The Effect of Reinforcement of Bamboo Matting, Bamboo Grids, and Geotextiles on Non-Woven Increasing the Carrying Capacity of Clay Soil Using the Loading Test

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Abstract. Nowadays, various soil improvement methods have been developed. One of them is the soil reinforcement method as an alternative solution to subsidence and low soil bearing capacity. This study aimed to determine the effect of reinforcing bamboo mats, bamboo grids, and geotextiles non-woven on increasing the bearing capacity of clay soil and comparing the bearing capacity of each variation with the value of the bearing capacity without reinforcement. This research is an experimental study using the loading method with the modeling of the underburdened soil conditions. This study uses woven bamboo reinforcement, bamboo grids, and geotextiles non-woven. Each effect of the reinforcing material on the clay is sought for the ultimate bearing capacity value. The results showed that: (1) the type of soil according to the USCS classification in Kalangan Hamlet, Bangunjiwo Village, Kasihan District, Bantul Regency, Yogyakarta Special Region is inorganic clay with high plasticity, fat clays with code CH (high clay plasticity). According to AASHTO, the soil classified in group A-7-6 (40), (2) the addition of reinforcing bamboo mats, grids bamboo, and geotextiles non-woven can increase the ultimate bearing strength (3) strengthening the bamboo grid can provide an increase in value. The ultimate bearing strength (qult), which is dominant, is 3.4 times that of the original soil without reinforcement with a bearing capacity ratio (BCR) of 3.44 or a 234.43% increase in percentage. This study shows that bamboo is more effective in transferring and spreading loads to the soil.

1. Introduction
The current rapid population growth and construction implementation are increasingly being carried out, such as clay soil, which must continue to be carried out. Because clay soil has various classifications with different characteristics, there is strong and stable soil and exceptional handling and treatment to make the soil more stable. Limited land for constructing facilities such as roads means that limited land cannot avoid construction on soft clay soils. In Indonesia, a heap is often built on peaceful grounds that have low soil-bearing strength.

Also, soft clay soil has a high plasticity index, making this soil expand and shrink when exposed to water or commonly known as expansive soil. Of course, this will be very dangerous to the construction that will be built on it. Seeing conditions like this, buildings or roads built on soft clay soil must pay attention and consider how much carrying capacity and land subsidence. The construction achieves the best quality. The soils in west lampung, Sumatera area had medium to very high swelling potential.
These results suggest a risk of erosion in the area, which could cause soil degradation and a change in water quality. These soils are likely to affect land productivity and aquifer replenishment and will cause negative environmental and economic impacts. Thus, soil improvement techniques are needed. It is important to maintain vegetative cover; these soils and revegetation may be required [7].

Currently, various soil improvement methods have been developed. One of them is the soil reinforcement method as an alternative solution to subsidence and low soil bearing capacity. One of the alternatives given to this modeling is by using woven bamboo and grids of bamboo. The choice of bamboo as an alternative for reinforcement is because bamboo has a relatively good tensile strength [8]. Another method used to improve its mechanical characteristics is to provide soil reinforcement in a geosynthetic sheet spread over soft soil as a subgrade. Mixing beach sand will always increase the CBR value, but if the percentage of sand is too much, the soil will easily collapse (negative swelling). The clay mixture with beach sand the optimum percentage of beach sand will be 85% [12].

The objectives of this study are: (1) Knowing the type of clay soil in Kalangan Hamlet, Bangunjiwo Village, Kasiian District, Bantul Regency, Yogyakarta Special Region based on the soil classification system. (2) Knowing the effect of reinforcing bamboo mats, grids bamboo, and geotextiles non-woven on increasing clay soil bearing capacity. (3) Comparing the carrying capacity of each variation of the reinforcement material with the value of the bearing capacity without reinforcement.

