JURNAL IPTEK

MEDIA KOMUNIKASI TEKNOLOGI

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Axial Bearing Capacity Analysis of Pile Foundation Using Nakazawa Method

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INFORMASI ARTIKEL

Jurnal IPTEK – Volume 24 Nomor 1, Mei 2020

Halaman:
45 – 52

Tanggal Terbit :
29 Mei 2020

DOI:
10.31284/j.iptek.2020.v24i1.900

ABSTRACT

Pile foundation serves to distribute all the loads in the building to the ground. There are several calculation methods for bearing capacity of the pile foundation, one of them is the Nakazawa method. Nakazawa method adapted from the calculation used in Japan where it is relevant for soft soils. The aim of this research is to obtain the axial bearing capacity of the pile foundation that can withstand axial forces using the Nakazawa method. The parameter that used for the calculation is modified or average N-value ($\overline{N}$). The analysis result shows the $\overline{N}$ value is smaller than N existing, indicate that Nakazawa tends to use the weaker value of N blows. It means the calculation is considered a softer type of soils than the existing ones. The value of point bearing capacity, Rp, assimilate to the pattern of N-SPT. The result value of friction bearing, Rf, in respect of depth shows the linear trending. Rf along the pile depends on the friction interaction between soil and structure. This phenomenon influenced by the soil type. The value of cohesion along the pile augment means the ability of soils to stick to the pile/structure is also high. It explains why the value of friction bearing is bigger with respect to depth.

Keywords: *Axial bearing capacity; Nakazawa method; N-SPT modified; Pile foundation*

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ABSTRAK

Pondasi tiang pancang berfungsi untuk menyalurkan beban dari bangunan atas ke tanah bawah. Beberapa metode perhitungan dapat dipakai untuk menghitung daya dukung satu tiang pancang, salah satunya adalah metode Nakazawa. Metode Nakazawa diadaptasi dari perhitungan di Jepang yang sangat relevan penggunaannya untuk tanah lunak. Tujuan dari penelitian ini adalah untuk mendapatkan nilai daya dukung tanah dasar satu tiang yang dapat menahan beban axial menggunakan metode Nakazawa. Parameter yang digunakan untuk perhitungan adalah nilai N modifikasi atau N rata-rata ($\overline{N}$). Hasil analisis menunjukkan bahwa nilai $\overline{N}$ lebih kecil dari nilai N asli, mengindikasikan bahwa Nakazawa cenderung menggunakan nilai pukulan N yang lebih kecil. Hal tersebut juga menunjukkan penggunaan jenis tanah yang lebih lunak. Nilai daya dukung ujung tiang, Rp, memiliki pola yang sama dengan pola nilai N-SPT. Hasil perhitungan daya dukung gesek tiang, Rf, per kedalaman menunjukkan tren yang linear. Nilai Rf sepanjang tiang bergantung pada nilai interaksi antara tanah dan struktur. Fenomena ini dipengaruhi oleh jenis tanah. Nilai kohesi sepanjang tiang terus naik, artinya kemampuan tanah untuk mengikat ke tiang (struktur) juga tinggi. Hal tersebut menjelaskan nilai daya dukung gesek semakin membesar sesuai kedalaman.

Kata kunci: *Metode Nakazawa; Daya dukung axial satu tiang; N-SPT modifikasi; Pondasi tiang*

PENERBIT

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INTRODUCTION

Background

In a country that earthquake often occurs, the construction in Indonesia should consider several factors. One of them is the safety of the foundation including the calculation method used. The most important part of the building structure planning is the pile foundation. It serves to distribute all the loads in the building to the ground [1].

The in-situ data of this analysis is taken from the construction of the bridge's pile of Surabaya's Outer West Ring Road (planning project) STA 0+400, Surabaya, Indonesia which has the type of silty clay soil. In every design, the worst-case scenario should be applied. Thus, the bearing capacity analysis could be modeled into soft soil analysis.

There are several calculation methods for bearing capacity of pile foundation that can be used; Mayerhoff, Mayerhoff Modification, Luciano Decourt [2] [3], Nakazawa, etc. Nakazawa method adapted from a calculation that usually used in Japan. As we know, Japan is also an earthquake-prone country dominated by soft soil [4]. Based on that reason, this calculation method is considered suitable for the construction of this article case compared to the other calculation methods.

Based on the background described, the purpose of this paper is an assessment to obtain the axial bearing capacity of the pile foundation that can withstand axial forces using the Nakazawa method.

