Axial Bearing Capacity Analysis of Pile Foundation Using Nakazawa Method

Laras Laila Lestari¹, Jaka Propika², Aisyah Dwi Puspasari³

¹²Department of Civil Engineering, Faculty of Civil Engineering and Planning, Institut Teknologi Adhi Tama Surabaya, Surabaya, 60117, Indonesia
³Department of Civil Engineering, Chung Yuan Christian University, Zhongli District, Taoyuan City, Taiwan 320

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 (N̅). The analysis result shows the N̅ 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

EMAIL
laraslaila.lestari@itats.ac.id
jakapropika@itats.ac.id
aisyahdwipus@gmail.com

PENERBIT
LPPM- Institut Teknologi Adhi Tama Surabaya
Alamat:
Jl. Arief Rachman Hakim No.100, Surabaya 60117,
Telp/Fax: 031-5997244

Jurnal IPTEK by LPPM-ITATS is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License.

PENGERI
Jurnal IPTEK
Volume 24
Nomor 1, Mei 2020
Halaman: 45 – 52
Tanggal Terbit: 29 Mei 2020
DOI: 10.31284/j.iptek.2020.v24i1.900

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 (N̅). Hasil analisis menunjukkan bahwa nilai N̅ 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
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.

| 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

| Consistency | Very soft | Soft | Medium | Stiff | Very stiff | Hard |
|-------------|-----------|------|--------|-------|------------|------|
| N-value     | < 2       | 2 – 4 | 4 – 8  | 8 – 15| 15 – 30    | > 30 |
| q_u (kg/cm²)| < 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.
The following is the equation for calculating the allowable axial bearing capacity $R_a$ using the Nakazawa method [7].

$$R_a = \frac{1}{n} R_u = \frac{1}{n} (R_p + R_f) \quad \ldots \quad (1)$$

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, $R_u$, ultimate bearing capacity in the addition of point bearing and friction of the pile detailed in Equation 2.

**Figure 1. Load Transfer Mechanism of Axially Loaded Piles**

*Source: Sosrodarsono and Nakazawa, 2000*

The ultimate bearing capacity $R_u$ is obtained from the following equation

$$R_u = q_d A + U \sum l_i \cdot f_i \quad \ldots \quad (2)$$

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 $q_d \bar{N}$ with $L$ is the length of equivalent penetration on the supporting layer of soil (Figure 3). $D$ is diameter of pile and $\bar{N}$ is the average value of N-SPT on the tip of pile based on the following equation.

$$\bar{N} = \frac{N_1 + N_2}{2} \quad \ldots \quad (3)$$

Here, $\bar{N}$ denotes the average value of N-SPT for planning foundation soil on the tip of the pile ($\bar{N} \leq 40$); $N_1$ denotes N-SPT on the tip of the pile; and $N_2$ 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

(a) Supporting soil considered "clean"
(b) Supporting soil considered "not clean"

(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 $f_s$ 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      | $N \leq (10)$   | $N/2 \leq (12)$ |
| Cohesive soil   | $c \text{ or } N \leq (12)$ | $c/2 \text{ or } N/2 \leq (12)$ |