2. Literature Review

2.1 Clay Soil

Clay soil is soil with microcolonies to sub-microconic size originating from the weathering of the chemical elements that make up the rock. Clay soil is tough when it is dry, and it is not easy to peel off with just fingers. The permeability of clay is very low. It is plastic at moderate water content. In western America, for clays whose plasticity is characterized by a soapy form or made from wax, it is called “gumbo.” Whereas in higher water conditions, the clay will be sticky (cohesive) and very soft [10].

2.2 Bamboo

Bamboo is a type of wood used as a construction material, either as a primary or secondary material. This type of wood is widely used as a building structure because the price is relatively low. Compared to other materials, bamboo has several advantages, including strong, ductile, straight, flat, and stiff stems. Bamboo has twice the tensile strength than wood, while its compressive strength is 10% higher than wood's compressive strength. When compared with steel which has a specific gravity between 6.0 - 8.0 (while bamboo sg = 0.6 - 0.8), the tensile strength of steel is only 2.3 - 3.0 smaller than the tensile strength of bamboo because bamboo poles have a tensile strength per its specific gravity unit 3-4 times greater than that of steel [6]. Bamboos that can use as plait include apus or ali bamboo (Gigantochloa apus), legi or andong bamboo (Gigantochloa verticii / ata), and bamboo wulung or atter (Gigantochloa atter).

Research on bamboo matting as a soil base strengthening has been conducted previously. From the research results, it knew to what extent the ability of bamboo is a reinforcing material for stabilization of the foundation soil. On the other hand, the weaknesses of bamboo include its relatively low durability. Bamboo is easily attacked by fungi and insects, so that its durability is very dependent on the weather and the environment. Bamboo without preservation directly related to soil and weather can only last about 1 to 3 years [9]. According to Janssen, the factors that influence the tensile strength of bamboo are the water content, the cross-section of the stem, and the presence or absence of books [9]. Another factor that influences bamboo's tensile strength must consider is the type and age of the bamboo. In other research the gabion-tetrapod-gabion reinforcement can be considered as more effective reinforcement combination to reduce scour with an average scour of 4.03 cm in the beginning of the channel, 2.64 cm in the middle of the channel and 1.97 in the end of the channel [5].

2.3 Land Subsidence

If the land is subjected to loading on it, the land will be stretched and a decline settlement. The amount of stretch along the depth of the layer represents the total subsidence of the soil. The decrease can occur
due to changes in soil composition, particle relocation, deformation of soil particles, discharge of water or air from the pores, and other causes. In the vertical direction, the decrease is referred to as ΔH. Generally, a non-uniform reduction is more dangerous than a total reduction. Several causes for the decline due to loading that works on the ground: (1) Shear failure due to excessive soil bearing capacity will cause a decrease in some differential settlements and a decrease in the entire building. (2) Damage due to large deflection in the foundation. This damage generally occurs in deep foundations. (3) Shear distortion on the supporting soil from the supporting soil. (4) Soil subsidence due to changes in pore numbers.

Figure 1. Example of Damage to Buildings Due to Subsidence

2.4 Soil Failure Model Without Reinforcement
The soil must bear the load of any engineering construction placed on the soil without shear failure. The amount of soil shear stress under foundation depends on size of the load and the size of its foundation. If the load is large enough or the size of the foundation is too small, the shear stress that occurs can exceed the shear strength of the soil, which can cause the bearing capacity of the foundation to collapse [2].

Based on model testing, Vasic divided the foundation failure mechanism into three types, namely [3]:

2.4.1 The Collapse of The Common Slide (General Shear Failure)
Common Sliding collapse happens in soil that is not easily compressed, with a specific shear force or submerged state. An earth wedge forms right at the base of the foundation, which presses underground until the ground drains plastically. The outward movement was held back by the passive prisoners divided. When the passive resistance is exceeded, swelling occurs on the surface. The overturning of the foundation followed the sudden collapse.
2.4.2 The Collapse of The Local Shear (Local Shear Failure)
The collapse occurred on the ground, easily compressible or soft ground. The slip plane did not reach the ground level but stopped somewhere. The Tenggela foundation is due to increased loads at a relatively deep depth so that the nearby soil is compressed. There is little soil swelling but no foundation overturning. The graph shows that with an increase in load, the decrease will also increase so that the maximum load may not be achieved.

