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Analysis of the Effect of Variations in Bored Pile Foundation Dimensions on Foundation Performance and Material Costs

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Abstract
Bored pile foundation is one of the common choices used to support building structures such as the Mega Kuningan Tower construction project. In this study, variations in the dimensions of bored pile foundations will be investigated to determine their effect on foundation performance and material costs. This study evaluates several variations in bored pile foundation diameter and depth to determine the optimal combination that meets the foundation performance requirements while minimizing material costs. Parameters evaluated include bearing capacity, settlement, and structural integrity. Material cost analysis is performed for each dimension variation. The results of this study are expected to provide a better understanding of how bored pile foundation parameters affect structural performance. This information has the potential to help engineers design more efficient and reliable foundations in a variety of soil and environmental conditions.

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Keywords: Bored pile foundation, foundation bearing capacity, settlement, material costs

Introduction

Jakarta is the capital of Indonesia and the center of the economy and government. Nowadays, it is very difficult to get residential land in Jakarta due to the large number of residents and migrants living there. To solve this, many property developers are now offering residential land for rent, flats, hotels or apartments. In addition to addressing space issues, building construction must consider security, safety, and the interests of the community in accordance with engineering ethics. Therefore, buildings must be designed by considering various factors that affect them, such as the environment, soil, seismic aspects, work methods, and material cost (Mochtar and Prastyo, 2024; Mochtar and Saputra, 2023) [6,7].

Bored pile foundations are constructed by first drilling into the ground before inserting the assembled rebar and then casting concrete. In cases where there is water in the ground, an iron pipe, or *temporary casing*, is required to hold the walls of the hole against collapse. This pipe will be removed during the concrete casting process. Bored Pile has many advantages, such as eliminating pile caps, requiring less due to its larger diameter to increase the bearing capacity of the pile, producing no vibration during the execution process, and can penetrate shallow soils more easily.

The choice of the type of pile foundation depends on the function of the *upper structure* to be carried by the foundation, the magnitude and weight of the upper structure, the condition of the soil on which the foundation is built, and the cost of the foundation compared to the upper structure (Sardjono, 1998) [9]. The materials used to form the piles, the dimensions, depth, spacing between piles, the number of piles used, and the pile arrangement all affect the bearing capacity of this group of bored pile foundations. In addition, they have lower vibration (Thasnanipan *et al*., 1998) [10].

The case study is in multi-story Mega Kuningan building, Indonesia (Figure 1 and 2); it uses existing foundation of 1 meter diameter as many as 3 piles per group that will be varying the pile foundation in this study with pile diameter of 0.8 m and 0.6 m.. In order to ensure the capacity of the soil to support the load of the structure above it, a preliminary inspection is necessary because the foundation is very close to the ground. According to Hardiyatmo (2002) [3], this project's soil examination uses a static method derived from the cone penetration test (CPT) (Figure 3), an index that indicates the bearing capacity of the soil

Using an empirical formula. From the above background review, the authors try to study, analyse the effect of variations in *Bored Pile* dimensions on foundation performance and material costs.

Methodology

This research methodology is a literature study, and is expected to analyse the effect of variations in the dimensions of the foundation diameter plan on alternative variations in the diameter of foundation piles on foundation performance and more optimal material costs. Data analysis includes comparison analysis of bored pile foundation capacity, bored pile foundation lateral bearing capacity and settlement, and finally material cost.

Literature Review

A. Soil

Soil plays a vital role in civil engineering as it is the main element that supports almost all types of structures. Soil always plays an important role in any construction work. Soil is the supporting base of a building or the construction material of the building itself. In general, all buildings are made above or below ground level, so a foundation system is needed that will transfer loads from the building to the ground (Bowles, 1997) [1].

In pile foundation planning, soil investigation should be carried out with the following objectives:

1. Obtain information about soil and rock layers.
2. Seek information on the presence of groundwater table.
3. Obtain data on the physical and mechanical properties of rocks.
4. Identify soil parameters for foundation analysis or simulation of second-level construction processes.

