

ANALYSIS OF PILE FOUNDATION BEARING CAPACITY BASED ON SPT AND CPT DATA IN THE SEI SILAU BARAT – PRAPAT JANJI ROAD BRIDGE PROJECT

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Abstract

This study aims to analyze the bearing capacity and settlement of pile foundations based on Standard Penetration Test (SPT) and Cone Penetration Test (CPT) data on the Sei Silau Barat–Prapat Janji Road Bridge Project, and compare the results with the analysis using Allpile Software. The method used is quantitative analysis based on soil investigation data. The calculation of bearing capacity based on SPT data uses the Meyerhof, Tomlinson, and Luciano Decourt methods, while CPT data uses the Meyerhof and Vesic methods. The analysis also includes the bearing capacity of pile groups, foundation settlement, and verification of the superstructure load using SAP2000. The results show that the Meyerhof method based on SPT data produces the largest ultimate bearing capacity of 305.67 tons, while based on CPT data the Vesic method produces 150.72 tons. The efficiency value of the pile group is 0.642, with all group bearing capacities greater than the structural load. The settlement of single piles ranged from 24.70–27.06 mm, while the group settlement was 78.10–85.57 mm. The Allpile analysis also demonstrated a bearing capacity that met the load requirements. Based on these results, the pile foundation for the project was declared safe and capable of supporting the bridge structure's loads according to design requirements.

Keywords: Allpile; CPT; bearing capacity; pile foundation; SPT.

INTRODUCTION

Bridges are an integral part of the road network infrastructure, with their functions inseparable from each other. Uninterrupted connectivity is crucially determined by the presence of bridges, which serve as links across terrain, rivers, and other infrastructure, such as railways or irrigation structures. Therefore, bridges are crucial for maintaining the continuity of the movement of goods and services, as well as for providing road services to road users (Bina Marga, 2023). In bridge projects, the use of pile foundations is often chosen because the soil conditions at the construction site are generally soft soil, clay, or layered soil that has a low bearing capacity on the surface. To ensure that the planned pile foundation is able to withstand the applied load, an accurate bearing capacity analysis is required based on soil investigation data. In this study, the types of soil data used in foundation planning are Standard Penetration Test (SPT) and Cone Penetration Test (CPT) data. This test aims to measure soil parameters such as N - SPT, end resistance, and side friction which are used to calculate the bearing force of the pile foundation using various methods. In addition, the bearing capacity of the pile foundation can also be analyzed using Allpile software, a computer program based on the finite element method for analyzing soil behavior and soil structures, as well as SAP2000 software which is used to calculate the superstructure load on the bridge.

This research was conducted with the aim of analyzing the bearing capacity of pile foundations based on SPT and CPT data and Allpile software on bridges, which were then compared with the calculation of superstructure loading using SAP2000 Software. By conducting this research, the author hopes to obtain accurate and valid results regarding the bearing capacity of pile foundations according to field conditions. In addition, this research can also contribute to the development of science and technology, especially in the field of civil engineering, as well as provide recommendations and input for academics and practitioners involved in the planning and implementation of pile foundations. The research problem is formulated to answer the calculation of the bearing capacity of single and

group piles based on SPT and CPT data, settlement of single and group piles, and analysis using Allpile software. The study also compares the capacity results with the superstructure loading using SAP2000.

LITERATURE REVIEW

Bridges are vital infrastructure supporting economic activity, so strong structures and foundations are essential. The bearing capacity of pile foundations is crucial in ensuring the structural load is transferred to the supporting soil. Yufitra Rus et al. (2021) compared the bearing capacity based on laboratory data, N-SPT, and CPT with the PDA test at the PT. Kaltim Ammonium Nitrate project in Bontang. The pile was 50 cm in diameter and 20 m deep. The Luciano Decourt method based on N-SPT produced the closest value to the PDA with a difference of around 7–23%, while the Tomlinson method tended to be smaller and the Bagemann method was larger at that location. Ayu Puspita et al. (2021) analyzed the bearing capacity of deep foundations based on N-SPT in weathered soil of the Citalang Formation in Subang using Meyerhoff. The ultimate bearing capacity values varied according to the drill point and depth, indicating that increasing depth generally increases capacity but variations in soil layers can cause inconsistent changes. Mardianti et al. (2022) used SPT and CPT data to analyze the bearing capacity of piles in the construction of the Jambi University Teaching Hospital Building and emphasized that the superstructure load should not exceed the foundation's allowable capacity. Jusi et al. (2022) compared bearing capacity and settlement based on CPT, SPT, and laboratory tests using the Mayerhof and Vesic methods. Lumban Gaol and Hadiantri Muhdinar Pasariibu (2025) analyzed the axial bearing capacity and implementation costs of spun piles based on SPT. The results showed differences in capacity between the Meyerhoff and Vesic methods, as well as variations in group efficiency depending on the formula used. This series of previous studies served as a basis for comparison for the analysis of the Sei Silau Barat–Prapat Janji Bridge project.

