Analysis of Bored Pile Foundation Bearing Capacity Based on Cone Penetration Test Data (Case Study: Cilellang Weir Location)

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Abstract—**The use of a bored pile foundation is an alternative in planning deep foundations. The function of this bored pile foundation is more or less the same as other deep foundations such as piles but has a slight difference in the process. The bored pile foundation begins with drilling the ground to the planned depth, followed by the installation of steel reinforcement and then concrete mortar. This study aims to evaluate the Cone Penetration Test (CPT) data on the bearing capacity of the bored pile foundation. Calculation of bearing capacity from Cone Penetration Test (CPT) data using the Schmertmann & Nottingham method and the Mayerhof method. Based on CPT data, the percentage calculation of ultimate bearing capacity at location S1 with the Schmertmann & Nottingham method is more optimistic ±17.28% compared to using the Mayerhof method for bored pile diameters of 60 and 80 cm, while for bored pile diameters of 40 cm, calculations using the Mayerhof method show more optimistic by 21.89%. The percentage calculation of ultimate bearing capacity at location S2 using the Schmertmann & Nottingham method is ±11.66% more optimistic than using the Mayerhof method for bored pile diameters of 60 and 80 cm, while the diameter of the bored pile 40 cm, the calculation using the Mayerhof method shows a more optimistic result of 33.82%.**

Keywords—*bored pile, CPT, bearing capacity*

I. Introduction

Bored pile foundation is a foundation that is built by drilling the ground first, then filled with reinforcement and casted. Bored piles are used when a solid subgrade that has a large bearing capacity is located very deep, which is approximately 15 meters and the condition around the building ground has a lot of standing large buildings such as high-rise buildings so that it is feared that it can cause cracks in buildings that have been built. There is a result of vibrations caused by piling activities when a pile foundation is used. The bearing capacity of the bored pile is obtained from the end bearing capacity, which is obtained from the pile base pressure, and the friction bearing capacity, which is obtained from the friction bearing strength or the adhesion force between the bored pile and the surrounding soil. Bored pile interacts with the soil to produce a bearing strength that is capable of carrying and providing security to the superstructure. To produce an accurate bearing capacity, an accurate soil investigation is also needed. There are two methods commonly used in determining the bearing capacity of bored piles, namely by using the static method and the dynamic method [1].

The static method is a method of calculating the bearing capacity based on the state of the soil and the sleeve of a pile in a project. The data on the value of cone penetration resistance (q_c) and the value of total penetration (q_s) are also the analytical factors that will be used to calculate the bearing capacity of the pile in the static analysis method. While the dynamic method is testing the pile using calendaring data based on data analysis of recorded wave vibrations that occur when the pile is hit with a hammer. A pile hammer is a tool used to provide enough energy to the pile to penetrate the ground [2].

The bearing capacity during the planning process can be determined using CPT-test. Based on the CPT-test investigation, it can be seen that the resistance to penetration of cones and soil adhesion resistance is an indication of the bearing capacity of the soil layer by using the empirical formula.

The bearing capacity of the pile foundation is derived from the pile end bearing capacity and the friction resistance of the pile sleeve. The pile end bearing capacity occurs when the pile base reaches the depth of the hard soil layer or soil that has a high bearing capacity while the friction resistance is the result of the interaction between the pile sleeve and the soil layer around the pile sleeve [3].

II. Research Methodology

A. Investigation with Dutch Cone Penetrometer Test (DCPT).

Digging is a process of inserting the CPT tool perpendicularly into the soil to determine the magnitude of the resistance to penetration of the soil at the depth of the soil layer penetrated by the CPT tool [4].

CPT-test is widely used in Indonesia, this test is very useful to obtain the value of variations in density of sandy soil that is not dense. In dense sandy soils as well as gravel and rocky soils, the use of CPT tools becomes ineffective, because they have difficulty penetrating the soil. The values of static cone resistance or cone resistance (q_c) obtained from the test can be directly correlated with the bearing capacity of the soil and settlement of shallow foundations and pile foundations [4].

B. Bearing Capacity to Support Bored Pile from CPT-test Data

Among the different tests in the field, cone penetration test (CPT) is often very much considered the role of geotechnical. This cone penetration test (CPT) can also classify soil layers and can estimate the bearing capacity and characteristics of the soil. In planning the pile foundation, soil data is very necessary in planning the bearing capacity of the bored pile before construction begins, to determine the ultimate bearing capacity of the pile foundation.

