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Bearing Capacity and Deformation of Timber Pile-Raft Foundation on Soft Soil Deposits

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Abstract

A pile-raft foundation is a type of foundation that combines two different types of foundations, a raft base and a pile foundation. These raft bases are one of the most practical economic solutions for buildings because both the support capacity of the raft and the support capability of the pile both work. The paper presents results of the test bearing capacity of piled-raft foundations made from timber in the laboratory and analyzes numerically the deformations that occur in piled raft foundations made of timber. The results of the loading test on the Bakau piled raft foundations in the laboratory obtained the maximum load that can be held by the foundation before experiencing a failure of 85.00 kN with a deformation value of 21.50 mm. Whereas from the load vs. deformation curve, the ultimate bearing capacity is obtained by the Bakau piled raft foundations at 59.00 kN with an ultimate settlement of 6.00 mm. From the results of the validation between the loading test results of the foundation model in the laboratory and the results of numerical analysis, which compared the results of laboratory tests and the results of plaque analysis, the soil with reinforcement of Timber piled raft foundations gave results that were not much different.

Keywords: bearing capacity, numerical deformation, timber pile-raft foundation, soft soil

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1. Introduction

The foundation is a fundamental part of the structure that carries and transfers loads from the superstructure to the bearing ground and is located at a certain depth from the ground surface. Structures ranging from simple residential buildings to skyscrapers have a foundation of the required type. On the basis of type (vertical, lateral, earthquake, wind) and direction of loads on the superstructure and bearing ground properties, the foundation type for the structure changes.

A shallow foundation is preferred for vertical loads and stiff soil, while a deep foundation is preferred for lateral loads and soft soil. The land availability issue in the world causes the construction industry to shift to areas where soil is not suitable for shallow foundations; deep foundations are preferred in such soil types. Pile foundation is given to structures in soft soil, which transfer loads both by bearing and shearing. In some situations, pile foundation alone does not fulfill the requirement of foundation for a structure; in this case, pile and raft are used together to get the required substructure [1].

The raft-pile foundation is a practical economic solution for buildings because both the bearing capacity of the raft and the bearing capacity of the piling are working together. The foundation of the raft-pile acts as a combined construction consisting of three retaining elements, namely: a friction pile, a raft, and soil [2]. When compared with conventional foundations, the design of the raft-pile foundation forms a new dimension of the structure of the interaction of soil particles because the new philosophical design uses piles that are maximized to the carrying capacity based on the interaction of the soil and the pile. The raft-pile foundation of these leads to an economical foundation with a slight decrease if the soil has a soil modulus that increases in proportion to depth [3].

Studies on the effectiveness of the use of raft-pile foundations have been carried out by some of the researchers [4], [5]. Jamil et al. [6] conducted an experimental study of the settlement behavior of piled raft foundations with batter and vertical piles. It is concluded that using a batter pile instead of a vertical pile causes a settlement reduction and an increase in load carrying capacity, and it is recommended to study the settlement and load carrying capacity of a pile raft foundation when a horizontal load is acting on the foundation.

Alhassani et al. [7] conducted research on the on the performance of a piled-raft foundation supported by either connected or unconnected piles. The conclusions can be drawn that, using an unconnected piled raft, the settlement

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efficiency is approximately constant in the experienced range of displacement and the percentage of load carried by piles.

Jayarajan et. al. [8] conducted research to demonstrates the PDR method for preliminary design and the finite element method for detailed analysis of piled raft foundations. The parametrical study of piled raft is performed through PLAXIS-3D software by considering four different pile configurations. The load-settlement response obtained through PDR method agrees very well with the response calculated through PLAXIS software and hence it can be used effectively during preliminary study to arrive at an optimum pile arrangement required for detailed analysis.

Indonesia is a country that has a tropical climate and has a vast forest area, so Indonesia is a country that is very rich in wood material, both in type and quantity, and can be used as a foundation material for raft- piles [9]. The use of wood as a pile raft foundation material to increase the carrying capacity of the soil and overcome settlement has several advantages, including being an being an easily obtainable material, having a having a relatively lower cost, being simple and easy to implement, and having a relatively short implementation time.

