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Comparison of Elastic Settlement of Pile Foundations Using Analytical Methods and Finite Element Methods

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ABSTRACT

The foundation is part of the lower structure that functions to transmit the superstructure load to the soil base which is strong enough to support it and is usually dominated by the allowable settlement limit, in order to avoid danger to the superstructure. This study aims to analyze the bearing capacity and settlement of driven pile using analytical methods and Finite Element Method using Plaxis software. This study compares variations settlement and axial bearing capacity of piles with 300 mm, 400 mm, and 500 mm diameter. Based on the results obtained, the bearing capacity of the driven pile with plaxis is 20.25 – 26.63% higher than the calculation using the Schmertmann method. In terms of settlement, the results obtained are 3,371 mm for the D 300 mm, 3,289 mm for the D 400 mm, and 3,209 mm for the D 500 mm. All three settlement are still within safe limits.

Key words: *Driven Pile, Bearing Capacity, Settlement, Pile Diameter, Finite Element Method*

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INTRODUCTION

Foundation is part of the lower structure which function is transmit the load of the superstructure to the ground which is strong enough to support it (Yuliawan & Rahayu, 2018). Foundation design is usually dominated by limits on the permissible settlement, in order to avoid harm to the superstructure (Horikoshi & Randolph, 1999). Therefore an analysis of the settlement of the foundation is important because if the strength of the soil is unable to carry the load of the foundation, excessive settlement or soil collapse will occur.

The construction of the Integrated Cancer Service Building in a hospital in South Jakarta was used as a case study chosen by the author in analyzing the carrying capacity and settlement that occurred in the building. The failure of the cancer building will be dangerous for workers, patients, and people around the cancer building.

The construction of the Cancer Building at “X Hospital” uses pile foundations with a diameter of 400 mm. Based on N-SPT data, the type of soil in the first layer to about a depth of 9 m from the surface is a soft to stiff layer and the hard soil layer is quite deep, namely silt soil with medium plasticity (medium clayey silt) in about 17 m from the ground surface.

Based on the available data, it is necessary to determine the size of the pile foundation that is safe against settlement that will occur. In the calculations, pile sizes of 300 mm, 400 mm and 500 mm are used. This calculation itself is carried out using analytical and finite element methods with the Plaxis auxiliary program. This research was conducted to determine the value of the ultimate bearing capacity of each pile size and the elastic settlement that occurs using the analytical method and the finite element method using the Plaxis program.

A previous study was carried out by Warih, et al (2020) concluded that based on an analysis of the calculation of the bearing capacity of single pile foundations in groups using the U.S Army Corps method, a permit carrying capacity of 788.28 kN was obtained, the Meyerhoff method obtained a permit carrying capacity of 851.29 kN and the finite element method (Plaxis) obtained a permit carrying capacity of 935.12 kN. From the calculation results it can be concluded that the safest pile bearing capacity to use is the pile bearing capacity using the U.S Army Corps method.

RESEARCH METHOD

Research location

The chosen location was the “X Hospital” Integrated Cancer Service Building Development Project in the South Jakarta area. The object studied in this study is the comparison of ultimate bearing capacity and foundation settlement using 3 sizes of pile diameters of circular cross section, namely; 300mm, 400mm and 500mm. The purpose of this study was to obtain the carrying capacity of group piles and single piles by taking into account the settlement and efficiency of pile groups from 3 sizes of pile diameters.

Flowchart and Methodology

The data collection process is important and needed in the success of this research. The data collected was in the form of primary data and secondary data. The data that was successfully obtained are:

a. Primary data, was obtained by researchers directly through field observations and debriefing with supervisory consultants as resource persons.
b. Secondary Data, is data obtained by researchers from existing sources, this data includes support reactions of structural loads obtained from modeling in ETABS, soil data in the form of SPT and CPT testing results.

Figure 1 is show the research flowchart.

