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A Bearing Capacity of Bamboo Cluster Pile on Saturated Soft Soil Based on the Direct load Test and CPT'S Data

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Abstract: One of the constructions that can be used to overcome the problem of soft soil is through pile mattress bamboo construction. This construction consists of bamboo arranged as mattresses and bamboo arranged as cluster of piles. The cluster pile consists of several bamboo culms tied together (cluster pile). Cluster pile capabilities that are not analysed for strength can result in wastage or construction failure. Hence, this study was intended to analyse the ability of clusters pile through recorded direct observation and compare them based on sonder (CPT) data. The method is carried out by direct observation of the model at the research site. The model observed are clusters with a length of 8 m, inserted into soft soil and then vertical loading is carried out until the soil that supports it collapses. There are 3 types of clusters pile, namely cluster piles C3, C4, and C7. The results showed that the ultimate bearing capacity of the cluster based on the direct load test was relatively the same as the calculated with sonder data. Thus, this study established the ultimate bearing capacity (P_{ult}) which can be determined using the equation, P_{ult} = 7.4056Ac, where P_{ult} in (kg), and Ac is cluster area in (cm^2).

Keywords: Cluster pile, soft soil, bearing capacity, direct load test, CPT (sonder)

1. Introduction

Soft soil in Indonesia is estimated to cover about 20 million hectares or about 10 percent of Indonesia's total land area. Soft soil is mostly found in the area around the coast, as shown in Figure 1. (Kimpraswil, 2002). The development of the city requires various facilities and infrastructure. One of the facilities and infrastructure needed is land transportation facilities, both roads, and railways. The paths that are passed for land transportation are often on soft ground, so there are problems with infrastructure development.

One of the building constructions that can be used to overcome the problem of soft soil is the construction of a pile mattress bamboo. This construction consists of bamboo as a mattress and bamboo as a pile. The pile used for the construction of the bamboo mattresses is often formed in one cluster of bamboo culms, namely several bamboo culms tied into one cluster. The number of bamboo in one cluster requires proper arrangement so that there are not many cavities.

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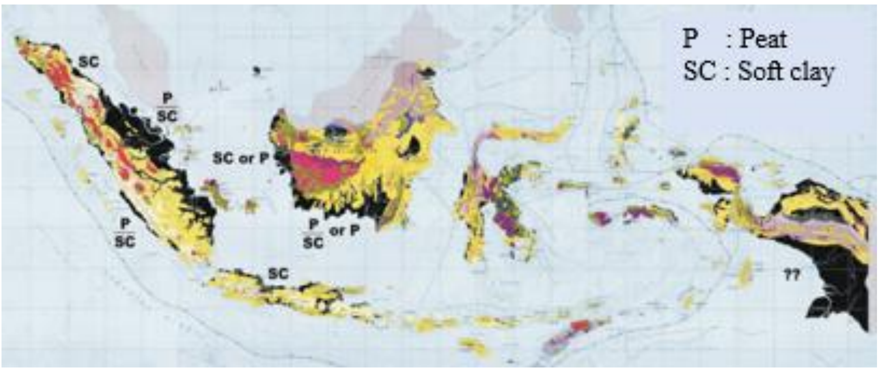

Fig. 1 - Soft soil map in Indonesia (Kimpraswil, 2002)

The bearing capacity of the bamboo cluster pile that is inserted into soft soil is often not technically studied but directly installed using an estimation method. The ability of the bamboo cluster pile whose strength is not controlled can lead to waste or construction failure. Based on the description above, it is necessary to research to provide steps or ways to get the value of the bearing capacity of the bamboo cluster pile in the field directly.

Construction engineering for soft subgrade improvement that has been adopted and has been widely accepted in Indonesia (Kimpraswil, 2002) is the vertical drain (Figure 2), pile slab (Figure 3), and mattresses with or without piles (Figure 4).

