

THE PERFORMANCE OF BAMBOO MAT WITH PILES AS REINFORCEMENT OF PEAT SOIL

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ABSTRACT: Peat soil is classified as problematic soil when used as a subgrade. The bearing capacity of this soil is generally very low, including a low CBR (California Bearing Ratio) value, settlement, and relatively high water content. This soil is not sufficiently reinforced, so it requires an embankment as a subgrade of stabilized soil to achieve a sufficiently high CBR value. This study aims to evaluate the performance of a bamboo mat reinforcement system, combined with reinforced piles and a subgrade of marble ash stabilized soil. The study began by testing the interaction between the peat soil and the reinforcement material, followed by observations from a series of CBR tests that measured load-penetration relationships in a test box placed on subgrades consisting of soil reinforced with piles and bamboo mats. Reinforcement piles are distinguished by their lengths of 20-50 cm as single piles and pile groups. Bamboo mats are placed between the peat soil surface and the subgrade. The subgrade is compacted in 10 cm and 20 cm increments. CBR tests are conducted on each reinforcement system scheme. The results showed that bamboo mat reinforcement increased the CBR value by 1.8 times, reinforced piles increased the CBR value by 1.2-1.5 times, and the combination of both increased the CBR value by 2.2-2.7 times compared to the reinforced soil. Long-term curing of the subgrade of clay soil with 6% marble ash had an impact on increasing the CBR value by 1.1-1.3 times compared to the short-term subgrade CBR value.

Keywords: Bamboo mat, Pile reinforcement, Peat soil, CBR, Subgrade

1. INTRODUCTION

Peat soil is a type of soil characterized by low bearing capacity and significant excessive settlement [1]. This type of soil requires a reinforcement system to improve its performance. The reinforcement system can include piles or lateral reinforcement. Pile foundations are substructure elements that transfer construction loads to the soil layer through skin friction between the pile wall and the soil, plus end-bearing [2]. Pile capacity is influenced by the degree of roughness of the pile wall in relation to frictional resistance [3]. Applying polymer along the pile walls can increase the frictional resistance component by up to 30% [4]. The connection between the pile and the pile cap, in addition to frictional and end resistance, determines the strength of the pile. Piles connected with a steel jacket can produce good tensile strength [5]. The pile cap, which connects the group of piles, can be constructed as a slab [6]. The reinforced pile head as a retaining wall can use a reinforcement system made of geosynthetics or bamboo mattresses and bamboo pile mattress [7-9].

Construction performance over reinforced peat layers will improve if embankments are provided as a subgrade. The subgrade contributes to supporting the loads above it. Soil with poor characteristics results in high settlement, which can reduce the

stability of the structure above it. The size and shape of pavement material particles, including the subgrade, affect the performance of the pavement layer above it [10]. Reinforced subgrades and underlying layers can provide improved performance. The horizontal reinforcement system can use up to three layers of geotextile [11]. Simulations of embankment loads on clay soil without a reinforcement system resulted in significant settlement [12]. The characteristics of the embankment, which also acts as a subgrade, influence the performance of the construction above it. Occasionally, the subgrade is soft clay or expansive clay. These types of soil exhibit low density and low CBR [11,12]. This soil needs improvement with additional stabilization materials such as chemical stabilization methods [13,14]. Several soil stabilization materials have the potential to improve soil properties and strength, such as geopolymers, waste oyster shell, polystyrene, cement, lime, volcanic ash, and fly ash materials [15-21]. Environmentally friendly waste materials, such as marble ash, are a beneficial alternative. The use of this material can reduce environmental pollution and increase the unconfined compression strength by 3.5 times [21,22].

The pile reinforcement system contributes to increasing the bearing capacity and modulus of subgrade reaction [3]. Several reinforcement systems can be used, including concrete slabs,

geogrids, bamboo reinforcement, reinforced piles, and riveted plate systems. Reinforced piles can act as shear resisters, thereby reducing the risk of landslides [25]. Reinforced piles are capable of significantly increasing the resistance [26]. Reinforced piles can also be useful in reducing the development of expansive soils [27].

The pile capacity is obtained from the friction component along the pile as frictional resistance, also known as skin friction, and the pile end resistance component as end bearing [28]. The end bearing of soft soils such as peat is less dominant than the frictional resistance. Increasing the frictional resistance along the pile can be achieved by using polymers, resulting in a 30% increase in pile capacity [4]. The frictional resistance of piles is influenced by the roughness of the pile walls. The friction angle between the soil and other materials increases with the roughness of the material's surface. This suggests that piles used for reinforcement can provide higher frictional resistance between the pile and the soil if the pile walls are modified with rougher skin friction. Increasing pile capacity can be made possible by the use of screw piles [29].

Reinforced piles woven with bamboo can increase the pile's ruggedness and also function as a pile restraint. Woven bamboo is known to have high shear strength and can restrain the pile system, thereby reducing horizontal deformation. The high shear strength of woven bamboo can contribute to increasing the skin friction of the reinforced pile, thereby increasing the pile's capacity. Using stabilized soil made from waste material, such as marble ash, improves subgrade performance above the peat layer. The mixture of marble ash added to the clay soil is as much as 6%, according to previous research [30].

Previous studies have employed various methods of pile reinforcement development, each with its own limitations and varying degrees of success. Therefore, continuous development efforts are needed in pile reinforcement systems, especially in the skin friction component. The object of this research is peat identification and its relationship to skin friction, the thickness of the peat soil layer in relation to the bearing capacity, and the design load. This study aims to obtain the performance of the bamboo mat as a reinforcement installed between the peat surface and the subgrade, the performance of the reinforcement system from the combination of the bamboo mat and reinforced piles, and the subgrade performance of marble ash stabilized soil in the short term and long term.

2. RESEARCH SIGNIFICANCE

The use of bamboo combined with reinforcement piles can be an alternative

reinforcement system for peat soil layers. This material is readily available and easy to shape due to its flexible nature. It is durable when continuously submerged in water-saturated soil layers. This research aims to enhance the performance of the reinforcement system by incorporating embankments, which also serve as a subgrade. The subgrade is designed from clay material stabilized with marble ash obtained from industrial waste, making it readily available, economical, and having a positive impact on reducing air pollution. The performance of the reinforcement system and subgrade is reviewed through CBR tests in a laboratory-scale physical model.