Land and Foundation

Soil is a collection of natural mineral grains (aggregates) that can be separated by mechanical means when the aggregate is stirred in water. The terms sand, clay, silt, and mud are used to describe particle sizes within a defined grain size range, and also to describe the physical properties of soil. For example, clay is a type of soil that is plastic and cohesive, while sand is a type of soil that is neither plastic nor cohesive (non-cohesive). However, almost no soil in nature consists of only one type of particle size; rather, soil is a mixture of several consistencies of soil particles. Soil particles are formed from broken rocks that have been changed by chemical and environmental effects, including weathering and erosion. Soil particles are loosely arranged, creating soil formations consisting of pore spaces. A foundation is the part of a structure that receives the building's load and transfers it to the supporting soil. Pile foundations were used at the study site because soil data indicated the use of deep foundations. Foundations must be designed according to soil conditions, layer profiles, structural loads, and potential settlement.

Soil Investigation: CPT and SPT

The CPT (probe) or sounding test is used to obtain end resistance and side friction as parameters for calculating pile capacity. In this thesis, the CPT analysis uses the Meyerhoff and Vesic methods. The SPT uses the N-SPT value as the basis for classification and calculation of pile capacity using the Meyerhoff, Tomlinson, and Luciano Decourt methods. Soil investigation data is needed to describe the characteristics of the soil layers that will receive the pile load. The SPT test results in this study showed an increasing N value with depth and were used in conjunction with CPT data in calculating capacity and settlement.

Carrying Capacity and Subsidence

The ultimate pile capacity consists of the end resistance and the cover resistance. In the analysis, the allowable capacity is determined by dividing the ultimate capacity by the safety factor. Single pile settlement is calculated for each method, while group settlement is calculated from the capacity and the planned pile group arrangement.

$$Q_u = Q_p + Q_s$$

$$Q_{all} = Q_u / SF$$

$$\text{Permit} = 10\% \times D$$

In addition to manual calculations, Allpile software was used to model capacity and settlement based on inputs of pile geometry, pile properties, loading, soil conditions, and advanced parameters. SAP2000 was used to obtain superstructure loads for comparison against pile group capacity.

Analysis Framework

Thus, the analysis flow consists of data collection, method determination, calculation of single and group pile capacity, settlement calculation, verification using Allpile, and comparison with SAP2000 loading.

METHOD

The research employed a quantitative analysis method based on document study. The data used consisted of the results of SPT and CPT soil investigations, as well as shop drawings for the Sei Silau Barat–Prapat Janji Bridge construction project in Asahan Regency. No additional field testing was conducted. The research stages include literature review, data collection, data processing, analysis and discussion, and then drawing conclusions and recommendations. The N-SPT method for bearing capacity analysis is used by Meyerhoff, Tomlinson, and Luciano Decourt, while the CPT data uses Meyerhoff and Vesic. The results are compared with Allpile software and SAP2000 loading. SPT data were obtained at boring point B–1. The N-SPT value of 2.00 m intervals was used in the analysis, while CPT data came from point S–1. Shop drawings were used for the geometry and foundation arrangement. The pile length for the SPT analysis was 18 m and for the CPT analysis was 8 m.