2. Literature Review

2.1. Physical characteristics of timber

Some of the physical characteristics of timber include : a) timber specific gravity, b) natural timber durability, c) timber colour, d) hygroscopic, e) timber structure, f) timber fibre, g) timber weight, h) timber hardness, i) tactile impression, j) odour and taste. k) decorative value.

2.2. Mechanical characteristics of timber

Mechanical characteristics or timber strength is the ability of wood to withstand external loads. What is meant by external loads are forces outside the object that have a tendency to change the shape and size of the object. Timber strength plays an important role in the use of timber as a building material, furniture industry and other uses. Mechanical characteristics of timber include tensile strength, compressive strength, flexural strength, shear strength, compression, split strength, timber ductility and timber hardness.

2.3. Chemical characteristics of timber

The chemical components in timber are important because they determine the usefulness of a particular type of timber. Also by knowing it, we can distinguish the types of timber. The chemical composition of wood is used as an identifier of timber resistance to timber destroying creatures.

2.4. Raft-pile foundation system

Pile raft foundations are a practical economic solution for buildings because the bearing capacity of the raft and the bearing capacity of the piles both work together (see Fig. 1).

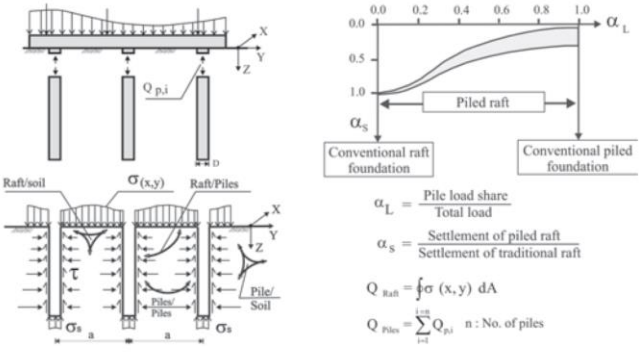

Figure 1. Principle of piled-raft [11]

The pile-raft foundation acts as a combined construction consisting of 3 (three) anchoring elements, namely friction pile, raft, and soil. When compared to conventional foundations, the design of raft-pile foundations forms a new dimension of interaction structure of soil particles due to the new design philosophy of using piles that are maximized to the limit of bearing capacity based on the interaction of soil and piles. The raft-pile foundation leads to an economical foundation with little settlement if the soil has a soil modulus that increases proportionally with depth [10].

Raft foundations are a combination of footings that cover the entire area beneath the structure and support all walls and columns despite very heavy building loads or small soil allowable stresses. In the design of large building foundations in deep compressible soils, it can be found that raft foundations will provide an adequate safety factor against ultimate bearing capacity failure, but the compression will be excessive. When topsoil exhibits very high compressibility values and low shear strength, the raft foundation surface will experience large settlement, even greater than the allowable settlement for that foundation.

Friction piles are used to help increase soil density figures to aid raft foundation work and reduce differential and total settlement. Friction piles prove to be efficient when their shear strength increases with depth and their compressibility decreases with depth. These two actions mean that friction piles reduce settlement even when the foundation receives a high load, and automatically the bearing capacity of the foundation will also increase when the load is channeled into the high shear strength soil beneath the pile.

2.5. Foundation loading test method

In principle, this foundation loading procedure is carried out by applying a vertical load placed on the pile head, and then the amount of vertical deformation that occurs is measured using a dial mounted on the pile [12]. The deformation that occurs consists of elastic and plastic deformation. Elastic deformation is deformation caused by elastic shortening of the pile and soil, while plastic deformation is deformation caused by collapse of the supporting soil at the end or around the pile [13].

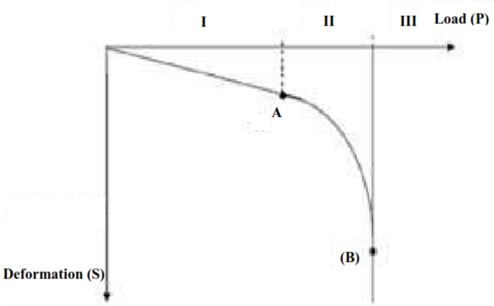

Figure 2. Load vs deformation curve [14]

Thus, this pile loading experiment will give quite precise results if the amount of deformation is carefully measured. Because what we want to know is up to what load the support layer will experience total collapse. Total collapse will occur at a certain load and will experience continuous settlement behavior. If the relationship between deformation and load is depicted in the form of a curve, it will be seen that the curve will consist of 3 (three) parts as shown in Fig. 2.