LITERATURE REVIEW

Soil Characteristics

The parameter that used for axial bearing capacity calculation of pile foundation with Nakazawa method is N-value or usually called by N-SPT blows. It is obtained from a standard penetration test (SPT). Soil characteristics could be determined depends on the N-SPT shown in Table 1 for sand soil types [5] and Table 2 for clay soil types [6]. The N value is modified and recalculated as in Equation 3.

Table 1. Sand Soil Types Characteristics Depends on The N-SPT

N-value	Relative Density D_r		Friction Angle	
			Peck	Mayerhof
0 – 4	Very loose	0.0 – 0.2	< 28.5	< 30
4 – 10	Loose	0.2 – 0.4	28.5 – 30	30 – 35
10 – 30	Medium dense	0.4 – 0.6	30 – 36	35 – 40
30 – 50	Dense	0.6 – 0.8	36 – 41	40 – 45
> 50	Very dense	0.8 – 1.0	> 41	> 45

Source: Liu et al, 2015

Table 2. Clay Soil Types Characteristics Depends on The N-SPT

Consistency	Very soft	Soft	Medium	Stiff	Very stiff	Hard
N-value	< 2	2 – 4	4 – 8	8 – 15	15 – 30	> 30
q_u (kg/cm^2)	< 0.25	0.25 – 0.5	0.5 – 1.0	1.0 – 2.0	2.0 – 4.0	> 4.0

Source: Satrya et al, 2014

Calculation of Axial Bearing Capacity

The axial bearing capacity of the pile foundation is obtained from the total of bearing resistance and skin friction resistance as shown in Figure 1.

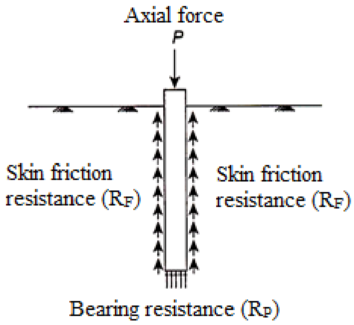


Figure 1. Load Transfer Mechanism of Axially Loaded Piles

Source: Sosrodarsono and Nakazawa, 2000

The following is the equation for calculating the allowable axial bearing capacity R_a using the Nakazawa method [7].

$$R_a=\frac{1}{n}R_u=\frac{1}{n}(R_P+R_F) \quad .... (1)$$

Here, n denotes Safety factor as shown in Table 3; R_u denotes ultimate bearing capacity (Ton); R_P denotes point bearing capacity (Ton); and R_F denotes friction bearing capacity (Ton).

Allowable bearing capacity is obtained from the ultimate bearing capacity of the pile over the safety factor depends on the load and construction types (Table 3.). Meanwhile, Ru, ultimate bearing capacity in the addition of point bearing and friction of the pile detailed in Equation 2.

Table 3. Safety Factor

Condition	Highway bridge		Railway bridge	Port construction	
	Supporting pole	Sliding pole		Supporting pole	Sliding pole
Fixed load	3	4	3	> 2.5	
Fixed load + temporary load	-	-	2	-	
Earthquake	2	3	1.5 (1.2)	> 1.5	> 2.0

* Numbers in parentheses → if the train load is calculated

Source: Sosrodarsono and Nakazawa, 2000

The ultimate bearing capacity R_u is obtained from the following equation

$$R_u=q_d.A+U.\sum l_i \,.\, f_i \quad .... (2)$$

where q_d denotes end bearing capacity (Ton/m^2); A denotes pile tip area (m^2); U denotes pile perimeter (m); l_i denotes the thickness of the soil layer, to calculate friction of pile (m); and f_i denotes maximum friction of the soil layer, to calculate friction of pile (Ton/m^2).

End bearing capacity q_d is obtained from the graph of *L/D* (Figure 2) and $q_d/\overline{N}$ with *L* is the length of equivalent penetration on the supporting layer of soil (Figure 3). *D* is diameter of pile and $\overline{N}$ is the average value of N-SPT on the tip of pile based on the following equation.

$$\overline{N}=\frac{N_1+\overline{N}_2}{2} \quad .... (3)$$

Here, $\overline{N}$ denotes the average value of N-SPT for planning foundation soil on the tip of the pile ($\overline{N} \leq 40$); N_1 denotes N-SPT on the tip of the pile; and $\overline{N}_2$ denotes the average value of N-SPT along with 4D above the end of the pile.