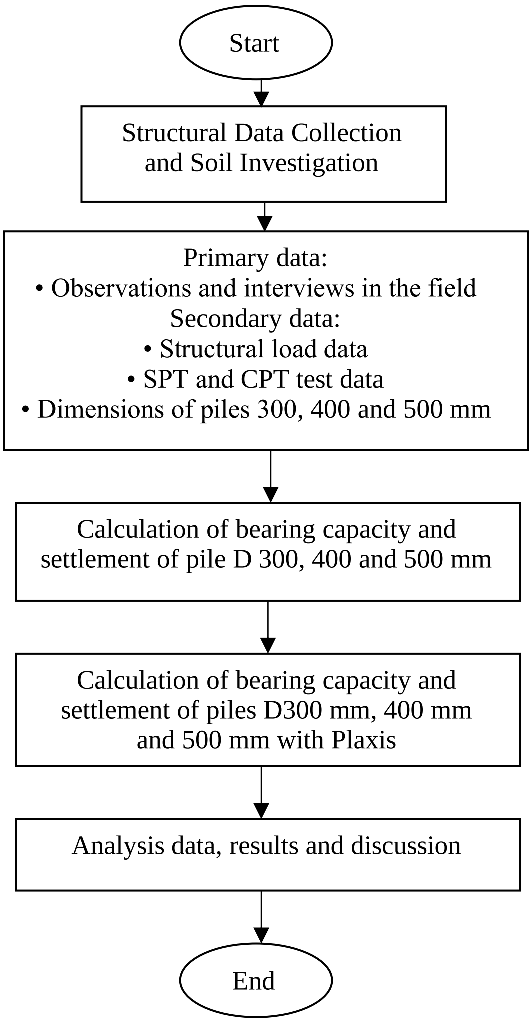

Figure 1. Research Flowchart

The foundation used in this project is the deep foundation. This type of foundation has a significant depth in a competent layer (capable of supporting) according to the required capacity lateral loading large capacity lateral pressure which is very necessary (Kurniawan & Hadimuljono, 2020).

Pile foundations are used when foundation soils at normal depths are unable to support the load, whereas hard soils are located at very great depths. In principle, a deep foundation is a foundation that supports the load of the building relying on the end resistance and frictional resistance of the walls (Hardiyatmo, 2018)

In determining the bearing capacity of a foundation, adequate soil testing is usually required. In Indonesia, there are 2 types of soil testing that are often used, such as the Standard Penetration Test (SPT) and Conus Penetration Test (CPT) methods. For research at this time only SPT data is used as a reference for calculating bearing capacity and settlement. The SPT test is carried out due to the difficulty of obtaining undisturbed soil samples on granular soils. In this test, the properties of sandy soil are determined by measuring the relative density directly in the field.

This bearing capacity calculation is carried out based on N-SPT data. To determine the bearing capacity of the pile foundation, following the general formula obtained from the sum of the end resistance and the pile skin friction, it can be expressed in the form:

$$Q_u = Q_p + Q_s \quad (1)$$

where Q_u is the ultimate bearing capacity of the pile, Q_p is the ultimate bearing capacity of the pile ends, and Q_s is the ultimate skin friction capacity of the pile.

The ultimate pile end bearing capacity (Q_p) can be formulated as follows:

$$Q_p = q_p \times A \quad (2)$$

The ultimate bearing capacity of skin friction (Q_s) can be formulated as follows:

$$Q_s = \sum_{i=1}^{n} f_{si}\ l_i\ p \quad (3)$$

where A is the pile cross-sectional area, f_{si} is the pile cover friction per unit area in the 1st segment, l_i is the length of the i-th pile segment, and p is the circumference of the pile cross-section.

To predict the magnitude of the friction in the blanket and the end resistance, the method of Schmertmann, 1967 is used. This method uses the N-SPT correlation to determine the value of the blanket friction and end resistance as shown in Table 1.

Table 1. Skin friction & end bearing of pile

Types of soil	Skin friction (kg/cm^2)	End bearing (kg/cm^2)
Sand	0,019 N_{SPT}	3,2 N_{SPT}
Silty clay mixed with sand, silty sand, silt	0,04 N_{SPT}	1,6 N_{SPT}
Plastic clay	0,05 N_{SPT}	0,7 N_{SPT}
Brittle limestone, rocky sand	0,01 N_{SPT}	3,6 N_{SPT}

Source : Schmertmann, 1967

The variation of factor of safety (SF) that has been widely used in pile planning is 2.5. Based on the size of the pile, the axial compression bearing capacity is calculated using the formula:

$$Q_{all} = \frac{Q_p + Q_s}{\mathrm{SF}} \quad (4)$$

For the calculation of the ultimate bearing capacity of a group of piles by taking into account the pile efficiency factor, it is expressed by the formula:

$$Q_g = E_g \times n \times Q_u \quad (5)$$

where E_g is the efficiency of group piles, n is the number of piles in a group.