2.4.3 The Collapse of The Sliding Punch (Punching Shear Failure)
On the collapse of this type, it can say soil shear failure does not occur. Due to the load, the foundation only penetrates and pushes soil to the side, which causes compression of the soil near foundation. Compression of soil near the penetration of foundation develops only in the limited zone just at the base and around the foundation's edge.

2.5 Reinforced Soil Failure Model (Geosynthesis)
The results of research by Koerner show that generally, geosynthetic damage, in this case, is geotextile, occurs during installation and construction. Aggregate placement and Pime Frame compaction by heavy equipment resulting in a high voltage on the geotextile [4].

![Figure 3. Type of failure in shallow foundations with geographic reinforcement](image)

(a) The collapse of the bearing capacity above the geogrid layer
(b) Compressive collapse or fracture in the geogrid layer
(c) Creep or creep collapse in the geogrid layer
(d) A tensile collapse in the geogrid layer

2.6 soil bearing capacity
Bearing capacity is a soil parameter that is favorable to the strength of the soil that supports a load on it. Soil bearing capacity is affected by the amount of water in it, soil cohesion, inner shear angle, and normal soil stress. The soil must bear the load of any engineering construction placed on the soil without shear failure and settlement that can be tolerated for the construction. Failure of soil shear can cause excessive building distortion and even collapse. Apart from shear failure, excessive settlement can also result in structural damage. In general, the criteria that must be considered in foundation planning are [3]:

2.6.1 Stability
foundation planning must fulfill the safety factor against collapse due to exceeding carrying capacity. In the calculation of carrying capacity, generally used number 3.

2.6.2 Decrease Settlement
The foundation must be within the tolerable value limits. In particular, non-uniform subsidence should not result in damage to the structure. Vertical sand column are very effective in reducing the settlement. At depths of -10 cm the most effective use of horizontal sand layer reduces clay soil moisture content by 53.30%, which means reducing water content by 3.62% from the original soil conditions. At a depth of 20 cm, using terucuk bamboo is most effective at reducing water content by 3.55% from the original clay soil content [11].
3. Methodology
In the implementation of the research, the experimental research method was used by carrying out the loading method and modeling the burdened soil conditions. This research uses the foundation model made from iron plates measuring 20 cm x 20 cm x 10 cm. The test tub measured 100 cm x 100 cm x 40 cm, with a 4 mm iron plate thickness. A hydraulic jack is used to provide a load above the foundation and determine the amount of load, installed proving ring is a 3-ton capacity. In this test, the clay soil to be used is not less than 30 cm. Then installed bamboo mats, bamboo grids, and geotextiles non-woven at a certain depth by recording each time the decline occurred. The time for one lap is 1 minute.

3.1 Setting Up Testing
A sketch of the test model can be seen in the image below:

![Figure 4. Setting Up Testing](image)

![Figure 5. Modeling Testing](image)

Information: 1). IWF steel frame as a working load bearing; 2) Iron test tub as soil testing medium; 3) Wood as a support to strengthen the frame; 4) Proving Rings; 5) Hydraulic Jacks; 6) Dial gauge; 7) Iron foundation model.

3.2 Material Preparation
The soil media used in this study was expansive soil taken from the Kalangan Hamlet, Bangunjiwo Village, Kasihan District, Bantul Regency, Yogyakarta Special Region. The soil that has been drained first is then broken into pieces until it passes the No. 4. Furthermore, before put into the test tub, the soil is mixed with water, so the water content conditions are almost by the conditions in the field. Also for every one sack of soil weighing 60 kg requires water as much as 14 liters. Mixing is carried out until
the soil and water become homogeneous, and the soil conditions become plastic. After it is well mixed, the soil is then put into the test tub and compacted by crushing it by hand until the density obtained is almost by the maximum density according to the CBR test.

