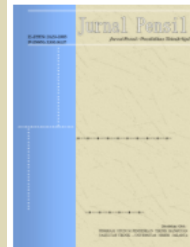


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ANALYSIS OF THE EFFECT OF CROSS-SECTIONAL ON THE BEARING CAPACITY AND SETTLEMENT OF PILE FOUNDATION FOR THE SCADA BUILDING

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Abstract

Bengkulu is an area with a potential risk of the Mentawai Pagai Megathrust subduction earthquake; therefore, it is necessary to evaluate the bearing capacity and foundation settlement of the buildings. This study aims to analyse the influence of variations in dimensions and cross-sectional shapes on the bearing capacity and foundation settlement of the Scada building using the Poulos and Davis method, the Reese and Wright method, the Luciano Decourt method, and the finite element method. Based on the results of the Standard Penetration Test (SPT), the influence of variations in shape, namely square and circular with dimensions of 300 mm, 400 mm, and 500 mm, as well as depths of 7m, 9m, 11m, and 13m, affects the bearing capacity and foundation settlement. The analysis was conducted by comparing the bearing capacity and settlement of pile foundations in the Scada building using various methods. The analysis results show that the bearing capacity, deflection magnitude, and smallest settlement are below the permitted settlement limit, i.e., less than 10% of the foundation dimensions. The comparison between static and numerical methods, or the Bearing Capacity Ratio (BCR) approaching 1, is more efficient and safer to use. In this analysis, the BCR value closest to 1 was obtained for a 500 mm foundation using the Reese and Wright method at a depth of 9 m, yielding a bearing capacity of 439.04 tonnes for a single pile and 292.69 tonnes for a pile group

Keywords: Bearing Capacity, Settlement, Piled Foundation

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Introduction

The SCADA building is one of the essential buildings in the Benteng Kobema Bengkulu Regional Water Supply System. This building functions as a control and monitoring system for the operational management of the water supply system (Handoko et al., 2017). In the planning of SCADA construction, the foundation plays an important role as a support for the building above it to distribute the load into the ground (Aprizaldi & Saputro, 2022; Lestari et al., 2024; Suraji et al., 2023). Foundations are one of the structural elements of a building that rest directly on the ground and serve to transfer and resist loads from the building to the ground (M. wianto, 2024; Patah et al., 2023; Suraji et al., 2023; Yuslinda & Rani, 2025; Prativi et al., 2022). There are generally two types of foundations, which are shallow foundations and deep foundations. Depending on the type of structure and its depth, a suitable foundation type is selected (Azizi et al., 2023; Mananoma et al., 2024; Nurjanah, 2024; saputra et al., 2025; Rafidatul Hidayani et al., 2024; saputra, bachtiar, 2025; K. M. E. Putri et al., 2025).

The main issue to be addressed in this study is how to determine the bearing capacity and settlement of foundations in order to obtain efficient and safe foundations for use, taking into account various variations in dimensions, cross-sections and depths. This allows for the selection of optimal and conservative foundation designs before implementation in the field for similar projects in the future. This study specifically considers the potential risk of subduction of the Mentawai Pagai Megathrust in the Bengkulu region, thus requiring an evaluation of the load-bearing capacity and foundation settlement of buildings. (Fahrezi et al., 2025; Litman, 2021; Nainitania & Darmawan, 2020; Misliniyati et al., 2024). The evaluation of load-bearing capacity and foundation settlement under this potential earthquake is crucial, making this research highly relevant and important for infrastructure considerations in the region. The purpose of this study is to investigate the influence of differences in dimensions, cross-section, and depth of the foundation on the bearing capacity and settlement of pile foundations. (Yanita et al., 2025).

In the Benteng Kobema Regional SPAM project, the type of foundation used is a pile foundation. Pile foundations are a type of foundation in the form of piles that are installed until they reach a hard soil layer (Mardianti, 2022). The primary function of this foundation is to transfer the load of the building to soil that is strong enough at a certain depth (I. Sofiyatul Khusnah & Sara Wibawaning Respati, 2021). Pile foundations are used when the ground's bearing capacity proves to be insufficient to support the building load load-bearing structure over it (Nu'man, 2023; Wiqoyah & Nugroho, 2022; Fattahi et al., 2024).

The selection of methods in bearing capacity analysis and pile foundation settlement is highly dependent on the availability of soil data obtained from the research site, which can be in the form of Standard Penetration Test (SPT) data. SPT is a dynamic penetration test that provides an overview of soil resistance to the piling process (Wiweka PP & Setyanto, 2024; Rus & Irwaniansyah, 2021).