3. MATERIALS AND METHODS

3.1 Materials

The reinforcement materials used in this study consisted of piles, woven bamboo, and bamboo mats placed between the peat surface and the subgrade. The shape of the reinforcement piles and bamboo mats is as shown in Fig. 1. The subgrade placed on top of the bamboo mat is clay soil stabilized with marble ash Fig. 2. The properties of the bamboo used show that the maximum bending load obtained is 2693.5 N with a deflection of 22.739 mm and the maximum tensile force obtained is 6407.1 N with a deformation of 22.739 mm. The soil used was clay soil from Meikarta, Bekasi Regency, West Java. Meanwhile, the marble ash is waste from a marble factory in Banten. The marble ash has a main content of CaCO_3 is 76.78%, Al_2O_3 is 14.30%, and SiO_2 is 1.28%.

3.2 Preparation of Testing Scheme

The reinforced layer consists of peat, while the stabilized subgrade consists of clay. The model test conducted in the study used a test box measuring 120 cm x 90 cm x 90 cm. The test box was filled with peat soil compacted every 10 cm to 50 cm according to field density. The peat soil layer was reinforced with a system of piles and bamboo mats. The reinforcement piles were distinguished as single piles and pile groups consisting of 4 (four) piles with a distance of 10 cm. The diameter of the pile (d) was taken as 5 cm by considering the ratio of length to diameter of the pile for the model test, which gave satisfactory results of 1:10 [31]. The pile spacing can be between 2 and 5 times the pile diameter, but reducing it from 5 times the pile width to 2 times the pile width results in a 60-90% increase in bearing capacity [32].



Fig. 1. Bamboo mat



Fig. 2. Mixture of clay and 6% marble ash

The reinforcement system and its dimensions can be seen in Table 1. The length of the pile (L) is differentiated at 20 cm, 35 cm, and 50 cm, respectively, with a diameter of 5 cm. It can be used as a deep foundation model [33]. The length of the pile required to produce satisfactory performance is obtained at a ratio of the length of the pile to the thickness of the peat soil layer ≥ 0.3 [34]. Meanwhile, to obtain a small settlement and substantial bearing capacity, the minimum pile length is $3/5$ of the thickness of the peat layer [35]. The size of the bamboo mat for a single pile is 10 cm, while for a pile group it is 20 cm x 20 cm (Fig. 3).

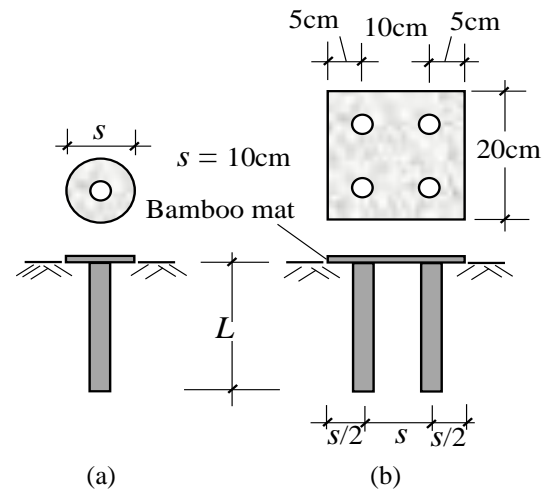


Fig. 3. Schematic of: (a) Single pile; (b) Pile group

The clay soil is stabilized with 6% marble ash. The use of 6% marble ash was determined based on previous research [30]. Subgrade CBR values reached above 5% in soil stabilized with 6% marble ash at a thickness of approximately 20-30 cm [30]. The base soil is compacted with a thickness of 10 cm and 20 cm, respectively, according to the density obtained from the results of standard compaction tests in the laboratory, both the maximum dry density and the optimum moisture content [30]. This soil mixture is used as a subgrade layer with a thickness of 10 cm and 20 cm.

Table 1. Reinforcement system testing scheme

Symbol	Bamboo mat size (cm)	Pile length (cm)
SBL0	D 10	0
SBL20	D 10	20
SBL35	D 10	35
SBL50	D 10	50
GBL0	20 x 20	0
GBL20	20 x 20	20
GBL35	20 x 20	35
GBL50	20 x 20	50

3.3 Methods

The process of using bamboo mat reinforcement started with conducting a direct shear test on soil specimens that included the bamboo mat reinforcement. For comparison, steel and concrete were also used as reinforcement materials. Specimens for the direct shear test consisted of soil-steel, soil-concrete, and soil-bamboo mat. The lower portion consisted of reinforcement material and the upper portion consisted of soil, each tested

at different normal stresses. The results of this test are presented in the form of interactions between the soil and the reinforcement system. The parameter obtained from this test is the friction angle between the soil and the reinforcement material.

The performance of the reinforcement system was observed through CBR testing in each test scheme. Load readings are taken for each penetration that occurs according to the specified times. CBR testing was conducted on a 10 cm thick subgrade for both single pile and pile group reinforcement. CBR testing was conducted after the subgrade had been cured for 7 days for the short-term model. After testing the first layer, compaction of the stabilized soil was continued until it reached a thickness of 20 cm. CBR testing was again conducted on the subgrade surface after the soil had been cured for 7 days. As a control, testing was also conducted on unreinforced peat soil and bamboo mats without piles. This physical model test was conducted to illustrate the implementation of the reinforcement and subgrade system in the field [3]. The complete physical model test scheme in the laboratory is shown in Fig. 4.



Fig. 4. The physical model test in the laboratory

The 20 cm subgrade was further cured for 70 days to determine the CBR performance of the stabilized subgrade over the long-term. CBR tests were conducted at each point along the peat soil reinforcement system. The field CBR testing procedure followed ASTM D4429 [36]. The CBR

of stabilized soil was tested on the ground surface with load penetration.