In addition, the stages of soil investigation are as follows:

1. Evaluation and study of site conditions. Site conditions may include topography, vegetation, access roads, existing buildings, geology, regional seismicity, site regulations, structural loads, etc.
2. Preliminary soil investigations, to plan subsequent soil investigations, drilling and field tests were conducted in limited numbers.
3. A detailed soil investigation, this can help planners and contractors determine the type, depth and bearing capacity of foundations and anticipate settlement.

B. Bored pile foundation

Bored pile foundations are usually used in stable and rigid soils where it is possible to form a stable hole with drilling tools. Dry, *casing*, and *slurry* methods are commonly used in bored piles. The first method corresponds to cohesive and face type soils a.

1. **Dry method implementation**
   This method is suitable for cohesive soils with a water table below the bottom of the borehole or if the permeability of the soil is quite small. Concrete casting can be done before the influence of water.
2. **Implementation with casing**
   Casing is required where ground collapse in the borehole may occur. Under certain conditions, casing must be inserted with a *vibrator*. The casing should be long enough to cover all parts of the ground that may collapse as a result of excavation and to counteract artesian pressure. Casing is also used in casting above ground or in the middle of water.
3. **Implementation with Slurry**
   This method can only be used for situations that require *casing*. The *slurry* height in the borehole must be sufficient to provide higher water pressure around the borehole. With the use of *slurry* it is generally desirable not to leave the *slurry* too long in the excavation so that the mixture does not result in a form of viscous material that sticks to the borehole walls. Placement of this viscous material can reduce the frictional capacity of the borehole blanket.

C. Bearing capacity of bored pile foundations

Calculating bearing capacity can be done by relying on specific test equipment, such as Standard Penetration Test (SPT) and Cone Penetration Test (CPT), or based on soil shear strength characteristics from field and laboratory soil tests. The bearing capacity of bored pile foundations in soil usually depends on the bearing capacity of the pile tip and the shear capacity between the soil layer and the foundation structure. The analysis of the bearing capacity of bored piles begins with studying how to support the load of bored piles. Bored piles can be divided into *end-bearing* piles and *friction* piles. The length of the pile determines the shear ability of the soil. The end bearing capacity of the pile (Qp) and the bearing capacity of the pile blanket (Qs) form the bearing capacity of the pile.
The type of collapse that occurs, which consists of single pile collapse and block collapse, greatly affects the bearing capacity of the combined pile.

D. Bored pile foundation settlement

Subsidence, or settlement, is the term used to indicate the movement of a particular point on a building with respect to a fixed reference point. Non-uniform settlement is usually more harmful to a building than total settlement. According to Hardiyatmo (2008) [4], in addition to *bearing capacity failure*, any excavation process is always associated with changes in the stress state in the soil. Changes in shape are always followed by changes in stress, which usually result in foundation settlement.

1. **Estimated settlement of single pile foundations (Single Pile)**
   Immediate settlement or commonly referred to as elastic settlement is the settlement of foundations that occur in soil layers located in saturated fine-grained soils that occur immediately after the working load. To calculate the elastic settlement (Se) of a single pile on a foundation can be divided into three components. So that the total settlement that occurs is the result of the sum of the three components.
2. **Pile group foundation settlement**
   The settlement of a pile group under load is an accumulation of immediate settlement and consolidation settlement (Si and Sc). Immediate settlement, which is a form of elastic settlement, occurs immediately after stresses act on dry or partially saturated fine-grained soils without involving changes in *moisture content.* Stress acting on saturated (and nearly saturated) fine-grained soils will produce time-dependent strains. Time-dependent settlement is called consolidation settlement.
3. **Permissible Settlement**
   The permissible settlement of a building construction depends on several factors. These include: the type, height, function of the building, and the amount and speed of settlement and its distribution. If the settlement that occurs is slow, the more likely it is that the structure can adjust to the settlement that occurs without

construction collapse or structural damage due to the influence of creep. Therefore, the criteria for foundation settlement that occurs in sand and clay soils are different.