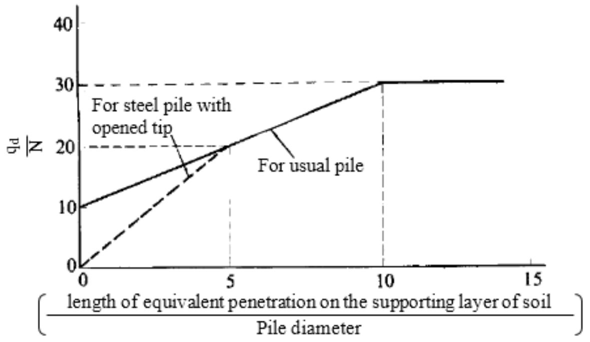
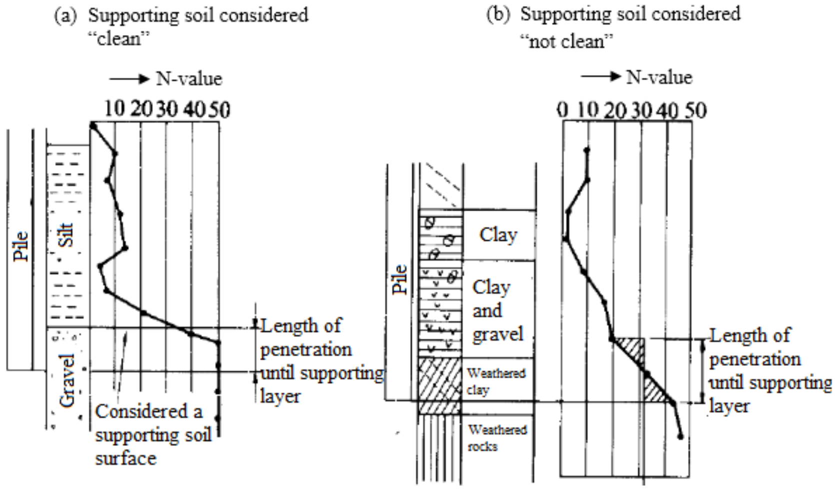


Figure 2. Calculation Diagram of The Ultimate Bearing Capacity of The Foundation Soil at The End of The Pile
Source: Sosrodarsono and Nakazawa, 2000



(1) N-value for planning foundation soil on the tip of the pile is obtained from Equation 3.
(2) The distance from the point where part of the area corresponds to the N-value distribution diagram from the foundation soil and the N line (the shaded part in the figure) is the same for the pile tip and is considered as the length of penetration.

Figure 3. Determination of Length of Equivalent Penetration on The Supporting Layer of Soil
Source: Sosrodarsono and Nakazawa, 2000

The maximum friction of the soil layer f_i depends on the type of pile and characteristics of soil as shown in Table 4. C is the cohesion of the foundation soil around the pile and is considered as 0.5 q_u (unconfined compression strength).

Table 4. Intensity of Friction on Pile

Foundation soil	Pile type	
	Precast	Cast in-situ
Sandy soil	$\frac{N}{5}$ (≤ 10)	$\frac{N}{2}$ (≤ 12)
Cohesive soil	c or N (≤ 12)	$\frac{c}{2}$ or $\frac{N}{2}$ (≤ 12)

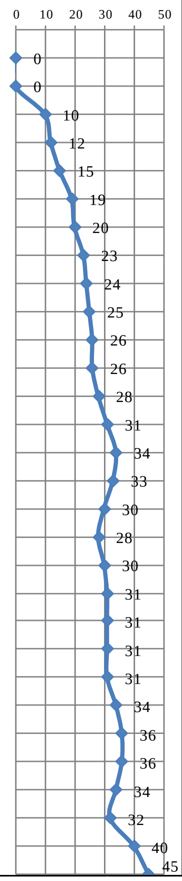
Source: Sosrodarsono and Nakazawa, 2000

DATA COLLECTION

Data in this research derived from in-situ data located in Surabaya's Outer West Ring Road (planning project) STA 0+400, Surabaya Indonesia. The data used is N-SPT value and interpolated deep bore data as seen in Table 5.

Nakazawa methods calculation in axial bearing capacity is using values of $\overline{N}$ obtained from Equation 3. Following is the example of $\overline{N}$ calculation in the depth of 16 meters (Figure 4). The N_1 value in 16 m is 33, $\overline{N}_2$value along 4D above 16 m is Average N values from depth of 13.6 to 16 m.

