

Analysis of Spun Pile Bearing Capacity Based on Spt Data Using Analytical and Software Modeling Approaches

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Abstract— Foundations are crucial structural elements that support the entire building load. At the study site, soil conditions are variable and complex, consisting of clay and sand layers with non-uniform bearing capacity, making accurate foundation capacity assessment essential. This study compares the bearing capacity of spun piles using analytical calculation with the Luciano Decourt method, numerical modeling with GEO5 software, and field verification through PDA Tests. SPT values were used as input for both calculation methods. Results indicate that the analytical method predicts a bearing capacity of 202.41 tons, lower than the PDA Test result of 296.7 tons, while GEO5 modeling produces 361.48 tons, closer to field conditions. The difference arises because the analytical method relies on a simplified SPT-based calculation, whereas GEO5 processes soil data into more detailed parameters and computes soil response at each layer incrementally. These findings confirm that numerical modeling provides a more representative estimate of bearing capacity, while differences with analytical calculations remain acceptable in geotechnical practice. This study offers a reliable reference for designing spun pile foundations on complex soils, enhancing design accuracy and structural safety.

Keywords: *Spun Pile, Bearing Capacity, SPT, PDA Test.*

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1. Introduction

Infrastructure development in Indonesia has expanded rapidly in recent years due to population growth, economic development, and increasing demand for urban facilities [1]. This growth drives the need for safe and reliable structural systems, where foundations play a critical role in transferring structural loads to supporting soil layers [2]. In major cities like Medan, subsurface conditions are highly variable, consisting of clay, sand, and soft soil layers with differing bearing capacities at various depths [3]. These geotechnical variations pose challenges in designing foundation systems capable of ensuring structural stability and safety.

Among deep foundation types, spun piles are widely used because of their high strength, uniform quality, and ease of installation [4]. Evaluating the axial bearing capacity of spun piles typically involves soil investigation tests, with the Standard Penetration Test (SPT) commonly applied as the basis for empirical methods such as the Luciano Decourt method [3], [4]. In addition, numerical modeling using geotechnical software like GEO5 allows for comprehensive prediction of pile behavior under axial loading [1], [2]. To verify design assumptions and ensure reliability, in-situ tests such as the Pile Driving Analyzer (PDA) are often conducted to measure actual pile performance in the field [3], [5].

Despite the widespread use of spun piles, there is limited research evaluating their performance in Medan by systematically comparing analytical predictions, numerical modeling, and field measurements [1], [6]. The complex soil stratification and variability in SPT results can lead to uncertainties in pile design if these comparisons are not conducted [7], [8]. Addressing this gap is

essential for obtaining accurate and reliable assessments of pile bearing capacity [9].

Therefore, this study focuses on the Jl. H. Adam Malik No. 20 construction project in Medan, where spun pile foundations are used as the primary substructure [2], [4], [5]. The objective is to analyze the bearing capacity of spun piles using the Luciano Decourt method and GEO5 modeling, and compare both approaches against field PDA test results. The findings aim to provide insights into the performance of spun piles under Medan's geotechnical conditions and serve as a reference for engineers and practitioners involved in similar construction projects [10].

2. Method

The soil investigation was conducted at the construction site of a showroom and office building in Medan City, Indonesia. Subsurface exploration was carried out using Standard Penetration Tests (SPT). Boreholes were drilled to a maximum depth of 24,45 m, with SPT measurements performed at 2 m intervals in accordance with ASTM D1586 standards. Disturbed soil samples were collected during drilling for soil classification and laboratory testing to determine relevant soil parameters, including unit weight and soil type. In this study, the axial bearing capacity analysis focused on a single spun pile. To validate the analytical and numerical results, dynamic load testing was conducted using a Pile Driving Analyzer (PDA) on the selected pile to obtain actual field bearing capacity data.

The bearing capacity of the single pile was calculated analytically using the Luciano Decourt method based on corrected SPT N-values. The ultimate bearing capacity (Q_u) was determined by summing the end bearing resistance (Q_p) and shaft resistance (Q_s). A safety factor of 2.5 was applied to obtain the allowable bearing capacity. Furthermore, numerical analyses were performed using SAP2000 to simulate structural response and load distribution along the pile, while GEO5 software was utilized to model pile–soil interaction considering soil stratification. The analytical and numerical results were then compared with the PDA test results to evaluate the accuracy and reliability of each method. The following is the research flowchart, providing a more systematic overview of the steps carried out in this study.