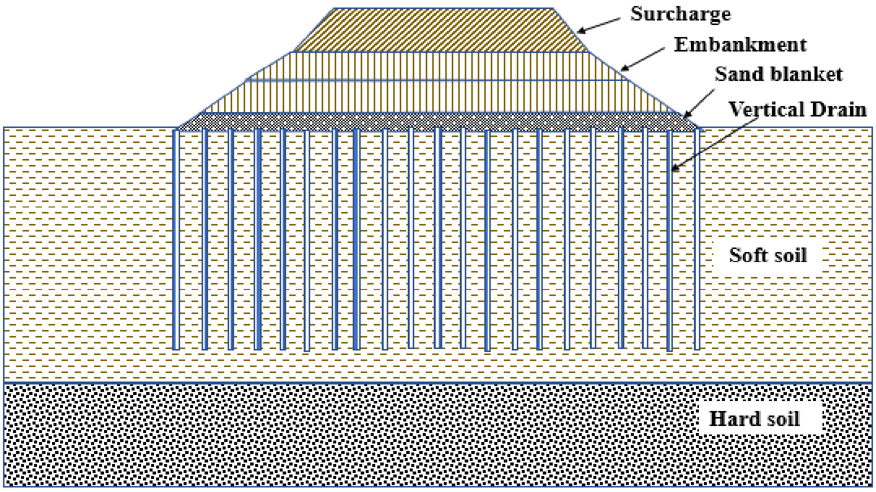

Fig. 2 - Soft soil handling with additional loads and vertical drain (Kimpraswil, 2002)

Fig. 3 - Soft soil handling with pile slab

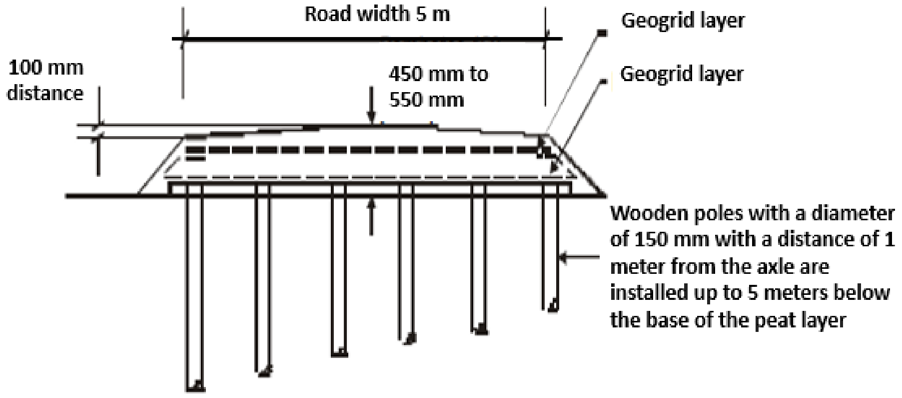

Fig. 4 - Pile mattress construction (Kimpraswil, 2002)

2. Concept of Determine Load Bearing

The load acting on the pile will be held by the soft soil. The stiffness of the bamboo culms on saturated soft soil is much greater than the stiffness of the soil that supports it, so if the load increases, the soil will collapse first. The amount of soil support until it collapses (Qu) can be calculated by Equation (1).

Figure 5. shows that the magnitude of soil subsidence until the pile collapses in general there are two concepts, the first is the concept of deformation-controlled capacity, PF0.1, and the second is the concept of ultimate capacity, Pu.

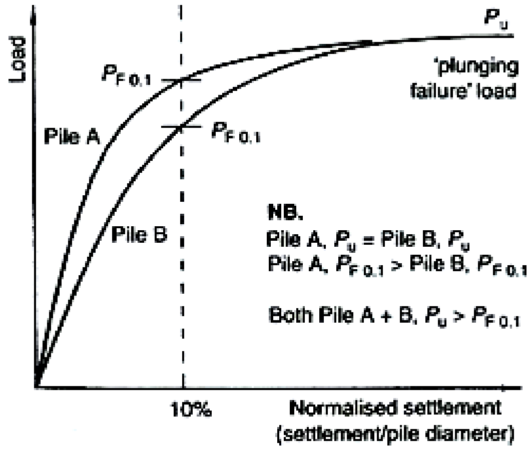

Fig. 5 - Definition of pile failure (Bell & Robinson, 2012)

The first concept states that the pile collapses when the pile deformation reaches 10% of the pile tip diameter (Bell & Robinson, 2012). The load supported by the pile is shown by Equation (1).

$$Q_{tot} = n.Q_{ult} \text{ lt} \qquad (1)$$

With: Q_{tot}= the total load received by the clusters, n=the number of clusters per meter of fill length and Q_{ult}= the ultimate load of one cluster.

3. Research Methods

The research method is steps taken to solve the identified problems. The main problem is to compare the ultimate force of the bamboo cluster from the direct load test with the ultimate force of the bamboo cluster based on sonder data. Direct load data was obtained from direct load testing. Sonder data was carried out by sonder testing at the research location points.

