A Comparison of Mini Pile Bearing Capacity based on Sondir Data and Experimental Test

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Abstract: The problem that arises due to the use of Mahang wood as a pile foundation is the exploitation of forest products on a large scale. This is because building a two-story building requires 2-3 Mahang wood for every square meter of the building. The replacement of Mahang wood into Mini Pile for building foundation is one alternative solution to overcome this problem. In the implementation of the test, four mini piles measuring 12x12x250 cm were made, erection at two points with an embedded depth of 4.5 m. Static loading test has been carried out to determine the actual capacity of the mini pile by loading the design load calculated using the Bagemann method with CPT test data. The results showed the actual capacity of one point was 4.137 tons with a settlement of 1.77 mm. This value was 2.81 times higher than the ultimate load (Pu) for the single pile design based on the CPT test.

1 INTRODUCTION

One type of foundation that is commonly chosen by the community in Bengkalis Regency to build a 2 to 4 story building is Mahang wood (*Macaranginae*) with a length of 6 to 7 m. The use of that wood as a foundation is almost the same as a concrete pile, including the method of erection by a Drop Hammer. This wood has been estimated to be strong in bearing loads, easy to acquire and economical in its application, especially in clay soil areas such as Bengkalis Regency. Nevertheless, there has been a problem of using forest products on a large scale only to build 2 to 4 storey buildings which require 2-3 mahang wood for every square meter of building.

Replacing mahang wood with mini pile concrete for building foundations is an alternative to reduce these problems. Where the mini pile has dimensions that can be adjusted to the needs, has strong resistance and quality can be controlled.

2 LITERATUR STUDY

Mini Pile is one type of pile foundation that is used to support the foundation of a construction such as bridges, docks, buildings, dolkens and others. The shape of the mini pile is generally in the form of a box or triangle with a cross section variation of 20 x 20 cm to 40 x 40 cm and a length variation between 3m to 9m. If a longer length of the mini pile is needed, it can be connected to a welded iron plate (Pamungkas E.T, et al, 2021).

2.1 Sondir Test

Sondir test, also known as Cone Penetration Test (CPT) is often used to estimate the bearing capacity of soil in deep foundations. However, it is sometimes also used to estimate the bearing capacity of shallow foundations. This has been confirmed by Eslami 2020, that the conus end resistance in the CPT test is the same as the pile end resistance. The test is carried out by pushing the cone into the ground. The soil resistance at the tip of the cone as well as the soil shaft friction was measured. So that the value of the cone

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resistance (q_c) and friction data (f_s) is obtained (Fahriani F, 2015).
There are two types of sondir, the first is the light with a capacity of 0-250 kg/cm² and the second is the heavy with a capacity of 0-600 kg/cm². The type of soil that is suitable for sondir with this tool is soil that does not contain rocks (Hairina R).

2.2 Bagemann Method

According to Yusti, 2014, piles on cohesive soil generally have conical resistance (q_c) related to undrained cohesion (c_u), namely:

$$C_u . N_k = q_c \text{ (kg/cm}^2\text{)} \tag{1}$$

The value of N_k ranges from 10 to 30, depending on the sensitivity, compressibility and adhesion between the soil and cone. Generally in design calculations using Nk between 15 to 20. The pile end resistance is taken at the average q_c value calculated from 8D above the pile base to 4D below the pile end. Safely, the frictional resistance of the unit area (f_s) of the pile can be taken as equal to the frictional resistance of the cone side (q_f):

$$f_s = q_f \text{ (kg/cm}^2\text{)} \tag{2}$$

The ultimate capacity of the pile, expressed by the equation:

$$Q_u = A_b . q_c + A_s . q_f \tag{3}$$

Where A_b is area of the bottom end of the pole (cm^2); A_s is pile blanket area (cm^2); q_c = f_b is conus resistance (kg/cm^2); q_f is frictional resistance of cone side (kg/cm^2).

The ultimate bearing capacity of the pile (Q_u), is calculated by the general equation:

$$Q_u = Q_b + Q_s = A_b . f_b + A_s . f_s \text{ (kg)} \tag{4}$$

Where f_b is pile unit end resistance (kg/cm^2); f_s is pile unit friction resistance (kg/cm^2).

