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Analysis of Mini Pile Foundation in Istiqlal Mosque Loa Bakung Samarinda Construction Project Based on CPT and SPT Data

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Abstract – Construction methods are component within construction projects in order to achieve the project's objectives, namely cost, quality, and time. The use of appropriate, practical, fast, and safe methods greatly assists in completion of tasks within a construction. This ensures that the predetermined targets of time, cost, and quality can be achieved. The purpose is to understand the implementation methods of work and analysis of the load-bearing capacity of hydraulic jack-in pile. Hydraulic Jack-In Pile is a method for driving foundation piles using a hydraulic jack-in system. It consists of a hydraulic ram positioned in parallel with the pile. To press the pile, a pressing plate mechanism is placed at the top of the pile, and a gripping mechanism is employed to hold the pile, then the pile is pressed. The hydraulic jack-in pile is considered effective because it is more environmentally friendly, relatively faster and easier. The load-bearing capacity of the pile can be determined directly. The concrete driven piles used in the Istiqlal Mosque Construction are precast reinforced concrete piles with dimensions are 20 x 20 cm, 30 x 30 cm, and 40 x 40 cm, using concrete grade K-500. The pile driving in the construction project of Istiqlal Mosque involves total 87 points. From the average pile driving results at a depth of 36 meters and the difference in the calculated bearing capacity of the mini piles for the three respective dimension variations based on CPT data is 11.57%, 27.57%, and 44.27% larger than the SPT data.

Keywords: methods, hydraulic jack in, pile foundation

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1. Introduction

Civil buildings are divided into two parts: the upper structure and the substructure, which distinguishes them by the structure above and the supporting ground below. If the encountered supporting ground is problematic, such as soft soil, the selection of the foundation type becomes more challenging. The main issues when dealing with a building on soft soil are its bearing capacity and settlement [1]. In the present time, with the advancement of increasingly sophisticated technology over time in all fields, particularly in the field of construction engineering, several important aspects must be considered in the planning of multi-story building construction. These aspects include environmental considerations, economic factors, and safety aspects. Therefore, a well-thought-out plan is necessary so that any potential obstacles that may arise in the future can be effectively overcome [2], [3].

Considering the increasing level of the economy in Indonesia, particularly in the East Kalimantan region, especially in the city of Samarinda, which is actively undergoing development in various sectors, ranging from religious development like the construction of the Istiqlal Mosque, which is a significant Islamic center and a place of worship, particularly for the community in the KORPRI Housing Complex and Loa Bakung Village. However, this is accompanied by the growing population and the aging of the mosque's building. Therefore, there is a need for mosque building rehabilitation to maintain the comfort of worship for the community, promote Islamic teachings, and foster interfaith tolerance.

Soil plays a crucial role, thus in construction work, the form and structure of the soil must be carefully examined due to the uncertain conditions of various soil types. Soil is the Earth's dynamic surface layer, and changes in soil are influenced by several factors such as air, water, and the shifting of tectonic plates [4]. First and foremost in fieldwork is foundation work, as foundations hold a vital and significant role in civil engineering projects. In general, a foundation can be defined as a part of a building's construction that serves to place the building and transmit the loads from the upper structure to the foundation soil below, which is sufficiently strong to withstand these loads without experiencing soil sliding failure and differential settlement in its structural system [5]. Hence, there's a need for discussion regarding the implementation of pile foundation work and the maximum load-bearing capacity of the foundation under the applied loads.

There are two commonly used types of deep foundations in Indonesia: driven piles and bore piles. Driven piles are extensively used in Indonesia as deep foundations for various structures such as bridges, multi-story buildings, factories, towers, docks, and highways [6]. The implementation methods for driven piles include several techniques: drop hammer, jack-in pile, diesel hammer, and vibratory hammer [7].

The Hydraulic Jack-In Pile equipment is highly suitable for construction projects located in the middle of cities or crowded areas as it does not produce noise and vibrations that could affect the surrounding buildings. However, in contrast to the drop hammer equipment, the Hydraulic Jack-In Pile equipment generates noise, air pollution, and can potentially cause damage to nearby structures due to its operations [8].

The jack-in pile method is a foundation piling system where the pile is driven into the ground using a hydraulic jack with a counterweight or reaction system to apply force without generating vibrations [7].