E. Safety Factor

Reese and O'Neill (1989) [8] suggest that the selection of safety factor (SF) for pile foundation planning can be considered from the following factors: type and importance of the structure, soil variability, thoroughness of soil investigation, type and number of soil tests conducted, on-site load test availability (pile load test), supervision/quality control in the field, and possible actual design loads that occur during the service load of the structure (Hardiyatmo, 2010) [5].

Analysis and Discussion

A. Upper Structure

After structural analysis is carried out on Mega Kuningan building, Indonesia (Figure 1), the output results data are obtained; the maximum internal forces of column due to load combinations is shown in Table 1. The maximum forces on the base column are used as the plan load on the analysis of the number of bored pile foundations.

B. Axial bearing capacity

Table 2 shows the comparison of result of calculation of ultimate bearing capacity. It can be seen that the larger pile diameter the higher axial bearing capacity.

C. Lateral bearing capacity of bored pile foundation

Table 3 shows the comparison of lateral bearing capacity with various pile diameters, and Table 4 shows the deflection of each pile diameter variation. It shows that the deflection value of the lateral bearing capacity that occurs based on the diameter variation shows that the larger the diameter used, the greater the deflection results.

D. Analysis of number of poles required

In determining the maximum number of axial load piles, the axial load strength (Table 2) is used based on the results project data with an axial load Pu max value of 15770.57 kN (Table 1). One meter diameter *bored pile* requires 2.3 or using 3 piles, 0,8 meter diameter bored pile requires namely 3.42 or using an arrangement of 5 piles, and 0,6 meter diameter bored pile requires 5.7 or using an arrangement of 9 piles.

E. Analysis of bored pile foundation

Table 5 is the recapitulation of the pile group bearing capacity comparison of calculation methods and diameters. All the pile diameters are safe for the group capacity Qg is higher than Pu load of building column, meaning that engineers have alternatives of bored pile groups for their foundation design. Table 6 shows the comparison of settlements for various pile diameters; it can be seen that the larger pile diameter the smaller settlement of the pile. Finally, Table 7 shows the material cost of various pile diameter with pile depth of 26 meter; it can be seen that the larger pile diameter the lower material cost.

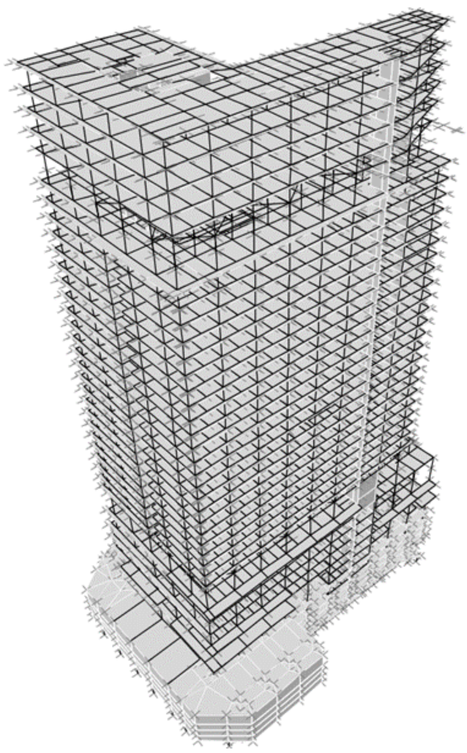
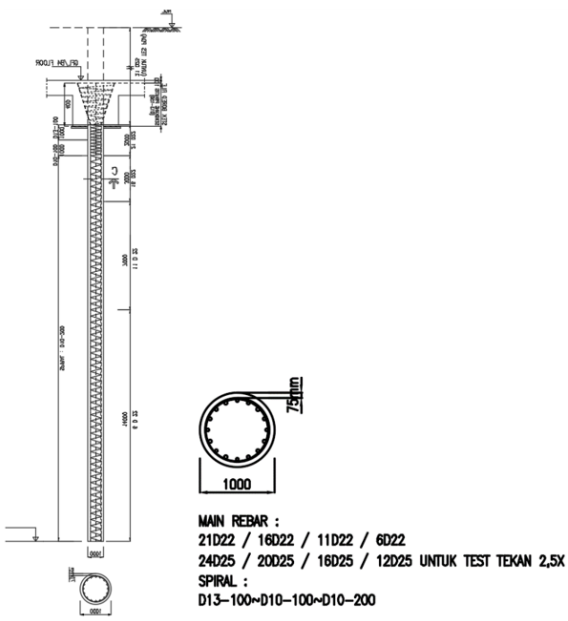