To calculate the bearing capacity of the bored pile based on the CPT test data, it can be done using:

1. Aoki & De Alencar Method

The ultimate bearing capacity of the bored pile foundation is expressed by the following formula:

$$Q_u = (q_b . A_b) \qquad (1)$$

In equation (1), Q_u is the ultimate bearing capacity (kN), q_b is the cone resistance (kN/m^2) and A_b is the cross-sectional area of the pile (m^2). The bearing capacity per unit area (q_b) is obtained by the following formula:

$$q_b = \frac{q_{ca}(base)}{F_b} \qquad (2)$$

The value of q_{ca} (base) is the average cone resistance 1.5D above the pile tip and 1.5D below the pile tip. While the value of F_b is an empirical factor that depends on the type of soil.

Table 2. Empirical factor F_b (Titi & Farsakh, 1999)

Pile type	F_b
Bored pile	3.5
Steel	1.75
Precast concrete	1.75

In calculating the capacity of the bored pile foundation with the CPT-test, the bearing strength of the bored pile sleeve is not taken into account. This is because the soil friction resistance that occurs in the bored pile foundation is considered very small so it is considered non-existent.

To obtain the allowable bearing capacity (Q_a), it is necessary to divide the ultimate bearing capacity by a certain safety factor.

For pile bases raised with $d < 2$ m:

$$Q_a = \frac{Q_u}{2.5} \qquad (3)$$

For the base of the pile without magnification at the bottom:

$$Q_a = \frac{Q_u}{2} \qquad (4)$$

2. Schmertmann & Nottingham Method

The ultimate bearing capacity (Qu), calculated by the equation:

$$Q_u = A_b . f_b + A_s . f_s \qquad (5)$$

In equation (5), A_b is the cross-sectional area of the pile (cm^2), f_b is the end resistance of the pile unit (kg/cm^2), A_s is the pile sleeve area (cm^2), and f_s is the unit frictional resistance (kg/cm^2).

Value of f_b is obtained by the following formula:

$$f_b = \omega . q_{ca} \le 150 \text{ kg/cm}^2 \text{ (15000 kN/m}^2) \qquad (6)$$

The value of ω is the correlation coefficient, and q_{ca} is the average cone resistance (kg/cm^2). Determination of the value of ω in order to pay attention to the influence of gravel content or OCR obtained from the following table:

Table 1. Factor ω

Soil Condition	Factor ω
Normal consolidated sand (OCR = 1)	1
The sand contains a lot of coarse gravel Sand with OCR = 2 to 4	0.67
Fine gravel; sand with OCR = 6 to 10	0.5

The value of q_{ca} is the average value of q_{c1} and q_{c2}, where q_{c1} is the average value of cone resistance (q_c) along zone $8d$ above the pile base. While q_{c2} is the average value of cone resistance (q_c) along zone $4d$ below the the pile base, where d is diameter of the pile.

The f_s value is obtained by the following formula:

$$f_s = K_f . q_f \le 1.2 \text{ kg/cm}^2 \text{ (120 kPa)} \qquad (7)$$

The value of K_f is a dimensionless coefficient, while q_f is the frictional resistance of the cone side (kg/cm^2). When the pile is in the sand, K_f depends on the ratio L/d (L = depth, and d = pile diameter). In the first $8d$ depth from ground level, K_f is interpolated from zero at ground level to 2.5 at $8d$ depth. Lower than this depth, the value of K_f decreases from 2.5 to 0.891 at a depth of $20d$, or, taking the overall $K_f = 0.9$.
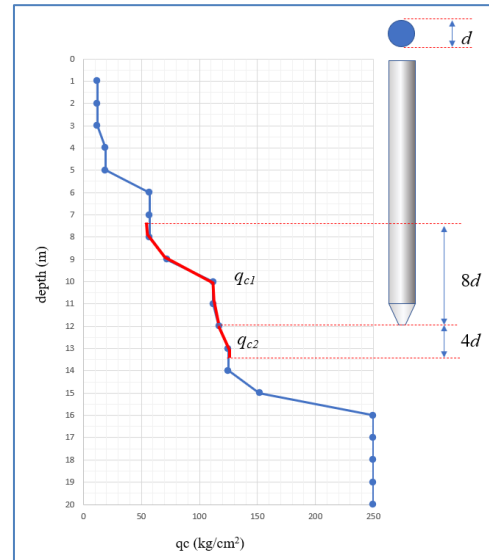
Figure 1. Zoning pictures of q_{c1}- q_{c2}

Another method, for piles in sandy soils (not applicable for clay soils), the unit frictional resistance can be determined from the cone resistance (q_c) using the following formula.

$$f_s = K_c . q_c \le 1.2 \text{ kg/cm}^2 \text{ (120 kN/m}^2) \qquad (8)$$

The value of K_c is a dimensionless coefficient whose value depends on the type of pile. Open end steel piles ($K_c = 0.8\%$), closed bottom end pipe piles ($K_c = 1.8\%$), and concrete piles ($K_c = 1.2\%$).