Table 5. N-SPT and Deep Bore Value

Depth (m)	Soil description			NSPT (N_1)	N-Value	C (t/m^2)	γ_{sat} (t/m^3)
	Type	Color	Consistency				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
0	-	-	-	-			
1			-	0.00			
2			-	0.00			
3			Medium	10.00			
4			Stiff	12.00			
5				15.00		3.31	1,763
6	Silty Sandy Clay	Brownish Yellow		19.00			
7				20.00			
8				23.00			
9				24.00			
10			Very Stiff	25.00		7.12	1,698
11				26.00			
12				26.00			
13				28.00			
14				31.00			
15				34.00		13.04	1,767
16			Hard	33.00			
17				30.00			
18			Very Stiff	28.00			
19				30.00			
20				31.00		11.92	1,751
21	Silty Clay	Grey		31.00			
22				31.00			
23				31.00			
24				34.00			
25			Hard	36.00		12.29	1,771
26				36.00			
27				34.00			
28				32.00			
29				40.00			
30				45.00			

Source: Transportation and Geotechnic Laboratory ITS, 2017

Figure 5 shows that in the Nakazawa method, $\bar{N}$ value is smaller than N existing (N_1) until the depth of 15 m. Meanwhile, the $\bar{N}$ value from 15 m – 18 m is bigger than N existing (N_1) due to the average value 4D above it, has bigger values. The $\bar{N}$ value from 20–23 m shows no difference between 2 conditions following the constant value of N-SPT.

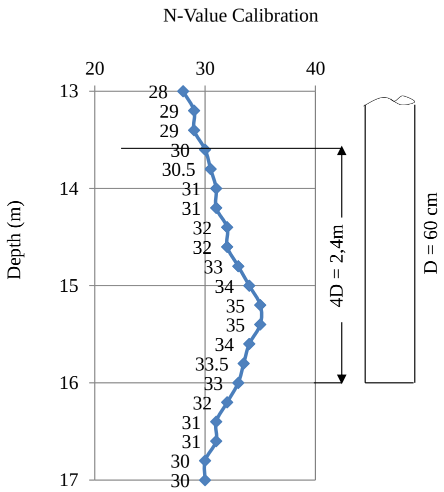


Figure 4. N-Value Calibration
Source: Calculation result, 2019

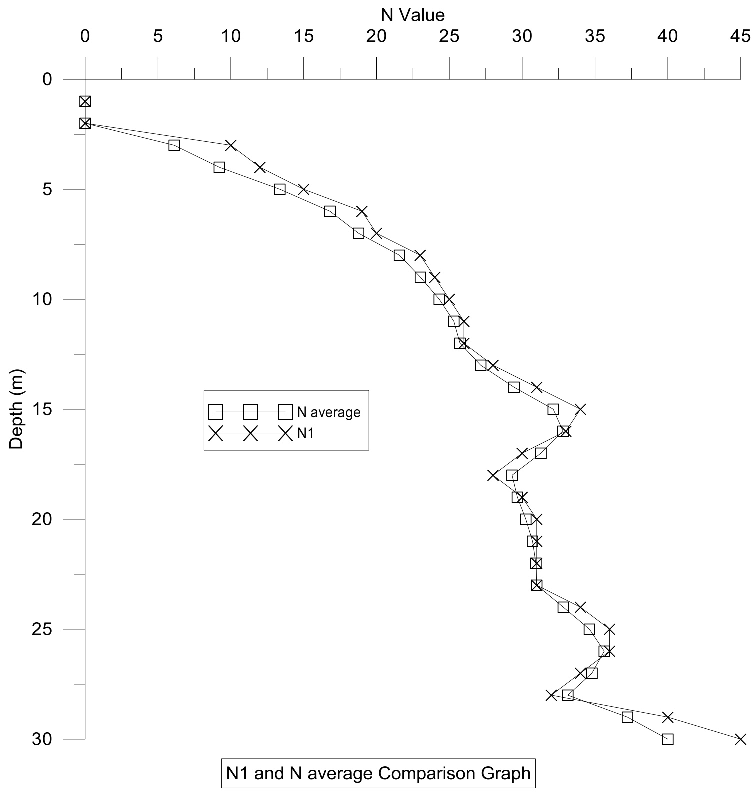


Figure 5. N1 and $\overline{N}$ Comparison Graph
Source: Calculation result, 2019

RESEARCH ANALYSIS

Axial Bearing Capacity

The result calculation of axial bearing capacity by using the Nakazawa method in the depth of 0–30 meters is shown in Figure 6. The graph indicates the value of point bearing capacity, Rp, assimilate to the pattern of N-SPT. This is proved by the theory that N-SPT value represents soil bearing capacity from the number of N-SPT blows. It is known that the greater the value of the N-SPT blows, the harder the soils. It requires more blows thus the split barrel drive as an SPT apparatus can penetrate the soil ground as deep as 15 cm.