Fig 3: D Modeling Project Study Mega Kuningan Building, Indonesia



v

Fig 2: Detail of Existing Bored Pile

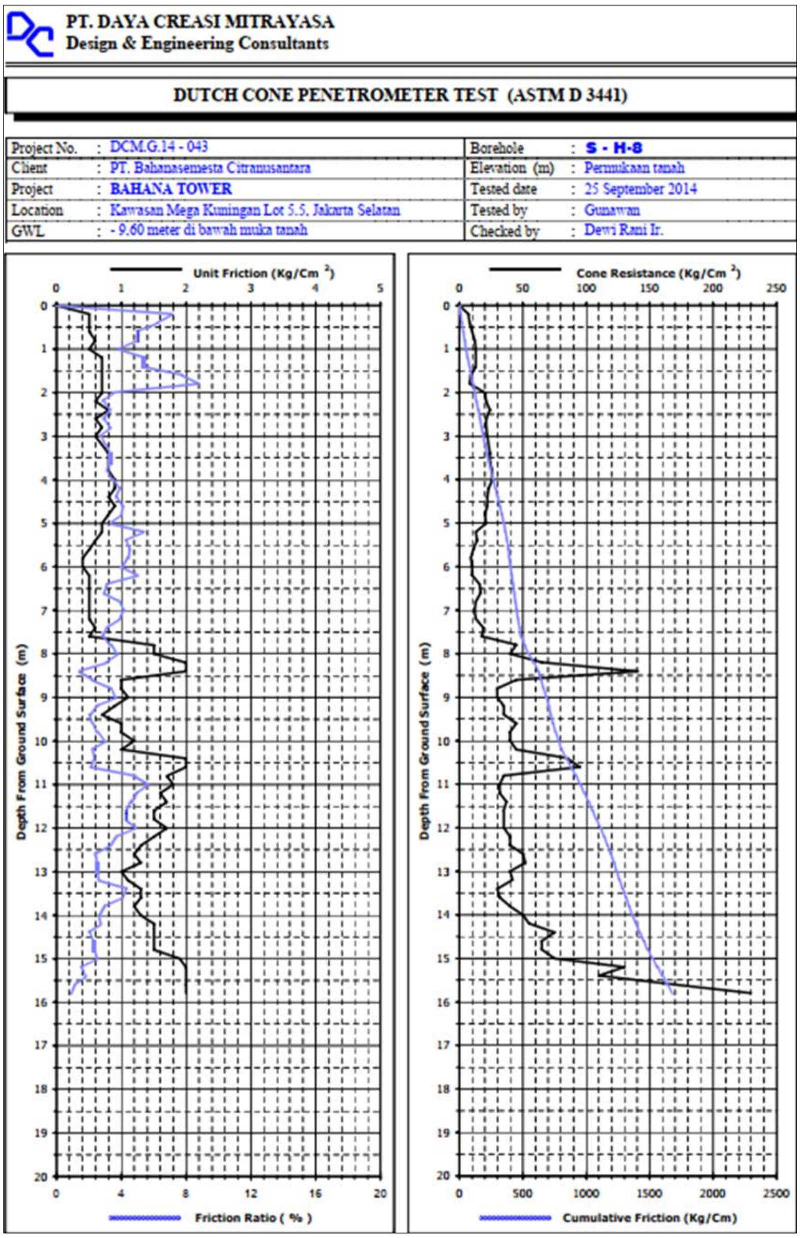


Fig 3: CPT Graph

Table 1: The Maximum Forces of Column due to Load Combinations (Gibran, 2024)