The main step which is part of the research method is to determine the cross-sectional area of the test cluster. There are 3 types of clusters arranged with configurations C3, C4, and C7 (Figure 6). The number of each type of cluster 3 pieces have different areas according to the diameter of the bamboo that composes it. The cluster area is determined by measuring the cluster circumference of the three types of clusters. Tests were carried out for each type of cluster with as many as 3 tests, namely three C3 tests, three C4 tests, and three C7 tests so the total number of tests was 9 tests.

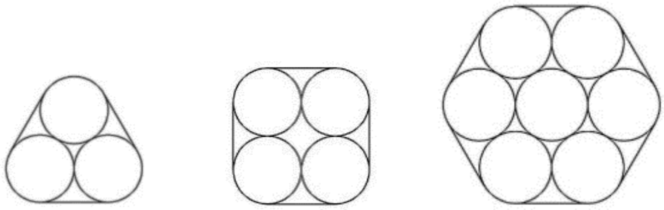

Fig. 6 - Types of bamboo clusters

The next main step is to determine the ultimate force of the bamboo culm cluster as a result of the direct load test. The data obtained from the test are direct load (P) and displacement of the cluster (δ). This data was analysed to determine the ultimate bearing capacity of the bamboo cluster.

The tools used for the load test are a set of sonder tools that are equipped with a manometer and a length scale, and a set of platforms for the direct test made of bamboo, wood, and fastening tools (rope, nails). The test platform is shown in Figure 7.

Fig. 7 - The platform of the cluster load test

The next main step is sonder testing which is carried out to obtain sonder data in the form of conus resistance parameters (qc) and total friction (ft) or often called the total of skin resistance (JHP). These two parameters are used to determine the ultimate bearing capacity of the cluster based on Mayerhoff's theory which is shown by Equation (2).

$$\mathbf{P_{Ult} = q_c . A_b + ft . Kll} \qquad (2)$$

If ft is ignored then Equation (2) becomes equation (3).

$$\mathbf{P_{Ult} = q_c . A_b} \qquad (3)$$

with P_{ult} = ultimate bearing capacity, q_c = conus resistance, ft = total friction, Kll = cluster circumference (q_c and ft values based on sonder test).

The results of the ultimate cluster bearing capacity of the two methods were compared to determine the difference. The results of this study are expected to be used as a reference to determine the bearing capacity of the cluster practically in the field with saturated soft soil conditions without soil tests.

This cluster-bearing capacity study uses the second concept, namely the concept of ultimate capacity with the assumption that the ultimate cluster force is taken when the soil has started to collapse (Bell & Robinson, 2012) because in its application the soil that supports the cluster collapses first. The first step before testing the ultimate load is that each cluster is installed by pressing the cluster into the subgrade layer to the desired depth. The ends of the bamboo clusters are kept from being damaged during pressing by protecting them with steel tubes covering the cluster heads. The cluster test point number is shown in Figure 8.

Fig. 8 - Cluster test point number

The final conditions of the end of the cluster before being tested are shown in Figures 9a, 9b, and 9c. The top end of the cluster is slightly above the groundwater level.

Fig. 9 - Position of cluster ready to be tested (a) cluster C3; (b) cluster C4; (c) cluster C7

The three types of clusters that have been set up (Figure 9) are then tested for the ultimate bearing capacity (P_{ult}) of the cluster until the soil collapses when the cluster is still down due to the load, but there is no increase in pressure (ultimate cluster force is reached). Applying force to the cluster using a modified sonder tool (Figure 10a) equipped with a manometer and a length scale (Figure 10b).