The bearing capacity and foundation settlement analysis were conducted by evaluating several methods, namely the Poulos and Davis (1980) method, the Reese and Wright (1977) method, the Luciano Decourt (1987) method, and the finite element method. These methods were selected based on the available calculations and data types, aiming to provide accurate and conservative results for soil and building conditions (Ningsih & Setiawan, 2023). This study utilised SPT data obtained at the research location. Due to the limited availability of data received from the research location, we also used finite element analysis. Finite elements have the potential to represent field conditions more accurately because they can simulate complex geometry and structures in a nonlinear manner (Mase et al., 2022).

Generally, the combined approach tends to compare static methods with dynamic methods. Ramadhan et al. (2022) conducted research by comparing bearing capacity values obtained using the static method with those obtained using the dynamic method, specifically the Pile Driving Analyzer (PDA) as field validation, to determine the bearing capacity of several methods that could approximate the bearing capacity of field-testing using PDA. In this study,

static and numerical methods' bearing capacity values were compared to determine if the bearing capacity values of the methods utilized could be used to estimate the bearing capacity of the numerical method (Prilia et al., 2021). In this study, a comparison of carrying capacity values was conducted using static methods and numerical methods due to limited data availability, to determine whether the carrying capacity values from the methods used could approximate the carrying capacity of numerical methods.

Analysis of bearing capacity with varying dimensions shows that the larger the cross-sectional area of the pile, the greater the bearing capacity of the foundation (Gazali et al., 2024 ; Yunus, 2018). Foundations with a square cross-section have a greater bearing capacity than those with a circular cross-section (Ramadhan et al., 2022). A comparison of static and numerical methods was conducted to ensure the efficiency and safety of the foundation. Other studies show that dynamic methods such as the Pile Driving Analyzer (PDA) are capable of approximating field test results (Sari et al., 2023). So, a combination of static, dynamic, and numerical methods is important for the optimal and safe planning of pile foundations.

Research Methods

This study employs the Research and Development (R&D) method. The research was conducted over a period of four months, located at the PTSP FT Department of Yogyakarta State University, from August to November 2023. The target users of the application are faculty members, woodworking workshop lab administrators, and students of PTSP FT Yogyakarta State University.

The study uses purposive sampling, focusing on selected informants with rich cases for in-depth study. The researcher employed data collection instruments to gather relevant data for the study, ensuring the process is systematic and organized. The instruments used in this study include materials, media, and user assessment. The validation process in this study involved one material expert and one media expert, both of whom are lecturers at PTSP FT Yogyakarta State University. These experts acted as validators, providing assessments of the feasibility of the research product. The material expert evaluated three aspects: the content of the website application, the feasibility of the website application, and the presentation of the website application. Meanwhile, the media expert assessed two aspects: the application aspect and the media aspect. The user assessment involved a lecturer from PTSP FT Yogyakarta State University., who serves as the coordinator of the woodworking workshop, as well as two woodworking workshop technicians. The users assessed two aspects: the application aspect and the media aspect.

Table 1. Material Expert Validation Instrument

Number	Aspect	Indicator
1	Website Application Material	Relevance of Material Presentation of Material Web Application Quality
2	Web Application Feasibility	Knowledge Material
3	Website Application Presentation	Application Presentation

Table 2. Media Expert Validation Instrument

Number	Aspect	Indicator
1	Application	Ease of application and navigation Website appearance App benefits

Number	Aspect	Indicator
2	Media	Website Presentation Media Benefits of Use

Table 3. User Assessment Instrument

Number	Aspect	Indicator
1	Application	Ease of use and navigation Website appearance App benefits
2	Media	Website Presentation Media Benefits of Use

The feasibility categories are presented in Table 4.

Table 4. Feasibility categories

Answer Score	Category
$X > Mi + 1.5 (SDi)$	Feasible
$Mi < X < Mi + 1.5 (SDi)$	Moderately Feasible
$Mi - 1.5 (SDi) < X < Mi$	Less Feasible
$X < Mi - 1.5 SDi$	Not feasible

Description:

X = obtained score

$Mi = \frac{1}{2} \times (\text{maximum score} + \text{minimum score})$

$SDi = \frac{1}{6} \times (\text{maximum score} - \text{minimum score})$

The analysis process was then converted into percentages. The calculation of the percentage results is as follows:

$$p = \frac{f}{n} \times 100\%$$

Description:

P : percentage value

f: frequency for which the percentage is calculated

n : number of cases (total frequency/number of individuals)

The software development research method adopts the waterfall development model. This method follows a systematic and sequential approach, starting from system requirements analysis and progressing through the stages of analysis, design, coding, testing/verification, and maintenance. The waterfall model is named as such because each stage must wait for the completion of the previous one, starting with the requirement stage. The waterfall system development model is illustrated in Figure 1.

This research was conducted at the Benteng Kobema Regional Water Supply System construction site located in Lubuk Puar Village, Merigi Sakti Subdistrict, Central Bengkulu Regency, Bengkulu Province, as shown in Figure 1. At the time of the research, the Benteng

Kobema Regional Water Supply System SCADA building had been constructed with a planned pile foundation, which was square in shape, measuring 400 mm in size and 9 metres in depth. There were four soil sampling points or CPT at the research site.