3. The Mayerhof Method

Calculation of the bearing capacity of the pile on sandy soil using the Mayerhof equation (1976; 1983) in Hardiyatmo [5].

End resistance for piles in sandy soil is calculated by the following equation:

$$f_b = \omega_1 . \omega_2 . q_{ca} \qquad (9)$$

The f_b value is the unit end resistance, for the bored pile, it is taken 70% or 50%. The q_{ca} value is the average q_c (kN/m^2) in zone $1d$ below the pile tip and $4d$ above it.

The value of ω is the coefficient of modification of the effect of the scale, if $d < 0.5$ m, then $\omega_1 = 1$. If $d > 0.5$ m, then:

$$\omega_1 = \left(\frac{(d+0,5)}{2d}\right)n \tag{10}$$

Where d is the diameter of the pile, and n is the exponential value. $n = 1$ for loose sand ($q_c < 5$ MPa), $n = 2$ for medium density sand (5 MPa < qc < 1.2 MPa), $n = 3$ for dense sand ($q_c > 1.2$ MPa).

The value of ω_2 is the modification coefficient for pile penetration in a dense sand layer, if the pile penetration depth in dense sand layer (m) $L > 10d$, then $\omega_2 = 1$. If $L < 10d$, then $\omega_2 = L/10d$.

For piles, the unit frictional resistance is taken as one of:

$$f_s = K_f . q_f \quad \text{with } K_f = 1 \tag{11}$$

or, if the cone side frictional resistance is not measured:

$$f_s = K_c . q_c \quad \text{with } K_c = 0.005 \tag{12}$$

f_s is the unit frictional resistance (kg/cm^2), K_f = coefficient of modification of conical frictional resistance, K_c = coefficient of modification of conical resistance.

For bored piles, Mayerhof suggests using reduction factors of 70% and 50% in calculating pile friction resistance using equations (11) and (12).

C. Location

The location of the CPT-test is in the Cilellang Weir in Wajo Regency, South Sulawesi Province, at a position of 4° 14' 14.6" latitude and 119° 56' 34.6" longitude. Cilellang Weir is located in Sabbangparu District, Wajo Regency to irrigate the Cilellang Irrigation area with an area of 1113 Ha. The shape of the weir is more accurately called Long Storage because its function is more to store water during the rainy season.

Figure 2. Cilellang Weir (Long Storage)

D. Bored Pile Technical Planning Data

Bored pile technical data to be tested in the calculation:

- Length of Bored pile : 10 m
- Diameter of Bored pile : Ø (40, 60 & 80) cm
- Number of CPT-test point : 2 points (S1 & S2)

Figure 3. CPT-test Location

III. Results and Discussion

The selected method to estimate the bored pile bearing capacity is the method of Schmertmann & Nottingham and Mayerhof. Both of these methods consider the effect of q_c on the top and bottom of the pile tip based on the diameter value.

Nottingham (1975) was the first to develop equations for various soil layers. Nottingham concluded that Begemann was very valid for determining q_b of pile for granular soils as well as cohesive soils using both mechanical and electrical penetrometer data [6]. Meyerhof (1983) developed the results of the CPT test and loading tests on piles and bored piles to provide an accurate design equation and graph, in which the effect of pile tip diameter is also taken into account [6].

The CPT-test was carried out at 2 points, namely at the location of the irrigation intake structure. CPT test results are presented in the form of a graph of the relationship of depth to the value of the cone resistance (q_c) and total friction.

