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A Comparison of Individual Bored Pile Bearing Capacity Using the Results of Standard Penetration Test (SPT) and Pile Driving Analysis (PDA) Test of the Railway Bridge Foundation

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ABSTRACT

Prediction of the bearing capacity of deep foundations using analytical methods from the results of the standard Penetration Test has been carried out until now due to practical consideration. However, with the many types of empirical formulas proposed by various researchers, it is necessary to test the validity of the values predicted by the empirical formulas. During the construction stage, the bearing capacity of deep foundations can be checked using the Pile Driving Analysis (PDA) Test. This study aimed to compare the foundation bearing capacity prediction results using analytical methods of Luciano Decourt (1982), Reese and O'Neil (1999), and Building Standard Law of Japan with the results from PDA test. The comparison indicate that the analytical method of Luciano Decourt (1982) predict bearing capacity with the smallest error rate, which is 1.97% to 38.99% with safaty factor (SF) 2 to 3 on a relatively homogeneous and heterogeneous soil conditions. Prediction of bearing capacity of bored pile foundations using analytical methods O'Neil & Reese (1999) and Building Standard Law of Japan provide better performance for soil types which is dominated by cohesive soils with safety factor (SF) 2.

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1. INTRODUCTION

Foundations are structures that are very important in construction to transfer the load of the building or the bridge to soil. In some cases, shallow foundations are inadequate to support the structural load, and deep foundations are required [1]. Types of deep foundations are classified according to geologic condition, installation method, structural material, ground effect, function, cross-section, loading, isolation, inclination, and other characteristics [2].

Various analytical methods are developed to predict the bearing capacity of deep foundations. Although analytical methods based on laboratory test data can produce good predictions, analytical methods using empirical formulas from soil investigations data, such as the Standard Penetration Test (SPT), continue to be developed. The development of this empirical analysis method aimed to make the analysis process more practical and faster. Several studies compared the bearing capacity of the analytical method and field test [3], [4], [5], [6], [7]. However, with the development of various methods of analyzing the bearing capacity of deep foundations, it is necessary to determine which method estimates the closest value of the bearing capacity prediction data compared to the bearing capacity of the test results in the construction stage.

This study aimed to continue discussing bearing capacity estimation for two deep foundations of railway bridges in Java with differences in their soil characteristics. The first one is a railway bridge identified as BH 122 in Krian, Sidoarjo, from the Surabaya-Solo railway line, where soil characteristics are dominated by cohesive soil. The second one is named BH 05 in Kulon Progo, Yogyakarta, from Kedundang Station-Yogyakarta International Airport (YIA) railway line, where the soil characteristics contain silty clay and sand. The calculation method of bearing capacity uses the method of Luciano Decourt (1982) [8], O'Neil & Reese (1999) [9], and the Building Standard Law of Japan (Japanese Method) [5]. A comparison was made with the PDA test results to validate the bearing capacity in the construction.

2. METHOD

2.1 N-SPT Correction

The procedure of the Standard Penetration Test (SPT) can be referred to as ASTM D1586 [10] or SNI 4153:2008 [11]. SPT can provide useful and reliable data for the geologic characterization of a site, primarily due to its simplicity and relatively low cost [12]. However, the estimation of SPT can produce inaccurate results due to environmental conditions such as the presence of groundwater levels. The raw SPT data could be improved by applying certain correction factors [13]. Therefore, Terzaghi dan Peck [14] propose a correction for the N-SPT value at points below the groundwater level and the N-SPT value > 15 with the following formula:

$$N'\text{-SPT} = 15 + 0.5\,(N-15) \quad (1)$$

Where:

N'-SPT = correction of the number of strokes

N-SPT = the number of strokes in the field

2.2 N-SPT correlation with soil parameters

N-SPT is only an index of soil behavior and does not directly measure any of the conventional engineering properties of soil [13]. However, N-SPT correlation with soil parameters is carried out to provide the data needed to complete the prediction formula for the bearing capacity of the bored pile foundation. Equations (2) to (4) are empirical equations that can be used to determine the value of soil cohesion (c_u) based on the SPT test data [15].