2.2.1 Ultimate End Resistance

The ultimate capacity of the pile embedded in the cohesive soil is the sum of the side frictional and the end resistance of the pile. The amount of frictional resistance of the pile depends on the material and shape. Generally, for homogeneous soils, the frictional resistance of the walls in the form of adhesion between the pile side and the soil will have a large effect on the ultimate capacity.

$$Q_b = A_b . f_b \tag{5}$$
$$f_b = c_b N_c \tag{6}$$

Where $c_b$is cohesion in undrained soil conditions located below the pile end whose values are taken from undisturbed soil samples (kN/m^2); N_c is bearing capacity factor (function of φ).

For cracked clay, c_b must be taken from the shear strength of cracked clay. Reduction due to cracked soil conditions needs to be given, because this effect reduces the contact between the pile side and the soil. For piles embedded in soft to medium clay soils, the end resistance value is usually not large, so the method of calculating the bearing capacity of piles in cohesive soils is generally more focused on determining the pile frictional resistance (Q_s).

2.2.2 Ultimate Wall Friction Resistance

To determine the frictional resistance of piles driven in clay, the adhesion factor (α) collected by McClelland (1974) is used as shown in Figure 1. The frictional resistance of piles is expressed as follows:

$$Q_s = A_s . f_s \tag{7}$$
$$f_s = c_d = \alpha . c_u \tag{8}$$

Where Q_s is ultimate friction resistance (kN); c_d is adhesion between the pole and the soil (kN/m^2); α is adhesion factor is taken from Figure 1; c_u is average undrained cohesion along the pile (kN/m^2).

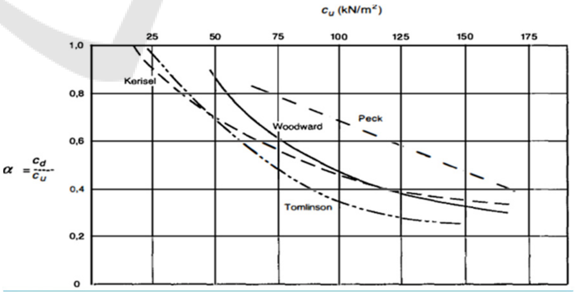

Figure 1: Adhesion factor (α) collected by McClelland (1974).

2.2.3 Pile's Ultimate Bearing Capacity

The ultimate bearing capacity of the pile is calculated by the following equation:

$$Q_u = A_b . f_b + F_\omega . A_s . f_s - W_p \text{ (kg)} \tag{9}$$

Since the self-weight of the pile (W_p) is close to the weight of the soil displaced by the pile, $A_b.p_b$ can be considered equal to W_p. Therefore, the pile bearing capacity in cohesive soils becomes:

$$Q_u = A_b.f_b + F_\omega.A_s.f_s \quad \text{(kg)} \qquad (10)$$

Where F_ω is shape factor of pile (equal to 1 for uniform pile diameter).

2.3 Pile Foundation Settlement

According to Fahriany 2015, the estimation of settlement that occurs in pile foundations is a complicated problem caused by several factors, such as disturbances in soil stress during erection and uncertainty regarding the distribution and position of load transfer from the pile to the soil.

$$S = \frac{D}{100} + \frac{Q\,L}{A_p\,E_p} \qquad (11)$$

Where *S* is single pile foundation settlement; *D* is pile diameter; *Q* is pile bearing capacity; *L* is pole length; A_p is pile cross-sectional area; E_p is modulus of elasticity of concrete pile material.

2.4 Static Loading Test

According to Hardiyatmo, 2002, the static loading test was carried out with several objectives, such as:

- Determine the graph of the load and settlement relationship, especially in the load around the expected design load.
- Ensure that foundation failure will not occur before the target load is reached. Its value is several times the design load. This value is used as a safety factor.
- Determine the actual ultimate capacity, check the results of the calculation of the pile capacity obtained from the static and dynamic formulas.

The standard test method for deep foundations under static axial compressive load consists of 7 procedures, one of which is the slow maintained test load method.

The Slow Maintained test load Method (SM Test) is recommended by ASTM D1143-81, this method is generally used in field research before further work is carried out, the testing procedure consists of:

a. Pile load is divided into eight equal stages, namely 25%, 50%, 75%, 100%, 125%, 150%, 175% and 200% design load
b. Each increase in load must maintain the rate of descent which must be less than 0.01 in/hour (0.25 mm/hour)
c. Maintain 200% design load for 24 hours
d. After the required time is reached, reduce the load by 25% with a gap of 1 hour between reduction times.

e. After the load has been applied and removed, reload the pile for load testing in increments of 50% of the design load, allowing 20 minutes for additional load.
f. Then increase the load in increments of 10% of the design load.