1. In region I, where up to a certain load the deformation-load curve forms a straight line. This means that up to a certain load, the amount of settlement is proportional to the magnitude of the applied load. Here it can be interpreted that the working loads are mostly used to cause elastic deformation, both in the pile itself and in the supporting soil. The elastic deformation in the pile is elastic shortening, while in the supporting layer it is a consolidation process.
2. In region II, where the parabolically curved section (line AB) occurs, if the settlement that occurs is proportional to the magnitude of the working load. Here the settlement is a function of time, meaning that if a load is allowed to work longer, it will result in greater deformation. In this case, the applied load has caused the supporting soil to collapse.
3. In region III, where the curve is steep to the vertical line. In this section, it can be seen that a certain load of a fixed magnitude will cause continuous or increasing deformation. The load that will result in increasingly larger deformations is called the maximum load.

In the interpretation of axial loading tests, there are several methods used to calculate the allowable load on a single pile foundation [15].

a. Davisson Method
b. Mazurkiewicz Method
c. Chin Method
d. Buttler dan Hoy Method
e. De Beer Method

3. Research Methodology

3.1. Soil characteristics testing

Soil characteristics testing is carried out in the soil mechanics laboratory with testing standards referring to SNI, ASTM, and AASHTO. The types of tests carried out include water content testing, content weight testing, specific gravity testing, Atterberg limits testing, sieve analysis testing, compaction testing, free compressive strength testing, and direct shear testing.

3.2. Testing the characteristics of bakau timber

For testing the mechanical characteristics of bakau timber, it was carried out in the material testing laboratory with testing standards referring to ASTM [16]. The types of tests carried out include tensile strength testing, compressive strength testing, parallel and perpendicular to the fiber, flexural strength testing, and split strength testing. Samples of mangrove wood characteristics testing can be seen in Fig. 3.

Table 1. Test method for laboratory testing of soil characteristics

No.	Testing of type	Test Method	
		ASTM	SNI
1.	Sieve analysis	C-136-06	SNI 03-1968-1990
2.	Atterberg limit		
	a. Liquid limit (LL)	D-423-66	SNI 03-1967-1990
	b. Plastiticity limit (PL)	D-424-74	SNI 03-1966-1990
	c. Plastiticity index (PI)	D-4318-10	SNI 03-1966-2008
3.	Specific gravity (Gs)	D-162	SNI 03-1964-1990
4.	Weight c of soil saturated (γ_{sat})	D-2216-98	SNI 03-1743-1989
5.	Water content (w_c)	D-2216-98	SNI 03-1965-1990
6.	Weight of dry soil (γ_{dry})	D-854-72	SNI 03-1970-2008
7.	Pore value (e)	D-854-72	SNI 03-2473-1991
8.	Porosity (n)	D-7063-11	SNI 13-3604-1994
9.	Degree of saturation (S_r)	D-854-72	SNI 03-2812-1992

Table 2. Test method for testing of bakau timber characteristic

No.	Type of testing	Test Method
1.	Moisture content (w)	ASTM D–143-94
2.	Specific gravity	ASTM D–143-94
3.	Tensile strength parallel to grain	ASTM D–143-94
4.	Tensile strength perpendicular to the grain	ASTM D–143-94
5.	Compressive strength parallel to grain	ASTM D–143-94
6.	Compressive strength perpendicular to the grain	ASTM D–143-94
7.	Shear strength	ASTM D–143-94
8.	Flexural strength	ASTM D–143-94

Figure 3. Bakau timber testing sample

3.4. Foundation modeling in the laboratory

The soft soil in the form of clay that has been tested for its characteristics is put into a testing tub measuring 60 cm x 100 cm x 160 cm. The density of the subgrade was 80% of the maximum density obtained in the standard compacted density test. In this study the subgrade was modeled as 60 cm high.