To clarify the stages of analysis carried out in this study, a methodological flowchart was prepared to illustrate the sequence of processes, starting from the SPT data used in analytical calculations and GEO5 modeling, the analytical bearing capacity calculations, SAP2000 modeling to determine the superstructure loads acting on the foundation, GEO5 modeling, comparison with PDA test results from both analytical calculations and software modeling, and finally the evaluation stage. The research flowchart is presented in Figure 1 below.



Figure 1. Flow Diagram

The following Table 1 presents the soil data obtained from field tests used in the analysis. The data consist of Standard Penetration Test (SPT) results conducted at the project site, including sampling depths, N-SPT values, and observed soil properties. These data are used as the basis for calculating the bearing capacity of single piles.

Table 1. SPT data

No	Depth (m)	Description	N-SPT
1	2,45	Medium Sand	6
2	4,45	Silty Clay	14
3	6,45	Silty Clay	24

4	8,45	Sandy Clay	8
5	10,45	Sandy Clay	2
6	12,45	Sandy Clay	14
7	14,45	Sandy Clay	4
8	16,45	Silty Sand	5
9	18,45	Silty Sand	11
10	20,45	Silty Sand	27
11	22,45	Silty Sand	59
12	24,45	Silty Sand	60

2.1 Analytical approach

In the calculation using the Luciano Decourt method, the following is the formula for the bearing capacity of a single spun pile foundation based on Standard Penetration Test (SPT) data [11]:

$$\begin{aligned} Q_{ult} &= Q_p + Q_s \\ Q_{ult} &= \alpha \cdot (N_p \cdot K) \cdot A_p + \beta \cdot (N_s/3 + 1) \cdot A_s \\ Q_{all} &= Q_{ult}/sf \end{aligned} \quad (1)$$

Where:

- Q_{ult} = Ultimate bearing capacity of the soil at the foundation (ton)
- Q_{all} = Allowable bearing capacity of the pile (ton)
- Sf = Safety factor
- Q_p = End-bearing resistance at the pile tip (ton)
- Q_s = Shaft resistance due to lateral adhesion (ton)
- N_p = The average SPT value from 4 diameters above to 4 diameters below the pile base.
- N_s = Average SPT value along the embedded length of the pile
- A_s = Surface area of the pile shaft (m²)
- A_p = Cross-sectional area of the pile base (m²)
- α, β, K = Coefficients

The Luciano Decourt method applied in this study was used to estimate the ultimate bearing capacity of piles based on correlations with N-SPT values. This method considers the contributions of both end bearing resistance and skin friction, which are influenced by the type of pile and the soil characteristics. Therefore, base resistance coefficients, shaft resistance coefficients, and soil coefficients are required as empirical correction parameters. The values of these coefficients are presented in Table 2, Table 3, and Table 4.

Table 2. Pile Base Coefficient α [11]

Soil/pile	Driven Pile	Bored Pile	Bored Pile (Bentonite)	Continuous Hollowauger	Root Pile's	Inject (high pressure)
Clay	1	0,85	0,85	0,3	0,85	1
Intermediate Soils	1	0,6	0,6	0,3	0,6	1
Sands	1	0,5	0,5	0,3	0,5	1

Table 3. Pile Shaft Coefficient β [11]

Soil/pile	Driven Pile	Bored Pile	Bored Pile (Bentonite)	Continuous Hollowauger	Root Pile's	Inject (high pressure)
Clay	1	0,8	0,9	1	1,5	3
Intermediate Soils	1	0,65	0,75	1	1,5	3
Sands	1	0,5	0,65	1	1,5	3

Table 4. Soil coefficient K [12]

Soil Type	K value (t/m ²)	K value (kPa)
Pure Clay	12	117,7
Silty Clay	20	196
Sandy Silt	25	245
Sand	40	392
Clayey Silt	15	147,1
Sandy Clay	22	215,7
Clayey Sand	30	294,2
Silty Sand	35	343,2

2.2 Modeling Using SAP2000 Software

The main purpose of using this software is to obtain a safe, efficient, and reliable structural design in accordance with civil engineering requirements [13]. In this modeling, SAP2000 is employed to calculate and determine the magnitudes of the structural loads to be supported by the foundation. The resulting loads are then input into GEO5 software for soil bearing capacity analysis and foundation capacity evaluation. Figure 2 below presents the superstructure modeling in accordance with the working drawings, with the objective of obtaining the loads to be supported by the foundation:

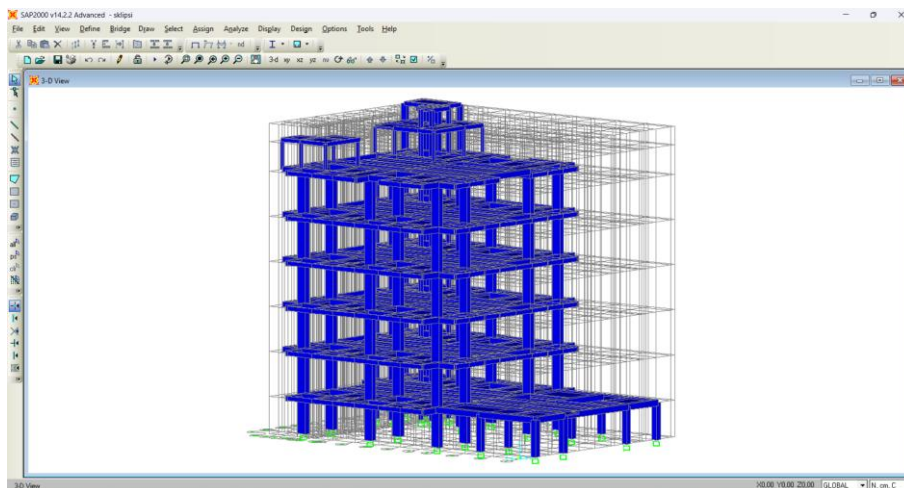


Figure 2. Modeling SAP2000

The above modeling represents the input of all structural components according to the design, including columns, beams, slabs, foundations, dead loads, live loads, and load combinations, which

together form the complete building structure. From this modeling, the magnitudes of the structural loads that will be supported by the foundation are obtained after running the analysis process.

2.3 Modeling Using GEO5 Software

The modeling using GEO5 aims to provide a clearer understanding of the foundation's bearing capacity. The input data include N-SPT values, soil stratification, and structural loads. The structural loads used in the GEO5 modeling were obtained from structural analysis with the help of SAP2000. These loads include dead load (DL) and live load (LL), combined in accordance with SNI 1727:2020.

In this study, the applied ultimate load combination is $1,2DL + 1,6LL$. The maximum axial load acting on a single pile is 1129,15 kN. This load is then input into the GEO5 program as a static axial compressive load to assess the ultimate bearing capacity of the spun pile foundation. The analysis is performed under the ultimate limit state using a safety factor of 3,14. Thus, the results of this modeling will indicate the foundation bearing capacity used in the structure [14].

The numerical analysis was conducted using GEO5 software, which requires input parameters in accordance with the field conditions and the configuration of the pile being analyzed. These parameters include the N-SPT values as the basis for correlating the soil's mechanical properties, the technical specifications of the driven pile, and the soil stratification for each layer. The stages of entering the N-SPT values are presented in Figure 3, while the input of the pile specifications and soil stratification is shown in Figure 4.