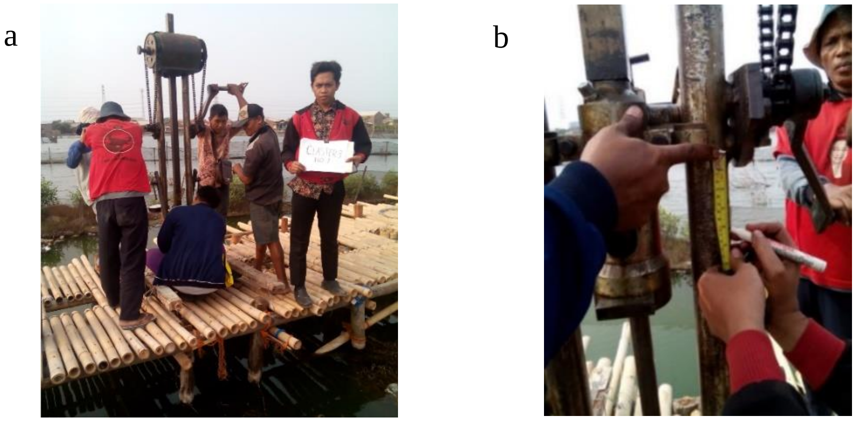

Fig. 10 - Cluster test (a) cluster load test; (b) cluster displacement reading

4. Results and Discussion

4.1 Cluster Area

Based on the circumference of the cluster and the configuration of the cluster, then with the Autocad mathematical trial, a graph of the relationship between the circumference of the cluster and the area of the cluster can be determined as shown in Figure 11.

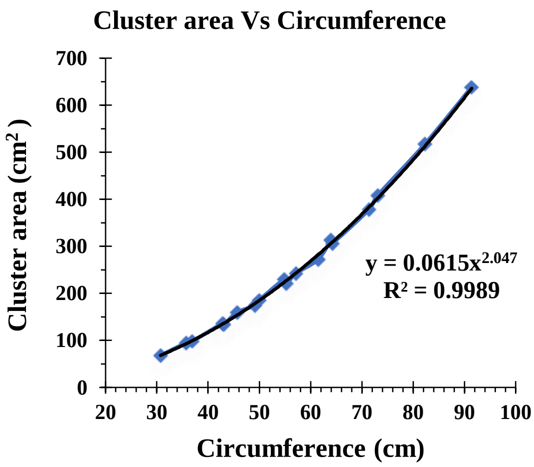

Fig. 11 - Graph of cluster circumference VS cluster area

Based on the graph in Figure 11, it can be determined the area of the cluster based on the circumference of the cluster with Equation (4).

$$Y = 0.0615.X^{2,047} \quad (4)$$

where Y = the area of the cluster, and X = the circumference of the cluster. Based on Equation (4), the cluster area data can be calculated and displayed in Table 1.

Table 1 - Types of clusters and area of clusters

Type of cluster	Average Circumference (cm)	Average Area (cm^2)
C3	45,67	153,50
C4	48,11	170,80
C7	67,22	338,68

4.2 The Ultimate Force with a Direct Test in the Field

The results of the ultimate force with a direct test in the field of the bamboo cluster are shown in Figures 12, Figure 13, and Figure 14.