Then timber piles with a length of 40 cm were staked into the ground with a distance of approximately 25 cm between the poles, after which a timber raft of two layers in the direction of the cross section and longitudinal section was placed on top of the piles that had been staked earlier and tied together using wire. The dimensions of the timber raft used are 50 cm wide and 80 cm long, as shown in Figures 4, 5, and 7. The embankment soil, clay, was then placed on top of the timber raft reinforcement, which was modelled as a 25 cm high embankment.

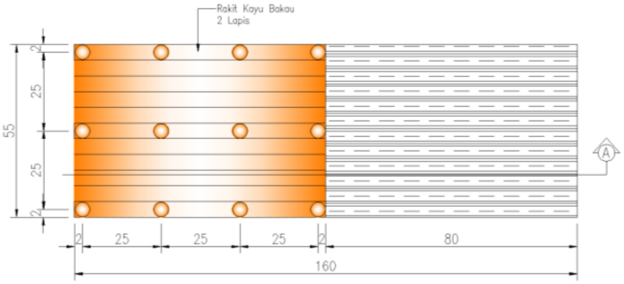

Figure 4. Layout model pile – raft foundation

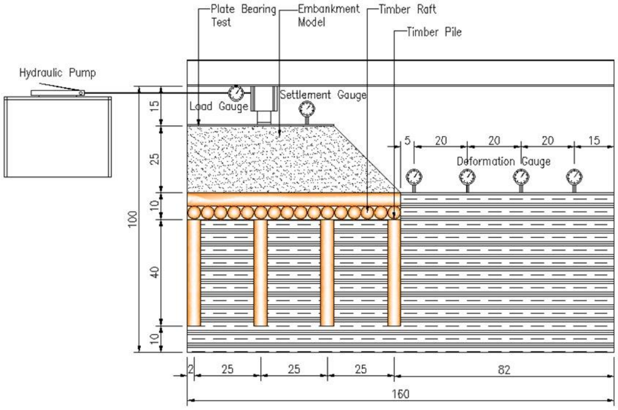

Figure 5. Model testing setup in laboratory

Figure 6. Testing foundation models in the laboratory

The steel plate (plate bearing test) is placed on the surface and will later be loaded using a hydraulic jack. Dial indicators (dial gauges) were placed in five (5) positions. The first was directly above the loading test plate; the second was placed on the subgrade about 5-10 cm to the side of the trial embankment slope, the third on the subgrade 25-30 cm from the slope, the fourth on the subgrade 45-50 cm from the slope, and the last was placed at a distance of 75-80 cm from the trial embankment slope. During the test, the load was added slowly while reading the movement of the dial gauge, observing the settlement pattern and surface deformation.

4. Results and Discussion

4.1. Results

a) Soil characteristics testing results

From the results of tests carried out in the laboratory, soil characteristics data are obtained in Table 3.

b) Test results for bakau timber characteristics

From the test results carried out in the laboratory, the mechanical characteristics of mangrove wood are shown in Table 4.

Table 3. Soil characteristics test results

No.	Type of testing	Unit	Results
1.	Water content (w)	%	36.00
2.	Specific gravity (Gs)	-	2.75
3.	Atterberg limit		
	a. Liquid limit(LL)	%	50.36
	b. Plasticity (PL)	%	37.23
	c. Plasticity index ((PI)	%	13.12
4.	Soil grain analysis		
	a. Coarse-grained soil	%	45.90
	b. Fine-grained soil	%	54.10
5.	Soil classification		
	a. USCS Method	-	MH & OH
	b. AASHTO Method	-	A-7-5
6.	Unconfined compression test (q_u)	kg/cm	0.72
7.	Compaction		
	a. Water content optimum (w_{opt})	%	41.75
	b. Dry weight (γ_{dry})	gr/cm^3	1.22
8.	Direct shear		
	a. Cohesion (c)	kg/cm^2	0.104
	b. Internal shear angle (Φ)	^{0}	17.32

Table 4. Results of bakau timber characteristic test

Types of testing	Unit	Results
Moisture content	%	21.580
Tensile strength	MPa	18.515
Modulus of elasticity tensile strength	MPa	690.423
Compressive strength parallel fiber	MPa	23.757
Modulus of elasticity parallel fiber	MPa	964.596
Compressive strength perpendicular fiber	MPa	14.710
Modulus of elasticity perpendicular fiber	MPa	591.230
Bending strength	MPa	106.224
Strong split	MPa	29.910