Figure 1. Map of Research Location

The SCADA building was designed using pile foundations because the CPT test results conducted for soil investigation showed that the hard soil layer was at a depth of 9 metres. The SCADA building was designed with pile foundations because CPT tests conducted during soil investigations showed that the soil had a hard layer at a depth of 9 meters. Figure 2 shows the foundation plan for the SCADA building, where it can be seen that the foundation used is a group pile foundation. Single pile foundations were also analyzed in this study. The choice between single pile foundations or group pile foundations depends heavily on several key factors, primarily structural load, soil conditions, type, efficiency, and design economics. (Mulyono & Agustina, 2022).

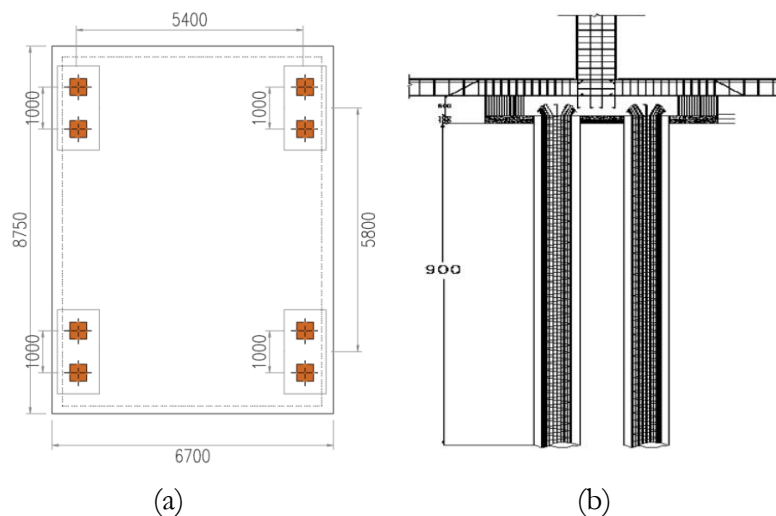


Figure 2. (a) Foundation Configuration Plan, (b) Details of Pile Foundations

An analysis was conducted to determine the effect of variations in the cross-sectional area of square and circular foundations measuring 300 mm, 400 mm, and 500 mm, as well as variations in depth of 7 m, 9 m, 11 m, and 13 m on the load capacity and amount of foundation settlement. Figure 2 shows the details of a group of pile foundations with a circular cross-section size of 500 mm and a depth of 9 m.

The soil data presented is important information for bearing capacity and foundation settlement analysis, including soil classification, layer depth, N-SPT value, undrained shear strength (Cu), soil bulk density (γ), and internal friction angle (ϕ) as shown in Table 5. In this study, SPT BH-04 data were used, as shown in Figure 1.

Table 5. Soil Type Classification Data Based on SPT

Depth (m)	Soil Type	N-SPT	Cu	γ	ϕ
0-2	<i>Silty</i>	6	3.6	19.3	20°
2-4	<i>Silty Clay</i>	5	3.0	18.5	25°
4-6	<i>Silt</i>	16	9.6	19.7	25°
6-8	<i>Silt</i>	37	22.2	20.5	25°
8-10	<i>Silt</i>	49	29.4	20.7	25°
10-20	<i>Silt clay</i>	50	30.0	20.6	25°

Figure 3 illustrates the building structure modelled in SAP 2000 software in the Benteng Kobema Regional SPAM building. The structure model consists of columns, beams, shear walls, and steel roof trusses. After the structure modelling in SAP2000, load analysis was carried out based on the identified load patterns and types. The function of these structural elements is to sustain and transfer the loads on the structure to the ground (Yusmar et al., 2021).

The load analysis was carried out based on SNI 1727:2020 regarding minimum loads and other criteria for buildings and other structures. In this building, the planned loading includes dead load (DL), live load (LL), and earthquake load (E). The dead load calculated includes the weight of the structure itself and additional dead loads (Syah & Rutama, 2023; Irawan & Machmoed, 2024).

After all loads were entered, the maximum load value acting on a single point of the building foundation was obtained, as shown in Figure 3 below:

- P (Axial Load) : 543.962 kN
- V (Shear Force): 55.083 kN
- M (Moment) : 60.7 kNm

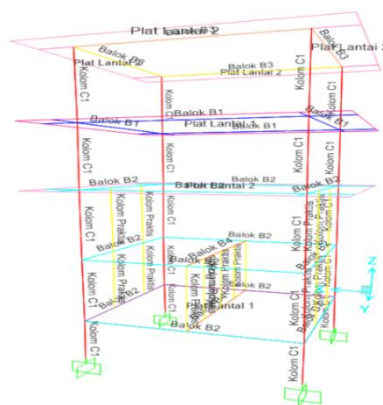


Figure 3. Building Structure Modelling of the SCADA Building in SAP2000.