The proposed pile efficiency equation is approximate and is based on pile arrangement, relative spacing and pile diameter, excluding pile length, pile shape variations and soil properties, as well as depth and influence of the groundwater table. One of the suggested equations is Converse-Labarre :

$$E_g = 1 - \theta \frac{(n'-1)m + (m-1)n'}{90\ m\ n'} \quad (6)$$

Where n' is the number of piles in one row, m is the number of rows of piles and θ is the arc tan *d/s* in degrees.

In determining the efficiency of a group of piles, it is necessary to calculate the center-to-center distance of the piles. Fellenius (2006) suggests the following minimum spacing of piles:

$$S = 2{,}5\,D + 0{,}02\,L \quad (7)$$

Where S is center to center of pile, D is pile diameter and L is pile length

Settlement can occur due to the load of the working structure. The settlement of the foundation is caused by activities in the ground such as the influence of the weight of buildings standing on the ground and the carrying capacity of the soil layer that is not uniform (Hasyim, 2015). The total value of the settlement of a pile acting under a vertical load is given by the formula:

$$\mathrm{S_e} = \mathrm{S_{e(1)}} + \mathrm{S_{e(2)}} + \mathrm{S_{e(3)}} \quad (8)$$

Where S_e is the total settlement, $S_{e(1)}$ is the elastic settlement, $S_{e(2)}$ is the settlement due to end bearing load, $S_{e(3)}$ is the settlement due to friction.

$$S_{e(1)} = \frac{(Q_{wp} + \xi Q_{ws})L}{A_p E_p} \quad (9)$$

$$S_{e(2)} = \frac{Q_{wp} C_p}{D q_p} \quad (10)$$

$$S_{e(3)} = \frac{Q_{ws} C_s}{L\ q_s} \quad (11)$$

Q_{wp} : pile end bearing capacity
Q_{ws} : pile skin friction capacity
ξ : coefficient of skin friction (0,5 – 0,67)
E_P : elastic modulus of pile
C_p : empirical coefficient (Table 2),
q_p : tahanan ujung batas tiang.
C_s : $(0{,}93 + 0{,}16\sqrt{L/D})C_p$, (12)
L : length of pile in m

Table 2. C_p based on types of soil

Types of soil	Driven Pile	Bored pile
Sand (stiff to loose)	0,02-0,04	0,09 – 0,18
Clay (stiff to soft)	0,02-0,03	0,03 – 0,06
Silt (stiff to looses)	0,03-0,05	0,09 – 0,12

The simplest relationship for settlement of pile groups is given by Vesic, 1969, with the following equation:

$$S_{g(e)} = \sqrt{\frac{B_g}{D}}\,S_e \quad (12)$$

where $S_{g(e)}$ is pile group settlement, B_g is pile group width and D is pile diameter.

Allowable settlement for pile groups can be seen in Equation 13 below:

$$S_{izin} = \frac{\mathrm{L}}{250} \quad (13)$$

RESULTS AND DISCUSSION

Analysis of the bearing capacity of the piles using the static method using data from the N-SPT test results. Schmertmann used the N-SPT correlation to determine the friction bearing capacity and the end bearing capacity of the pile foundation.

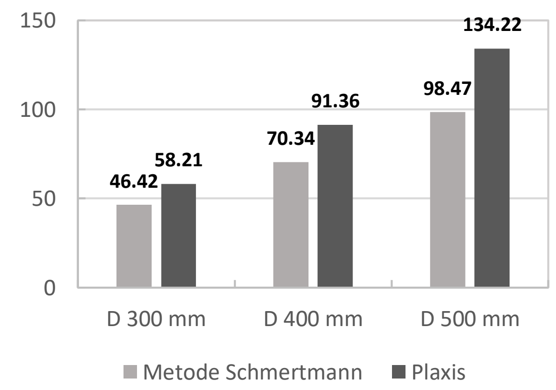

Figure 2. Comparison of the Pile Capacity between Schmertmann and Plaxis Methods

The variations in diameter used are 300 mm, 400 mm, and 500 mm. The results showed that the larger the pile diameter, the greater the bearing capacity, this is due to the difference in the cross-sectional area and the perimeter area of the pile which affects the end bearing capacity and pile friction.