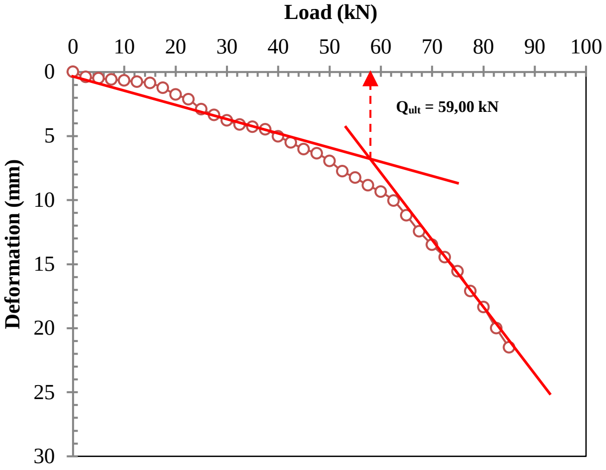

Figure 7. Load vs. deformation curve

c) *Results of loading test of timber pile-raft foundation*

From the results of loading tests with plate bearing tests in the laboratory, the load vs. deformation relationship curve of the timber raft-pile foundation model was obtained as shown in Fig. 7

In determining the value of the ultimate bearing capacity (Q_{ult}) of the bakau pile-raft foundation model that has been tested for loads, the Butler and Hoy (1977) method is used. This method considers the failure of the load when the load intersects two tangent lines to the curve of the relationship between the load vs. deformation at different points. The first tangent line is the initial straight line which is assumed to be an elastic pressure line. For the second tangent line obtained is limited as a slope of 0.05 kN on the load vs. deformation curve.

From the relation load vs. deformation curve in Figure 7 using the Butler and Hoy method above, the ultimate bearing capacity (Q_{ult}) value of 59.00 kN with an ultimate deformation (δu) was obtained at 6.00 mm.

4.2. Discussion

a. *Numerical deformation of timber pile-raft foundation*

Numerical analysis description of the pattern of soil failure and areas that have experienced large deformations and shows changes in soil movement due to the influence of the reinforcement of the raft-pile foundation.

Table 5. Deformation readings that occur on the timber pile-raft foundation

Load				Information
20 kN	40 kN	60 kN	80 kN	
-2.15	-7.30	-12.10	-22.50	Settlement
0.40	1.10	3.25	5.00	Dial 1
0.30	1.00	2.00	3.00	Dial 2
0.15	0.80	1.25	1.40	Dial 3
0.00	0.10	0.30	0.50	Dial 4