Single Pile Bearing Capacity

The bearing capacity of a pile, which refers to the potential of the pile to support the imposed load, must be determined without causing excessive settlement or structural damage (M. S. Putri et al., 2018).

SPT (Standard Penetration Test) data processing to obtain the bearing capacity of a pile can use the equation from Poulos and Davis (1980) as follows:

$$Q_b = A_b \times P_b' \times N_q$$

$$Q_s = A_s \times P_o' \times K_d \operatorname{tg} \delta$$

$$Q_u = Q_b + Q_s$$

$$Q_a = Q_u / SF$$

Where Q_b is the ultimate tip resistance (tons), P_b' is the adequate vertical pressure at the base of the pile (tons/m²), N_q is the tip bearing capacity factor, depending on the angle of internal friction in the soil (Φ), Q_s is the ultimate wall friction resistance (tons), and SF is the safety factor (3).

Reese and Wright (1977) presented the calculation of pile foundation bearing capacity based on SPT data as follows:

$$Q_p = 9 \times C_u \times A_p$$

$$Q_s = \alpha \times C_u \times P \times L$$

$$Q_u = Q_p + Q_s$$

Luciano Decourt (1987) calculated the bearing capacity of single pile foundations based on SPT data using the following formula:

$$Q_u = [\alpha \times (\tilde{N}_p \times K) A_p] + \left(\frac{\tilde{N}_s}{3} + 1\right) \times A_s$$

Where \tilde{N}_p is the average SPT value approximately 4D below the pile base and 4D above the pile base, A_s is the pile length from the surface base multiplied by the pile circumference (m²), \tilde{N}_s is the average N-SPT along the embedded pile, α is the base pile coefficient, and β is the pile skin coefficient.

Group Pile Bearing Capacity

For pile group bearing capacity analysis, the bearing capacity of individual piles must be accumulated with the pile group and the number of foundations. According to Poulos and Davis (1980), Reese and Wright (1977), and Luciano Decourt (1987), the bearing capacity of pile groups can be determined using the following equation:

$$Q_g = Q_a \times n \times E_g$$

$$Q_{ag} = Q_g / SF$$

Where Q_g is the bearing capacity of the pile group (tons), n is the number of piles, and E_g is the efficiency of the pile group.

Single Pile Settlement

Poulos and Davis (1980) memberikan perkiraan penurunan tiang Tunggal sebagai berikut :

$$S = \frac{Q \times I}{E_s \times D}$$

$$I = I_o \times R_k \times R_h \times R_\mu$$

Where Q is the working load (tons), E_s is the modulus of elasticity of the soil (tons/ m^2), and D is the diameter of the pile (m).

According to Reese and Wright (1977), the settlement of a pile foundation after receiving a vertical load will experience three types of settlement, as shown in the following equation:

$$S = S_s + S_p + S_{ps}$$

$$S_s = \frac{(Q_p + \alpha \times Q_s)L}{A_p \times E_p}$$

$$S_p = \frac{C_p \times Q_p}{D \times q_p}$$

$$S_{ps} = \frac{\left(\frac{Q_p}{L}\right)D}{(E_s(1-\mu_s^2)I_{ws})}$$

Where S_s is the settlement due to axial deformation, S_p is the settlement due to the load at the end of the pile, and S_{ps} is the settlement of the soil layer along the foundation pile due to the load transferred through the pile.

Luciano Decourt (1987) calculated the settlement of pile groups using the following formula:

$$s = (K \times N\text{-SPT} \times A) / Q_u$$

Where K is the correction factor, A is the surface area, and Q_u is the ultimate bearing capacity.

Group Pile Settlement

In pile foundation calculations, pile bearing capacity is often based on settlement requirements. Pile settlement mainly depends on the ratio of end resistance to pile load. If the load supported per pile is less than or equal to the end resistance of the pile, the settlement that occurs may be tiny.

Poulos and Davis (1980) presented the following calculation for group pole reduction:

$$S_g = \frac{q \times B_g \times I}{2 \times q_c}$$

With:

L_g and B_g are the width of the pile group, and q_c is the end bearing capacity. To determine the settlement of the pile group proposed by Reese and Wright (1977) and Luciano Decourt (1987), namely:

$$S_g = S \times \sqrt{\frac{B}{D}} < 10\%D$$

Where S refers to the total settlement of a single pile foundation (m), B indicates the width of the pile group (m), and D is the pile diameter (m). With $S_{total} \leq S_{allowable}$ and $S_{allowable} = 10\% \times B$.

Finite Element Method

Plaxis 8.6 is a finite element software program used for 2D geotechnical analysis and slope stability, as well as other geomechanical analyses in geotechnical engineering and rock mechanics. Through intuitive graphics for entering soil properties data, it can produce complex finite element models and receive detailed displays showing the calculation results. The entire calculation process in this program is carried out automatically, based on accurate number writing procedures.