Plastic clay, $c_u = 12.5\ N'\text{-SPT}$ (kPa) (2)

Silty clay, $c_u = 10\ N'\text{-SPT}$ (kPa) (3)

Sandy clay, $c_u = 6.7\ N'\text{-SPT}$ (kPa) (4)

2.3 Analytical Method for Piles Bearing Capacity

The ultimate bearing capacity of a pile is the maximum load the pile can carry without failure or excessive settlement of the ground. It depends on the soil type, cross-section, and pile length [16]. In general, the formula in Eq. (5) and (6) is used for calculating the ultimate bearing capacity of the pile for deep foundations (Q_u). According to SNI 8460-2017, a deep foundation should be designed with a safety factor of 2.5 at the minimum [17].

$$Q_u = \frac{Q_p + Q_s}{SF} \quad (5)$$

$$Q_u = \frac{q_p.A_p + q_s.A_s}{SF} \quad (6)$$

Where:

Q_p = Theoretical bearing capacity for the tip of foundation, or end bearing (Ton)

q_p = Theoretical unit tip-bearing capacity (Ton/m^2)
A_p = Effective area of the tip of the pile (m^2)
Q_s = Theoretical bearing capacity due to shaft friction, or adhesion between foundation shaft and soil (Ton)
q_s = Theoretical unit friction capacity (Ton/m^2)
A_s = Effective surface area of the pile shaft (m^2)
SF = Factor of Safety/Safety Factor

Pile bearing capacity could be estimate from soil laboratory test or soil investigation result, such as SPT and CPT (Cone Penetrometer Test) [18]. The method to analyze the bearing capacity of the empirical bored pile foundation using the data from the SPT test is as follows:

A. Luciano Decourt Method (1982)[15]

- Stress at the end of the pile, q_p

$$q_p = (\overline{N}_p . K) \quad (7)$$

Where:

$\overline{N}_p$ = average value of SPT around 4B above and 4B below the pile foundation, where B is the diameter of the foundation

K = coefficient of soil characteristic value:
12 ton/m^2 for clay
20 ton/m^2 for clay silt
25 ton/m^2 for sandy silt
40 ton/m^2 for sand

- Stress due to lateral attachment, q_s

$$q_s \text{ (ton/m}^2) = \left(\frac{\overline{N}_s}{3} + 1\right) \quad (8)$$

Where:

$\overline{N}_s$ = average value along the length of the pile embedded within the boundary $3 \leq N \leq 50$

B. O'Neil & Reese Method (1999) [9]

The empirical method of Reese and O'Neill (1988) is considered reliable in estimating the bearing capacity of a pile foundation based on soil data [19]. The method was explained with the following formulas.

- Bearing capacity at pile tip, Q_p for cohesive soil:

If foundation depth < 3B, then:

$$Q_p = \frac{2}{3}\left[1 + \frac{1}{6}\frac{D}{B}\right] . N^*_c . s_u \quad (9)$$

If $s_u \geq 96$ kPa and the depth of the foundation base ≥ 3B, then:

$$Q_p = 9.S_u \quad (10)$$

If $s_u < 96$ and the depth of the foundation base ≥ 3B, then:

$$Q_p = \frac{4}{3}[\ln (I_r + 1)]. s_u = N^*_c.s_u \quad (11)$$

Where:

N^*_c = bearing capacity factor (Table 1)
s_u = undrained shear strength between pile tip and 2B under pile tip
I_r = stiffness index affected by soil stiffness

Table 1. Relationship of the value of Su to I_r dan N^*_c [9]

s_u (kPa)	$I_r = E_s/3s_u$	N^*_c
24 kPa	50	6.5
48 kPa	150	8.0
≥ 96 kPa	250 - 300	9.0

- Bearing capacity at pile tip, Q_p for non-cohesive soil:

$$Q_p \text{ (kPa)} = 57.5 \text{ N-SPT} \leq 29 \text{ MPa} \quad (12)$$

Q_p (tsf) = 0.6 N-SPT $\leq$ 30 MPa (13)

- Ultimate Shaft Resistance Capacity, Q_s for cohesive soil:

$f_s = \alpha.\ s_u$ (14)

Where:

α = dimensionless correlation coefficient, which value is determined by:

α = 0 between the soil surface to1.5 m depth or to a depth with changes in water content at a deeper location.