4. RESULTS AND DISCUSSIONS

4.1 Soil Interaction with Bamboo Mat

The interaction between the soil and the reinforcement material is obtained from the results of the direct shear test. The results of the clay soil gradation test are shown in Fig. 5. The results of the direct shear test between soil and reinforcement materials are shown in Fig. 6. The interaction between soil and reinforcement materials is presented in the friction angle parameter. The friction angle value between soil and steel is 28.87°, between soil and concrete is 37.33°, and between soil and bamboo mat is 38.15°.

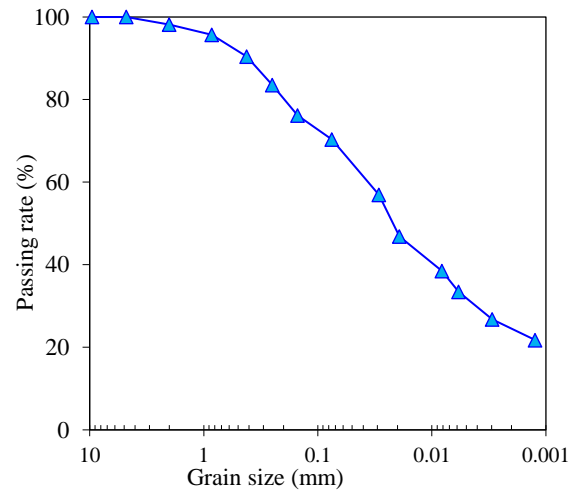


Fig. 5. The gradation curve of clay

The shear strength parameters obtained from the direct shear test results are shown in Table 2. The roughness of the bamboo mat surface can contribute to the increase in the friction angle between the soil and reinforcement materials. Concrete material appears to produce a smaller friction angle than a bamboo mat because it has a smoother surface. The same thing is obtained on the steel surface, which is much smoother, resulting in a much smaller friction angle compared to the other two materials.

Table 2. Shear strength parameters

Materials	Cohesion (kPa)	Friction angle (°)
Soil-bamboo mat	4.16	38.15
Soil-concrete	1.75	37.33
Soil-steel	4.84	28.87

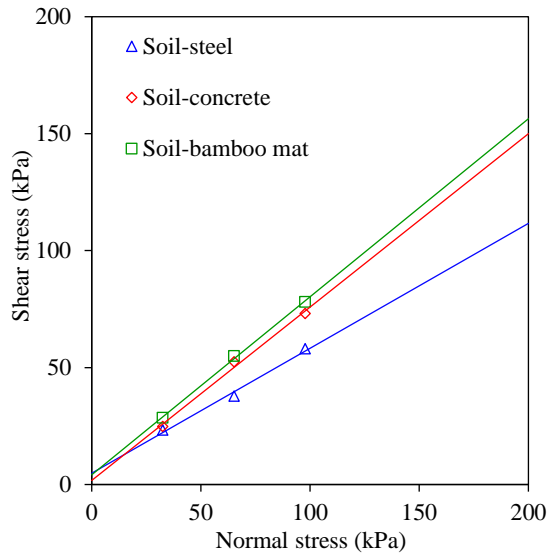


Fig. 6. Direct shear test results

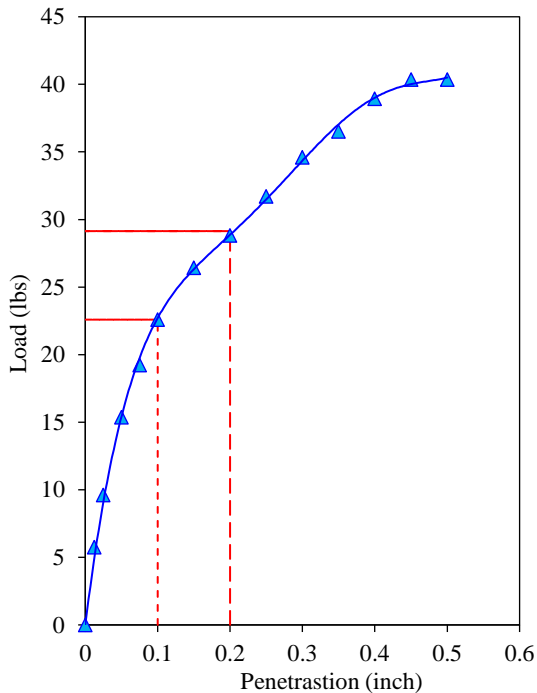


Fig. 7. CBR test result for peat soil

4.2 California Bearing Ratio Test

The results of the CBR test on unreinforced peat soil can be shown in Fig. 7. The unreinforced peat soil with bamboo mats and piles showed a very low CBR value of 0.75%. The CBR value of the studied peat soil was quite low and was classified as very soft soil because it had a CBR value of less than 3% [37]. Peat soil has low shear strength and high water

content [38].

This type of soil cannot be used as a construction subgrade, so a reinforcement system is needed on the peat soil layer. In addition to the reinforcement system, the construction base soil above the peat layer needs to be planned with a good subgrade to achieve the CBR value required for road construction. Peat soil improvement provides opportunities for infrastructure development in areas with poor soil conditions [39].

The CBR test results on a 10 cm thick subgrade with a 7-day curing period are shown in Fig 8. The CBR test results on a single pile are shown in Fig 8a, and the CBR test results on a pile group are shown in Fig 8b. The CBR test results are presented in terms of load-penetration relationships.

The load appears to be higher with the use of a reinforcement system. Reinforcement with bamboo mats without piles (SBL0) has a significant impact on supporting the load. The performance of the reinforcement piles on single piles with length of 20 cm (SBL20), single piles with length of 35 cm (SBL35), and single piles with length of 50 cm (SBL50) can contribute to increasing the subgrade's ability to support the load.

The reinforcement performance of the bamboo mat-piled combination is even more evident in the pile groups with length of 20 cm (GBL20), the pile groups with length of 35 cm (GBL35), and the pile groups with length of 50 cm (GBL50). The loads supported by the subgrade are significantly higher than those of unreinforced peat soil. The performance of the pile group is still significantly higher than that of a single pile. The pile group and the surrounding soil work together to support the loads above it.

A 10 cm thick subgrade appears to limit its load-bearing performance to a certain penetration. This may be due to the pressure distribution having reached the peat surface and the reinforcement system having reached its maximum strength. This effect is evident from the decrease in load after reaching the maximum load.