Calculation of pile foundation bearing capacity using the finite element method with the following steps: Describe the geometry of the foundation and soil layers based on N-SPT data using a 12-nodal axisymmetric model and Mohr-Coulomb soil modelling, and enter the pile and soil parameters (Suradi et al., 2024). Perform the calculation program in several stages, starting from the construction stage, through safety factor calculation, and concluding with settlement. The results of the finite element method provide bearing capacity and settlement values, which are presented in Figure 4.

The finite element method has advantages over manual calculation methods and simple approaches such as the bishop method, as it is capable of producing more comprehensive outputs. This analysis not only provides safety factor values but also presents detailed information on soil deformation, effective stress distribution, pore water pressure, and soil response to loads. This enables a more comprehensive and realistic understanding of soil behaviour.

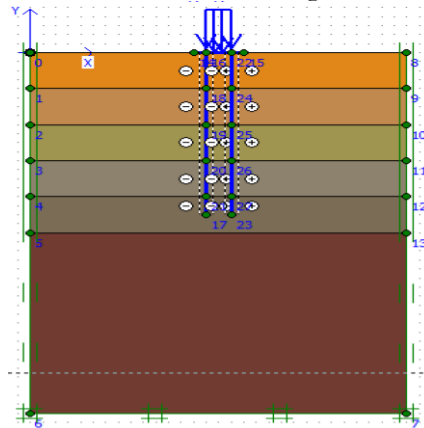


Figure 4. Foundation modelling using the finite element method.

The ultimate bearing capacity (Q_u) of piles using the finite element method is as follows:

$$Q_{all} = P_{all} = \frac{Q_u}{\sum -M_{sf}}$$

$$Q_u = P_{all} \times \sum -M_{sf}$$

Where $Q_{all} = P_{all}$ is the bearing capacity of the pile (60 tons), Q_u is the ultimate bearing capacity (tons), and $\sum -M_{sf}$ is the ratio of the actual strength parameter to the reduced strength parameter.

Analysis of Deflection Due to Lateral Forces

In lateral force analysis, piles are classified according to their connection model with the pile cap, specifically as fixed-end piles and free-end piles. This connection model greatly influences the behaviour of piles in supporting lateral loads (Kawengian et al., 2018; Liongono et al., 2024)

Using the Broms (1964) method for piles in cohesive soil, pile deflection is related to the dimensionless factor βL , with:

$$\beta = \left(\frac{k_h d}{4.E_p.I_p} \right)^{\frac{1}{4}}$$

The deflection of the pile tip at ground level (Y_0) is expressed by an equation that depends on the type of pile restraint as follows:

$$y_0 = \frac{Hu x \beta}{kh x d}$$

Hu is the horizontal shear force, β is the dimensionless deflection factor, kh is the horizontal soil reaction modulus, and D is the foundation diameter. The condition is that the value must be less than 6 mm.

Bearing Capacity Ratio

The bearing capacity ratio (BCR) is the ratio between the bearing capacity of the static method based on SPT data and methods that approximate field conditions, such as the bearing capacity of the dynamic method, namely PDA (pile driving analyzer). Due to the limited availability of data obtained from the research location, a comparison was made between the bearing capacity of the static method and the numerical bearing capacity, namely, finite elements. Finite elements have the potential to represent field conditions more accurately because they can simulate complex geometries and structures non-linearly (Mase et al., 2022 ; Wismantharharjo et al., 2020).

The value of BCR is taken as a benchmark to assess the closeness of the support capacity of the static method to the finite element results. An ideal BCR value is nearly 1, indicating congruence with the results of the finite element (Ramadhan et al., 2022). With the use of BCR, designers can specify the reliability of the analytical procedure employed and adjust it whenever there is a discrepancy, resulting in more efficient and safer foundation design.

Results and Discussion

Comparison of Single Pile Foundation Bearing Capacity

The analysis of foundation bearing capacity was carried out using a method that refers to predetermined safety factors. Based on the graph shown, the foundation bearing capacity is influenced by the depth of piling. The deeper the piling and the larger the foundation cross-section, the greater the bearing capacity (Solin & Estikhamah, 2022). The evaluation of foundation bearing capacity is carried out using an approach that includes calculating the bearing capacity with reference to predetermined safety factors. Referring to the graphic illustration below, as shown in Figure 5, the value of the foundation bearing capacity is influenced by the depth of the pile. The bearing capacity will increase in line with the depth and size of the foundation cross-section installed.