α = 0.55 if $s_u/p_a \leq 1.5$ and varies linearly between 0.55 dan 0.45 for s_u/p_a between1.5 and 2.5.

p_a = atmospheric pressure (101 kPa)

- Ultimate Shaft Resistance Capacity, Q_s for a non-cohesive soil

$q_s = \beta.\sigma_v'$ (15)

where:

β = dimensionless correlation coefficient between effective vertical stress and $q_{s\text{-}max}$ for layer i.

Nilai β ditentukan sebagai berikut:

The value of is determined as follows:

For sandy soil with N-SPT (uncorrected) $\geq$ 15 B/ 0.3 m:

$\beta = 1.5 - 0.245\ [z]^{0.5}$ (16)

For sandy soil with N-SPT (uncorrected) < 15 B/ 0.3 m:

$\beta = [N'\text{-}SPT/15]\ \{1.5 - 0.245\ (z)^{0.5}\}$ (17)

Where:

σ_v' = vertical effective stress at the center of the soil layer

z = vertical distance from the soil surface to the layer under consideration (m)

C. Building Standard Law of Japan (Japanese Method) [5]

The total load capacity of bored pile is calculated using Equation (5). Stress at pile tip (q_p) and friction bearing capacity (Q_s) calculated using Equation (18) and (19) as follows:

- Stress at pile tip, q_p

Cast in place bored pile foundation, $q_p = 150N$ (18)

- Friction bearing capacity, Q_s

$Q_s = \left(\frac{10}{3}.\bar{N}_s.L_s + \frac{1}{2}.\bar{q}_u.L_c\right).\varphi$ (19)

Where:

$\bar{N}_s$ = Average value along the embedded pile with limits $\leq$ 30

L_s = total length of the pile in contact with sand

$\bar{q}_u$ = average shear strength of clay with a value $\leq$ 200 kPa

L_c = total length of the foundation piles in contact with the clay

φ = cross-section circumference of the foundation

3. RESULTS AND DISCUSSION

3.1. Characteristics of the Soil

The SPT (Standard Penetration Test) test results for the BH 122 Surabaya-Solo railway bridge in Krian, Sidoarjo, and The BH 05 Bridge Crossing Kedundang Station - Yogyakarta International Airport (YIA) in Kulon Progo, Yogyakarta is compared in Figure 1. The figure also includes the N'-SPT value for bridge BH 05, which is the N-SPT value after being corrected using the Terzaghi and Peck formula.

Based on Figure 1, the type of soil in the BH 122 bridge area in Sidoarjo is dominated by cohesive soil types, namely silt and clay. While the soil composition in the BH 05 bridge area in Yogyakarta is more heterogenic, the top layer of soil to a depth of 15 m is a cohesive soil type, and at the bottom is sandy soil. The position of the groundwater level in the abutment area of the two bridges is relatively near to the topsoil, 1 m below ground level for the BH 122 bridge and 1.8 m below the ground level for the BH 05 bridge.

