

Analysis of Safety Factor and Deflection for Single Pile Using Numerical Method

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Abstract. The foundation is part of the building's substructure that is in direct contact with the ground and serves to support the load of the upper structure. Deep foundations are one type of foundation designed to withstand both axial and lateral loads. Additionally, the safety factor also influences the bearing capacity value of the foundation. Lateral loads acting on the pile foundation can cause the deflection. The magnitude of deflection in the pole can be determined from field testing or by performing a manual analysis. The purpose of this study is to analyze the magnitude of the safety factor and deflection values that occur using numerical analysis. An Axisymmetric model is used for circular structures with a (more or less) uniform radial cross section and loading scheme around the central axis, where the deformation and stress state are assumed to be identical in any radial direction. Based on the research results conducted on a single pile D50 (500 mm), the safety factor value obtained was $2.878 > 2.5$ with the deflection of $0.059 \times 10^{-3} \text{ m} < 0.025 \text{ m}$. The results obtained indicate that the safety factor and deflection values still meet the required regulations.

1 Introduction

Economic growth in Indonesia, according to the BPS-Statistics Indonesia, was 5.04% in the third quarter of 2025. This indicates that development in Indonesia is experiencing a positive trend due to the ongoing national infrastructure network program. Development in Indonesia is currently quite rapid, as evidenced by the contribution of the construction sector to Indonesia's Gross Domestic Product (GDP) in the third quarter of 2015, where the BPS recorded the construction sector's contribution at 4.21% after industry, trade and agriculture [1]. This gives an indication that the construction industry plays a very important role in the Indonesian economy. Considering the construction sector's rapid growth, a method is needed to plan construction safely, accurate and quickly.

Based in this, a quick and precise solution is needed in the construction of a building. Therefore, accuracy in analysis is required, taking into account the construction execution time on site. The solution to this problem is to utilize a field of knowledge related to numerical methods. Where a tool is used to speed up the calculation of the

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necessary analysis results. This research is specifically focused on the substructure of a building, namely the foundation. The foundation is one of the crucial elements in a building's construction. Lateral deflection in piles is influenced by various factors, such as soil type, pile dimensions, and lateral loads due to earthquakes or soil pressure, while foundation settlement is an important indicator in ensuring structural stability [2]. Carefully calculation and planning are necessary for foundation calculations in building construction. In its implementation in the field, an analysis is also needed to ensure that the results or manual calculations can be compared with the results of numerical calculations from the software.

Stable soil conditions play an important role in building construction. Soil serves as the primary supporting medium that will bear the entire load of the building, which will be transferred to the hard soil layer. Errors in understanding soil characteristics and conditions can lead to damage to building failure. In the foundation structure, knowledge of the working soil characteristics is required to obtain appropriate foundation dimensions and criteria. The horizontal bearing capacity of pile foundations is the ability of the piles to withstand horizontal forces acting on them [3]. Pile foundations can resist horizontal forces by distributing passive pressure in the soil along the depth of the piles [4]. Pile foundations efficiently transfer loads from the structure to stable, dense soil, minimizing the risk of significant sinking and structural failure [5][6].

This study focuses on the substructure of the building, specifically analyzing single pile foundation failures often occur due to lateral loads. Therefore, an analysis of the foundation pile conditions is necessary. This research will analyze a single pile by examining the parameter values of deformation, deflection and its safety factor using the finite element method as a tool. This calculation uses modeling in solving geotechnical problems by dividing the soil-structure system into small elements, which then numerically solves for stress, deformation, and stability behavior. This method is very reliable for analyzing complex geotechnical problems that cannot be solved using conventional methods.

2 Method

The behavior of piles in bearing lateral loads is categorized into two conditions, active and passive pile. Piles with lateral loads that occur directly on the pile head are categorized as active piles and piles that have lateral soil movement are categorized as passive piles [7], see at **Fig. 1**.