In the construction project of creating Parallel and Right Angle Taxiways at Aji Pangeran Tumenggung Pranoto Airport in Samarinda, the work involves driving mini piles with dimensions of 20 x 20 cm using a diesel hammer. The soil bearing capacity is calculated using Cone Penetration Test (CPT) and Standard Penetration Test (SPT) data using the Meyerhof method, along with data from the PDA Test for comparison [9] [10]. Meanwhile, in the construction project of the Control Room Building in Tanjung Batu, Tenggarong Seberang Sub-district, Kutai Kertanegara, the foundation of driven piles is recalculated and redesigned using the Meyerhof method [11]. In this study, an analysis is carried out for the foundation of mini piles with dimensions of 20 x 20 cm, 30 x 30 cm, and 40 x 40 cm using CPT and SPT data with the Meyerhof method.

2. Method

The research was conducted at the Istiqlal Mosque Construction Project in KORPRI Housing, located at Jakarta Street, Block I, Number 12, Loa Bakung, Samarinda, East Kalimantan. The activity's location is depicted in Figure 1. The subject under investigation is the implementation of driven piles using the hydraulic jack-in pile system. Data collection stages were carried out through direct observation in the field. Capturing documentation in the form of photos during each stage of the project and utilizing them as attachments in the article [12]. The process began with data collection and recording the pile driving results in the pile foundation capacity monitoring format. Analysis of the pile foundation capacity was conducted based on Cone Penetration Test (CPT) values.

Figure 1. The location of the Istiqlal Mosque Construction
Source: Google maps, 2023

2.1. Mini Pile Bearing Capacity Based on CPT Data

Cone Penetration Test (CPT) technology offers rapid testing, reliable data, and cost-effectiveness when compared to traditional site characterization methods. Additionally, it is particularly suitable for investigating soft soil conditions. The method of determining pile bearing capacity based on CPT data provides different calculations for end-bearing and skin friction of the pile. Hence, an evaluation of this method is necessary to obtain an approach that provides pile bearing values close to the actual values. The Meyerhof method (1963) is one of the techniques used to determine the bearing capacity of mini piles based on CPT data [13].

$$Qp = \frac{qc \times Ap}{FK1} \tag{1}$$

$$Qs = \frac{JHL \times As}{FK2} \tag{2}$$

$$Qult = Qp + Qs \tag{3}$$

Where :
Qp = Pile Bearing Value (ton),
qc = Conus Value (Kg/cm2),
Ap = Cross Sectional Area Pile (cm2),
Qs = Pile Friction Bearing Capacity (ton),
JHL = Jumlah Hambatan Lekat (Kg/cm2),
As = Side Pile Area (cm2),
FK = 3 and 5 (Safety Factor)

Based on material strength

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$$Qa = \sigma'b \times Ap \quad (4)$$

$$\sigma'b = 0{,}25\text{-}0{,}33 \times f'c \quad (5)$$

Where,

Qa = Pile Bearing Value (ton),

σ'b = Allowable Stress of Conrete (0,25-0,33),

Ap = Pile Bearing Value (cm^2).

2.2. Mini Pile Bearing Capacity Based on SPT Data

The bearing capacity of driven pile foundations can be determined based on the end-bearing resistance and the pile-soil friction. The capacity of pile foundations can be determined by analyzing the Standard Penetration Test (SPT) data obtained from field soil testing or by conducting Pile Driving Analysis (PDA) tests. Therefore, an evaluation of these methods is necessary to obtain an approach that provides pile bearing values close to the actual values. The Mayerhof method is one of the techniques used to determine the bearing capacity of mini piles based on SPT data using the Meyerhof method [14]. For the load inclined, it is advisable to use power calculations for the soil bearing capacity on shallow foundations with the Meyerhof method because it obtains a relatively more stable increase in soil bearing capacity [15].

Based on Standart Penetration Test (SPT) Data:

$$Qp = 4.Ap.Np \quad (5)$$

Where :

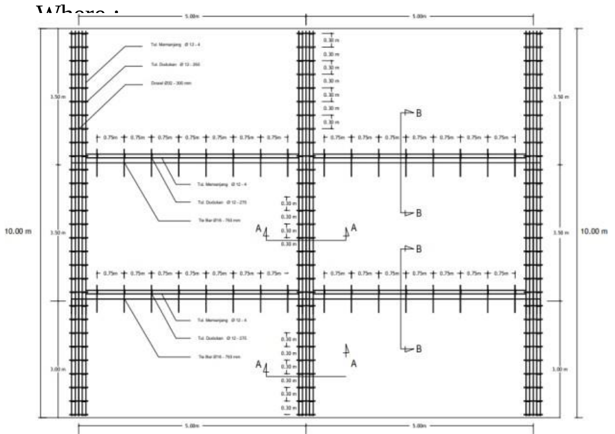
Qp = Pile Bearing Value (ton)