Table 1. N-SPT Value (N Value)

Depth	N Value	Density Level
2.00 meters	8	Off/low
4.00 meters	15	Currently
6.00 meters	26	Currently
8.00 meters	32	Dense/high
10.00 meters	47	Dense/high
12.00 meters	51	Very dense/high
14.00 meters	53	Very dense/high
16.00 meters	59	Very dense/high

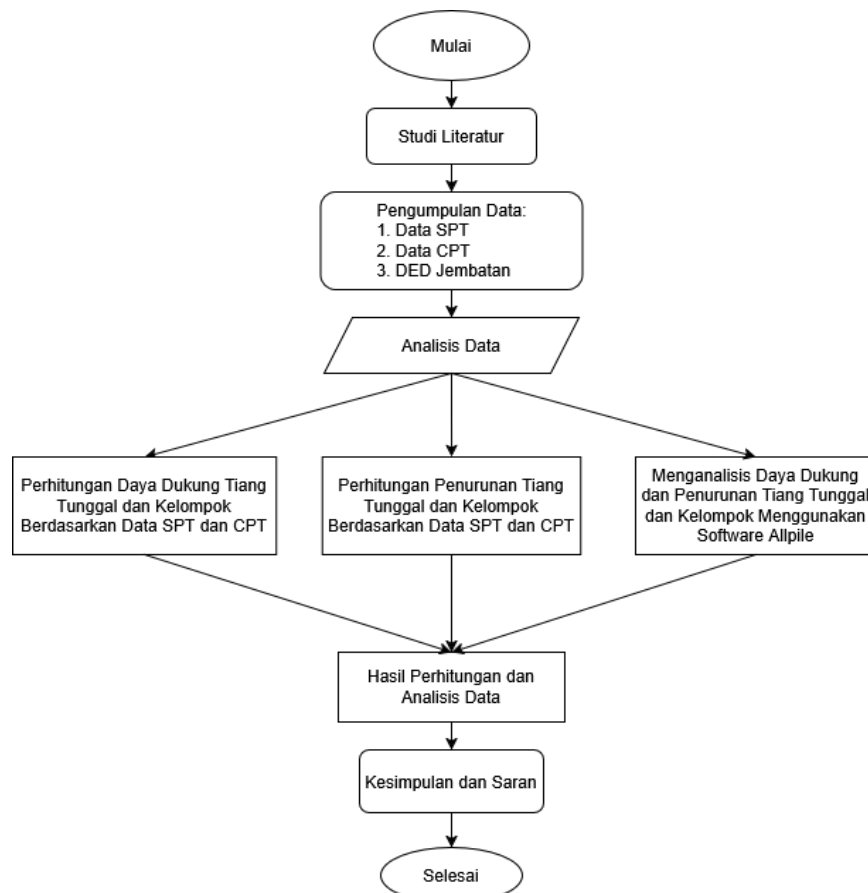


Figure 1. Research Flowchart

RESULTS AND DISCUSSION

Single Pile Bearing Capacity Based on SPT

Based on SPT data, the capacity of a single pile was calculated using Meyerhoff (1976), Tomlinson, and Luciano Decourt (1987). The summary results show differences in capacity influenced by the calculation methods for tip resistance and cover resistance.

Table 2. Summary of Single Pile Bearing Capacity Based on SPT and CPT Data

Testing Method	Single Pile Bearing Capacity Calculation Results			
	Qp (ton)	Qs (tons)	Qu (ton)	Qall (ton)
N-SPT Data				
Mayerhoff	176.34	126.96	303.30	101.10
Tomlinson	85.49	129.83	215.32	71.77
Luciano Decourt	166.7	65.48	232.22	77.35
CPT Data				
Meyerhoff	112.96	26.56	139.60	42.99
Vesic	113.04	37.68	150.72	50.24

Single Pile Bearing Capacity Based on CPT

Based on CPT data, the Meyerhoff method produces a Qp of 112.96 tons, a Qs of 26.56 tons, a Qu of 139.60 tons, and a Qall of 42.99 tons. The Vesic method produces a Qp of 113.04 tons, a Qs of 37.68 tons, a Qu of 150.72 tons, and a Qall of 50.24 tons. Overall, the Meyerhof method based on N-SPT yielded the highest single pile permissible bearing capacity of 101.10 tons. Luciano Decourt's value was 77.32 tons, Tomlinson's was 71.77 tons, and Allpile's was 64.513 tons.

Pole Group Efficiency

The pile group was designed in a 3×5 formation. The group efficiency was calculated using three formulas. The Conversion–Labberre value of 0.642 was used because it was the minimum value of the calculated formulas.