3.3 Preparation of Testing Variations
There are four variations in the test: original soil without reinforcement material, soil with woven bamboo reinforcement material, soil with bamboo grid reinforcement material, and soil with geotextile reinforcement non-woven. Testing with bamboo woven reinforcement materials, namely by dismantling the soil from the previous test and then compacting it by crushing it by hand, until the density obtained is almost by the density in the field. After that, it is dug up to about 2 cm from the soil's surface and then installed with woven bamboo and backfilled using the soil. Then level the soil surface and soak it for 24 hours. Before being tested, a soil sample is taken to determine the water content.

4. Result and Discussion
4.1 Characteristics of Clay Soil
The results of the examination of soil characteristics are shown in Table 1 below:

| Table 1. Characteristics Testing Results |
|------------------------------------------|
| No. | Checking type                        | Result     |
|-----|--------------------------------------|------------|
| 1   | Water Content                        | 32.10 %    |
| 2   | Specific gravity 27.5°C              | 2.689      |
| 3   | Atterberg limit                      |            |
| 4   | Standard Comparison                  |            |
| 1   | Liquid limit (LL)                    | 75.57%     |
| 2   | Plastic limit (PL)                   | 29.76%     |
| 3   | Plastic Index (PI)                   | 44.95%     |
| 4   | OMC                                  | 39.2%      |
| 5   | Γd                                   | 1.232 gr/cm³ |
| 6   | Γb                                   | 1.716 gr/cm³ |
| 7   | CBR (0.1 inch)                       | 8.11%      |
| 8   | CBR (0.2 inch)                       | 6.26%      |
| 9   | Qu                                   | 2.43 kg/cm² |
| 10  | Cohesi (c)                           | 0.41 kg/cm² |
| 11  | Friction angle (φ)                   | 28.75°     |
4.2 Relationship Between Load and Settlement in Foundation Soil

![Graph of The Relationship between Load and Settlement on Foundation Soil](image)

In general, from Figure 6, if the load above the foundation soil gradually increased, the decrease will increase, which in the end, one time under certain conditions with a constant load of the foundation soil—experienced a considerable decline. It is in this condition that the ultimate support strength has occurred. It can also be illustrated that a relatively small decrease occurs at the beginning of the loading and increases slowly as the load increases. Due to the load loading, there is an increasingly significant decrease until the foundation soil has a maximum decrease (collapse).

4.3 Ultimate Support Strength of Foundation Soil

After loading testing with various reinforcing materials, the most excellent bearing capacity is found in material variations. Reinforcing bamboo grids. Ultimate carrying capacity value for each of them This variation can be seen in Table 2 below:

| Type of Test Object | Code | Ultimate Code Strong Support, qult (kg/cm²) | Qult average (kg/cm²) |
|---------------------|------|--------------------------------------------|-----------------------|
| Original Land       | TA1  | 0.31                                       | 0.305                 |
|                     | TA2  | 0.30                                       |                       |
| Bamboo Matting      | AB1  | 0.81                                       | 0.825                 |
|                     | AB2  | 0.84                                       |                       |
| Bamboo Grid         | GB1  | 1.02                                       | 1.02                  |
|                     | GB2  | 1.02                                       |                       |
| Non Woven           | GNW1 | 0.55                                       | 0.535                 |
|                     | GNW2 | 0.52                                       |                       |
Figure 7. Average Ultimate Bearing Strength on The Variation of Reinforcing Materials

From Figure 7 seen that the unreinforced foundation placed on the foundation soil in the form of clay soil has a low ultimate bearing strength of 0.305 kg/cm². Ultimate support strength increases because of it reinforcement of bamboo grids, bamboo mats, and geotextiles non-woven, respectively, at 1.02 kg/cm²; 0.825 kg/cm²; 0.535 kg/cm². This study shows that using a bamboo grid is the most effective because it can provide the highest carrying capacity of 1.02 kg/cm².

