INTERNATIONAL JOURNAL OF SUSTAINABLE CONSTRUCTION ENGINEERING AND TECHNOLOGY
VOL. 14 NO. 5 (2023) 364-373

IJSCET

http://publisher.uthm.edu.my/ojs/index.php/ijscet

ISSN : 2180-3242 e-ISSN : 2600-7959

International Journal of Sustainable Construction Engineering and Technology

Settlement Performance of Bamboo Dendrocalamus Asper for Improving Peat Soil Reinforcement Stability

Zeety Md Yusof[1,2*], Nur Azra Azeera Rozaini[1], Adnan Zainorabidin[1,2], Putera Agung Maha Agung[3]

[1]Faculty of Civil Engineering and Built Environment,
Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, Johor, MALAYSIA

[2]Research Center for Soft Soil (RECESS), Institute for Integrated Engineering (IIE),
Universiti Tun Hussein Onn Malaysia (UTHM), Batu Pahat, 86400, Johor, MALAYSIA

[3]State Polytechnic of Jakarta,
Department of Civil Engineering, Kampus Baru UI Depok 16425 West Java, INDONESIA

*Corresponding Author

DOI: https://doi.org/10.30880/ijscet.2023.14.05.030
Received 17 October 2023; Accepted 17 October 2023; Available online 31 October 2023

Abstract: Soil reinforcement is the geotechnical application for the soil mass reinforcement elements to increase the shear characteristics of the soil grid. Bamboo is a sustainable source for the wood industry that has been applied in construction soil foundations as a soil reinforcement material. The use of bamboo types Dendrocalamus asper for soft soil reinforcement stability is important and commonly used. Peat, as a very soft soil, is known as problematic soil, and organic soil has poor shear strength and high compressibility. In construction especially for peat soil foundation or subgrade, it has settlement and deformation because of loss of strength. The peat soil from Kampung Puteri Menangis, Benut Pontian Johor has been used in the experimental work to determine the displacement of the settlement performance characteristics without and with the laminated beams of bamboo Dendracalamus asper. Without bamboo, the displacement of the settlement reduces from 22.4% to 6.8% within 1 hour. The use of 1 layer of laminated bamboo reinforcement on the foundation base reduced the displacement of the settlement from 27.2% to 8.9%. The displacement continues to decrease from 19.3% to 5.8% for two layers of laminated bamboo reinforcement, and 18.9% to 5.9% for 3 layers of laminated bamboo reinforcement. At each stage and duration, the peat shows displacement in compression, and the settlement of the reinforcement stability is smaller than in the other stage.

Keywords: Peat, bamboo, settlement

1. Introduction

Soil that has a high organic content such as peat soil has been described differently from other soil because of its different characteristics and formation [1]. The different characteristics and formations come from the percentage of fiber content, organic content, and mineral content in the particles of the peat soil. The inconsistency of these components changed the natural physical properties of peat soil. The changes in physical properties affected the degree of decomposition of peat soil porosity and changed the shape structure of the peat particles [2].

*Corresponding author: zeety@uthm.edu.my

The decomposition of peat plays a main factor in changes in the components of peat such as changes in water content, color, and woody materials levels. The amount of water in the peat soil is the main factor contributing to the peat characterization of permeability, shear strength, bearing capacity, and compressibility [3]. These properties are different from sandy soil [4]. The weakness of peat soil characterization was giving a high impact on the geotechnical problems. The major geotechnical problems in the construction foundation are when the soil has problems in settlement and not good stability. Peat soil is very weak in its settlement and stability [3]. The stability of weak soil such as peat, clay, or residual soil can be improved by soil stabilization [5].

The settlement and stability of peat soil are the main parameters that geotechnical engineers highly focus on in designing the structure of the foundation [6]. Therefore, the prediction of settlement and stability either using physical or numerical modeling is important to achieve a successful design. The modeling of geotechnical behavior such as settlement and stability for peat soil was predicted to simulate the performance of the structure foundation [7]. The simulation was predicted with respect to time to simulate the performance structure foundation at the actual site [8].