The location of S1 is near the right intake, while the location of S2 is near the apron floor behind the weir structure (see Figure 3).
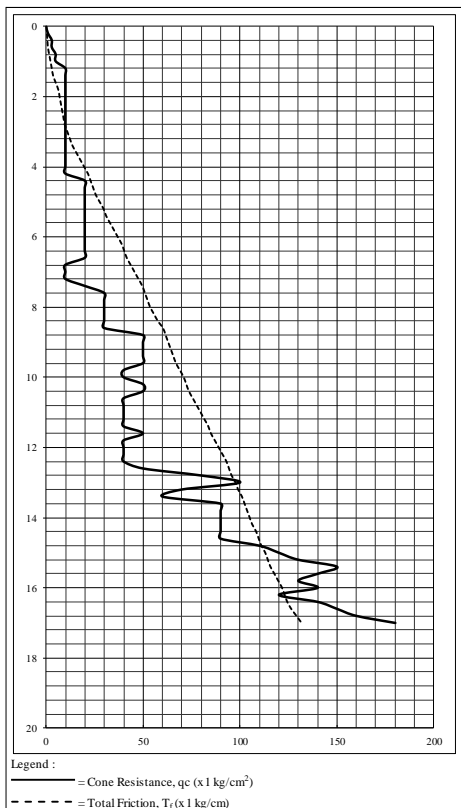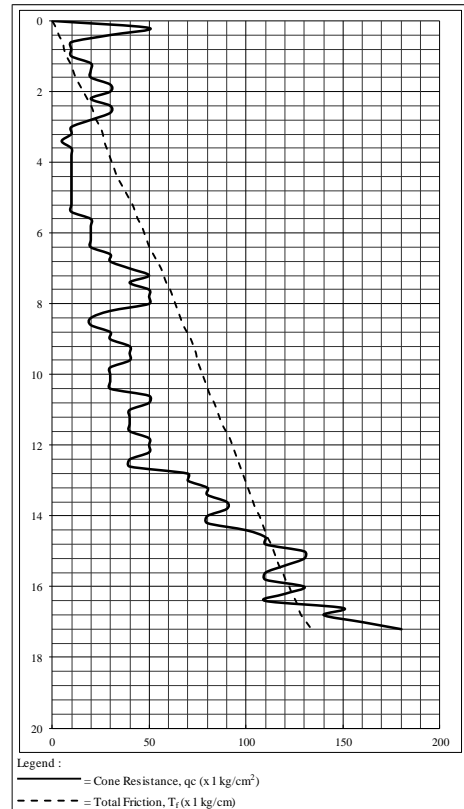

Figure 4. CPT-Test in S1

Figure 5. CPT-Test in S2

The graphs in Figure 4 and Figure 5 show the value of the cone resistance and cumulative frictional resistance up to the bed rock. At point S1 the depth of hard soil is obtained at a depth of 16.8 meters and at point S2 the depth of hard soil is obtained at a depth of 17.2 meters.

Based on the data at the two CPT-test points, an analysis of the bearing capacity of the bored pile was carried out regarding a depth of 10 meters.

The bearing capacity of the bored pile using the Schmertmann & Nottingham method for variations in pile diameter of 0.4, 0.6 and 0.8 meters is as follows.

Table 2. Calculation of the bearing capacity of bored piles using the Schmertmann & Nottingham method of several pile diameters at the CPT-test S1 point

No.	Diameter of pile (cm)	Conus Resistance (kN)	Friction Resistance (kN)	Ultimate Bearing Capacity (kN)
1	40	489.719	786.010	1275.729
2	60	1005.261	1179.015	2184.276
3	80	1896.380	1572.020	3468.399

Table 3. Calculation of the bearing capacity of bored piles using the Schmertmann & Nottingham method of several pile diameters at the CPT-test S2 point

No.	Diameter of pile (cm)	Conus Resistance (kN)	Friction Resistance (kN)	Ultimate Bearing Capacity (kN)
1	40	449.063	858.542	1307.605
2	60	1022.661	1287.813	2310.474
3	80	1830.076	1717.084	3547.159

The bearing capacity of the bored pile using the Mayerhof method for variations in pile diameter of 0.4, 0.6 and 0.8 meters is as follows.