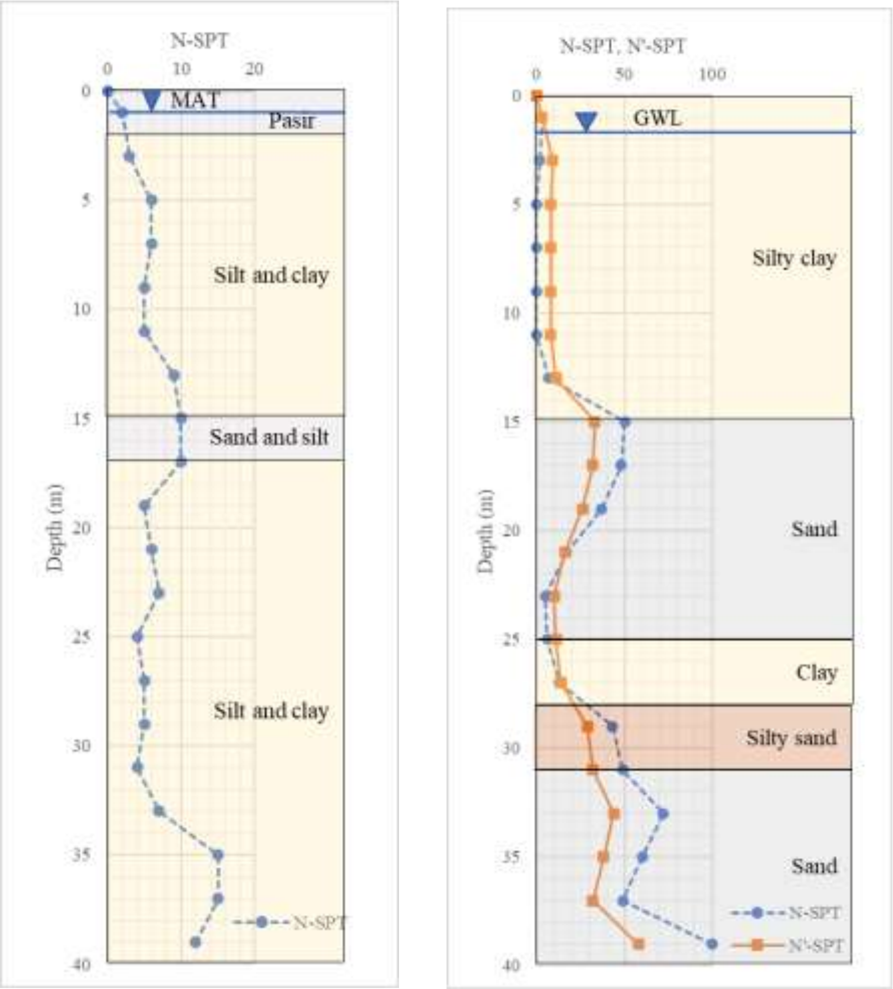

Figure 1 SPT test data in the bridge abutment area BH 122 (left) and BH 05 (right)

3.2. Bored Pile Foundation

The final depth of soil bearing capacity calculation for BH 122 and BH 05 is 39 m and 24 m depth. Calculation of the bearing capacity of the foundation in the bored piles was conducted using the analytical method from Luciano Decourt (1982), O'Neil & Reese (1999), and the Japanese method of the BH 122 and BH 05 bridges. The results of the calculation with various safety factor are shown in Table 2 and Table 3. The example of the bearing capacity estimation of bored piles from each method on the BH 122 bridge at a depth of (d) 12 m is shown in the following discussion.

A. Luciano Decourt Methods (1982)

Based on Figure 1, the type of soil at a depth of (d) 12 m of the BH 122 bridge is silt and clay, so the K value in the stress analysis at the end of the pile is 20 tons/m^2. The $\overline{\mathrm{N}}_{\mathrm{p}}$ is taken from the average N-SPT at about 4 meters (4B) above and below the pile tip location, i.e., 8 to 16 m depth. Meanwhile, $\overline{\mathrm{N}}_{\mathrm{s}}$ taken from the average N'-SPT from a depth of 1 to 12 meters. The bearing capacity of the bored pile foundation is calculated using Equations (7) and (8) as follows:

$\overline{\mathrm{N}}_{\mathrm{p}} = \frac{5+5+5+5+7+9+9+10+10}{9} = 7$

$\mathrm{A}_{\mathrm{p}} = \frac{1}{4}\,\pi.\mathrm{D}^2 = \frac{1}{4}\,\pi.1^2 = 0.79\ \mathrm{m}^2$

$\mathrm{Q}_{\mathrm{p}} = \left(\overline{\mathrm{N}}_{\mathrm{p}}.\mathrm{K}\right).\ \mathrm{Ap} = 7 \times 20 \times 0.79 = 109.96$ tonf.