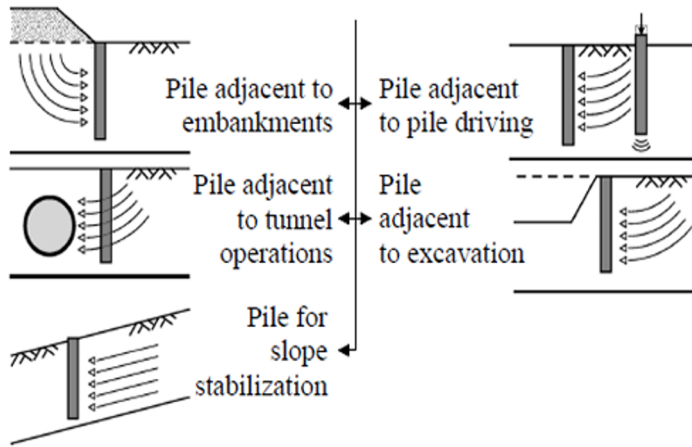


Fig. 1. Examples of passive piles [8]

This research uses secondary data from ongoing project data. Where soil data from **Table 1** and foundation dimensions are used according to the conditions on site. As for the flowchart of this research, it can be seen in **Fig. 2**, where after obtaining the soil and foundation data to be analyzed, foundation modeling is carried out using the axisymmetric method. This is because the appropriate method for applying 2D is the axisymmetric method.

Table 1. Soil Data

Thickness	Type of Soil	N	Consistency	γ	e	γ_{sat}	c	ϕ	E	v	k _x	k _y	Ψ
m	-	blows	-	kN/m ³	-	kN/m ³	kN/m ²	°	kN/m ²	-	m/day	m/day	°
2	Clay Sand	11	Loose	14.74	1.48	19.00	9.5	25	15,000	0.2	0.864	0.864	-
5	Clay Sand	38 - 40	Medium	16.36	1.23	19.00	8.8	28	30,000	0.25	0.0864	0.0864	-
4	Sand	60	Very Dense	13.48	2.16	19.00	9.8	35	60,000	0.35	0.00864	0.00864	5.00
4	Clay Sand	60	Very Dense	15.87	1.31	19.00	8.7	35	60,000	0.35	0.00864	0.00864	5.00

The finite element method is one of the methods specifically used to analyze deformation and stability in the field of geotechnical engineering, such as lateral deflection and soil bearing capacity. The actual conditions can be modeled in plane strain or axisymmetric. This method implements an easy-to-use graphical interface, allowing users to quickly create geometric models and element meshes based on cross-sections of the conditions to be analyzed [9]. In addition, the finite element method is a technique used to find a sufficiently accurate solution to both partial and integral differential equations [10]. The Finite Element Method is one of the most accurate and reliable programs for comprehensive analysis [7].

The material model used is Mohr Coulomb with an undrained type. Where undrained soil conditions are used, this refers to undrained or short-term material behavior in which

stiffness and strength are defined in terms of effective properties. A large bulk stiffness for water is automatically applied to make the soil as a whole incompressible, and pore pressures are calculated, even above the water table.

As for the single pile material itself, the material modeling uses linear elastic with non-porous properties, where the material behavior prevents pore pressures from occurring. After modeling and material input, the next step is to analyze the single pile, which involves applying construction phases. The first phase is the initial conditions, the second phase is the foundation construction, the third phase is applying the building load, and finally, we examine the resulting safety factor. For each phase, this is also done by providing an interface for each phase.

The modeling was done by drawing the geometry based on the pile dimensions as they exist in the field. For the conditions of this study, a round pile with dimensions of D50 (500 mm) and pile depth of 15 meters was used. The soil layers were adjusted to the soil conditions at the research location. After meshing, node points were created to visualize the value of each point as an illustration of the foundation's condition under the applied lateral load, as shown in **Fig. 3**.

After the analysis phase is completed, the next step is to present the results and discuss the findings of the analysis performed, taking into account several conditions related to the applicable regulations in accordance with SNI 8460-2017 [7]. Where there are requirements related to the maximum allowable settlement value, which must be less than 25 mm, and the required safety factor value, which must be at least 2.5. If the value of this requirement is met, it means the dimensions and depth of the foundation that has already been designed are safe enough to be implemented.