Table 3. Efficiency Values for Calculating the Bearing Capacity of Pile Groups

No.	Method	Efficiency value
1	Conversion Method – Laberre	0.642
2	Los Angeles Group Method	0.764
3	Simple Method	0.849

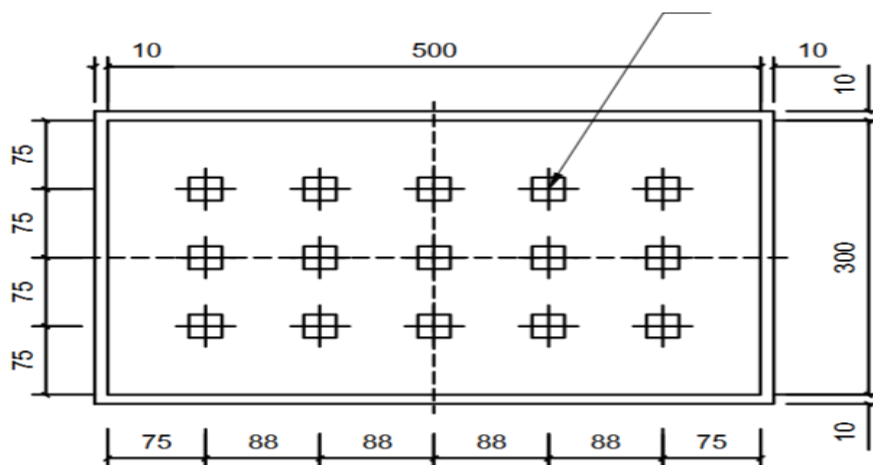


Figure 2. Group Pole Formation Arrangement

Bearing Capacity of Pile Group

After obtaining the single-pole capacity and group efficiency, the group capacity is calculated based on these results. A summary based on the N-SPT and CPT is presented in the following table.

Table 4. Bearing Capacity of Pile Groups Based on N-SPT Data

Method	Efficiency Value	Permitted Bearing Capacity Value of Pile Group		
		Mayerhoff	Tomlinson	Luciano Decourt
Conversion Method –Laberre	0.642	973.59 tons	691,142 tons	754,458 tons

Table 5. Bearing Capacity of Pile Groups Based on CPT Data

Method	Efficiency Value	Permitted Bearing Capacity Value of Pile Group	
		Mayerhoff	Vesic
Conversion Method – Laberre	0.642	413,994 tons	483,811 tons

Single Pole Lowering

Single pile settlement was calculated for each method based on N-SPT and CPT data. The settlement limit used was 10% of the pile diameter. With a pile diameter of 0.30 m, the allowable settlement limit was 30 mm.

Table 6. Results of Single Pile Settlement Calculation

Method Calculation Decline Single Pole	Calculation Results Pole Lowering Single (mm)	Control Pole Lowering Single (mm)	Category
Based on N-SPT data			
Mayerhoff	27.06	≤ 30	Safe (fulfil condition)
Tomlinson	26.13	≤ 30	Safe (fulfil condition)
Luciano Decourt	26.08	≤ 30	Safe (fulfil condition)
Based on CPT data			
Mayerhoff	24.70	≤ 30	Safe (fulfil condition)
Vesic	24.79	≤ 30	Safe (fulfil condition)

The results show a single pile settlement of 27.06 mm for Mayerhoff N-SPT, 26.13 mm for Tomlinson, 26.08 mm for Luciano Decourt, 24.70 mm for Mayerhoff CPT, and 24.79 mm for Vesic. All values are less than 30 mm, thus meeting the single pile settlement requirement.

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Group Pole Lowering

Table 7. Pile Group Settlement Values

Decrease Calculation Method Single Pole	Results of Calculation of Decreased Value Pole Group (mm)
Based on N-SPT data	
Mayerhoff	85.57
Tomlinson	82.62
Luciano Decourt	82.47
Based on CPT data	
Mayerhoff	78,099
Vesic	78,389

The group reductions obtained were 85.57 mm (Mayerhoff N-SPT), 82.62 mm (Tomlinson), 82.47 mm (Luciano Decourt), 78.099 mm (Mayerhoff CPT), and 78.389 mm (Vesic). These values are the results of calculating group reductions for each method.