3 METHOD

The research stages are divided into several stages as shown in Figure 3, and are described as follows:

a. Manufacture of mini pile specimens in the form of a square cross section with a size of 12x12x250 cm, using 4Ø10 main reinforcement and D6-200mm stirrup reinforcement as seen in Figure 2. The composition of the mixture refers to the regulation of the Minister of PUPR No. 28 of 2016 for the quality of K225. In addition, several specimens of concrete cubes of 15x15x15 cm were also made to determine the quality of the mini pile concrete.
b. Sondir testing was carried out at the location of the mini pile to determine the cone resistance data (q_c) and cone side friction resistance (q_f).
c. Calculate the amount of design load that will be given to the mini pile during testing. Determination of the carrying capacity of the plan (Q_u) using the Bagemann method by analyzing the sondir test data.
d. Mini pile erection at a predetermined location using a Drop Hammer (Figure 4). One point of the foundation using two mini piles with steel plate connection as shown in Figure 5. The depth of the pile is 2x2.5 m but the embedded depth of the mini pile is 4.5 m, which is 0.5 m not embedded as the set up of loading test.
e. The loading test was carried out based on the SM Test. Static load testing was carried out for two days with a load of 25, 50 ,75 and 100% of the design load. Then let stand for 24 hours and the load was reduced gradually. This load was given to determine the actual settlement that occurs in the mini mile based on the carrying capacity of the plan achieved. To facilitate load application, two mini pile points were placed at

a distance of 10 D or 120 cm as shown in Figure 6.

Figure 2: Mini pile specimens.

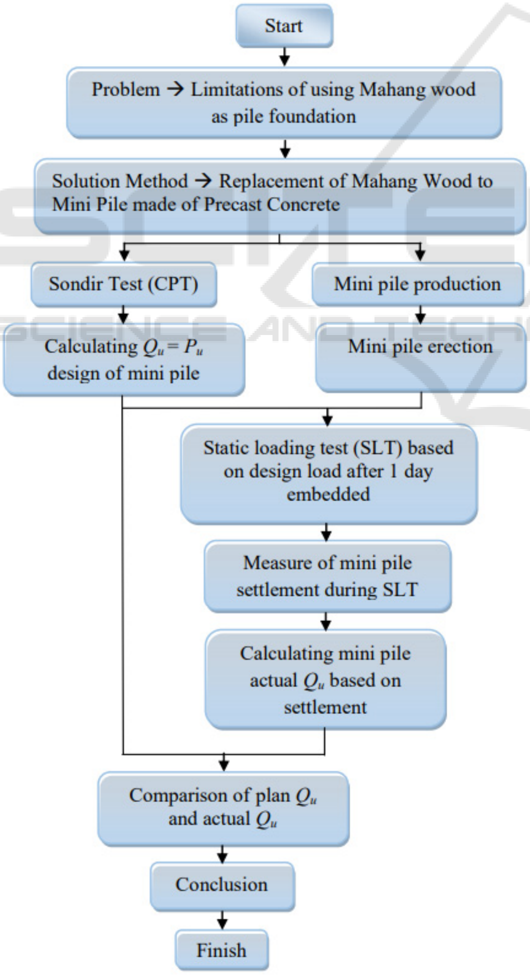

Figure 3: Research flow chart.

Figure 4: Erection of mini pile by drop hammer.

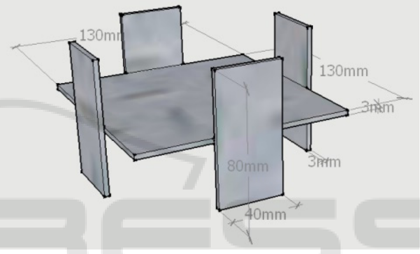

Figure 5: Steel plate connection.

Figure 6: Static loading test of mini pile.

f. During loading, settlement that occurs in the mini pile was recorded using a dial installed on the mini pile (Figure 7).

Figure 7: Recorder settlement using dial gauge.

g. The last stage is to determine the actual carrying capacity (Q_u) based on the real settlement during testing and the actual mini pile's Elasticity Modulus. Then compare the value of the actual carrying capacity with the carrying capacity of the plan.

4 RESULTS AND DISCUSSION

The results obtained are Sondir data, the quality of mini pile concrete, the value of the ultimate bearing capacity (Q_u) of the single pile used as the design load (P_u), the settlement (S) of the test results by the SLT method and the value of the actual ultimate bearing capacity (Q_u actual). The allowable load (P_a) of a mini pile/single pile with dimensions of 0.12 m × 0.12 m × 4.50 m which is embedded on soft clay.