$\overline{\mathrm{N}}_{\mathrm{s}} = \frac{2+2+3+4+6+6+6+5+5+5+5+7}{12} = 4.67$

$A_s = \pi.D.p = \pi \text{ x } 1 \text{ x } 12 = 37.67 \text{ m}^2$
$Q_s = \left(\frac{\bar{N}_s}{3} + 1\right). A_s = \left(\frac{4.67}{3} + 1\right) \text{ x } 37.67 = 96.34$ tonf.

IF safety factor (SF) 2, then:
$Q_u = \frac{109.96+96.34}{2} = 103.15$ tonf.

B. O'Neil & Reese Methods (1999)

Completing the method O'Neil & Reese (1999) requires soil cohesion parameters to determine the bearing capacity of cohesive soils. The cohesion of the silty clay is determined using Equation (3) as follows:
c_u at 12 meter = 10 N'-SPT = 10 x 7 = 70 kPa
c_u at 13 meter = 10 N'-SPT = 10 x 9 = 90 kPa
c_u at 14 meter = 10 N'-SPT = 10 x 9 = 90 kPa
For cohesive soil types, the value of the shear strength of the soil is assumed to be equal to the value of undrained cohesion (c_u), so the average shear strength value (s_u) at a depth of 12 to 14 meters:
$s_u = \frac{70+90+90}{3} = 83.33$ kPa (< 96 kPa)
$s_u < 96$ kPa and the base depth of the foundation $\geq 3B$, so that the pile end stress (q_p) is determined using Equation (11) as follows:
$N^*_c = 8.7$ (interpolation from Tabel 1)
$q_p = N^*_c.\ s_u = 9 \text{ x } 83.33 = 722.22$ kPa
$Q_p = q_p.\ A_p = 722.22 \text{ x } 0.79 = 567.23$ kN
$s_u/p_a = \frac{83.33}{101} = 0.83$

The value of $s_u/p_a \leq 1.5$, therefore α of 0.55 is used, and the frictional bearing capacity at a depth of 12 m is calculated using Equation (14) as follows:
$f_s = \alpha.\ s_u = 0.55 \text{ x } 83.33 = 45.83$ kPa
$Q_s = f_s.\ A_s = 45.83 \text{ x } 37.67 = 143.99$ kN

Cumulative value of Q_s from depth 0 to 12 m, $\sum Q_s = 1088.56$ kN
If the safety factor (SF) is 2, then:
$Q_u = \frac{45.83 + 143.99}{2} = 827.9$ kN = 82.79 tonf.

C. Japanese Methods

The bearing capacity of the bored pile foundation using the Japanese method is determined using equations (18) and (19) as follows:
q_p = 150 N'-SPT = 150 x 7 = 1.050 kPa
$Q_p = q_p.\ A_p = 1050 \text{ x } 0.79 = 824.7$ kN (82.47 tonf)
$\bar{q}_u = s_u = 83.33$ kPa
$Q_s = \left(\frac{10}{3}.\bar{N}_s.L_s + \frac{1}{2}.\bar{q}_u.L_c\right).\varphi$
$= \left(0 + \frac{1}{2} \text{x } 83.33 \text{ x } 1\right) \text{x } 3.14$
= 130.90 kN (13.09 tonf)

Cumulative Q_s from 0 to 12 meters depth, $\sum Q_s = 95.82$ tonf.
If a safety factor (SF) of 2 is used, then:
$Q_u = \frac{824.7+130.90}{2} = 891.4$ kN = 89.14 tonf.