The bearing capacity of a single pile foundation with Plaxis is greater than that of the Schmertmann method. This is because the Schmertmann method uses the N-SPT correlation to determine the friction bearing capacity and the pile end bearing capacity without being affected by the groundwater table.

While Plaxis gets the results obtained from modeling based on the finite element method.
Based on the results of calculating the settlement of a single pile using the Vesic method, the results are shown in Table 3.

Table 3. Single Pile settlement results with the Vesic Method

Pile diameter	Settlement	Allowable Settlement
300 mm	12 mm	< 25 mm
400 mm	15 mm	< 25 mm
500 mm	18 mm	< 25 mm

These results explain that the diameter of the pile affects the value of a settlement. It was found that the larger the pile, the greater the settlement that occurs. This is because the load transferred by the end tip of the pile and the load around the skin of pile increases with the diameter of the pile. If the modeling has been completed and successfully carried out, the output is obtained in the form of total displacement. These results were obtained after loading of 175.8 tons. The results of load reduction can be seen in Table 4. A single pile with the same loading and different pile diameter variations, it is found that the larger the pile, the smaller the settlement will occur. This is due to the wider diameter of the single pile, the smaller the settlement value of the single pile. From the three values above, it was found that the decrease that occurred was still within safe limits.

Table 4. Total Displacement by Plaxis

Pile Diameter	Displacement	Allowable Settlement
300 mm	3,4 mm	< 25 mm
400 mm	3,3 mm	< 25 mm
500 mm	3,2 mm	< 25 mm

After obtaining the results of the ultimate bearing capacity and settlement of a single pile, the calculation of the bearing capacity, settlement, and efficiency of the pile group can be carried out. The recapitulation results can be seen in Table 5.

Table 5. Calculation results of E_g, Q_g, and $S_{g(e)}$ for pile groups

D (mm)	N (buah)	E_g	Q_g (ton)	$S_{g(e)}$ (cm)
300	18	0,75	625	3,8
400	12	0,74	626	4,6
500	9	0,74	660	5,4

Based on the data above, it can be concluded that in order for a group of piles to be able to carry a load of 621.8 tons, a different number of piles is required due to the various pile diameters. For a diameter of 300 mm, 18 piles are required with a pile group efficiency value of 0.75 and a settlement of 3.8 cm. For a diameter of 400 mm, 12 piles are required with a pile group efficiency value of 0.74 and a settlement of 4.6 cm. For a diameter of 500 mm, 10 piles are needed with a pile group efficiency value of 0.74 and a settlement of 5.4 cm. Of the three values, the settlement of pile groups is still within safe limits (< 7.2 cm).

CONCLUSSION

Based on the results of the analysis, several conclusions were obtained. The results of calculating the ultimate bearing capacity of pile foundations with sizes of 300 mm, 400 mm and 500 mm based on SPT data using the Schmertmann method and the Plaxis program show that the ultimate bearing capacity is 20.25 – 26.63% higher than the Schmertmann method on the three pile diameters.
The value of the bearing capacity of the group pile foundation sizes of 300 mm, 400 mm, and 500 mm using the efficiency value of the pile group method of Converse-Labarre shows a value of 625 tons for a diameter of 300 mm, 626 tons for a diameter of 400 mm, and 660 tons for a diameter 500mm.
The settlement that occurs in the pile foundation using the Vesic method shows a value of 12 mm for a diameter of 300 mm, 15 mm for a diameter of 400 mm, and 18 mm for a diameter of 500 mm. The three reductions are still within the safe limit of 25 mm.
The results of calculations due to loading using Plaxis found that at 300 mm in diameter there was a decrease of 3.4 mm. Then a decrease of 3.3 mm in a diameter of 400 mm, and a decrease of 3.2 mm in a diameter of 500 mm. The three reductions are still within the safe limit of 25 mm.