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 $N$ obtained from Equation 3. Following is the example of $N$ calculation in the depth of 16 meters (Figure 4). The $N_1$ value in 16 m is 33, $N_2$ 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-Value | C (t/m²) | Ysat (t/m²) |
|-----------|------------------|------|---------|----------|-------------|
|           | Type             | Color| Consistency | (N₁)     | (6)         | (7) | (8) |
| 0         | -                | -    | -        | -        | 0.00        | 3.31 | 1,763 |
| 1         | Silt Sandy Clay | -    | -        | -        | 0.00        |       |      |
| 2         | -                | -    | -        | -        | 0.00        |       |      |
| 3         | Medium           | 10.00| 12.00    | 15.00    | 19.00       | 20.00 | 21.00 |
| 4         | Stiff            | 12.00| 19.00    | 20.00    | 23.00       | 25.00 | 26.00 |
| 5         | 15.00            |      |          |          | 12.00       | 4.31  | 1,763 |
| 6         | 19.00            |      |          |          | 20.00       | 7.12  | 1,698 |
| 7         | 20.00            |      |          |          | 23.00       | 13.04 | 1,767 |
| 8         | 24.00            |      |          |          | 25.00       |      |      |
| 9         | 26.00            |      |          |          | 28.00       |      |      |
| 10        | 28.00            |      |          |          | 30.00       |      |      |
| 11        | 31.00            |      |          |          | 33.00       |      |      |
| 12        | 34.00            |      |          |          | 36.00       |      |      |
| 13        | 36.00            |      |          |          | 39.00       |      |      |
| 14        | 39.00            |      |          |          | 42.00       |      |      |
| 15        | 42.00            |      |          |          | 45.00       |      |      |
| 16        | 45.00            |      |          |          | 48.00       |      |      |
| 17        | 48.00            |      |          |          | 51.00       |      |      |
| 18        | 51.00            |      |          |          | 54.00       |      |      |
| 19        | 54.00            |      |          |          | 57.00       |      |      |
| 20        | 57.00            |      |          |          | 60.00       |      |      |
| 21        | 60.00            |      |          |          | 63.00       |      |      |
| 22        | 63.00            |      |          |          | 66.00       |      |      |
| 23        | 66.00            |      |          |          | 69.00       |      |      |
| 24        | 69.00            |      |          |          | 72.00       |      |      |
| 25        | 72.00            |      |          |          | 75.00       |      |      |
| 26        | 75.00            |      |          |          | 78.00       |      |      |
| 27        | 78.00            |      |          |          | 81.00       |      |      |
| 28        | 81.00            |      |          |          | 84.00       |      |      |
| 29        | 84.00            |      |          |          | 87.00       |      |      |
| 30        | 87.00            |      |          |          | 90.00       |      |      |

Source: Transportation and Geotechnic Laboratory ITS, 2017

Figure 5 shows that in the Nakazawa method, $N$ value is smaller than $N$ existing ($N_1$) until the depth of 15 m. Meanwhile, the $N$ 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 $N$ 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
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.
CONCLUSION

The analysis result shows that in the Nakazawa method, N̅ 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.

BIBLIOGRAPHY

[1] D. K. Fitriyah, J. Propika, L. L. Lestari, H. Istiono, D. Pertwi, and R. Sekartadji, “Pile Foundation Analysis on High - Rise Building using Finite Element-Spring Method on Sandy Clay Soil,” IOP Conf. Ser. Mater. Sci. Eng., vol. 462, no. 1, 2019.
[2] J. E. Bowles, “Foundation Analysis and Design International Fifth Edition,” 1997.
[3] B. M. Das, Principles of Foundation Engineering, vol. №3. 2011.
[4] T. Kanda et al., “New soil maps of Japan based on the comprehensive soil classification system of Japan - First approximation and its application to the world reference base for soil resources 2006,” Japan Agric. Res. Q., vol. 52, no. 4, pp. 285–292, 2018.
[5] Y. Liang, L. Cao, and J. Liu, “Statistical Correlations between SPT N-Values and Soil Parameters: Part I: SPT N vs EPMT in Victoria Street Station Statistical Correlations between SPT N-Values and Soil Parameters,” Dep. Civ. Eng. Ryerson Univ., no. June, 2015.
[6] T. R. Satrya et al., “Engineering Geological Mapping at Center of Surabaya Region by Developing Geo-Tomography Image Analysis,” *Celeb. Int. Conf. Earth Sci.*, no. October 2015, 2014.

[7] S. Sosrodarsono and K. Nakazawa, *MEKANIKA TANAH & TEKNIK PONDASI*. JAKARTA: PT. PRADNYA PRAMITA, 2000.