Ap = Cross Sectional Area Pile (ft2)

Np = N-SPT value

$$Qs = \frac{As \times N}{50} \quad (6)$$

Where :



$$Qijin = \frac{-}{SF} \quad (8)$$

Where :

SF = Safety Factor (2,5 - 4)

3. Result and Discussion

3.1. Concrete Piles

Concrete driven piles can be categorized based on their construction method into two types, as follows:

a. Cast in Place Pile: This is a foundation that is cast in its final location by first creating a hole in the ground through soil boring (bored pile foundation).

b. Precast Reinforced Concrete Pile: These are concrete driven piles that are manufactured off-site or in a factory.

The concrete driven piles used in the Istiqlal Mosque Construction Project in Loa Bakung, Samarinda, are precast reinforced concrete piles with dimensions of 20 x 20 cm, 30 x 30 cm, and 40 x 40 cm, using concrete grade K-500.

Before using driven piles, a physical inspection of the pile materials is conducted, as follows:

a. There should be no cracks, defects, or breakage in the pile.

b. The joint plate at the end of the pile body must remain intact and in good condition.

c. The size of the cross-section and length of the pile must adhere to the specifications, with the following tolerances:

   1. The cross-section of the pile should not deviate by more than 6 mm from the design cross-section of the pile.
   2. Each side of the pile should not have a deviation greater than 6 mm per 3 m length.

The location of pile stacking is positioned near the pile driving point to facilitate the lifting process of the piles. If, under specific conditions, the piles are placed far from the pile driving point, a separate crane service should be provided to lift the piles from the stacking location to the piling equipment to ensure that the piling process is not hindered by time constraints.

3.2. Minipile

Mini piles are a type of pile foundation used to support various structures such as buildings, bridges, docks, retaining walls, and more [16]. Hydraulic Jack-In Pile is a method of pile installation in which the process involves pressing the driven pile into the ground using a hydraulic jack [17]. This hydraulic jack is equipped with a counterweight load to prevent the piling equipment from lifting and to assist in driving the pile until its designed bearing capacity is achieved. In the construction project

e-ISSN: 2723-3944

of the Istiqlal Mosque in Loa Bakung, Samarinda, a Hydraulic Jack-In Pile equipment with a capacity of 240 tons is used, as shown in Figure 2

Figure 2. Hydraulick Jack In Pile
Source: Documentation, 2023

Advantages of the pile driving process using Hydraulic Jack-In Pile include the following [18].

a. It doesn't generate noise during the piling process and doesn't produce significant smoke pollution compared to the use of diesel hammer piling machines.
b. It doesn't create vibrations around the piling location, making it safe for nearby structures.
c. By using the Hydraulic Jack-In Pile equipment, it's unlikely for cracks to form on the pile head, and the occurrence of necking (indentation in the foundation) as seen in bored pile systems is also avoided.
d. The estimated bearing capacity of the pile can be directly determined from the reading of the pressure gauge on the Hydraulic Jack-In Pile equipment. This is because the Hydraulic Jack-In Pile machine is equipped with a pressure gauge (in MPa units), as shown in Figure 3.

Figure 3. The pressure gauge found on the Hydraulic Jack-In Pile machine
Source: Documentation, 2023

The Hydraulic Jack-In Pile equipment has two positions of pile clamps (Clamping-Box) for applying pressure during the penetration of the pile into the ground. These clamp positions are located at the end and in the middle of the equipment (referred to as end grip and middle grip), as shown in Figure 4.

Figure 4. Position Grip (a) End Grip (b) Middle Grip
Source: Documentation, 2023

a. The pile driving position and the required working space of the piling equipment. By using the end grip, this Hydraulic Jack-In Pile equipment will require less working space compared to using the middle grip. The end grip is employed for driving pile points that are very close to existing structures.
b. Equipment capacity, with the end grip, the achieved capacity is only 70% of the total equipment capacity.

3.3. Measurement and Determination of Pile Points

Measuring pile points involves transferring drawings after land clearance. Thorough clearance is vital, as uncleared sites disrupt measurements. Precision is key to identify pile and foundation positions, acting as column centerlines. The process uses theodolite and water level instruments for centerlines (see Figure 5). Measurements start from Bench Mark (BM) and progress. Surveyors use theodolite for accuracy. Markers denote exact positions for driving.