Previous researchers have studied and proposed a few techniques to improve, solve, and manage the settlement construction of peat soil [9]. The techniques are based on peat depth categories. Some studies have shown that the researchers have highlighted several techniques such as excavating, replacement, sand drain, lightweight fills, and stone columns [10]. In the current situation where the population of residents is increasing every year, need constructions player to identify alternative ways, and proper methods are needed to avoid the instability of the foundation structure caused by peat settlement [11].

The population increase is equivalent to the growing land demand. The construction development on peatland needs major care from its design and construction to avoid the failure of underground areas. When loading was applied on the ground surface, the peat soil was settled and deformation in different conditions. This high excessive settlement affects durability and smoothness, the most common causes of foundation structure [12].

The settlement of soil was solved by reinforcement for many years, especially at construction embankments. The concept of soil reinforcement is to develop the reinforcement elements in a soil mass that increase the shear resistance of the soil matrix. There are many types of materials that are used as soil reinforcement that can make soil strong and more resistant to microbial invasion. The materials are such as geotextiles, geogrids, timber, and bamboo [13].

Bamboo's advantage is its durable and elastic properties. It is cheap and plentiful to meet the extensive need for economical construction, making it ideal for building construction materials. Due to the lack of information about the properties of bamboo, has utilization of bamboo in construction has been neglected. A further advantage of bamboo is its effectiveness in lowering groundwater levels and preventing lateral movement by isolating the original muddy soil like peat. Geotextile cannot be used independently directly on the peat area without the roll sinking into the extremely soft material. But if a geotextile placed over a bamboo fascine was found to be the most effective method of overcoming the said problems [14].

Bamboo has been renowned in the sustainability green engineering technology industry because of its environmentally promising characteristics. The bamboo culm can be dismantled into thin, slender laminae and then laminated into one group with adhesive to form genuine structural members. It can be used with a certain limit to the proportionate dimension of the bamboo culm and the low inflexibility of the bamboo [12 & 14]. Therefore, the composite material called laminated bamboo was created for the giant bamboo laminated beams (Dendrocalamus asper) that are commonly used in building construction materials. The laminated bamboo composite of Dendrocalamus asper bamboo has properties showing better performance, so it can be compared to some other structural composite wood products [15 & 16]. The use of reinforcement materials to improve soil-bearing capacity and reduce settlement has been proven to be a cost-effective solution for foundation design. However, there are cases in which vertical or sloped reinforcement may be used below the foundation. Therefore, this study shows the expected settlement of the foundation rest on the soil and reduces the corresponding settlement of the foundation compared to unreinforced soil.

2. Methodology

All the testing was conducted at the Research Centre for Soft Soil (RECESS) Laboratory at Universiti Tun Hussein Onn Malaysia (UTHM). Physical modeling of foundation equipment for this study has prepared to fulfill the objective of the study. A square box poly glass with a width of 50 cm x length of 50 cm x height of 70 cm measurement was prepared as shown in Fig. 1 (a) without bamboo and Fig. 1 (b) with bamboo. The peat soil from Kampung Puteri Menangis, Benut Pontian Johor has been used in the experimental work to determine the displacement of the settlement performance characteristics without and with the laminated beams of bamboo Dendracalamus asper. The 0.5 cm thick iron is placed in the middle of the surface of a layer of soil. The peat soil sample was cleaned and prepared and placed properly. The model of the bamboo laminated beam was prepared in size 30 cm x 25 cm x 0.9 cm. The foundation on the top of the peat is ready for loading test and then modeled in accordance with the established.

Different boxes with the exact measurements were prepared to test the settlement performance which is without bamboo and with bamboo. For without bamboo, the foundation of a square plate with sides 10 cm x 15 cm above a layer of reinforcement is placed. The selected load was applied on the foundation to the peat soil without bamboo. Two different types of time, which are 1 hour, and 2 hours were selected to measure the settlement performance. The different loads were applied which are 4, 6, 8, and 10 kg with respective time.

While the model of a bamboo laminated beam is placed at a predetermined depth, the same size foundation of a square plate with sides 10 cm x 15 cm above a reinforcement layer is placed. The selected load was applied on the foundation of the peat soil with bamboo. This step is the 1st layer of bamboo. Two different types of time, which are 1 hour, and 2 hours were selected to measure the settlement performance. The different loads were applied which are 4, 6, 8, and 10 kg with respective time. The same steps were applied to the 2nd layer and 3rd layer of bamboo.