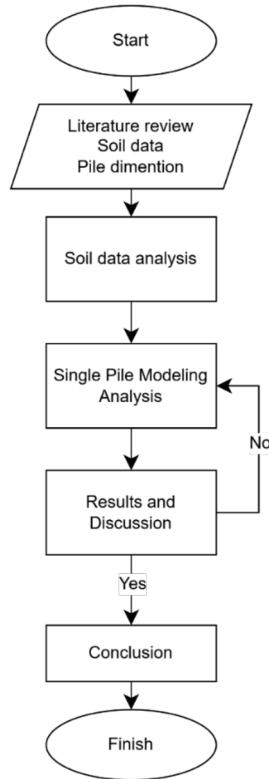


Fig. 2. Research flowchart

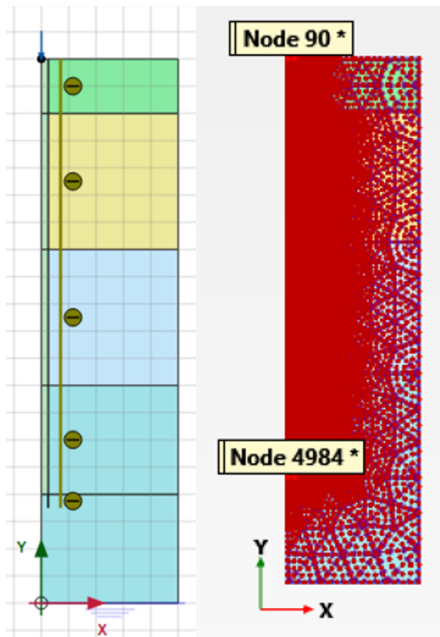


Fig. 3. An illustration of the foundation's

3 Results and discussion

The results and discussion of the analysis conducted using the finite element method can be explained as follow:

3.1 Results

After modeling and analysis are performed on the software using the finite element method, the next step is to obtain the output from the data running results. This output will determine whether the planned dimensions are appropriate based on the expected values according to applicable regulations.