Figure 5. Measurement and Determination of Pile Points using Theodolite
Source: Documentation, 2023

3.4. Pile Driving using Hydraulic Jack-In Pile Equipment

The pile driving work in the construction project of

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Istiqlal Mosque in Loa Bakung involves a total of 87 points to be driven. These are categorized as follows: 21 points under PC.1, 10 points under PC.2, 12 points under PC.3, and 44 points under PC.4. The distance between each pile point is 120 cm, as shown in the pile layout plan below (Figure 6).

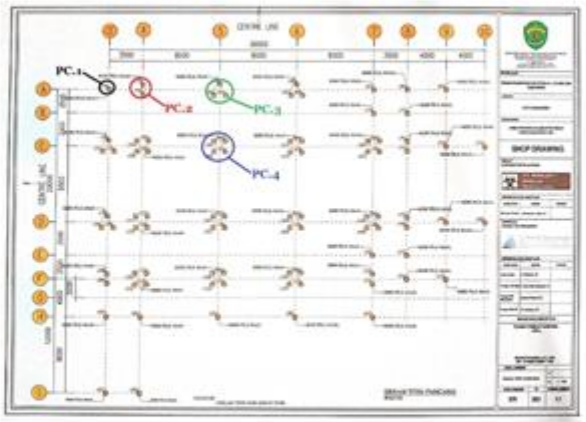

Figure 6. Pile Layout
Source: PT. Berkarya Berkah Bersaudara

In this project, pile segments of 9 meters are utilized for the lower portion, 9 and 10 meters for the middle, and 6 meters for the upper part. This creates 3-4 connection points per pile point. Using a "pencil pile" as the bottom segment during pile driving is essential to prevent soil heaving and facilitate penetration. The process of hydraulic jack-in pile driving is as follows:

1. Secure the first pile segment (bottom), which is 9 meters (pencil or pointed end).
2. Lift the first pile segment (bottom), which is 9 meters (pencil or pointed end).
3. Rotate or move the first pile segment (horizontally) to the pile point.
4. Insert the first pile segment into the pile clamping box on the equipment.
5. Align the pile segment vertically with the pile point.
6. Penetrate the pile segment into the ground by pressing it.
7. Press the pile segment until about 40 cm of the pile remains above the ground surface for subsequent connection.
8. Retrieve the second, third, and fourth pile segments, each 9 or 10 meters in length for middle segments and 6 meters for the top (connection segment).
9. Lift, move to the pile point, insert into the pile clamping box, and align vertically with the pile point and the already driven pile segment.
10. Weld the connections (joints 1, 2, 3, and 4), and press the connected pile segment after welding each joint.
11. If needed, use a dolly for assistance in pile penetration.
12. Pile driving is carried out until the designed bearing capacity of the pile is achieved or until the hydraulic jack-in pile equipment's capacity is reached (20 MPa with 2 cylinders or 10 MPa with 4 cylinders = 108 tons with a foundation bearing capacity of 92 tons).
13. Move to the next pile point.

The connection between pile segments is achieved using welded connections. Welding between pile segments is performed on the steel plate (bevel) available at the end of the pile body, as shown in Figure 7. The pile welding process is as follows:

1. Mini Pile segments are joined by welding steel plates onto both sections. Welding encompasses the perimeter, utilizing a 250 A capacity welding machine.
2. Prior to welding, aligned pile parts match the driven portion, with the connecting plate cleaned.
3. To ease welding, the driven pile is raised about +/- 40 cm from ground level. Welding a 40 x 40 cm square mini pile takes approximately +/- 10 minutes, readying it for the next drive.

Figure 7. Pile Welding
Source: Documentation, 2023

To aid in the pile driving process when the pile has slightly sunk into the ground and is about to reach harder soil, a pile driving assistance tool called a "dolly" is used.

This subtask is a part of the pile driving process that functions to increase the depth of the pile if the embedded pile hasn't reached the desired compression strength. In this project, the desired compression strength is 20 MPa with 2 cylinders or 10 MPa with 4 cylinders. On average, a dolly with a depth of 1 meter is used for each pile point.

When the pressure gauge hits 20 MPa with 2 cylinders or 10 MPa with 4 cylinders, signifying the pile's bearing capacity, the hydraulic jack-in pile equipment stops applying pressure. After halting pile driving, recording includes pile depth and pressure gauge readings from the equipment.

3.5. Bearing Pile Based on CPT Data

The analysis of the bearing capacity of mini piles with CPT data can be calculated using the Meyerhof method.

e-ISSN: 2723-3944

This calculation is based on the CPT values at 3 points with a depth of the mini pile = 36 m. The CPT data can be seen in Table 1. CPT or cone penetration testing is a static testing method that utilizes a cone at the end of a rod, which is directly pushed into the soil. To press the cone and measure the force, a mechanical jack is used with a regular speed [19].