REFERENCES

Azizi, A., Salim, M. A., & Ramadhon, G. (2020). Analisis Daya Dukung dan Penurunan Pondasi Tiang Pancang Proyek Gedung DPRD Kabupaten Pemalang. *Rancang Bangun, 6(2), 50–52*.

Bondar, C. B. (2020). *Perbandingan Analisis Daya Dukung Tiang Pancang dengan Metode Numerik Terhadap Metode Analitis (Proyek Pembangunan Bendung DI SEI Wampu Lokasi Bore Hole BK 01)* (Doctoral dissertation, Universitas Sumatera Utara).

Fadilah, U. N., & Tunafiah, H. (2018). Analisa Daya Dukung Pondasi Bored Pile Berdasarkan Data N-SPT Menurut Rumus Reese & Wright dan Penurunan. *IKRA-ITH Teknologi*, 2(3), 7–13.

Fadli, Z. A. (2021). Pengaruh Variasi Dimensi Tiang Bor terhadap Kapasitas Dukung Aksial, Kapasitas Dukung Lateral dan Penurunan (Studi Kasus : Proyek Paket 4 Pembangunan APSLC Universitas Gadjah Mada). *Undergraduate Thesis,* Universitas Islam Indoenesia.

Haq, D. (2018). Pengaruh Variasi Dimensi terhadap Kapasitas Dukung Fondasi Tiang Bor Kelompok dengan Menggunakan Metode Elemen Hingga.

Hardiyatmo, H. C. (2018). *Analisis dan Perancangan Fondasi I* (4 ed.). Gadjah Mada University Press.

Hardiyatmo, H. C. (2018). *Analisis dan Perancangan Fondasi II (4 ed.). G*adjah Mada University Press.

Hasyim, W. (2015). Keandalan Komponen Struktur Kolom Gedung dengan Kerusakan dan Penurunan Pondasi. *Rekayasa Infrastruktur,* 1(2), 44–58.

Horikoshi, K., & Randolph, M. F. (1999). Estimation of Overall Settlement Of Piled Rafts. *Soils and Foundation*, 39(2), 59–68.

Kurniawan, P., & Hadimuljono, B. (2020). *Applied Geotechnics for Engineers 1 (Vol. 1).* Penerbit Andi.

Das, B. M. (2011). *Principles of Foundation Engineering, SI (7 ed.).* Cengage Learning.

Muhshi, M., Ika Putra, A., & Agus Nugroho, S. (2020). Pemetaan Penurunan Elastis Fondasi Tiang Berdasarkan Data Sondir Kota Pekanbaru. Indonesian *Journal of Civil Engineering Education*, 6(1), 34–49.

Prilia, R., J. Manoppo, F., & Manaroinsong, L. D. K. (2021). Analisis Fondasi Tiang Bor dengan PLAXIS 3D (Studi Kasus: Proyek Pembangunan Gedung Pendidikan Fakultas Teknik Unsrat Jurusan Sipil). *Tekno*, 19(78), 139–150.

Rahman, A. A., Hariati, F., Chayati, N., & Taqwa, F. M. L. (2022). Korelasi Nilai Daya Dukung Ultimit Tiang Bor Hasil Analisis Dengan Hasil Pengujian PDA Test (Studi Kasus: Pembangunan Jalan Tol Bogor Ring Road Seksi III A Ruas Simpang Yasmin-Simpang Salabenda). *Jurnal Komposit: Jurnal Ilmu-ilmu Teknik Sipil*, *4*(2), 43-49.

Setiawan, A. (2016). Perancangan Struktur Beton Bertulang Berdasarkan SNI 2487:2013. Penerbit Erlangga. Jakarta.

Warih, B., Lukman, H., & Mudianto, A. (2020). Analisis Daya Dukung Pondasi Tiang Pancang dengan Metode Analitis Dan Software Plaxis (Studi Kasus: Proyek Pembangunan Rumah Kost Kebayoran Lama – Jakarta Selatan). *Jurnal Online Mahasiswa Universitas Pakuan,* 1, 1–11.

Yuliawan, E., & Rahayu, T. (2018). Analisis Daya Dukung dan Penurunan Pondasi Tiang Berdasarkan Pengujian SPT dan Cyclic Load Test. *Konstruksia*, 9(2), 1–13.