The subgrade thickness was increased to 20 cm to achieve better load-bearing performance. The results of the short-term CBR subgrade test with a thickness of 20 cm for both single piles and pile groups are shown in Fig. 9. The results of the long-term CBR subgrade test for 70 days are shown in Fig. 10. The subgrade above the peat soil contributes to supporting the load; this is seen in unreinforced peat soil. All reinforcement systems, including both bamboo mats and the combination of bamboo mats with single piles and pile groups, appear to be quite significant in supporting the working load. The pile capacity consists of shaft friction and the end bearing [40].

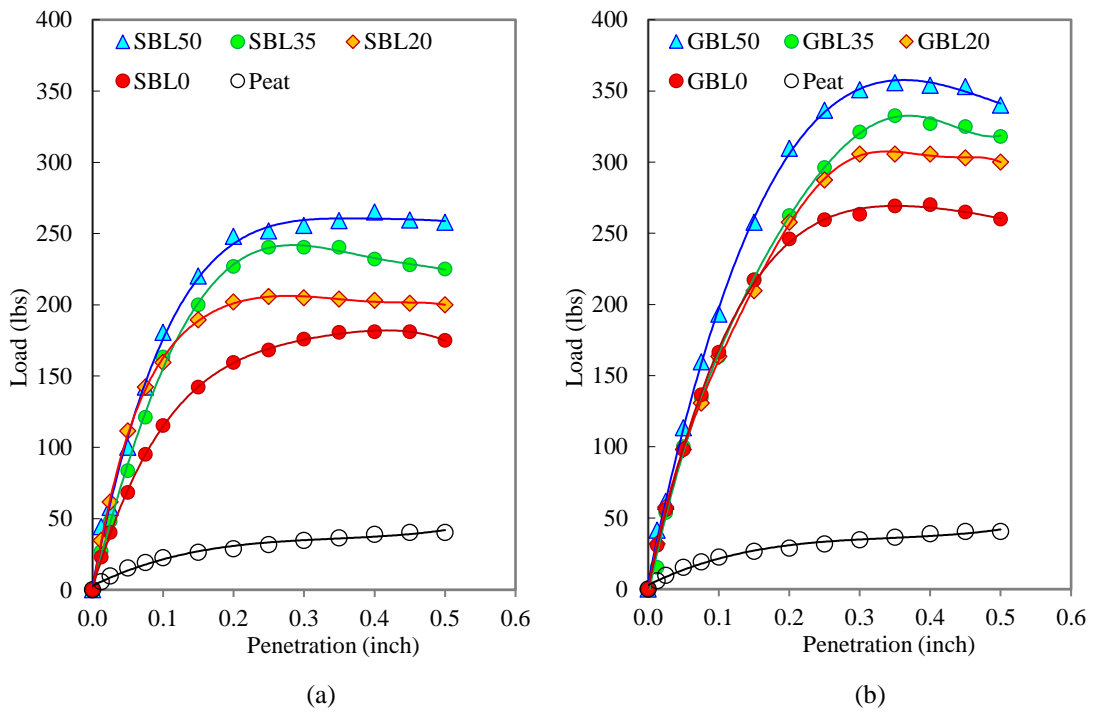


Fig 8. CBR test result for 10 cm of subgrade short term with (a) representing a single pile and (b) representing a pile group

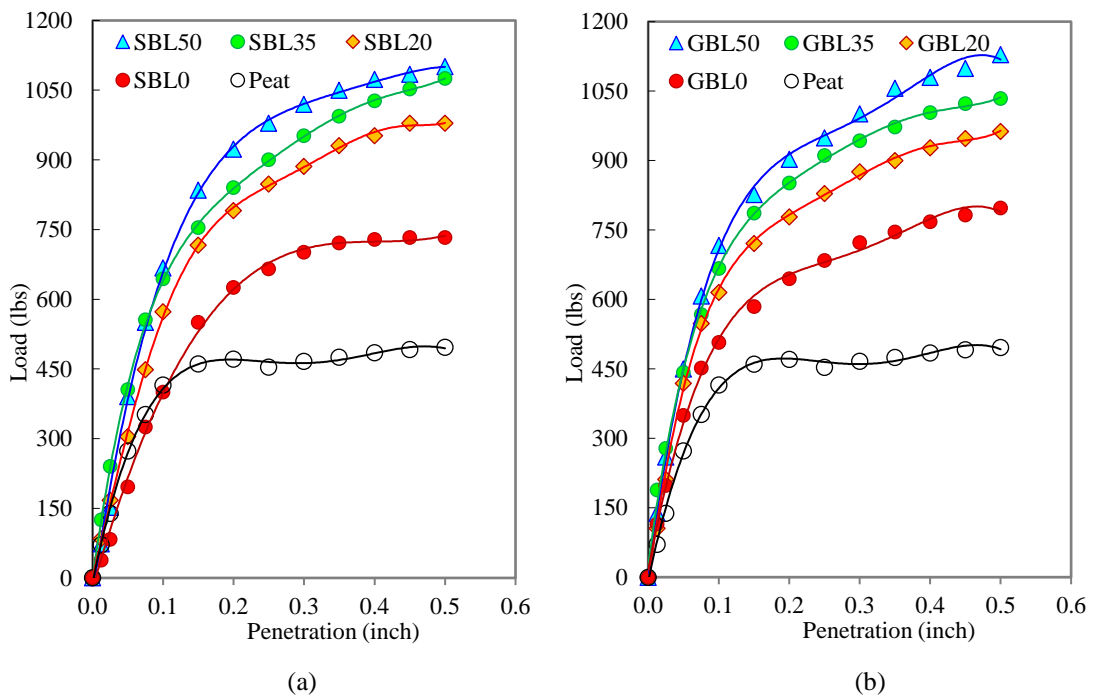


Fig. 9. CBR test result for 20 cm of subgrade short term with: (a) Single pile; (b) Pile group

The relationship between load and penetration in a 20 cm thick subgrade shows an increase in load as penetration increases for both single piles and pile groups. This suggests that the 20 cm thick subgrade acts as a supporting factor in supporting

the load. The soil layer has not yet collapsed, allowing the subgrade to support the additional load. Long-term curing appears to increase the subgrade's load-carrying capacity compared to short-term curing. This implies that extended curing has

enhanced the subgrade's performance.