4.1 Sondir Test Results

The Sondir test was carried out to a depth of 12 meters, with a groundwater level of ± 0.75 m from the ground level. Visual identification of soil types categorized as soft clay. The data presented is only at a depth of 1 to 5 meters, where the values of q_c and q_f have been averaged every one meter depth, as shown in Table 1.

Table 1: q_c and q_f value.

Depth (z = m)	*average q_c* (kg/cm^2)	*average q_f* (kg/cm^2)
0 – 1	1,3	0.073
1 – 2	0.9	0.04
2 – 3	0.4	0.020
3 – 4	0.4	0.0213
4 – 5	1.1	0.153

According to Galang M et al, 2017, the calculation of pile capacity using CPT data shows the results closest to the real capacity.

4.2 Concrete Quality Test

The results of testing the concrete cube at the age of 28 days obtained the average value of the concrete compressive strength of 283.65 kg/cm^2. This value was 26% higher than planned. Furthermore, with this value, the actual value of the concrete's modulus of elasticity was 22804.93 MPa.

4.3 The Ultimate Bearing Capacity Design (Q_u) of Single Pile

The value of the ultimate bearing capacity (Q_u) of a single pile was obtained using the Bagemann method as shown in Figure 8.

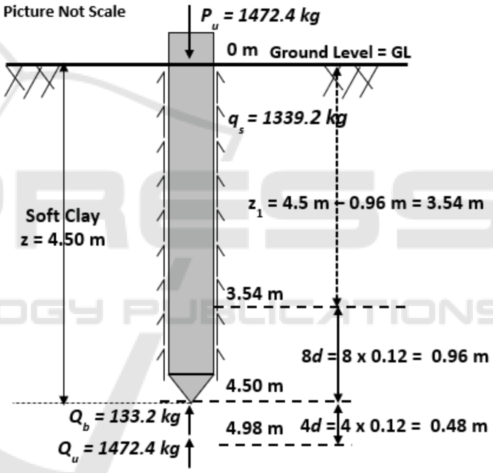

Figure 8: Mini Pile embedded.

$$Q_u = Q_b + Q_s$$
$$A_b = A_p = 0.0144\ m^2$$
$$f_b = q_{c\ rata-rata\ 8d\ \&\ 4d} = 0.925\ kg/cm^2$$
$$Q_b = A_b \times f_b = 0.0144 m^2 + 92.5\ kN/m^2$$
$$Q_b = 1.332\ kN \sim 133.2\ kg$$
$$A_s = 2.16\ m^2$$
$$f_s = q_{f\ rata-rata\ 0-4.5\ m} = 0.062\ kg/cm^2$$
$$Q_s = A_s \times f_s = 2.16 m^2 + 6.20\ kN/m^2$$
$$Q_s = 13.392\ kN \sim 1339.2\ kg$$

$$Q_u = 133.2\ kg + 1339.2\ kg$$
$$Q_u = P_u = 1472.4\ kg \sim 1.472\ ton$$

The value of Q_u was applied as the ultimate load design (P_u) for the single pile to obtain the actual settlement value of the pile during loading.

4.4 Settlement Value (S) Single Pole

Static loading test with full scale 1:1 was carried out one day after erection. The ultimate load is Pu=1.472 tons ×2= 2994 kg for two single piles with a distance (s) = 10d = 1.2 m. Although the application of the load by the 2 poles is in one plate holder to facilitate load balance, but with a distance between the poles of 10d resulting in an efficiency value (E) of the pole = 1 (Hardiyatmo, 2012), the loading received by each pole is still based on the load. The ultimate design for the single (P_u) pile is 1472 kg (not the group), as shown in Figure 9.

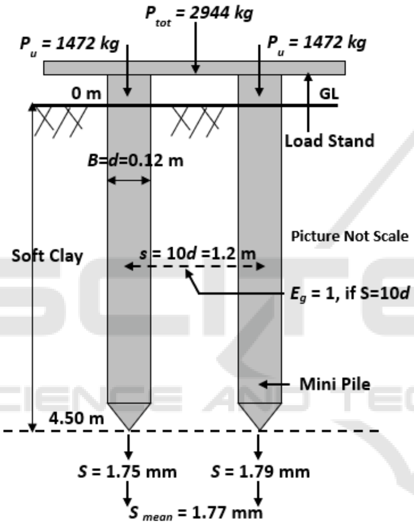

Figure 9: Application of loading to the final settlement of single pile.