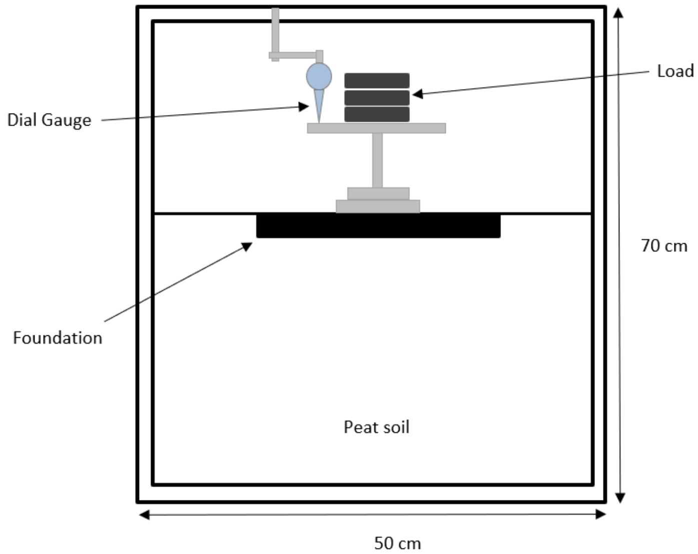


Fig. 1 (a) - Physical model of the foundation (without bamboo)

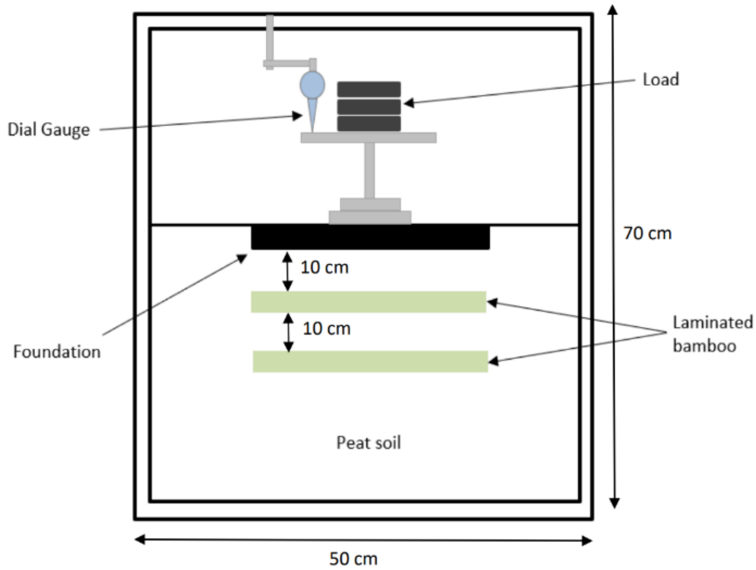


Fig. 1 (b) - Physical model of the foundation (with bamboo)

3. Results and Discussion

This research has divided the results into two parts. Part one is the results for physical and engineering properties, while part two is the results of the settlement test.

3.1 Physical and Engineering Properties of Peat Soil

The peat soil that was used as the main material in this study is taken from Kampung Puteri Menangis, Benut Pontian Johor. The results of the physical properties test showed that the value of specific gravity (G_s) is 1.26, and the value of the water content (w) is 672%. While, the value of organic content (OC), and fiber content (FC) respectively 67.429% and 75%. Thus, peat soil is classified as pseudo-fibrous peat (hemic) based on the degree of peat decomposition (H5-H7), hemic has fiber content in between fabric and sapric. Peat soil with medium organic content of organic content <75% and hemic to fibrous peat, peat soil with fiber content >20% (33% - 66%). The shear strength of the peat soil can be determined by a shear test such as an unconfined compression test. Based on the result of the unconfined compression test, the peat soil studied had undrained shear strength (C_u) of 9 kPa (Fig. 2). Therefore, peat soil in this study is classified as very soft soil for C_u value < 12.5 kPa.