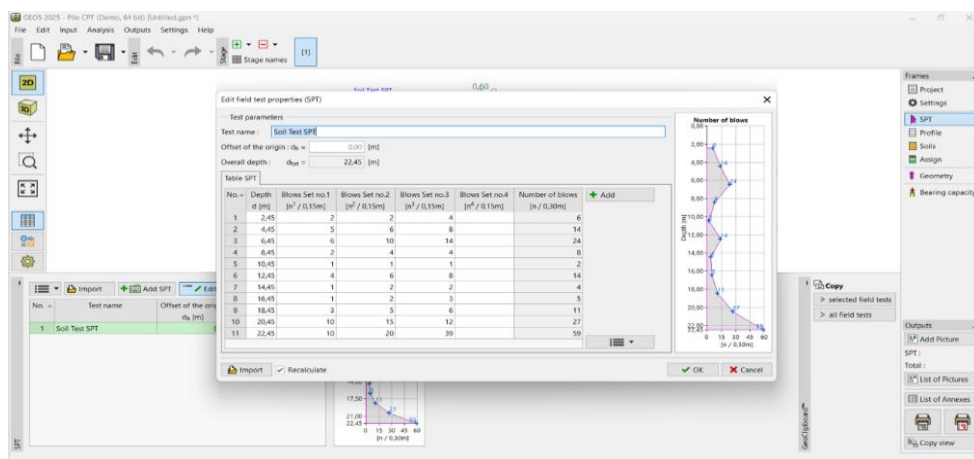


Figure 3. The Process of Inputting N-SPT data

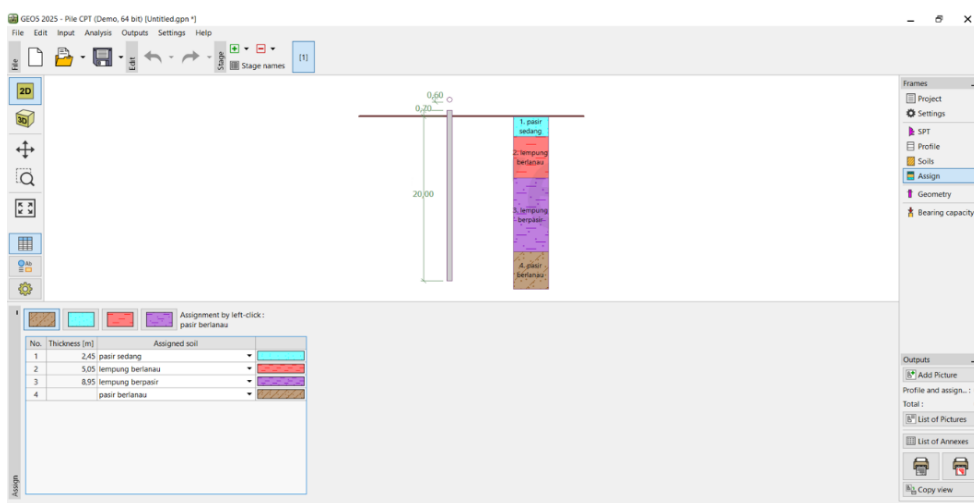


Figure 4. The process of inputting soil stratification and foundation specifications

3. Result and Discussion

The following presents the results and discussion obtained based on the methods used in the foundation bearing capacity analysis. In this analysis, the foundation has a depth of 20 meters and a diameter of 60 centimeters.

3.1 Results Analytical approach

As described above, this analytical calculation was carried out using the Luciano Decourt method, with pile specifications of 60 centimeters in diameter and 20 meters in depth. The results of the calculations are presented as follows:

$$Q_{ult} = Q_p + Q_s$$

$$\begin{aligned} Q_p &= \alpha \cdot (N_p \cdot K) \cdot A_p \\ &= 1 \cdot (32,333 \cdot 35) \cdot 0,2826 \\ &= 1 \cdot 1131,55 \cdot 0,2826 \\ &= 319,81 \text{ ton} \end{aligned}$$

$$\begin{aligned} Q_s &= \beta \cdot (N_s/3 + 1) \cdot A_s \\ &= 1 \cdot (11,50/3 + 1) \cdot 38,53 \\ &= 1 \cdot 4,833 \cdot 38,53 \\ &= 186,22 \text{ ton} \end{aligned}$$

$$\begin{aligned} Q_{ult} &= Q_p + Q_s \\ &= 319,81 + 186,22 \\ &= 506,03 \text{ ton} \end{aligned}$$

$$\begin{aligned} Q_{all} &= Q_{ult}/sf \\ &= 506,03/2,5 \\ &= 202,41 \text{ ton} \end{aligned}$$

3.2 Modeling Results Using SAP2000 Software

Based on the SAP2000 modeling that has been carried out, the magnitude of the load acting on the investigated foundation point, corresponding to the PDA test location, is located at Joint 120, as shown in Figure 5. After conducting the analysis, the load acting at that point based on the SAP2000 output was obtained as 4516.61 kN, as presented in Figure 6 below.