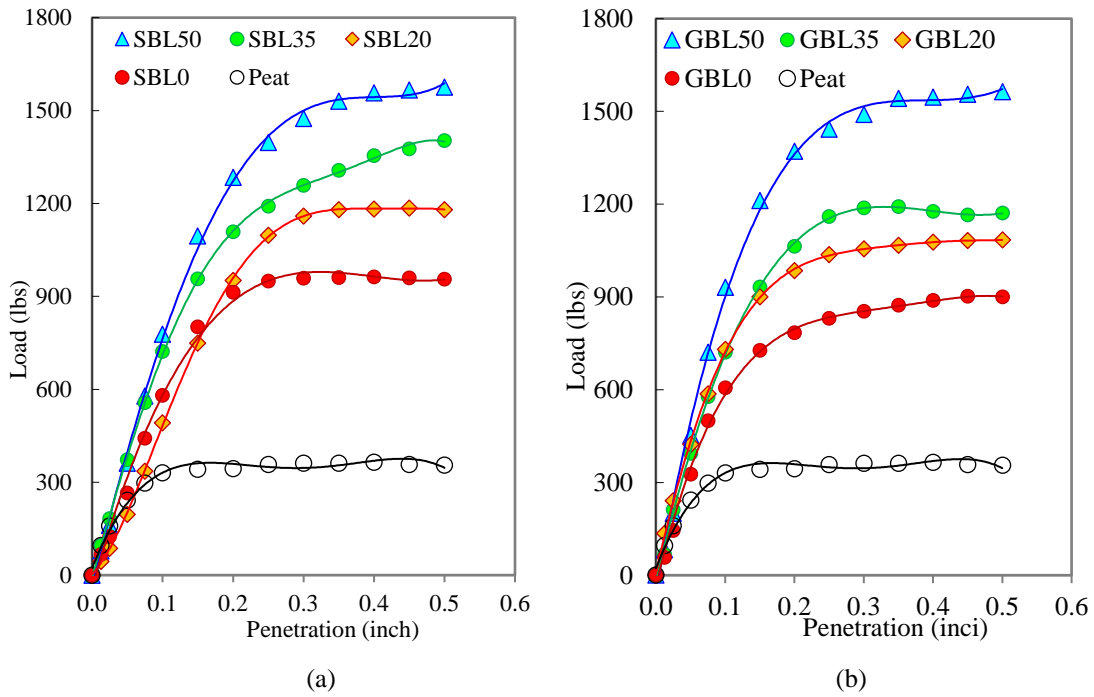


Fig. 10. CBR test result for 20 cm of subgrade long term with: (a) Single pile; (b) Pile group

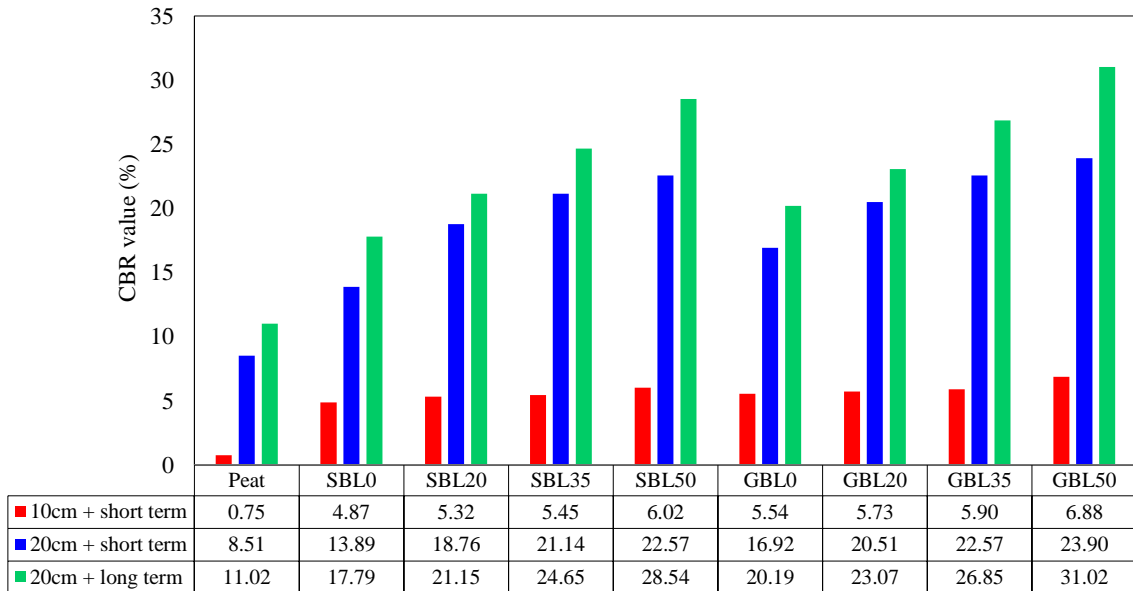


Fig. 11. CBR performance of subgrade

4.3 Performance of Subgrade

The CBR performance of the subgrade on each reinforcement system is shown in Fig. 11. The addition of the 20 cm of subgrade thickness in the short term resulted in an average of 3.49 times

higher than the 10 cm subgrade CBR. The long-term CBR value increased 4.20 times higher than the 10 cm subgrade CBR value and 1.21 times higher than the 20 cm subgrade CBR value. Thus, over a longer period of time, the soil CBR value still increased by 1.21 times.

A thicker subgrade has a higher CBR value.

This can be related to the higher soil density. The long-term strength of the compacted soil increases as the density increases and the water decreases, resulting in a harder soil due to the integration of the soil with the stabilizing material, as indicated by the increase in maximum dry density [15]. Stabilizing materials such as cement can increase the density and hardness of the stabilized soil [41]. Subgrades that have high density can provide high CBR values [13]. Soil density is related to the soil pore cavity; reducing the pore cavity contributes to increasing the density so that the soil can support loads with low penetration, and ultimately the CBR value of the soil increases [42].