Loads	Maximum Forces
Axial load (P) max	15770.57 kN
Moment (My) max	989391.8 kN
Moment (Mx) max	960732.1 kN

Table 2: Comparison of Diameter Variation Axial Bearing Capacity of Single Pile (Gibran, 2024)

Axial Bearing Capacity			
Diameter (m)	0.6	0.8	1
Qult (kN)	9490,085	15484,47	22894,37
Qall (kN)	2747,324	4606,774	6938,06

Table 3: Comparison of Diameter Variation Lateral Bearing Capacity (Gibran, 2024)

Lateral Bearing Capacity			
Diameter (m)	0.6	0.8	1.0
Hu (kN)	337,46	598,48	938,44

Table 4: Comparison of Diameter Variation Deflection (Gibran, 2024)

Diameter (m)	Pile deflection (m)
0.6	0.00716
0.8	0.00800
1.0	0.00870

Table 5: Comparison of Diameter Variation of Pile Group Bearing Capacity (Gibran, 2024)

Methods	Meyerhoff			Aoki de Alencar		
Diameter (m)	1	0.8	0.6	1	0.8	0.6
Qu (kN)	22894,37	15484,47	9490,085	4671,66	3356,34	2231,52
Pu (kN)	15770,57	15770,57	15770,57	15770,57	15770,57	15770,57
Qall (kN)	6938,06	4606,774	2747,324	1868,66	1342,54	892,61
Pile Number	3	5	9	15	20	30
Qg (kN)	16027	16584	16813	18219	16647	16066
Check	Safe	Safe	Safe	Safe	Safe	Safe

Table 6: Recapitulation of Settlement Comparison of Dimensional Variation Reduction (Gibran, 2024)

Meyerhoff			
Pole diameter (cm)	1	0.8	0.6
Total Settlement (cm)	9,00	11,20	13,20

Table 7: Cost Comparison Analysis of Bored Pile Diameter Variation (Gibran, 2024)

Diameter (m)	Depth (m)	Qall	Number of poles	Cost analysis
1	26	6938,0603	54	Rp. 2,285,130,204
0.8	26	4606,7735	90	Rp. 3,560,710,615
0.6	26	2747,3242	162	Rp. 4,367,005,812

Conclusion

Based on the results of the discussion on the analysis of bearing capacity and settlement and material costs of bored pile foundations in the Mega Kuningan Building project, it is concluded that in the analysis of structural loading obtained from the calculation of the maximum axial load is 15770.57 kN. It can be safely designed by using bored pile group with various diameter, either 0,6 m, 0,8 m, or 1 m One meter pile requires a group of three piles, 0,8 meter pile requires a group of five piles, and finally 0,6 meter pile requires a group of nine piles.

The magnitude of the decrease in the axial bearing capacity of the pile group with the variation of the larger diameter, the smaller the value of the pile decrease, due to the wider area in the pile group, the smaller the value of the pile decrease. The material cost per meter increases with the increase in bored pile dimensions, in this research case study with a total number of points of foundation the use of three bored piles foundation with a diameter of one meter with a length of 26 m and a pile group of 3 piles is more effective and efficient with a cost of Rp. 2,150,311,260. The variation of bored pile foundation dimensions has a significant influence on foundation performance, especially in terms of bearing capacity and settlement as well as material costs in project implementation.

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