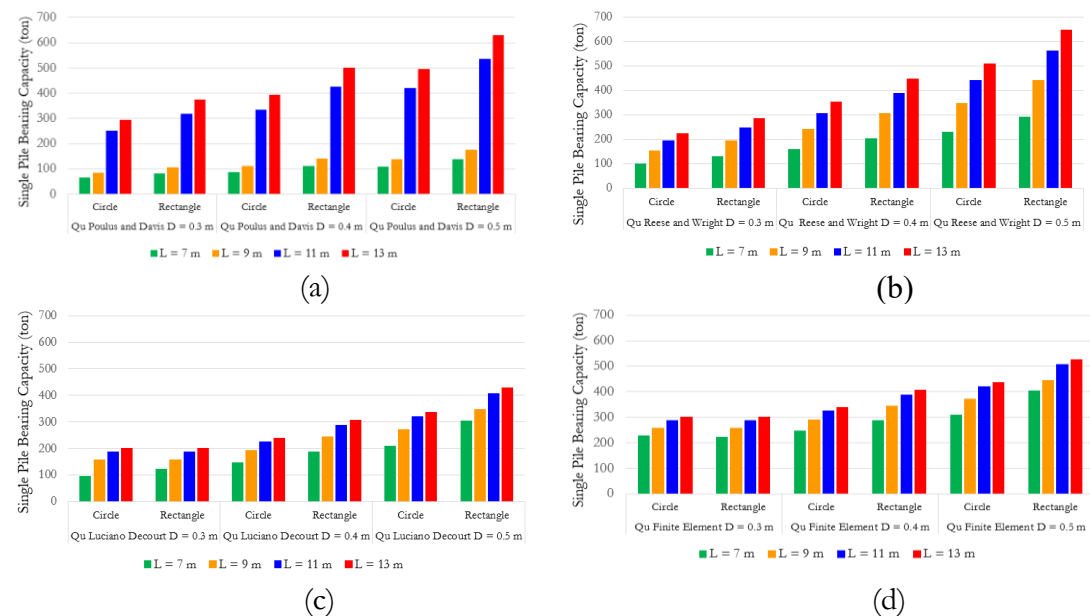


Figure 5. Load-bearing capacity of square and circular single pile : (a) Poulos and Davis Method, (b) Reese and Wright Method, (c) Luciano Decourt Method, (d) Finite Element Method.

Figure 5 illustrates a graph comparing the bearing capacity of pile foundations analysed using the equations of Poulos and Davis (1980), Reese and Wright (1977), Luciano Decourt (1987), and Finite Elements. It was found that differences in calculated bearing capacity affect the cross-sectional diameter and depth of the foundation. Foundations with larger cross-sectional diameters and greater depths generally have greater bearing capacity. However, many factors must be considered so that the design does not pose risks and cause unnecessary cost overruns. A comprehensive evaluation of soil conditions, selection of appropriate dimensions, compliance with technical standards, and consideration of cost efficiency are crucial in designing safe and optimal foundations (Hassaan, 2014).

The bearing capacity analysis using the Reese and Wright (1977) method has a greater bearing capacity compared to other static methods. This difference can be very significant due to the parameters used. The equation derived from this analysis indicates that the most significant bearing capacity is achieved in square pile foundations with a diameter of 500 mm at a depth of 13 m. However, in the site of the research, foundations with 9 m depth are considered safer and more efficient due to the state of the soil, where the soil layer at a depth of 9 m is already hard soil.

Comparison of Group Pile Foundation Bearing Capacity

The capacity of a single pile and the number of piles (n) for a group pile foundation can then be employed to get the group pile's bearing capacity (Q_g). The disposition of the number of piles impacts the bearing capacity of the group pile foundation. The pile group capacity is also calculated based on Poulos and Davis (1980) formula, the Reese and Wright (1977) formula, the Luciano Decourt (1987) formula, and the Finite Element formula, as shown below. The evaluation of foundation bearing capacity is carried out using an approach that includes calculating the bearing capacity with reference to predetermined safety factors. Referring to the graphic illustration below, as shown in Figure 6, the value of the foundation bearing capacity is influenced by the depth of the pile. The bearing capacity will increase in line with the depth and size of the foundation cross-section installed.