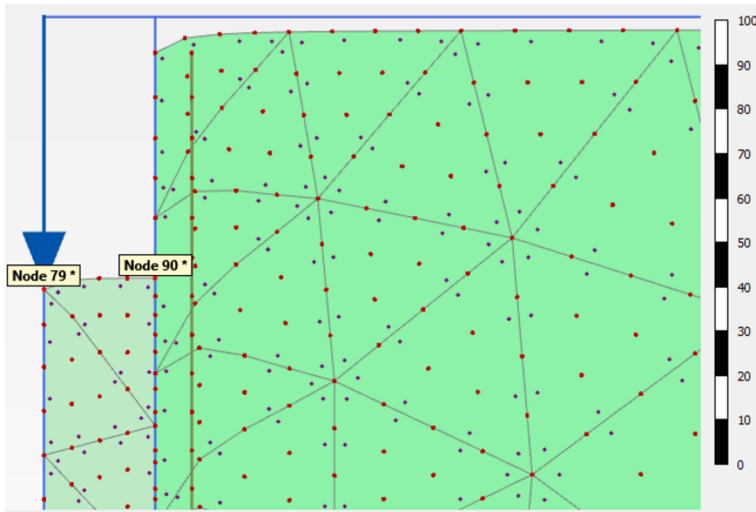


Fig. 4. Point on top the pile

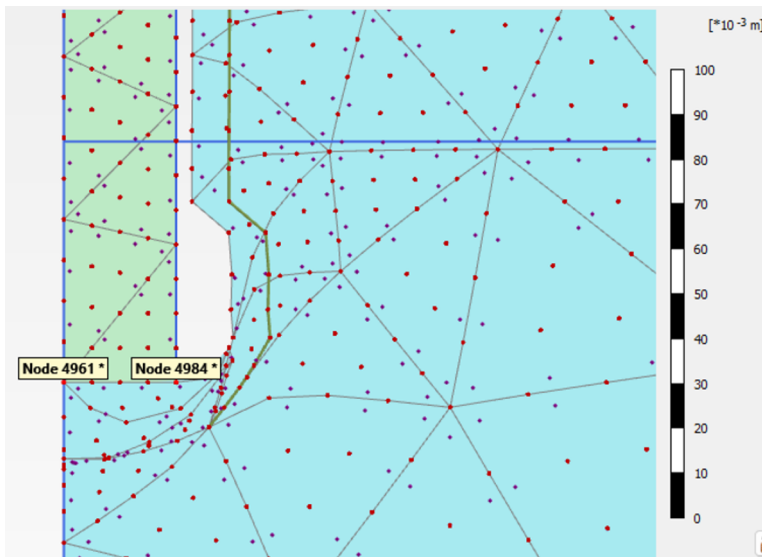


Fig. 5. Point on bottom of the pile

Based on the analysis results, the deformation value during the pile construction phase was found to be 0.1974×10^{-3} meters at element 367 at node 3275. The deformation value during the loading phase was found to be 0.01882 meters at element 9 at node 79, while the deformation during the safety phase was found to be 0.06140 meters at element 9 at node 79. These analysis results can be seen in **Table 2**. **Fig. 4** shows the condition where the pile foundation is positioned at the top, with a maximum deformation value of 0.06140 meters. **Fig. 5** shows the pile foundation positioned at the bottom with a maximum deformation of 0.06140 meters. The node value at the top position is node 90, while at the bottom position it is node 4984, as shown in **Fig. 3**. The resulting safety factor value is 2.878. As for the lateral values obtained, they can be seen in **Table 2**, where for node 90, the deflection value is $0,059 \times 10^{-3}$ meter. While for node 4984, the deflection value is $0,054 \times 10^{-3}$ meters.

Table 2. Result of the pile

Node	X (m)	Y (m)	Ux (10^{-3} m)	Uy (10^{-3} m)	Ux (10^{-3} m)
79	0,000	20	0	-61,396	0,061
90	0,250	20	-0,012	-58,838	0,059
4961	0,000	4	0	-53,684	0,054
4984	0,025	4	0,008	-53,679	0,054

3.2 Discussion

Based on the results obtained from the modeling analysis using the finite element method, including finding the deformation values for each construction phase and then finding the safety factor values for all construction phases that have been completed. The results of this analysis should meet the requirements of the established regulations, namely SNI 8460-2017. In the first phase, which is the initial phase, this condition is used to model the soil condition without any loading or construction. Where the initial phase condition is calculated using the K0 procedure, where direct generation of initial effective stresses, pore pressure, and state parameters, equilibrium is not guaranteed. For the loading type, we are using staged construction, with the pore pressure calculation type being phreatic. Phreatic is the direct generation of steady-state pore pressures from the phreatic level and cluster-related conditions.

For the next phase, which is the single pile foundation construction phase, starting from the initial phase, the calculation type is plastic. Plastic analysis can be elastoplastic, drained or undrained, while consolidation is not considered. Where in this phase, the maximum deformation value obtained is 0.1974×10^{-3} meters, which is smaller than the required value of 0.025 meters.

In the loading phase, starting from the foundation construction phase with a calculation type of plastic and a pore pressure calculation type of phreatic, where in this phase the foundation piles are subjected to a load of 500 kN/m, resulting in a deformation value of 0.01882 meters, which is less than the required 0.025 meters. Based on the conducted research, it shows that these numerical results and field tests yield results that are close [11]. The results from experimental and numerical methods show good agreement, where the effectiveness of the numerical model in simulating real

geotechnical applications, with the difference between experimental results and numerical predictions being within an acceptable range [12].

As for the safety factor phase, the phase starts from loading, with the calculation type being safety. Where this safety calculation is the calculation of the global safety factor by means of the strength reduction method. The mesh is not further updated during a safety analysis. In this safety factor phase, the value obtained is 2.878, which is greater than the required SF value of 2.5.

Based on the analysis conducted, for a pile dimension of D50 (500 mm) with a depth of 15 meters, it meets the requirements and can be implemented in the field. Therefore, the designed foundation construction already meets the required specifications. For the lateral load conditions in Figures 4 and 5, the position values for node 90 were found to be 0.059×10^{-3} meters and for node 4984, 0.054×10^{-3} meters. Based on these values, the requirements are still met, which is less than 0,025 meters. This is influenced by the type of soil, which can exhibit different deformation behaviors under pile load [13].

However, this still needs further review by conducting field testing with both axial and lateral tests. The results obtained from the field testing can be checked and analyzed for validation using the same method, which is numerical analysis with finite elements. The results from the field testing and the modeling results will provide a picture that can be used as a reference for field implementation.

4 Conclusion

Based on the analysis and discussion conducted, it can be concluded that the deformation values observed in each phase are less than the required maximum of 25 mm, while the resulting safety factor is greater than 2.5, exceeding the requirement. This indicates that the designed pile dimension values with a diameter of D50 (500 mm) and a pile depth of 15 meters meet the requirements.

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