Table 4. Calculation of the bearing capacity of bored piles using the Mayerhof method of several pile diameters at the CPT-test S1 point

No.	Diameter of pile (cm)	Conus Resistance (kN)	Friction Resistance (kN)	Ultimate Bearing Capacity (kN)
1	40	559.775	436.672	996.447
2	60	2105.849	655.008	2760.857
3	80	2878.297	873.344	3751.642

Table 5. Calculation of the bearing capacity of bored piles using the Mayerhof method of several pile diameters at the CPT-test S2 point

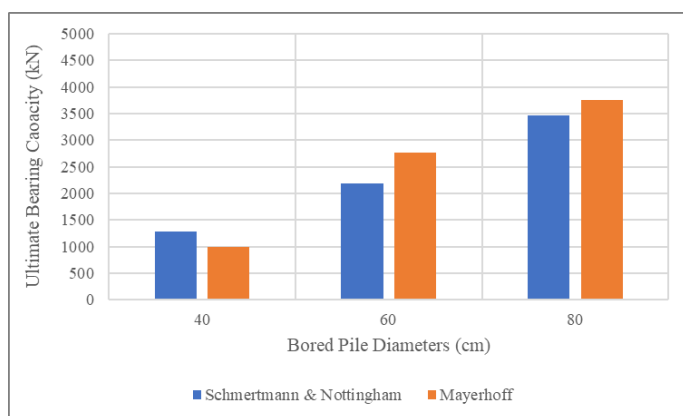| No.	Diameter of pile (cm)	Conus Resistance (kN)	Friction Resistance (kN)	Ultimate Bearing Capacity (kN)
1	40	388.415	476.968	865.383
2	60	1846.667	715.452	2562.119
3	80	3033.881	953.935	3987.816

Figure 6. Comparison graph of the bearing capacity of bored piles between Schmertmann & Nottingham and Mayerhoff calculations with several pile diameters (S1 Location)
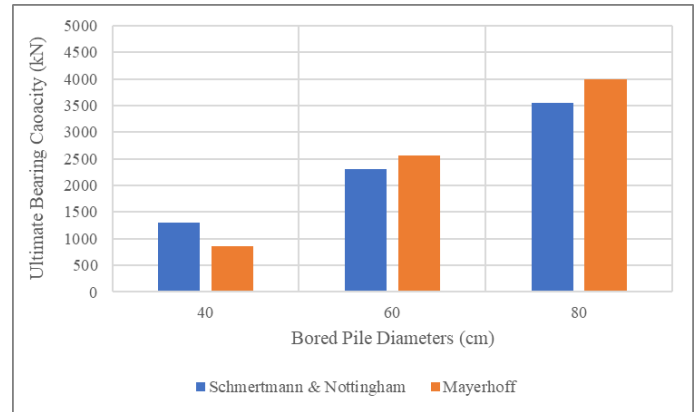
Figure 7. Comparison graph of the bearing capacity of bored piles between Schmertmann & Nottingham and Mayerhoff calculations with several pile diameters (S2 Location)

IV. Conclusion

Based on the calculation results of bored pile foundation bearing capacity, it can be concluded as follows:

1. The results of the calculation from CPT-test data at location S1, for bored pile diameter 0.40 m with the Schmertmann & Nottingham method Q_u = 1275.729 kN, diameter 0.60 m Q_u = 2184.276 kN and diameter 0.80 m Q_u = 3468.399 kN. While at location S2, for bored pile diameter 0.40 m using the Schmertmann & Nottingham method Q_u = 1307.605 kN, diameter 0.60 m Q_u = 2310.474 kN and diameter 0.80 m Q_u = 3547.159 kN.

2. The results of the calculation of CPT-test data at location S1, for bored pile diameter 0.40 m with the Mayerhof method Q_u = 996.447 kN, diameter 0.60 m Q_u = 2760.857 kN and diameter 0.80 m Q_u = 3751.642 kN. While at location S2, for bored pile diameter 0.40 m with Mayerhof method Q_u = 865.383 kN, diameter 0.60 m Q_u = 2562.119 kN and diameter 0.80 m Q_u = 3987.816 kN.

3. The percentage calculation of ultimate bearing capacity at location S1 using the Schmertmann & Nottingham method is ±17.28% more optimistic than using the Mayerhof method for bored pile diameters of 60 and 80 cm. while the diameter of the bored pile is 40 cm, the

calculation using the Mayerhof method shows a more optimistic result of 21.89%.

4. Percentage of ultimate bearing capacity calculation at location S2 using the Schmertmann & Nottingham method is more optimistic ±11.66% compared to using the Mayerhof method for bored pile diameters of 60 and 80 cm. while the diameter of the bored pile 40 cm, the calculation using the Mayerhof method shows a more optimistic result of 33.82%.

5. The difference obtained from the two methods is influenced by the q_a value which is the average value of the cone resistance at the top and bottom of the pile tip determined by the pile diameter.

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