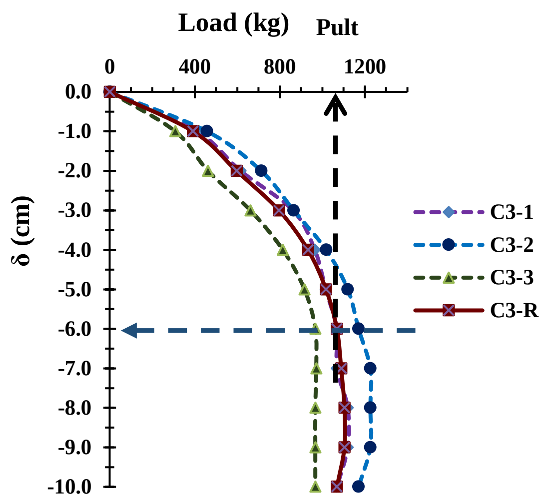

Fig. 12 - Load VS δ for cluster C3

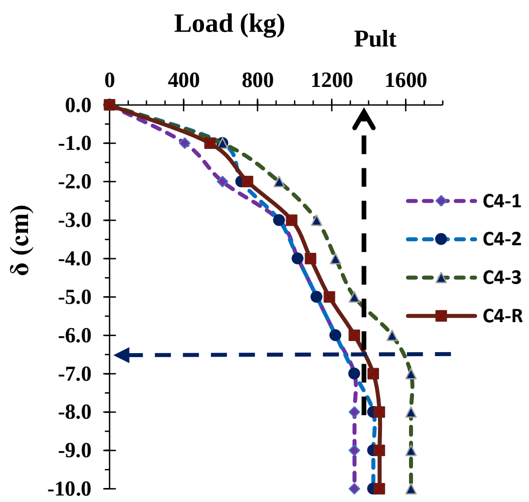

Fig. 13 - Load VS δ for cluster C4

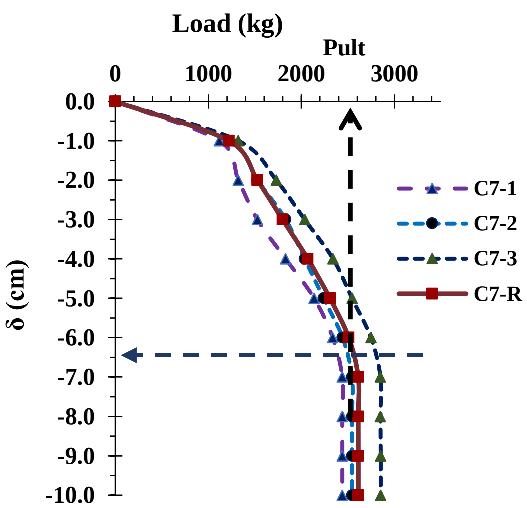

Fig. 14 - Load VS δ for cluster C7

C3 cluster testing obtained cluster area = 153.50 cm^2, P_{ult} = 1060 kg, deformation, δ = 6 cm (Figure 12). C4 cluster testing obtained cluster area = 170,80 cm^2, P_{ult} = 1350 kg, deformation, δ = 6.5 cm (Figure 13). C7 cluster testing obtained cluster area = 345 cm^2, P_{ult} = 2500 kg, deformation, δ = 6.0 cm. (Figure 14).

4.3 Ultimate Force Based on Sonder Data

The magnitude of the ultimate force based on sonder data is calculated by Equation (3). Sonder test data is shown in Figure 15. The magnitude of qc in Figure 15, for a depth of 6 meters is, qc = {(8+8+8+6)/4+ (8+8)/2}/2 = 7.75 kg/cm2, then based on Equation (3) the ultimate carrying capacity of each cluster can be obtained. P_{ult} calculation based on the value of qc can be seen in Table 2.

Table 2 - P_{ult} cluster based on sonder data

Type of cluster	Area (cm^2)	qc (kg/cm^2)	P_{ult} (kg)
C3	153,5	7,75	1190
C4	170,8	7,75	1324
C7	338,7	7,75	2625

4.4 P_{ult} the Direct Load Test VS P_{ult} Sonder

The magnitude of the ultimate force (P_{ult}) based on the direct load test and based on sonder's data with Meyerhof's theory is shown in Table 3.

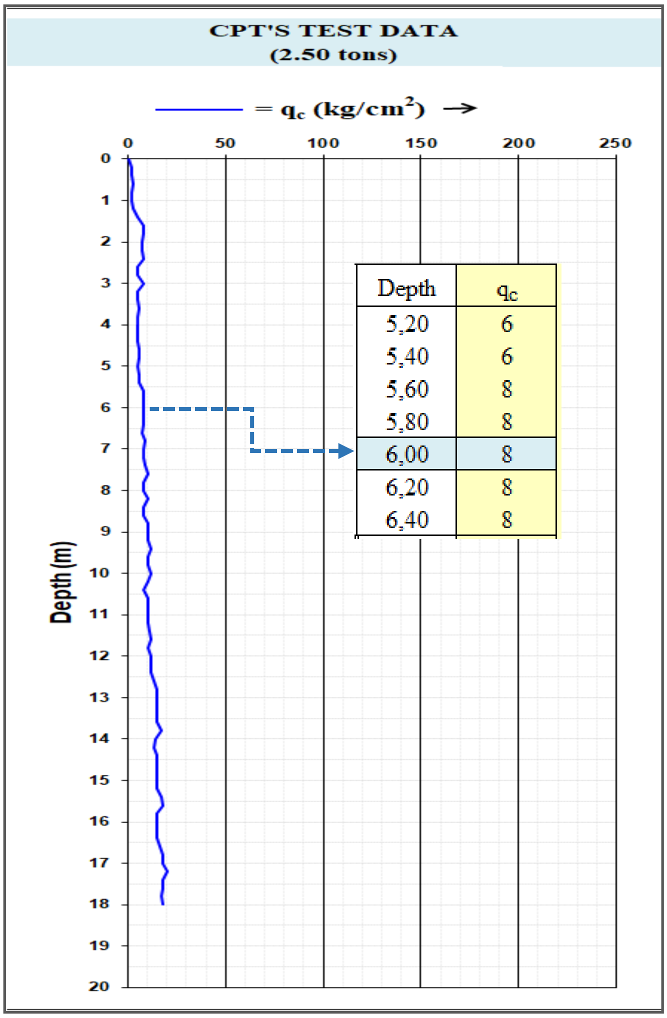

Fig. 15 - Graph of CPT test

Table 3 - P_{ult} load test VS P_{ult} sonder

Type of cluster	P_{ult} load test (kg)	P_{ult} Sonder (cm^2)
C3	1060	1190
C4	1350	1324
C7	2500	2625