Figure 5. PDA Test at grid point 2C

TABLE: Element Forces - Frames													
Frame	Joint	Station	OutputCase	CaseType	StepType	StepNum	P	V2	V3	T	M2	M3	FrameElem
Text	Text	m	Text	Text	Text	Unitless	KN	KN	KN	KN-m	KN-m	KN-m	Text
132	120	0	DEAD	LinStatic			-3173,194	-67,684	11,924	-0,2571	25,6043	-176,2275	132-1
132	7	1,875	DEAD	LinStatic			-3199,672	-67,684	11,924	-0,2571	3,247	-49,3207	132-1
132	120	3,75	DEAD	LinStatic			-3226,15	-67,684	11,924	-0,2571	-19,1103	77,5862	132-1
132	7	0	MODAL	LinModal	Mode	1	1,732E-11	-4,04E-12	-6,76E-12	9,121E-13	-6,7E-12	-5,75E-12	132-1
132	120	1,875	MODAL	LinModal	Mode	1	1,732E-11	-4,04E-12	-6,76E-12	9,121E-13	5,973E-12	1,819E-12	132-1
132	7	3,75	MODAL	LinModal	Mode	1	1,732E-11	-4,04E-12	-6,76E-12	9,121E-13	1,864E-11	9,39E-12	132-1
132	120	0	MODAL	LinModal	Mode	2	-1,17E-11	-2,63E-12	-3,22E-12	1,794E-12	-7,48E-12	-4,07E-12	132-1
132	7	1,875	MODAL	LinModal	Mode	2	-1,17E-11	-2,63E-12	-3,22E-12	1,794E-12	-1,45E-12	8,598E-13	132-1
132	120	3,75	MODAL	LinModal	Mode	2	-1,17E-11	-2,63E-12	-3,22E-12	1,794E-12	4,581E-12	5,792E-12	132-1
132	7	0	LIVE	LinStatic			-1828,889	-48,223	6,62	-0,1707	15,3439	-124,7314	132-1
132	120	1,875	LIVE	LinStatic			-1828,889	-48,223	6,62	-0,1707	2,9306	-34,3137	132-1
132	7	3,75	LIVE	LinStatic			-1828,889	-48,223	6,62	-0,1707	-9,4827	56,104	132-1
132	120	0	COMB1	Combination			-4442,472	-94,757	16,693	-0,3599	35,846	-246,7185	132-1
132	7	1,875	COMB1	Combination			-4479,541	-94,757	16,693	-0,3599	4,5458	-69,0489	132-1
132	120	3,75	COMB1	Combination			-4516,61	-94,757	16,693	-0,3599	-26,7544	108,6207	132-1
234	7	0	DEAD	LinStatic			-2682,499	88,895	3,544	0,138	-1,1946	204,7552	234-1
234	120	2,275	DEAD	LinStatic			-2650,372	88,895	3,544	0,138	-9,2576	2,5197	234-1
234	7	4,55	DEAD	LinStatic			-2618,246	88,895	3,544	0,138	-17,3206	-199,7157	234-1
234	120	0	LIVE	LinStatic			-1515,356	63,893	1,797	0,1095	-1,2936	146,6988	234-1
234	7	2,275	LIVE	LinStatic			-1515,356	63,893	1,797	0,1095	-5,3818	1,3416	234-1
234	120	4,55	LIVE	LinStatic			-1515,356	63,893	1,797	0,1095	-9,47	-144,0157	234-1
234	7	0	COMB1	Combination			-3755,498	124,453	4,962	0,1932	-1,6725	286,6573	234-1
234	120	2,275	COMB1	Combination			-3710,521	124,453	4,962	0,1932	-12,9607	3,5276	234-1
234	7	4,55	COMB1	Combination			-3665,544	124,453	4,962	0,1932	-24,2489	-279,602	234-1
342	120	0	DEAD	LinStatic			-2143,269	87,155	-0,95	-0,0921	-9,5646	196,421	342-1
342	7	2,275	DEAD	LinStatic			-2111,143	87,155	-0,95	-0,0921	-7,4027	-1,8578	342-1
342	120	4,55	DEAD	LinStatic			-2079,016	87,155	-0,95	-0,0921	-5,2407	-200,1365	342-1

Figure 6. The loads at grid point 2C obtained from the analysis run

3.3 Modeling Results Using GEO5 Software

Based on the modeling conducted through the input of N-SPT data, soil stratification, pile specifications, and loads obtained from the SAP2000 modeling, the output in the form of foundation bearing capacity was obtained. The bearing capacity results are shown in the following Figure 7.