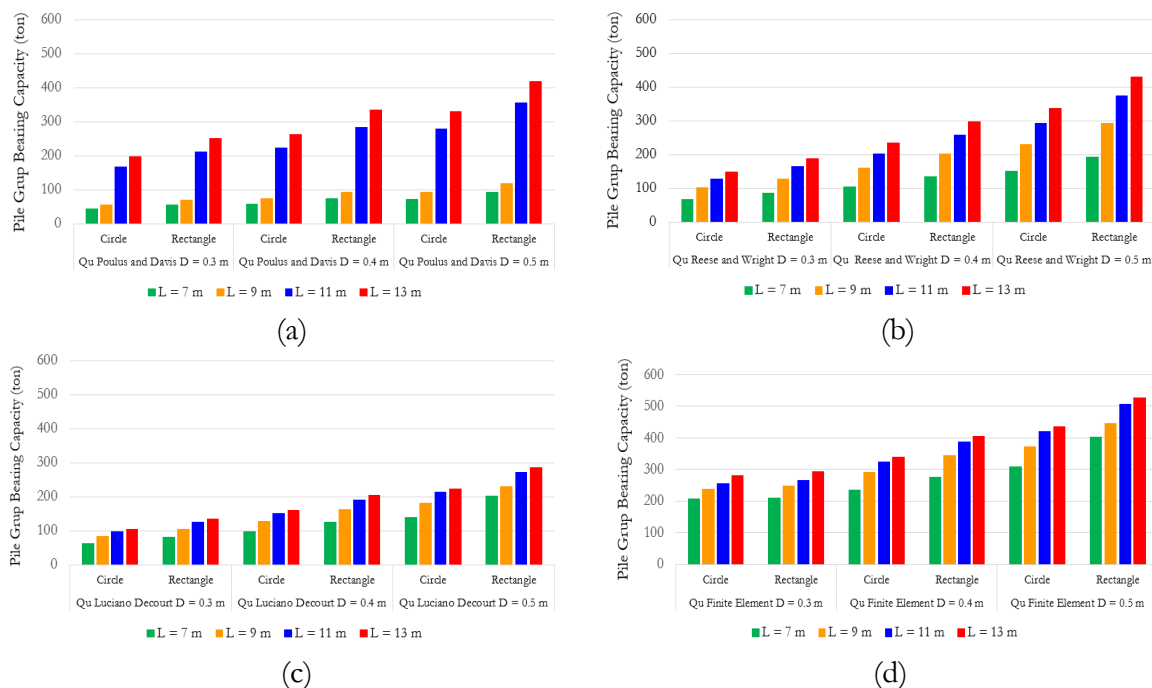


Figure 6. Load-bearing capacity of square and circular Group piles : (a) Poulos and Davis Method, (b) Reese and Wright Method, (c) Luciano Decourt Method, (d) Finite Element Method.

Figure 6 shows a comparison chart of the pile foundation bearing capacity calculated using the Poulos and Davis (1980), Reese and Wright (1977), Luciano Decourt (1987), and Finite Elements equations. As observed from the analysis results, foundations with larger diameters and depths have larger bearing capacity, but the selection of design must still consider soil conditions and cost-effectiveness. The maximum bearing capacity values were achieved with the Reese and Wright (1977) produces a high carrying capacity value that is not significantly different from the carrying capacity value obtained using the finite element method.

Specifically, square cross-section foundations demonstrate greater bearing capacity than circular cross-sections. From all analyses, the combination of a square cross-section and a depth of 13 metres produces high bearing capacity. However, based on the physical and geotechnical conditions at the research site, pile foundations at a depth of 9 metres are considered sufficiently safe and efficient. This is because at that depth, the soil layer is classified as hard soil, which is adequate to support the load, so there is no need for piling to a depth of 13 metres. Thus, the choice of foundation design not only considers theoretical bearing capacity, but also cost efficiency and actual soil conditions in the field.

Pile Settlement

Settlement of foundations is greatly influenced by the condition of the soil layers surrounding the foundation and the cross-sectional area of the columns (Ardiyanti et al., 2023). Piles with a larger cross-sectional diameter generally experience less settlement (Fajarsari & Sukirman, 2022). This occurs because a larger cross-sectional area allows the load to be distributed more evenly to the ground, thereby reducing the pressure on the ground per unit area and minimising settlement (Dwi Anggoro et al., 2022).

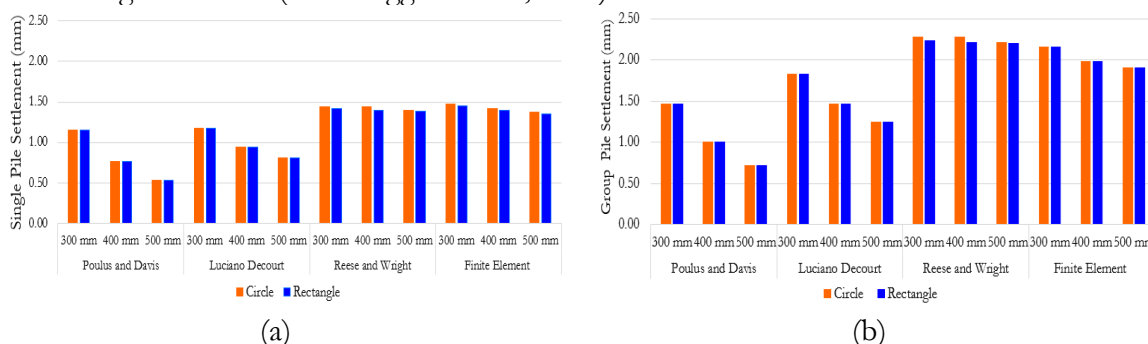


Figure 7. Foundation Settlement of Square and Circular Cross-Section Piles (a) Single Pile (b) Group Pile

Figure 7 shows the results of settlement using several pile foundation analysis methods, as each method has a different level of accuracy. In addition, the cross-sectional diameter and shape of the pile also affect the bearing capacity obtained. The Poulos and Davis (1980) method produced the smallest settlement value.