Allpile Software Program Analysis

Allpile analysis was conducted through the stages of Pile Type, Pile Profile, Pile Properties, Pile Section, Load and Group, Soil Properties, Advanced Page, and Run Analysis. The selected pile was a Driving Concrete Pile with metric units, a pile length of 18 m, a circular shape, and a diameter of 30 cm. For single pile and group pile loading, a Fixed Head was used. Soil Properties are populated using SPT/CPT data and groundwater levels. The Advanced Page is used for advanced parameter settings, and then the analysis is run on vertical analysis because the study examines vertical forces.

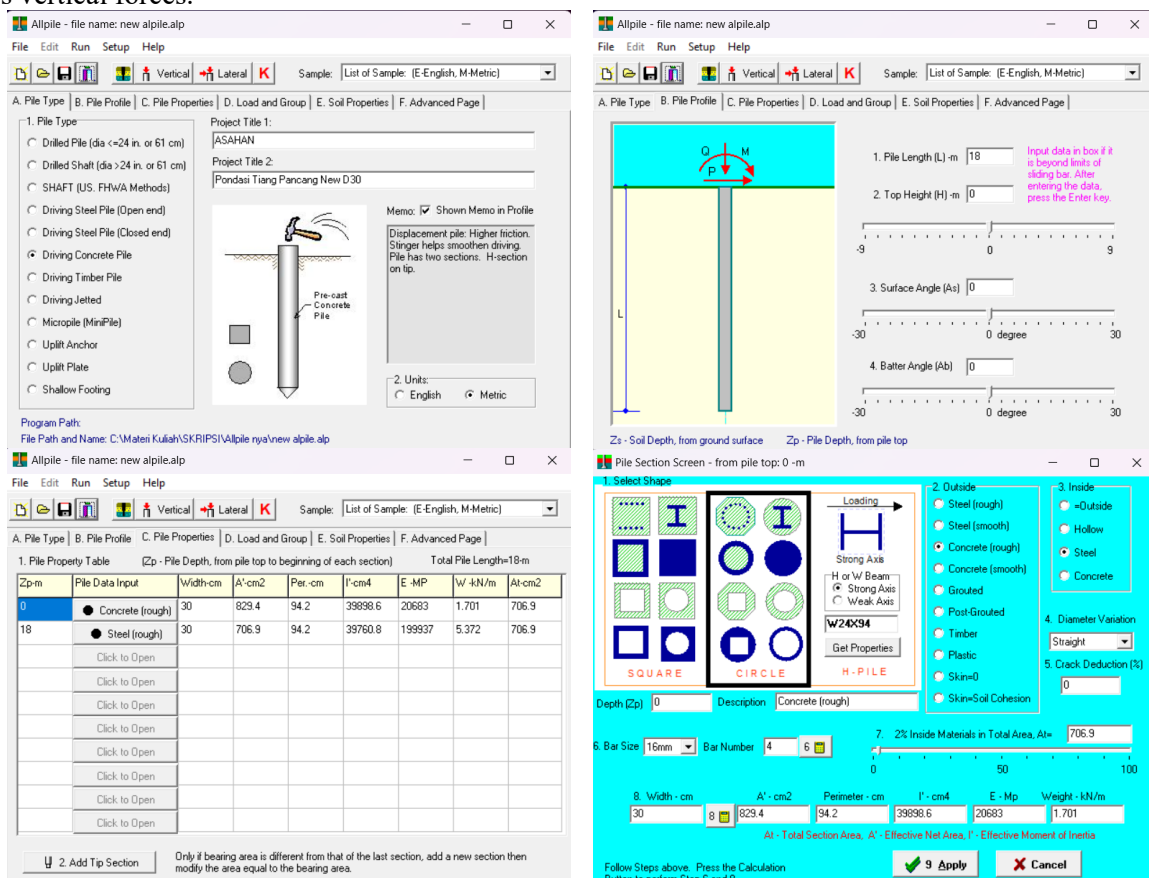


Figure 3. Input Pile Type, Pile Profile, Pile Properties, and Pile Section in Allpile Software

Allpile Analysis Results

The Allpile Detailed Report results show that for a single pile, based on the SPT data, the total ultimate capacity is 193,539 tons and the total allowable capacity is 64,513 tons. For a group of 15 piles, the total ultimate capacity is 2,903,083 tons and the total allowable capacity is 967,697 tons. These results are stated in the Allpile report to meet the loading conditions ($Q_{allow} > Q$).

