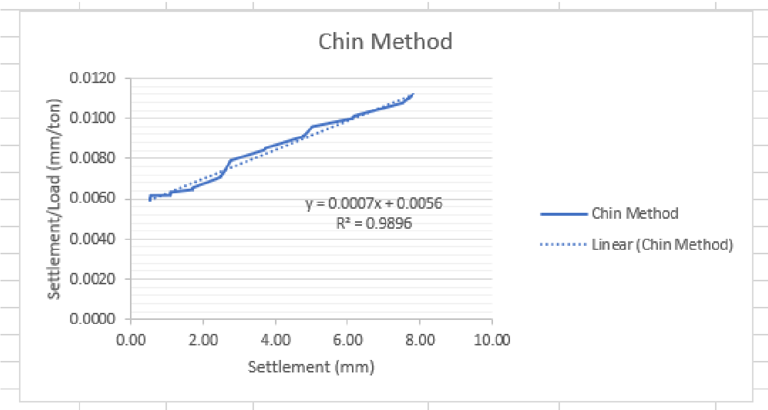

Fig. 5 Chin method result

The results of the ultimate bearing capacity of bore pile using Meyerhoff method, Reese & Wright method, and the interpretation of Static Loading Test using Chin method as shown in Fig. 6 and Fig. 7.

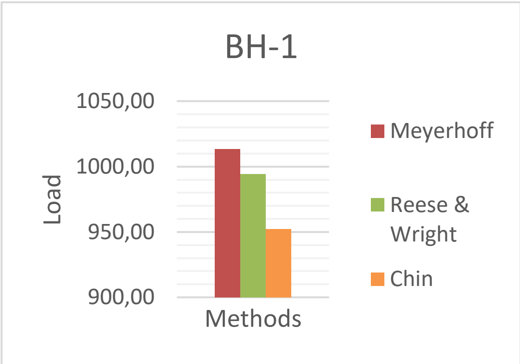

Fig. 6 Bore Pile Capacity at BH-1

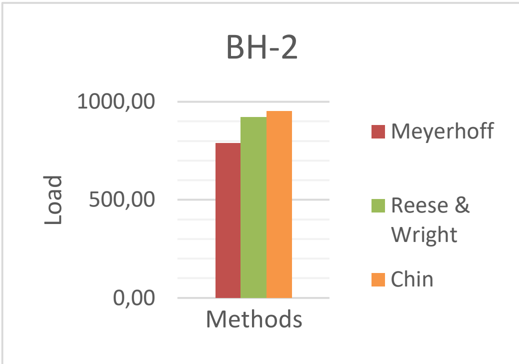

Fig. 7 Bore Pile Capacity at BH-2

The ultimate bearing capacity results of Meyerhoff method for the bore point of BH-1 and BH-2 are $1013.7\ ton$ and $789.62\ ton$, respectively. Reese & Wright method results are $994.27\ ton$ and $921.76\ ton$, respectively. The results of the Meyerhoff method compared to the Chin method have a difference in ultimate bearing capacity of $61.32\ ton$ at BH-1 and $162.76\ ton$ at BH-2. Then, Reese & Wright method compared to the Chin method has a difference of $41.89\ ton$ at BH-1 and $30.62\ ton$ at BH-2. This comparison shows that the Reese & Wright method has results that are closer to the Chin method than the Meyerhoff method.

5. Conclusion

The analysis of the ultimate bearing capacity of bore pile foundation based on CPT and SPT using Meyerhoff method and Reese & Wright method has been described in this study. The analysis results have been compared to the interpretation of Static Loading Test using Chin method. This study indicated that the ultimate bearing capacity using Reese & Wright method of 994.26 ton and 921.76 ton are closer to the interpretation result of static loading test from Chin method of 952.38 ton compared to Meyerhoff method.

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