Table 2. Bearing Capacity Estimation of Bored Pile BH 122 in Krian, Sidoarjo

d (m)	**Soil Type**	**N'-SPT**	**$\bar{N}_s$**	**Luciano Decourt (1982)**				**O'Neil & Reese (1999)**				**Japanese Method**		
				N rata2 (4B)	**Q_u (tonf)**			**c_u (kPa)**	**Q_u (tonf)**			**Q_u (tonf)**		
					SF = 2	**SF = 2.5**	**SF = 3**		**SF = 2**	**SF = 2.5**	**SF = 3**	**SF = 2**	**SF = 2.5**	**SF = 3**
1	Backfill sand	2	3	3	26.7	21.4	17.8	0	4.9	3.9	3.3	13.4	10.7	8.9
2		2	2	4	36.7	29.3	24.4	0	5.3	4.2	3.5	14.4	11.5	9.6
3	Silt and clay	3	2	4	39.8	31.8	26.5	30	16.1	12.9	10.7	23.7	19.0	15.8
4		4	3	4	43.5	34.8	29.0	40	26.0	20.8	17.3	33.8	27.0	22.5
5		6	3	4	48.2	38.5	32.1	60	33.6	26.9	22.4	50.3	40.2	33.5
6		6	4	5	60.7	48.6	40.5	60	37.3	29.8	24.9	54.7	43.8	36.5
7		6	4	5	65.4	52.4	43.6	60	40.7	32.6	27.1	58.9	47.1	39.3
8		5	4	5	69.6	55.7	46.4	50	43.8	35.1	29.2	56.9	45.6	38.0
9		5	4	6	81.7	65.3	54.5	50	48.1	38.5	32.1	60.9	48.7	40.6
10		5	4	6	85.9	68.7	57.2	50	55.4	44.3	37.0	65.3	52.3	43.5
11		5	4	7	97.9	78.3	65.3	50	66.5	53.2	44.3	70.8	56.7	47.2
12		7	5	7	103.1	82.5	68.8	70	78.9	63.2	52.6	89.1	71.3	59.4
13		9	5	8	117.3	93.8	78.2	90	91.1	72.9	60.8	108.3	86.6	72.2
14		9	5	8	123.6	98.9	82.4	90	100.1	80.0	66.7	115.7	92.6	77.1
15		10	6	8	130.4	104.3	86.9	100	110.8	88.7	73.9	129.5	103.6	86.3
16	Silt	10	6	8	152.9	122.3	101.9	0	103.8	83.1	69.2	0.0	106.0	88.4
17		10	6	8	159.7	127.8	106.5	0	109.2	87.3	72.8	0.0	108.6	90.5
18	Silt and clay	7	6	8	149.2	119.4	99.5	70	109.6	87.7	73.1	122.5	98.0	81.7
19		5	6	7	145.6	116.4	97.0	50	113.0	90.4	75.3	114.9	91.9	76.6
20		5	6	7	149.7	119.8	99.8	50	119.1	95.3	79.4	119.4	95.5	79.6
21		6	6	6	146.6	117.3	97.7	60	127.0	101.6	84.7	130.2	104.2	86.8
22		6	6	5	143.5	114.8	95.6	60	131.0	104.8	87.3	135.0	108.0	90.0
23		7	6	5	148.7	119.0	99.1	70	133.2	106.5	88.8	145.0	116.0	96.7
24		5	6	5	152.9	122.3	101.9	50	133.4	106.7	88.9	136.7	109.3	91.1
25		4	6	5	156.6	125.2	104.4	40	137.1	109.7	91.4	134.2	107.3	89.4
26		4	6	5	160.2	128.2	106.8	40	142.3	113.9	94.9	137.8	110.3	91.9
27		5	6	5	164.4	131.5	109.6	50	147.8	118.2	98.5	147.7	118.1	98.4
28		5	6	5	168.6	134.9	112.4	50	150.7	120.5	100.4	151.3	121.1	100.9
29		5	6	5	172.8	138.2	115.2	50	153.3	122.6	102.2	154.7	123.8	103.1
30		4	6	6	184.3	147.4	122.9	40	157.0	125.6	104.7	152.2	121.8	101.5
31		4	6	7	195.8	156.7	130.6	40	165.1	132.1	110.1	156.4	125.1	104.3
32		5	6	8	207.9	166.3	138.6	50	180.5	144.4	120.4	168.3	134.7	112.2
33		7	6	9	221.0	176.8	147.3	70	203.2	162.6	135.5	188.8	151.0	125.8
34		11	6	10	236.1	188.9	157.4	110	224.5	179.6	149.6	223.0	178.4	148.7
35		15	6	11	253.4	202.7	168.9	150	242.1	193.7	161.4	258.4	206.7	172.3
36		15	6	12	270.7	216.6	180.5	150	252.2	201.7	168.1	269.6	215.7	179.8
37		15	7	13	288.0	230.4	192.0	150	260.1	208.1	173.4	280.1	224.1	186.7
38		13	7	14	304.2	243.4	202.8	130	268.0	214.4	178.7	278.2	222.5	185.4
39		12	7	14	**312.1**	**249.7**	**208.0**	120	**276.6**	**221.3**	**184.4**	**281.7**	**225.4**	**187.8**