Table 8. Bearing Capacity Values Based on Allpile Software

	Allpile Software Calculation Results			
	Qp (ton)	Qs (tons)	Qu (ton)	Qall (ton)
Single Pole (SPT)	128,618	64,920	193,539	64,513
Single Pole (CPT)	68,228	33,243	101,472	33,824
Tiang Group (SPT)			2903.083	967,697
Tiang Group (CPT)			1522,085	507,361

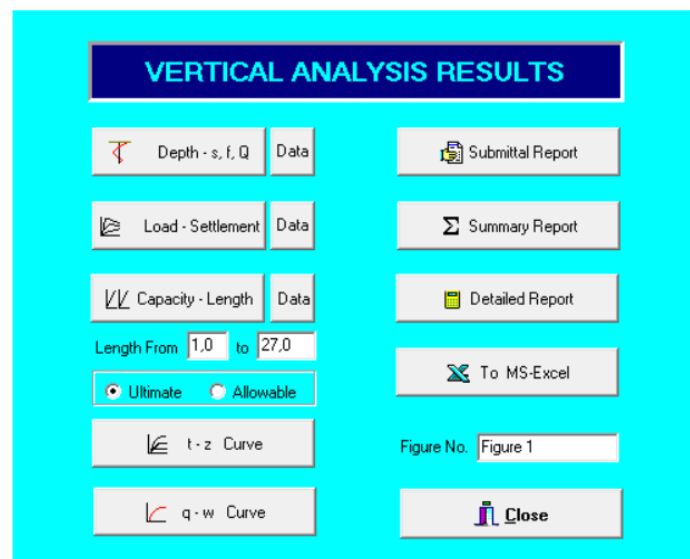


Figure 4. Run Analysis on Allpile Software

Superstructure Loading Using SAP 2000

SAP2000 analysis was used to obtain the forces resulting from the loading of the bridge superstructure. The results of the loading analysis were used as a benchmark for comparing the capacity of the pile group.

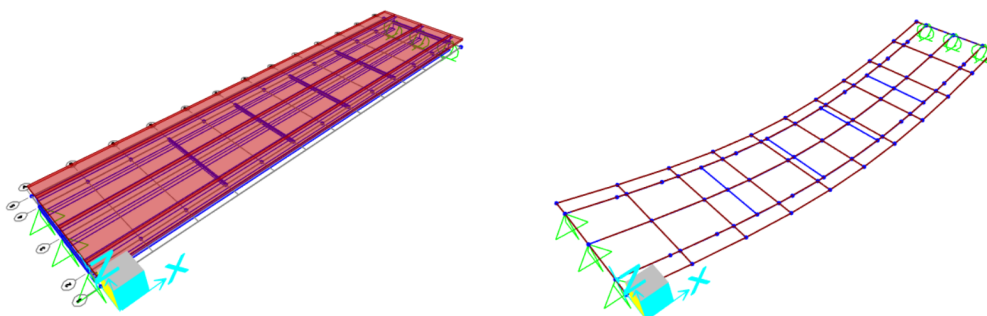


Figure 5. SAP2000 Analysis Results: 3D Model and Axial Forces

The superstructure loading result used in the comparison was 534,673 tons.

Discussion and Calculation Results

The analysis results show that the bearing capacity of the piles is influenced by the data source and calculation method. For single piles, Meyerhoff N-SPT provides the largest permissible bearing capacity value of 101.10 tons,

followed by Luciano Decourt 77.32 tons, Tomlinson 71.77 tons, and Allpile 64.513 tons. For pile groups, Meyerhoff's calculation provides a value of 973.59 tons, Allpile 967.697 tons, Luciano Decourt 754.458 tons, and Tomlinson 691.15 tons.