From Table 3, can be made a graph of the relationship between the area of the cluster with the P_{ult} based on the direct load test on the cluster and the Pult based on the sonder test is shown in Figure 16.

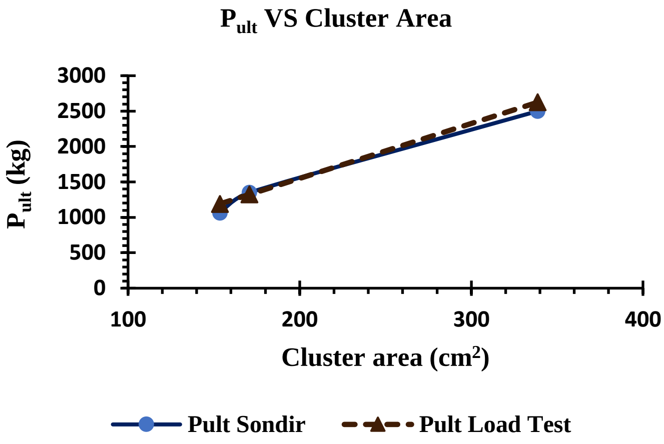

Fig. 16 - Comparison of P_{ult} direct load test with P_{ult} sonder test

Based on the results of the P_{ult} of both methods, it is noted that the magnitude of the P_{ult} resulting from the direct loading test is relatively the same as the result based on the sonder test. The magnitude of the bearing capacity of the cluster based on direct loading is shown in Figure 17.

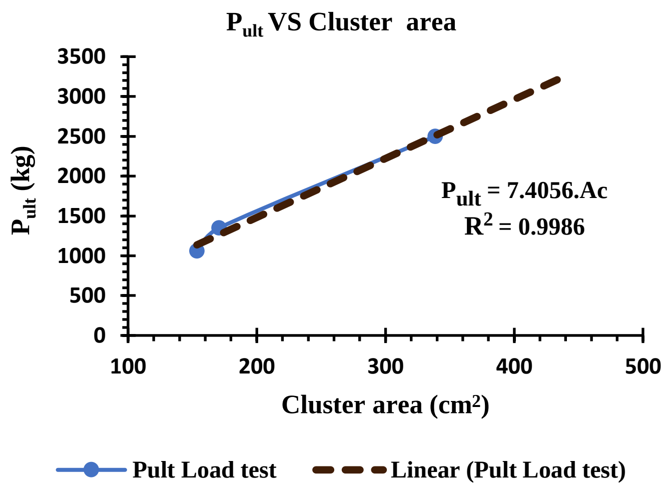

Fig. 17 - P_{ult} VS cluster area

From the trend graph in Figure 19, the relationship between P_{ult} and the cluster area can be written using Equation (5).

$$P_{ult} = 7.4056.Ac \quad (5)$$

With: P_{ult} = ultimate bearing capacity of the bamboo cluster (kg), and A_c is cluster area (cm^2).

5. Conclusion

The results of the study on the ability of bamboo clusters inserted into saturated soft soil to withstand loads showed that the ultimate bearing capacity (P_{ult}) based on the direct load test was relatively the same as the ultimate bearing capacity (P_{ult}) based on the sonder test. The ultimate bearing capacity of bamboo clusters on saturated soft soil can be approximated determined by the first step by measuring the circumference of the bamboo cluster, and the next step by calculating the bamboo cluster area. The third step is to determine the bearing capacity of the bamboo cluster which can be approximated by the equation, P_{ult} = 7.4065. (Ac), where P_{ult} = ultimate bearing capacity of the bamboo cluster (kg), and Ac = cluster area (cm^2).

It is important to understand the subgrade in general at the location where this method will be applied later because this concept method is where the soil should collapse first. The proposed development of further research can be done in more detail, namely by placing the instrument in the cluster either at the end or beside the cluster, which can record the stresses that occur under the cluster and beside the cluster.

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