Whereas, the value of friction bearing, Rf, in respect of depth shows the linear trending. In a comparison with point bearing in the depth of 16 meters, for example, friction bearing has twice the value of Rp. Rf along the pile depends on the friction interaction between soil and structure. This phenomenon influenced by the soil type. The type of soil from 0–30 meters is clay. Clay has its own internal strength named cohesion. The value of cohesion along 30 meters as shown in Table 5 is high, which means the ability of soils to *stick* to the pile (structure) is also high. It explains why the value of friction bearing is bigger with respect to depth.

Ultimate bearing capacity is the sum of point bearing and friction bearing capacity. The result could be seen in Figure 6. Furthermore, the allowable bearing capacity is the division of ultimate bearing capacity with a safety factor of 3. Thus, the pattern of allowable bearing capacity is similar to the ultimate bearing capacity but three times smaller. The graph could be seen in Figure 6.

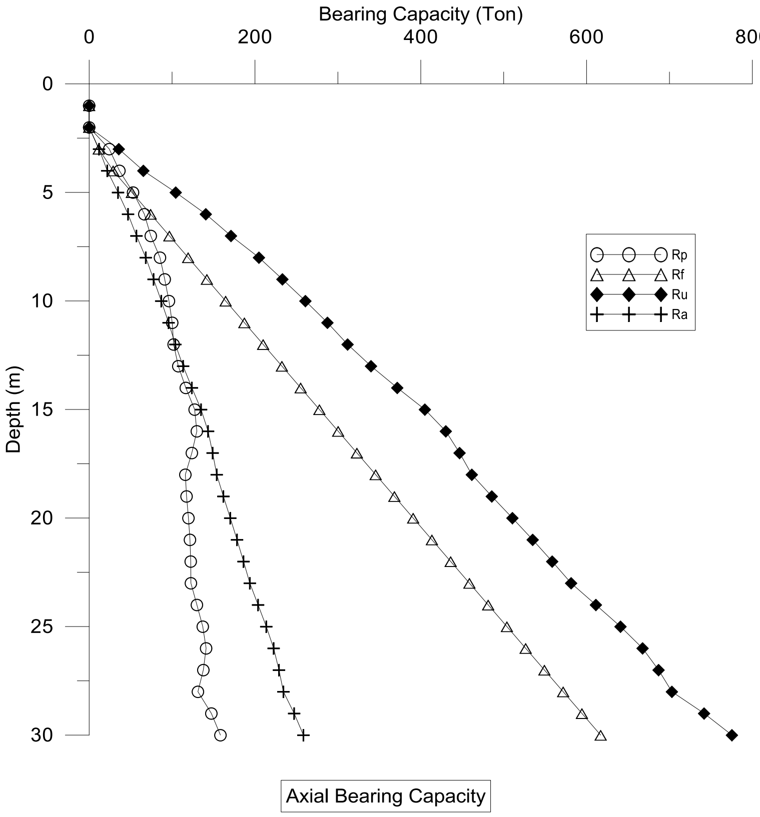


Figure 6. Axial Bearing Capacity (Ton) vs Depth (m)
Source: Calculation result, 2019

CONCLUSION

The analysis result shows that in the Nakazawa method, $\overline{N}$ value is smaller than N existing indicate that Nakazawa tends to use the weaker value of N blows. This concludes that in Nakazawa calculation, the bearing capacity is considered a softer type of soils than the existing ones. Hence, the axial bearing planning would be in the worst-case scenario.

The result calculation of axial bearing capacity by using the Nakazawa method indicates the value of point bearing capacity, Rp, assimilate to the pattern of N-SPT. This is proved by the theory that N-SPT value represents soil bearing capacity from the number of N blows.

The result value of friction bearing, Rf, in respect of depth shows the linear trending. Rf along the pile depends on the friction of soil-structure interaction. This phenomenon influenced by the soil type. The value of cohesion along 30 meters augment means the ability of soils to *stick* to the pile (structure) is also high. The curve also shows the cumulative value of frictions along with the pile. It explains why the value of friction bearing is getting bigger with respect to depth.

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