4.4 Performance of Bamboo Mat and Piles

The increase in the subgrade CBR value demonstrates the performance of the bamboo mat and reinforced piles. Several CBR test points each on a single pile with a subgrade thickness of 10 cm (SP10), a pile group with a subgrade thickness of 10 cm (PG10), a single pile with a subgrade thickness of 20 cm short term (SP20ST), a pile group with a subgrade thickness of 20 cm short term (PG20ST), a single pile group with a subgrade thickness of 20 cm long term (SP20LT), and a pile group with a subgrade thickness of 20 cm long term (PG20LT). The relationship between pile length and CBR value was shown in Fig. 12. Bamboo mat reinforcement without the use of reinforced piles was seen to produce a relatively high subgrade CBR value, especially at a subgrade thickness of 20 cm. The soil CBR value for a 20 cm thick subgrade without reinforced piles was found to be 13-20%, much higher than the CBR value of the subgrade without reinforcement of 8-11%. Bamboo mat reinforcement can increase the soil CBR value by about 1.8 times. The use of bamboo with horizontal reinforcement, such as geotextiles, is effective in supporting heavy construction on soft soil [43].

Percutaneous piles have a significant effect on increasing the subgrade CBR. The results showed an increase in the CBR value for 20 cm piles of 1.2 times, for 35 cm piles of 1.4 times, and for 50 cm piles of 1.5 times. The combination of bamboo mats with reinforced piles can increase the subgrade CBR value; for the combination of bamboo mats with reinforced piles, L 20 increased by 2.2 times, for the combination of bamboo mats with reinforced piles, L 35 increased by 2.5 times, and for the combination of bamboo mats with reinforced piles, L 50 increased by 2.5 times.

The use of composite reinforced bamboo with concrete showed a much higher ultimate load capacity compared to conventional concrete piles without bamboo reinforcement [44]. Long-term subgrade curing contributes to increasing the subgrade CBR value by approximately 1.1-1.3

times more than the short-term subgrade CBR value for both single piles and pile groups.

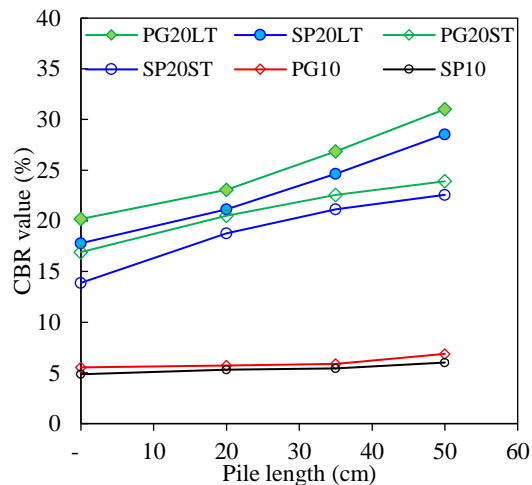


Fig. 12. Relationship between pile length and CBR value

5. CONCLUSIONS

Some conclusions obtained in this study include the interaction of soil with reinforcement materials, the performance of bamboo mat reinforcement, the performance of reinforcement piles, and the subgrade performance of stabilized soil. The friction angle between the soil and the reinforcement indicates the shear strength of the soil with reinforcement materials. The results showed that bamboo mats provide a higher friction angle than other materials because their surface is rougher, which also provides friction when the soil receives shear stress. Bamboo mat reinforcement can contribute to increasing the subgrade CBR. The results showed that the increase in soil CBR can reach 1.8 times even without the use of reinforcement piles. The effect of piles on the subgrade CBR value was found to increase by 1.2-1.5 times compared to the subgrade CBR with bamboo mat. The combination of bamboo mat and reinforcement piles can increase the subgrade CBR value by 2.2-2.7 times compared to the CBR value without reinforcement. Long-term subgrade curing contributes to an increase in the subgrade CBR value that is about 1.1-1.3 times higher than the short-term subgrade CBR value. Thus, based on this research, it can be suggested to use reinforcement from a combination of bamboo mats with piles and embankments as a subgrade for soil stabilization on peat soil.