The result of full loading of 1.472 tons per pile shows the final actual settlement value of (S) = 1.77 mm or equal to the ratio of 0.0147d (1.475% of the pile width). Where the test results are depicted in a graph of the relationship between the load and the settlement, as shown in Figure 10.

The settlement shown is less than that required by ASTM D 1143/D 1143M-07 in procedures B and C, where the maximum pile settlement is 0.15d (15% of the pile width), along with the failure of the pile. Likewise with the 2015 Wrana Bogumil the settlement that has occurred was not higher than 0.1d when the maximum load has been reached.

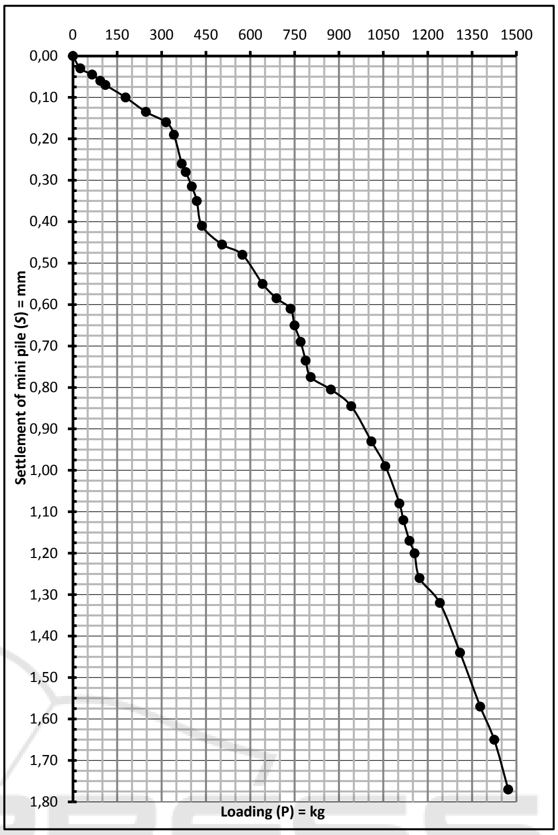

Figure 10: Relationship between load and single Pile settlement.

4.5 Actual Ultimate Capacity (Actual Q_u) Single Pile

This value is obtained by using the Vesic method which is based on the final actual settlement (S) that occurs, involving the value of the Elasticity Modulus of the mini pile material (E_p).

$$E_p = 22804.93\ MPa \sim 22804930\ kN/m^2$$

Furthermore, the value of the actual ultimate bearing capacity (actual Q_u) is as follows:

$$Q_{u\,aktual} = \frac{S - \frac{D}{100}}{L} \times A_p \times E_p$$

$$= \frac{0.00177\text{m} - \frac{0.12\ m}{100}}{4.50m} \times 0.0144m^2 \times 22804930kN/m^2$$

$$= 0.000126 \times 0.0144m^2 \times 22804930kN/m^2$$

$$Q_{u\,aktual} = 41.377\ kN \sim 4.137\ ton$$

The data above shows that the value (actual Q_u) is 2.81 times higher than the ultimate Q_u (P_u design) for single pile.

4.6 Allowable Load (P_a) Single Pile

The value of the allowable load (P_a) is obtained from the actual Q_u by involving the safety factor (SF = 2.5). The mini pile in this study was obtained as follows:

$$Q_a = P_a = \frac{Q_{u\,aktual}}{SF} = \frac{4.137}{2.5} = 1.65\ ton$$

The value is a safe load value (P_a) of 1.65 tons, in accordance with what is required to be held by one mini pile.

5 CONCLUSIONS

The results of the above studies can be concluded that the actual final settlement value of the pile S = 1.77 mm has been obtained from the SLT test at the ultimate load (P_u) = 1472.4 kg for one pile. The settlement value is less than that required by ASTM D 1143/D 1143M-07 of 0.15d and is still below the allowable settlement tolerance limit for pile foundations of 25.4 mm (1 inch). If the continued loading is higher than 2.994 tons for 2 piles, then the highest actual Q_u (close to field conditions) can be achieved when the pile settlement approaches the ASTM limit value and the allowable tolerance limit value for the pile foundation, this can be seen from the slope of the curve in the graph (Fig. 10) which is getting steeper and the pile settlement is still large as the load increases.

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