Table 1
Cone Penetration Test (CPT)

Pile Point	Depth (m)	Conus (qc) (Kg/cm2)	Jumlah Hambatan Lekat (JHL) (Kg/cm2)
S-01	16,20	200,74	2451,79
S-02	5,00	201,73	478,44
S-03	11,60	202,72	1161,93

The results of the bearing capacity calculation of Mini Piles based on CPT data at 3 points using the Meyerhof method are presented in Table 2.

Table 2
Result Of Bearing Capacity Analysis of Mini Pile Based on CPT

Pile Point	Qp (Ton)	Qs (Ton)	Qult (Ton)
Minipile 20 x 20			
S-01	26,765	39,228	65,993
S-02	26,897	7,655	34,552
S-03	27,02	18,59	45,620
	Average		**48,722**
Minipile 30 x 30			
S-01	60,222	58,843	119,065
S-02	60,519	11,483	72,002
S-03	60,816	27,886	88,702
			93,256
Average 40 x 40			
S-01	107,061	78,457	185,518
S-02	107,589	15,310	122,889
S-03	108,117	37,182	145,299
	Average		**151,239**

From Table 2, the average Qult for each dimension of the mini piles is obtained as follows: 48.722 tons, 93.256 tons, and 151.239 tons, respectively.

3.1. Bearing Pile Based on SPT Data

The analysis of mini pile bearing capacity using SPT data can be calculated with the Meyerhof method, the calculsation is based on the SPT value at a single point, which can be observed in Table 3. SPT data is a direct field experiment conducted to obtain the bearing capacity of soil by inserting a sample tube (split spoon) [20].

Table 3
Propertis Tanah

Depth	N- SPT		
0			
2	7		
4	8		
6	11		
8	9		
10	8		
12	13		
14	15		
16	16		
18	18		
20	15		
22	14		
24	17		
26	19		
28	16		
30	14		
32	33		
34	18	34.4	
36	20	36	Location of Pile End
38	15	36.8	
40	12		

The results from Table 3 indicate that the location of the pile end is at a depth of 36 meters with an N-SPT value of 20. The results of Mini Pile bearing capacity calculation based on Standard Penetration Test (SPT) data at one point using the Meyerhof method are presented in Table 4.

Table 4
Result Of Bearing Capacity Analysis of Mini Pile Based on SPT

Point	Minipile (cm)	Qp (Ton)	Qs (Ton)	Qult (Ton)	SF	Qijin (Ton)
BH-1	20 x 20	31,100	99,080	130,180	3	43,390
	30 x 30	67,850	144,120	211,970		70,660
	40 x 40	92,590	196,670	289,260		96,420

From Table 4, we obtained Qijin values for each dimension of the mini pile based on SPT data, which are 43.39 tons, 70.66 tons, and 96.42 tons, respectively.

Dimension (cm)	Bearing Capacity Comparison Minipile		
	CPT (Ton)	SPT (Ton)	Difference (%)
20 x 20	48,722	43,390	11,57%
30 x 30	93,256	70,660	27,57%
40 x 40	151,239	96,420	44,27%

4. Conclusions

The conclusion regarding the implementation of the driven pile foundation work using hydraulic jack-in-pile equipment for the Istiqlal Mosque Loa Bakung Samarinda

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construction project is as follows.

1. From the average pile driving results at a depth of 36 meters, the firm/hard soil or bedrock has been reached with an average of 3 additional strokes at each pile point.
2. Pile driving faced delays due to material delivery. The fabrication site is distant, and pile age required maturity, postponing driving.
3. The allowable bearing capacity of the mini piles using the Meyerhof method based on Cone Penetration Test (CPT) data obtained an average of Qult = 48.722 tons for the dimension of 20 x 20 cm, Qult = 93.256 tons for the dimension of 30 x 30 cm, and Qult = 151.239 tons for the dimension of 40 x 40 cm.
4. The allowable bearing capacity of the mini piles using the Meyerhof method based on Standard Penetration Test (SPT) data resulted in Qijin = 43.390 tons for the dimension of 20 x 20 cm, Qijin = 70.660 tons for the dimension of 30 x 30 cm, and Qijin = 96.420 tons for the dimension of 40 x 40 cm.
5. The difference in the calculated bearing capacity of the mini piles for the three respective dimension variations based on CPT data is 11.57%, 27.57%, and 44.27% larger than the SPT data.

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