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7. REFERENCES

- [1] Waruwu A, Susanti R. D., Endriani D., and Hutagaol S., Effect of Loading Stage on Peat Compression and Deflection of Bamboo Grid with Concrete Pile, *International Journal of GEOMATE*, Vol. 18, Issue 66, 2020, pp. 150–155, DOI: 10.21660/2020.66.62072.
- [2] Chalajour S. and Blatz J. A., Prediction of Drag Force on Piles Subjected to Negative Skin Friction Induced by Bridge Embankment Construction Based on Measured Field Data, *Transportation Geotechnics*, Vol. 51, Issue February, 2025, p. 101507, DOI: 10.1016/j.trgeo.2025.101507.
- [3] Waruwu A., Widjajakusuma J., Denzel B., and Calvin F., The Bearing Capacity of Peat Soil with Bamboo Reinforcement, *International Journal of GEOMATE*, Vol. 26, Issue 113, 2024, pp. 19–25, DOI: 10.21660/2024.113.4090.
- [4] Shulyatyev O. A. and Shulyatyev S. O., Influence of Pile Foundation Technology on the Skin Friction, *Smart Geotechnics for Smart Societies*, 2023, pp. 2100–2108, DOI: 10.1201/9781003299127-321.
- [5] Lase Y., Orientilize M., Prakoso W. A., Purnomo S., and Sumartono I. H., Experimental Study of Spun Pile To Pile Cap Connection Confined By Steel Jacket, *International Journal of GEOMATE*, Vol. 27, Issue 124, 2024, pp. 95–103, DOI: 10.21660/2024.124.4707.
- [6] Setiawan A. F, Santoso A. K., Darmawan M. F., Adi A. D., and Ismanti S., Nonlinear Analysis for Investigating Seismic Performance of a Spun Pile-Column of Viaduct Structure, *Civil Engineering Journal (Iran)*, Vol. 9, Issue 7, 2023, pp. 1561–1578, DOI: 10.28991/CEJ-2023-09-07-02.
- [7] Tiwari N. and Satyam N., An Experimental Study on the Behavior of Lime and Silica Fume Treated Coir Geotextile Reinforced Expansive Soil Subgrade, *Engineering Science and Technology, an International Journal*, Vol. 23, Issue 5, 2020, pp. 1214–1222, DOI: 10.1016/j.jestech.2019.12.006.
- [8] Dewi R., Hastuti Y., Sutejo Y., Iqbal M. M., and Arfan M., Peat Soil Improvement Method Using Woven Bamboo and Cerucuk. *International Journal on Advanced Science, Engineering and Information Technology*, Vol. 10, Issue 4, 2020, pp. 1617–1623, DOI: 10.18517/ijaseit.10.4.4199.
- [9] Maruf M. F., Hidayah E., Wahyuni S., Sisingih D., and Putra P. P., Load Sharing Mechanism of Bamboo Pile Mattress for Reinforced Embankment, *International Journal of GEOMATE*, Vol. 25, Issue 107, 2023, pp. 133–140, DOI: 10.21660/2023.107.3833.
- [10] Thai H. N., Kato A., Nguyen H. G., Nguyen T. D., Tong T. K., Nguyen V. T., Uchimura T., Maki T., and Kawamoto K., Effects of Particle Size and Type of Aggregate on Mechanical Properties and Environmental Safety of Unbound Road Base and Subbase Materials: A Literature Review, *International Journal of GEOMATE*, Vol. 20, Issue 78, 2021, pp. 148–157, DOI: 10.21660/2021.78.GX281.
- [11] Shooshpasha I., Hasanzadeh A., and Salari V., Impact of a Coarse Material Sandwich Approach on the Performance of Geotextile-Reinforced Clay. *International Journal of Integrated Engineering*, Vol. 17, Issue 1, 2025, pp. 232–246, DOI: 10.30880/ijie.2025.17.01.019.
- [12] Waruwu A., Telaumbanua D. P. T., and Waruwu T. O., Estimating Consolidation Settlement Using the Physical Properties of Clay Soil Under Embankment, *International Review of Civil Engineering*, Vol. 14, Issue 6, 2023, pp. 570–579, DOI: 10.15866/irece.v14i6.23311.
- [13] Tatsuoka F., Hashimoto T., and Tateyama K., Soil stiffness as a Function of Dry Density and The Degree of Saturation for Compaction Control, *Soils and Foundations*, Vol. 61, Issue 4, 2021, pp. 989–1002, DOI: 10.1016/j.sandf.2021.06.007.
- [14] Sudjianto A. T., Susilo S. H., Tolan P. M., Agung P. A. M., and Hasan M. F. R., Increasing the Stability of Expansive Soil Using Lapindo Sediments Materials, *International Journal of GEOMATE*, Vol. 25, Issue 108, 2023, pp. 154–162, DOI: 10.21660/2023.108.3767.
- [15] Muntaha M., Fitrie R. H. A., Wahyuni F., and Tajunnisa Y., The Use of Alkaline Activators With High Calcium Fly Ash As Soft Clay Stabilization Materials, *International Journal of GEOMATE*, Vol. 25, Issue 109, 2023, pp. 9–17, DOI: 10.21660/2023.109.3286.
- [16] Al-Bared M. A. M., Harahap I. S. H., and Marto A., Sustainable Strength Improvement of Soft Clay Stabilized with Two Sizes of Recycled Additive, *International Journal of GEOMATE*, Vol. 15, Issue 51, 2018, pp. 39–46, DOI: 10.21660/2018.51.06065.
- [17] Wu J., Min Y., Li B., and Zheng X., Stiffness and Strength Development of The Soft Clay