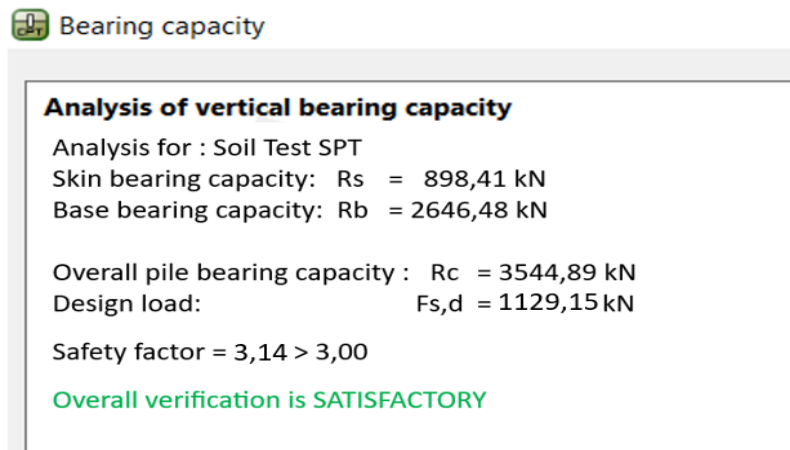


Figure 7. Foundation Bearing Capacity

Based on the modeling and analysis performed using the GEO5 software, the ultimate bearing capacity of the Spun Pile foundation was found to be 3,544.89 kN. From these results, a Safety Factor (SF) of 3.14 was obtained, indicating that the foundation is in a safe condition, as the safety factor exceeds the minimum recommended value of 3.00 according to the GEO5 software.

3.4 Discussion

Based on the axial bearing capacity analysis of the Spun Pile foundation, three comparative values were obtained from different methods. The analytical calculation using the Luciano Decourt method produced a bearing capacity of 202.41 tons, while the numerical modeling using GEO5 software resulted in a capacity of 361.48 tons. Meanwhile, the field test using the PDA Test showed a bearing capacity of 296.7 tons.

When compared to the field reference value, namely the PDA Test, it is evident that the GEO5 modeling result has a smaller deviation than the analytical calculation using the Luciano Decourt

method. This indicates that the numerical approach through GEO5 provides a bearing capacity estimate that is closer to the actual field conditions, while the Luciano Decourt method tends to yield a more conservative value. Therefore, in this study, the GEO5 modeling can be considered a more representative approach for describing the bearing capacity behavior of Spun Pile foundations in relation to the actual conditions measured through the PDA Test. Table 5 below presents a summary of the results obtained from the research conducted.

Table 5. Results and percentage of carrying capacity for the PDA test.

SPT Data Analysis	Single Qall (ton)	PDA Test (ton)	Percentage (%)
<i>Luciano Decourt</i>	202,41	296,7	68,2
<i>Software GEO5</i>	361,48	296,7	121,8

The difference between the analytical calculation using the Luciano Decourt method and the numerical modeling performed with GEO5 arises because the two methods operate in fundamentally different ways. The analytical method estimates pile bearing capacity using simplified formulas, relying on SPT values to approximate soil strength along the pile shaft and at the pile tip. In contrast, GEO5 converts the SPT data into more detailed soil parameters and then computes soil resistance progressively for each layer, including the mechanism by which the soil mobilizes greater resistance as the pile experiences increasing load.

The analytical method based on Luciano Decourt provides a simple and quick estimation of the pile bearing capacity, with a solid theoretical foundation and soil coefficients applicable to various soil types. However, this method assumes ideal soil conditions and has limitations in handling highly heterogeneous soil profiles, as indicated by the N-SPT results at the study site, which show layers of clay, silt, and sand, including combinations of these layers. Although the analysis is focused on a single pile, the method is less flexible in capturing complex interactions between soil layers.

On the other hand, numerical modeling using GEO5 software allows for more detailed simulation of layered soil and realistic loading conditions, providing a more comprehensive understanding of the performance of the single pile. Nevertheless, this method requires accurate input data, a deeper understanding of soil mechanics and software operation, and a longer computational time.

This more comprehensive calculation approach typically results in higher bearing capacity values from GEO5 compared to analytical methods. Although both methods use the same soil data, differences in calculation procedures, soil behavior modeling, and the determination of pile resistance limits naturally lead to variations in the results. Therefore, the relatively large discrepancy between the two methods is still considered reasonable in pile bearing capacity analysis.

4. Conclusion

Based on the axial bearing capacity analysis of the Spun Pile foundation, the analytical calculation using the Luciano Decourt method produced a bearing capacity of 202.41 tons, while the numerical modeling using GEO5 software resulted in a bearing capacity of 361.48 tons. Meanwhile, the field test using the PDA Test indicated a bearing capacity of 296.7 tons. From these results, it can be concluded that numerical modeling with GEO5 provides a more representative estimate of the bearing capacity compared to the analytical calculation using the Luciano Decourt method, as it is closer to the PDA Test results. Therefore, the GEO5 software approach can serve as a more accurate

reference for Spun Pile foundation design, while the analytical calculation remains useful as a conservative approach to ensure structural safety.

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