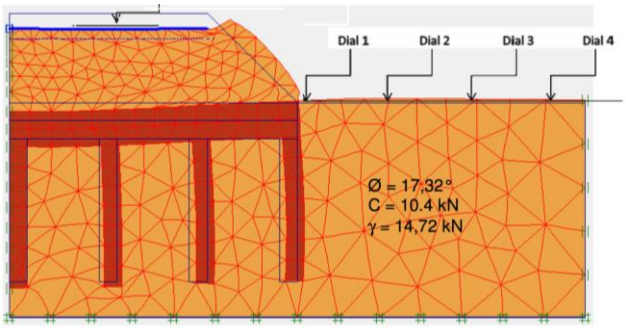

Figure 8. Numerical deformation of timberpile-raft foundation

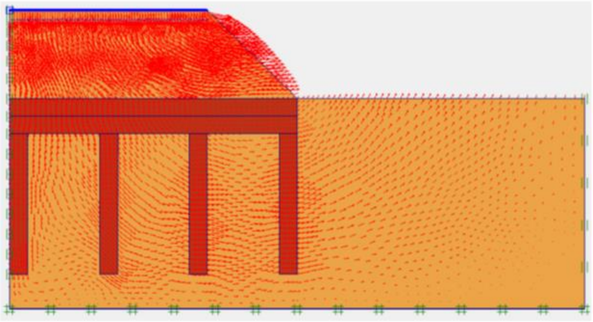

Figure 9. Stress distribution of timber pile-raft foundation

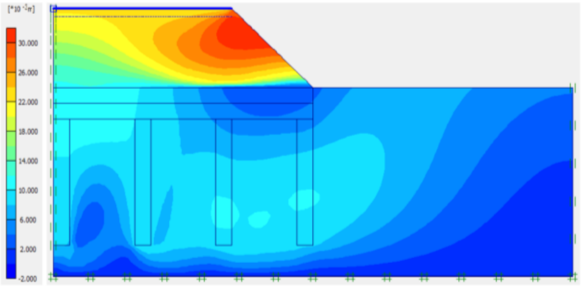

Figure 10. Shading deformation diagram of bakau pile-raft foundation

The results of numerical analysis of the bakau pile-raft foundation with a spacing of 25 cm can be seen in Fig. 8, Fig. 9, and Fig. 10. As for the reading of numerical deformations that occur at loads of 20 kN, 40 kN, 60 kN, and 80 kN, it can be seen in Table 5.

Figure 8 shows that the greater the burden the greater the deformation that occurs in the soil. Deformation that occurs at a load of 20 kN on dial 1 is 0.40 mm, on dial 2 is 0.30 mm, on dial 3 is 0.15 mm and on dial 4 is 0.00 mm. eformation that occurs at a load of 40 kN on dial 1 of 1.10 mm, on dial 2 of 1.00 mm, on dial 3 of 0.80 mm and on dial 4 of 0.30 mm. Deformation that occurs at a load of 60 kN on dial 1 is 3.25 mm, on dial 2 is 2.00 mm, on dial 3 is 1.25 mm and on dial 4 is 0.30 mm. Furthermore, the deformation that occurs at a load of 80 kN on dial 1 is 5.00 mm, on dial 2 is 3.00 mm, on dial 3 is 1.40 mm and on dial 4 is 0.50 m.

b. Numerical validation of timber pile-raft foundation

From the results of the loading test of the raft-pile foundation model in the laboratory and the results of the numerical analysis of the foundation, we obtain a comparison curve of the load vs. deformation relationship, as shown in Fig. 11.

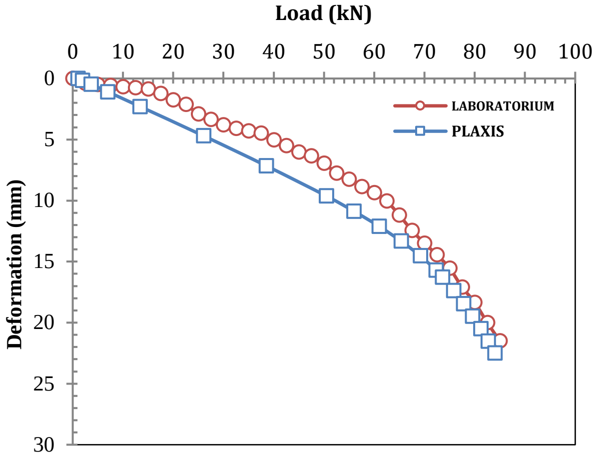

Figure 11. Load vs. deformation curve results laboratory and numerical analysis

From Fig. 11 above, it can be seen that there is a difference between the load and the deformation that occurs in the bakau pile-raft foundation model that is tested for loading in the laboratory and the results of numerical analysis. For loading tests carried out in the laboratory, a maximum load of 85.00 kN is obtained with deformation that occurs at 21.50 mm. As for the results of numerical analysis, the Plaxis 2D program obtained a maximum load of 83.98 kN with deformation that occurred at 22.50 mm.

5. Conclusion

From the results of research and data analysis that has been done, the following conclusions can be written the length of the the loading test of bakau pile-raft foundations in the laboratory obtained the maximum load that can be held by the bakau pile-raft foundation before failure of 85.00 kN with a deformation value of 21.50 mm. While from the load vs. deformation curve, the bearing capacity of the mangrove raft-base foundation is 59.00 kN with an ultimate reduction of 6.00 mm. The validation between the results of the load test model of the foundation in the laboratory and the results of numerical analysis where compared to the results of laboratory testing and the results of the analysis of plaids, the soil with the reinforcement foundation of the bakau pile-rafts gives results that are not much different.

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