Table 3. Bearing Capacity Calculation of Bored Pile BH 05 in Kulon Progo, Yogyakarta

d (m)	Soil Type	N'-SPT	$\overline{N}_s$	Luciano Decourt (1982)				O'Neil & Reese (1999)				Japanese Method		
				N rata2 (4B)	Q_u (tonf)			c_u (kPa)	Q_u (tonf)			Q_u (tonf)		
					SF = 2	SF = 2.5	SF = 3		SF = 2	SF = 2.5	SF = 3	SF = 2	SF = 2.5	SF = 3
1	Silty clay	3	3.0	2.0	40.1	32.0	26.7	30	15.3	12.3	10.2	42.9	34.3	28.6
2		3	3.0	2.0	44.8	35.8	29.8	30	17.9	14.3	11.9	45.7	36.5	30.4
3		2	2.7	1.0	31.0	24.8	20.7	20	14.7	11.8	9.8	34.0	27.2	22.6
4		2	2.5	1.0	35.0	28.0	23.3	20	12.7	10.2	8.5	34.8	27.8	23.2
5		0	2.0	1.0	37.3	29.8	24.9	0	9.1	7.3	6.0	8.2	6.6	5.5
6		0	1.7	1.0	39.7	31.7	26.4	0	9.1	7.3	6.0	8.2	6.6	5.5
7		0	1.4	0.0	24.3	19.5	16.2	0	9.1	7.3	6.0	8.2	6.6	5.5
8		0	1.3	0.0	26.7	21.4	17.8	0	9.1	7.3	6.0	8.2	6.6	5.5
9		0	1.1	1.0	46.7	37.4	31.2	0	9.1	7.3	6.0	8.2	6.6	5.5
10		0	1.0	2.0	66.8	53.4	44.5	0	9.1	7.3	6.0	8.2	6.6	5.5
11		0	0.9	5.0	122.1	97.7	81.4	0	22.4	17.9	14.9	11.0	8.8	7.3
12		0	0.8	9.0	195.2	156.1	130.1	0	38.8	31.0	25.8	16.5	13.2	11.0
13		7	1.3	12.0	256.0	204.8	170.7	70	159.3	127.5	106.2	127.7	102.2	85.2
14		7	1.7	16.0	334.6	267.7	223.1	70	215.0	172.0	143.3	151.3	121.0	100.9
15	Sand	33	3.8	19.0	751.6	601.3	501.1	330	254.5	203.6	169.6	498.9	399.1	332.6
16		33	5.6	22.0	885.9	708.7	590.6	221.1	285.2	228.2	190.1	503.3	402.6	335.5
17		32	7.2	24.0	984.1	787.3	656.1	214.4	309.7	247.7	206.4	495.7	396.5	330.4
18		32	8.6	25.0	1046.9	837.5	698.0	320	338.8	271.1	225.9	502.4	401.9	334.9
19		26	9.5	24.0	1034.4	827.5	689.6	260	331.6	265.3	221.1	430.3	344.2	286.9
20		26	10.3	21.0	951.1	760.9	634.1	260	354.4	283.5	236.3	438.4	350.7	292.3
21		16	10.6	18.0	860.0	688.0	573.3	160	317.3	253.8	211.5	314.2	251.3	209.4
22		16	10.8	15.0	768.9	615.1	512.6	160	330.5	264.4	220.3	322.7	258.1	215.1
23		5	10.6	13.0	704.5	563.6	469.7	50	278.6	222.9	185.7	185.2	148.1	123.4
24		5	10.3	12.0	**675.4**	**540.4**	**450.3**	50	**282.4**	**225.9**	**188.3**	**193.3**	**154.6**	**128.9**