- Stabilized by The One-part Geopolymer under One-Dimensional Compressive Loading, *Soils and Foundations*, Vol. 61, Issue 4, 2021, pp. 974–988, DOI: 10.1016/j.sandf.2021.06.001.
- [18] Wurie N. N., Zheng J., and Traore A. F., Mechanical, Leaching, and Microstructure Properties of Mine Waste Rock Reinforced and Stabilised with Waste Oyster Shell for Road Subgrade Use. *Materials*, Vol. 15, Issue 8, 2022, pp. 1–21, DOI: 10.3390/ma15082916.
- [19] Jili Q., Huan T., Weiqing Q., Guoqi H., Hongmei L., Abulimiti P., Maimaitiyusupu S., and Batugin A., Modification of Mechanical Properties of Shanghai Clayey Soil with Expanded Polystyrene, *Science and Engineering of Composite Materials*, Vol. 29, Issue 1, 2022, pp. 37–49, DOI: 10.1515/secm-2022-0004.
- [20] Yin Z., Lekalpure R. L., and Ndiema K. M., Experimental Study of Black Cotton Soil Stabilization with Natural Lime and Pozzolans in Pavement Subgrade Construction, *Coatings*, Vol. 12, Issue 1, 2022, p. 103, DOI: 10.3390/coatings12010103.
- [21] Xu M., Liu L., Deng Y., Zhou A., Gu S., and Ding J., Influence of Sand Incorporation on Unconfined Compression Strength of Cement-based Stabilized Soft Clay, *Soils and Foundations*, Vol. 61, Issue 4, 2021, pp. 1132–1141, DOI: 10.1016/j.sandf.2021.06.008.
- [22] Seyrek E., Engineering Behavior of Clay Soils Stabilized with Class C and Class F Fly Ashes, *IEEE Journal of Selected Topics in Quantum Electronics*, Vol. 25, Issue 2, 2018, pp. 273–287, DOI: 10.1515/secm-2016-0084.
- [23] Zorluer I. and Gucek S., The Effects of Marble Dust and Fly Ash on Clay Soil, *Science and Engineering of Composite Materials*, Vol. 21, Issue 1, 2014, pp. 59–67, DOI: 10.1515/secm-2012-0100.
- [24] Zumrawi M. M. E., and Abdalla E. A. E., Stabilization of Expansive Soil Using Marble Waste Powder, *Second Conf. Civ. Eng. Sudan*, Vol. 2, Issue December, 2018, pp. 266–271
- [25] Wang H., Zhang L., Shi C., Zhao L., and Zhang Y., Comparative Study of Anti-Slide Pile Reinforcement Schemes for Expansive Soil Canal Slopes in Cold and Arid Regions, *Journal of Civil Engineering*, Vol. 28, Issue 9, 2024, pp. 3741–3757, DOI: 10.1007/s12205-024-2704-x.
- [26] Li C., Chen W., Song Y., Gong W., and Zhao Q., Optimal Location of Piles in Stabilizing Slopes Based on a Simplified Double-Row Piles Model, *KSCE Journal of Civil Engineering*, Vol. 24, Issue 2, 2020, pp. 377–389, DOI: 10.1007/s12205-020-0712-z.
- [27] Gedara G. and Udukumburage S., Validation of Swelling Estimation Methods Using a Laboratory-Scaled Instrumented Soil Column, *International Journal of GEOMATE*, Vol. 27, Issue 124, 2024, pp. 112–119, DOI: 10.21660/2024.124.4735.
- [28] Oh Y. P. and Ismail M. A. M., Pile Length Optimization by Using Shaft Friction and End Bearing Curves Developed from Instrumented Pile Load Test, *Physics and Chemistry of the Earth, Parts A/B/C*, Vol. 129, 2023, p. 103278.
- [29] Sahil A. W., Uchimura T., Maejima T., and Kabir M. R., A Study on the Effect of Toe-Wing Position on Screw Pile Performance in Cohesionless Soil, *International Journal of GEOMATE*, Vol. 27, Issue 122, 2024, pp. 1–8, DOI: 10.21660/2024.122.4593.
- [30] Waruwu A., Purba S. M., Wijaya N. Y., Sumantri N. A., and Pangemanan I. L., The Performance of Soil Stabilization with Marble Ash in Physical Model Tests in The Laboratory, *International Journal of GEOMATE*, Vol. 27, Issue 124, 2024, pp. 49–56, DOI: 10.21660/2024.124.4647.
- [31] Shaheen M., Rabei M., Mansour M., and Nour El-Deen A., The Influence of Soil Reinforcement on the Performance of Single Pile and Pile Group Under Pullout Loads, *Engineering Research Journal*, Vol. 183, Issue 3, 2024, pp. 206–225, DOI: 10.21608/erj.2024.377302.
- [32] Memarian S., Ahadiyan J., and Reza K. H., Assessment of Vertical Pile Reinforcement Effect on Behavior of Foundations Placed on Slopes: An Experimental and Numerical Study, *Ain Shams Engineering Journal*, Vol. 14, Issue 12, 2023, pp. 1–13, DOI: 10.1016/j.asej.2023.102233.
- [33] Lukpanov R., Tsygulyov D., Zhantlessova Z., Altynbekova A., Yenkebayev S., and Kozhahmet M., Selection of Equivalent Material for Soil Testing Using Piles on a Scale Model Testing Apparatus, *International Journal of GEOMATE*, Vol. 26, Issue 117, 2024, pp. 11–18, DOI: 10.21660/2024.117.4167.
- [34] Waruwu A., Susanti R. D., Napitupulu N., and Sihombing J. O., The Combination of Bamboo Grid and Concrete Pile as Soil Reinforcement under The Embankment, *Magazine of Civil Engineering*, Vol. 106, Issue 6, 2021, p. 10610, DOI: 10.34910/MCE.106.10.
- [35] Waruwu A., Susanti R. D., Simbolon D. S., and Asfira D. W., Single Pile Capacity on Clay Soil Based on Results of Physical Model Test, *Media Komunikasi Teknik Sipil*, Vol. 29, Issue 1, 2023, pp. 32–39, DOI: 10.14710/mkts.v29i1.52111.
- [36] ASTM D4429-93. Standard Test Method for CBR (California Bearing Ratio) of Soil in

- Place, 1993.
- [37] Bowles J. E., Engineering properties of soil and their measurement. England: McGraw-Hill Book Company Limited, 1992.
- [38] Sutarno M. S., Mohamad H. M., and Suradi M. A. A., Unconsolidated Undrained Shear Strength Behaviour: Beaufort's Peat Soils, *International Journal of GEOMATE*, Vol. 28, Issue 129, 2025, pp. 21–29, DOI: 10.21660/2025.129.4522.
- [39] Mohamad H. M., Suhaimi A. A., Saida N. A., and Majain N., Peat Soil Behaviour Stabilised with by-Product of Manufacture of Edible Oils, *International Journal of GEOMATE*, Vol. 28, Issue 129, 2025, pp. 30–38, DOI: 10.21660/2025.129.4556.
- [40] Koga S., Watanabe K., and Yamamoto T., Evaluation of Vertical Bearing Characteristics For Soil-Cement Composite Piles, *International Journal of GEOMATE*, Vol. 25, Issue 108, 2023, pp. 146–153, DOI: 10.21660/2023.108.3741.
- [41] Al-Adly A. I. F., Reduction of under-Road Pavement Sinkhole Hazards by Soil Improvement, *International Journal of GEOMATE*, Vol. 29, Issue 131, 2025, pp. 76–83, DOI: 10.21660/2025.131.4926.
- [42] Li T., Kong L., and Liu B., The California Bearing Ratio and Pore Structure Characteristics of Weakly Expansive Soil in Frozen Areas, *Applied Sciences (Switzerland)*, Vol. 10, Issue 21, 2020, pp. 1–22, DOI: 10.3390/app10217576.
- [43] Zainuldin N., Ooi K. T., Ming Han L. Performance of the Bamboo Geotextile System 'GEOBAMTILE' for Road Construction on Deep Soft Ground, *E3S Web of Conferences*, Vol. 347, Issue 03010, 2022, pp. 1–10, DOI: 10.1051/e3sconf/202234703010.
- [44] Le T. P., Nguyen C. T., and Nguyen P. L., An Experimental Study on Compressive Strength of Concrete-Filled Bamboo Columns: Novel Drilling and Casting System, *International Journal of GEOMATE*, Vol. 28, Issue 127, 2025, pp. 1–11, DOI: 10.21660/2025.127.4698.

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