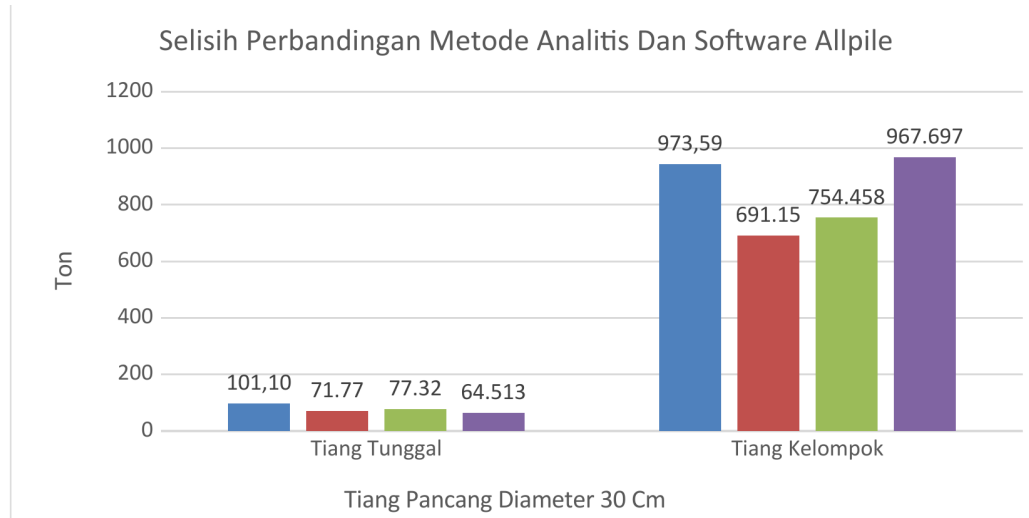


Figure 6. Comparison Chart of Single Pole and Group Pole

The graph shows that the capacity of a pile group is significantly greater than the capacity of a single pile due to the contribution of the number of piles and the group efficiency. The Allpile results for the pile group are close to the Meyerhoff results in the research recapitulation, while the Tomlinson method produces a lower group capacity. Based on settlement calculations, the single pile values ranged from 24.70 to 27.06 mm, while the group settlement values ranged from 78.099 to 85.57 mm. This comparison indicates a difference in response between the single and group pile systems in carrying the analyzed loads.

Verification of Structural Loads

Table 9. Bearing Capacity Values with SAP 2000 Loading Results

Method	Permitted Bearing Capacity Value of Pile Group	SAP 2000 Calculation Results
Mayerhoff	943.64 tons	534,673 tons.
Tomlinson	691.15 tons	
Luciano Decourt	754,458 tons	
Allpile	967,697 tons	

The comparison table shows the group capacity values from the Meyerhoff, Tomlinson, Luciano Decourt, and Allpile methods compared to the SAP2000 loading results of 534,673 tons. In the thesis discussion, the group capacity obtained from the analytical and Allpile methods is used to assess the adequacy of the bearing capacity to the structural load. Overall, the manual, Allpile, and SAP2000 analyses demonstrated that the project's pile foundations met the analyzed loading requirements. These results formed the basis for the research conclusions regarding foundation capacity and settlement.

Relationship of Results

Differences in capacity figures between methods are a consequence of the empirical approach and parameters used in each method. Therefore, this thesis compares several approaches simultaneously so that planning results can be seen from SPT and CPT data, software analysis, and superstructure loading.

CONCLUSION

Based on the results of the analysis and discussion regarding the bearing capacity of pile foundations based on SPT and CPT data on the Sei Silau Barat–Prapat Janji Bridge, the Meyerhof method with N-SPT data produces the largest permitted bearing capacity, namely 101.10 tons for single piles and 973.59 tons for pile groups. The settlement of single piles based on SPT and CPT data ranged from 24.70 to 26.63 mm, still below the 30 mm limit. The settlement of pile groups based on various methods ranged from 78.099 to 85.57 mm. Analysis using AllPile software yielded permissible bearing capacities of 64,513 tons for single piles and 967,697 tons for pile groups. These group capacity values were used in conjunction with manual analysis results to compare structural loads from SAP2000. With these results, the pile foundations in the project are declared safe and capable of supporting the bridge structure load according to the planning requirements used in the research.

Suggestion

Further research is recommended to use more complete soil investigation data, such as laboratory test results and PDA Test, so that the results of the bearing capacity analysis can be validated with actual conditions in the field. Using AllPile or other geotechnical analysis software can be used to verify manual calculations. In bridge foundation planning, in addition to bearing capacity, settlement, pile group efficiency, soil stratification, and loading according to applicable standards must be considered.

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