3.3. Comparison of Bearing Capacity from SPT Empirical Method and PDA Test Results

The evaluation of pile's bearing capacity by analytical methods and further checking of the result during field test is an important stage of the pile foundation design [20]. Based on the analysis of the bearing capacity of the bored pile foundation from PDA test results using CAPWAP application, the bearing capacity of the bored pile foundation of the BH 122 Bridge is 341 tonf and the bearing capacity of the bore pile foundation of the BH 05 Bridge at Yogyakarta International Airport (YIA) is 689 tonf. The bearing capacity of the foundation in bored piles using analytical methods with various assumptions of safety factors on Table 2 and Table 3 is compared to the results of the CAPWAP analysis and is shown in Table 4.

Tabel 4. Results of Error Rate Prediction of Bearing Capacity of Bored Pile Analytical Method

Bridge Identity	SF	Results	Luciano Decourt (1982)	O'Neil & Reese (1999)	Japanese Method
BH 122 (341 tonf)	2	Q_u (tonf)	312.06	276.60	281.69
		ε (%)	8.49	18.89	17.39
	2.5	Q_u (tonf)	249.65	221.28	225.35
		ε (%)	26.79	35.11	33.91
	3	Q_u (tonf)	208.04	184.40	187.79

Bridge Identity	SF	Results	Luciano Decourt (1982)	O'Neil & Reese (1999)	Japanese Method
		ε (%)	38.99	45.92	44.93
BH 05 YIA (689 tonf)	2	Q_u (tonf)	675.44	282.42	193.28
		ε (%)	1.97	59.01	71.95
	2.5	Q_u (tonf)	540.35	225.93	154.63
		ε (%)	21.57	67.21	77.56
	3	Q_u (tonf)	450.29	188.28	128.85
		ε (%)	34.65	72.67	81.30

Based on Table 4, it can be concluded the soil from BH 122 mainly consists of cohesive soil types. When using two as the factor of safety (SF), the slightest error rate between the bearing capacity from the analytical method and the PDA test results with a value of 8.49% for the Luciano Decourt method (1982), 18.51% for the O'Neil & Reese method, and 18.11% for the Japanese method. For a heterogeneous soil type such as BH 05, the Luciano Decourt method (1982) has the smallest error rate compared to the other two methods, which is 1.97%.

The Luciano Decourt method (1982) produces better predictions for relatively homogeneous soil conditions and heterogeneous soil types [4]. It may be because the Luciano Decourt method (1982) only uses the N-SPT value parameter, which estimates soil hardness directly from the field. Therefore, the prediction results are more accurate in calculating the bearing capacity of the soil. On the other hand, the method of O'Neil & Reese (1999) and the Japanese method use cohesive soil parameters based on the empirical correlation of the N-SPT value. Therefore, both methods can produce better bearing capacity predictions if the SPT test data is supplemented with laboratory test data.

4. CONCLUSION

From the study, it can be concluded that the prediction of the bearing capacity of the bored pile foundation using the analytical method of O'Neil & Reese (1999) and the Japanese method produces a fairly good prediction of the type of soil that is dominated by cohesive soil with the use of 2 as a safety factor (SF). While for heterogeneous soil types, both methods produce predictive data that are too pessimistic so that the foundation structure planning becomes uneconomical. Furthermore, the Luciano Decourt analytical method has the best predictive ability for relatively homogeneous and heterogeneous subsoil conditions, with an error range of 1.97% to 38.99% on a safety factor range of 2 to 3. It produces the smallest error rate of 8.49% for Bridge No. BH 122 and 1.97% for Bridge No. BH 05 when using the value 2 factors of safety.

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