4.4 Water Content

After the loading test was completed, the water content of the soil samples was taken at an elevation of -10 cm and -20 cm. Taking water content at an elevation of -10 cm and -20 cm, each layer serves to determine the reduction in groundwater content after loading with saturated water conditions.

Figure 8. Diagram of Moisture Content After Loading

From the test results in the diagram in Figure 8, the use of non-woven geotextiles is more effective in reducing the moisture content in clay soil with a value of 1.22%.

4.5 Value of BCR (Bearing Capacity Ratio)

From the test results in the diagram in Figure 8, the use of geotextiles is non-woven more effective in reducing water content in clay soil with a value of 1.22%.

4.6 BCR Value (Bearing Capacity Ratio)

The bearing capacity ratio (BCR) is the ratio between the value of the strengthened soil bearing capacity (qult) and the value of the bearing capacity of the soil without reinforcement (q0). It can be said that the use of this reinforcement can increase the BCR value. The recapitulation of the calculated BCR value and the percent increase in BCR can be seen in Table 3 below:
Table 3. Recapitulation of Carrying Capacity, BCR, and Percentage Increase in BCR

| Variation          | qult average (kg/cm²) | BCR     | % Enhancement |
|--------------------|-----------------------|---------|---------------|
| Original Land      | 0.305                 | 1       | -             |
| Bamboo Grid        | 0.825                 | 2.7049  | 170.49        |
| Bamboo Matting     | 1.02                  | 3.3443  | 234.43        |
| Non Woven          | 0.535                 | 1.7541  | 75.41         |

Figure 9. Graph of Soil Reinforcement Relationship with Percentage Contribution of Each Reinforcing Material

Table 3 and Figure 9 above bar chart show each reinforcement's contribution with the type of treatment with variations in the reinforcing material. It can be seen that the bamboo grid gives a more dominant contribution, which is 234.43%. This shows that the bamboo grid has contributed to the resistance to collapse. Concerning soil strengthening, bamboo grids distribute loads vertically (via sticky resistance) in the layers or transfer the load into bad material until supported by sufficiently strong soil (end resistance). With the reinforcement of bamboo, the stress in the soil spreads more so that the stress caused by the axial load becomes evenly distributed, resulting in settlementa small.

5. Conclusions

Based on data analysis from the tests that have carried out, the following conclusions can obtain:

a. The type of soil according to the USCS classification in Kalangan Hamlet, Bangunjito Village, Kasihan District, Bantul Regency, Yogyakarta Special Region is inorganic clay high plasticity, clay “fat clays with the code CH (clay high plasticity). According to the AASHTO, the soil is classified as group A-7-6 (40).

b. Additional reinforcement of bamboo mats, bamboo grids, and geotextiles non-woven can increase the bearing strength ultimate by 1.02 kg/cm², respectively; 0.825 kg/cm²; 0.535 kg/cm².

c. The strengthening of the bamboo grid can increase the ultimate bearing strength (qult), which is dominant, which is 3.4 times that of the original soil without reinforcement with a bearing capacity ratio (BCR) of 3.44 or an increase of 234.43%. This research shows that bamboo is more effective in transferring and spreading loads to the ground.

Based on the tests and results obtained, several things still need to be improved and developed, so the authors provide some suggestions for the next test, namely:

a. Adding many samples to obtain better and more accurate data avoids errors in analyzing test data.
b. It is advisable to test the foundation soil model or use the original type of embankment other than clay soil.

c. For the development of variations, the test can be done by changing the load acting on the soil surface by changing the pattern, diameter and distance.

d. It is necessary to test the embankment soil model with a larger scale model and be carried out outside the laboratory or in the field so that the data obtained is better and more accurate because it is closer to the application in the area.

e. Use of a dial gauge digital to increase accuracy in observation for more accurate results.

f. There is a limitation of perishable bamboo, so a physical test of bamboo is required to determine the characteristics of bamboo.

6. References

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