Deflection due to Lateral Force

The position of the clamping point is located at a certain depth from the ground surface, and foundation clamping points that are completely buried in the ground do not have a significant effect on pile reinforcement. This is due to the relatively small moment, which also results in horizontal pile deflection that is considered safe because its magnitude does not exceed the maximum deflection allowed for piles with clamped heads, which is 6 mm (Ramadhan et al., 2022). Based on Table 2, the pile deflection value (Y_0) is influenced by variations in dimensional size; the smaller the foundation cross-section size, the smaller the deflection that occurs.

Table 2. Deflection Values of Pile Foundations for SCADA Buildings

Shape	Diameter (mm)	Y_0 (mm)
Square	300	0.045
	400	0.052
	500	0.058
circle	300	0.045
	400	0.052
	500	0.058

Bearing Capacity Ratio

BCR values obtained from conventional approaches often differ from the results of analyses using the finite element method. Conventional approaches generally rely on analytical formulas and simple assumptions regarding soil and foundation behaviour, thus tending to provide more conservative bearing capacity estimates. Meanwhile, the finite element method is capable of analysing soil and foundation interactions in greater detail, including stress distribution, strain, and deformation. By considering the non-linear properties and variations in soil characteristics, this method produces more accurate and realistic bearing capacity estimates in accordance with field conditions

Based on Table 3, it can be determined that for an individual pile, the BCR value obtained from the Reese and Wright (1977) approach is close to 1, indicating that the computed bearing capacity is very close to the results obtained from the finite element approach. The BCR value for the bearing capacity of pile groups calculated using the conventional method, with values close to the Finite Element Method, was obtained from the Reese and Wright method. Therefore, provides results closest to the actual conditions of the study area.

Table 3. BCR Value Soil Bearing Capacity Single Pile Foundation and Group Piles Foundation

Method	Shape	Depth (m)	BCR Single Foundation	BCR Grup Foundation
Qu Poulus and Davis (1980)	circle	7	2.45	2.19
		9	2.79	2.05
		11	1.03	0.75
		13	0.91	0.67
	Square	7	1.92	2.03
		9	2.19	1.85
		11	0.81	0.68
		13	0.72	0.61
Qu Reese, and Wright (1977)	circle	7	1.30	1.15
		9	1.25	1.12
		11	1.10	1.09
		13	0.95	1.08
	Square	7	1.02	1.09
		9	0.98	1.04
		11	0.86	0.99
		13	0.78	0.99
Qu Luciano Decourt (1987)	circle	7	1.40	1.16
		9	1.49	0.92
		11	1.41	0.80
	Square	13	1.39	0.73
		7	1.03	1.08
		9	1.23	0.83

Method	Shape	Depth (m)	BCR Single Foundation	BCR Grup Foundation
		11	1.17	0.73
		13	1.15	0.67

Conclusion

Based on the analysis results of pile foundation bearing capacity from a series of variations referring to SPT (Standard Penetration Test) data, it was found that the method of Reese and Wright (1977) produced the highest bearing capacity when compared with other standard methods. The bearing capacity values obtained using the Reese and Wright (1977) method were closest to the results obtained using the finite element method. These results were obtained for a 500 mm foundation using the Reese and Wright method at a depth of 9 m, yielding a bearing capacity of 439.04 tonnes for a single pile and 292.69 tonnes for a group of piles. The bearing capacity value using the finite element method is 445.12 tonnes for a single pile and 308.23 tonnes for a group of piles. Thus, giving more indicative results of the actual situation in the study area.

The pile sizes determine the foundation bearing capacity. It is clear that the greater the pile cross-sectional area, the greater the foundation bearing capacity. This is because the cross-sectional surface area determines the amount of load that can be transferred to the ground. Based on the Poulos and Davis method (1980s), this method shows a smaller depreciation value for the decline in group pile foundations with a value of 0.72 mm and single pile foundations with a value of 0.54 mm.

Overall, from the various variations analysed, pile foundations with a 500 mm square cross-section and a depth of 9 metres proved to be the most efficient and safe solution. These dimensions are capable of providing adequate support and producing deflection and settlement that are still within permissible limits, thereby reducing the risk of structural damage.

For the perfection of research, to obtain more optimal results, the author suggests conducting pile bearing capacity analysis using sondir data with a comparison of several calculation methods, such as the Vesic method, etc., as well as conducting a budget plan analysis to determine the most efficient type of foundation and dimension variations, and creating an efficient 3D foundation model.

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