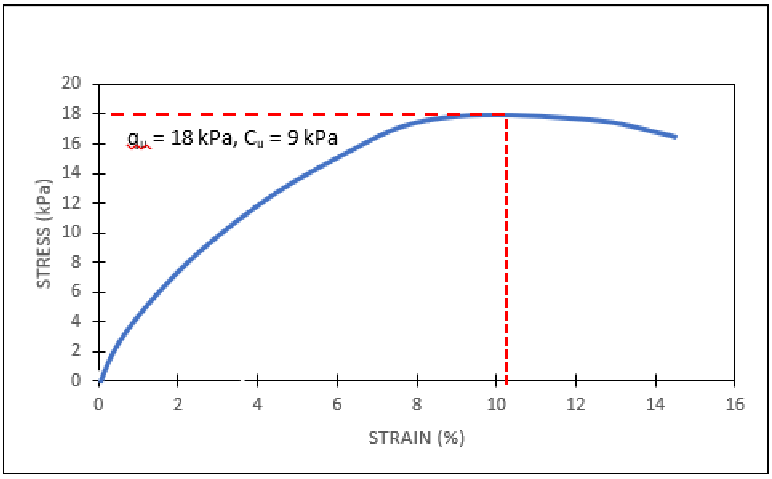


Fig. 2 - Compression Strength

3.2 Settlement Performance for Peat Soil Foundation

The load testing model of a foundation in the laboratory shows the relationship between load and settlement.

Unreinforced Peat Soil

Fig. 3 shows the testing without bamboo reinforcement in the measure used of a foundation size of 10 cm x 15 cm. It is obtained that the displacement of the settlement collapse load which resulted in 3.052 mm to 10.706 mm approximately in 22.4% to 6.8% from 1 hour to 2 hours loading. The displacement of 3.052 mm to 3.934 mm shows in the range of 22.4% after a 4 kg/cm^2 load was applied from 1 hour to 2 hours. When the load increased to 6 kg/cm^2, the displacement 5.609 mm to 6.319 mm shows in range a decrease of 11.2% from 1 hour to 2 hours after the applied load. The displacement of 7.721 mm to 8.389 mm shows in range a slight decrease to 7.9% at a load of 8 kg/cm^2 and follows the displacement of 9.969 mm to 10.706 mm in a range to 6.8% at a 10 kg/cm^2 load after 2 hours. Even though the displacement of the settlement shows the performance of displacement decreases as much as 15.6% in different 1 hours, it doesn't show a very excessive settlement.

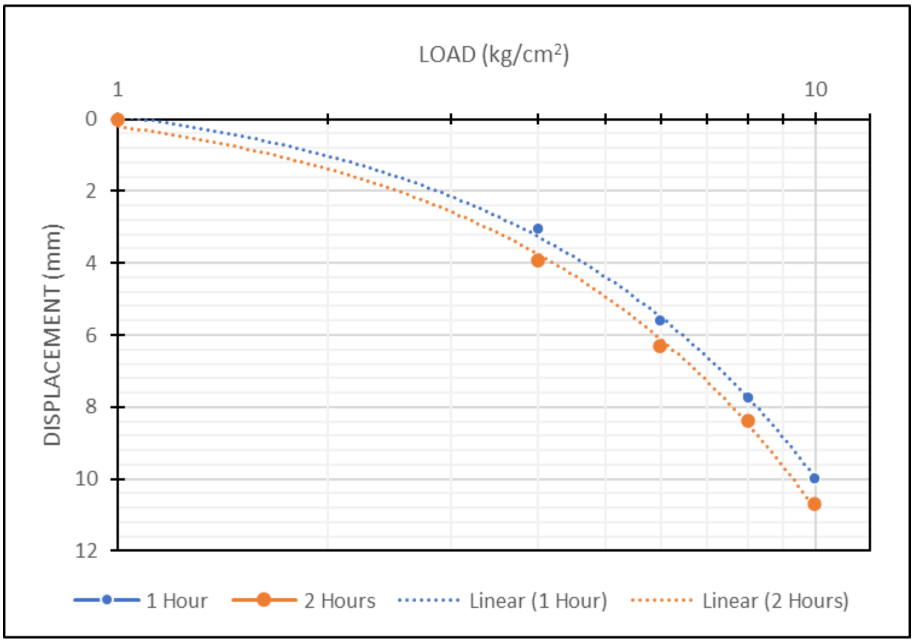
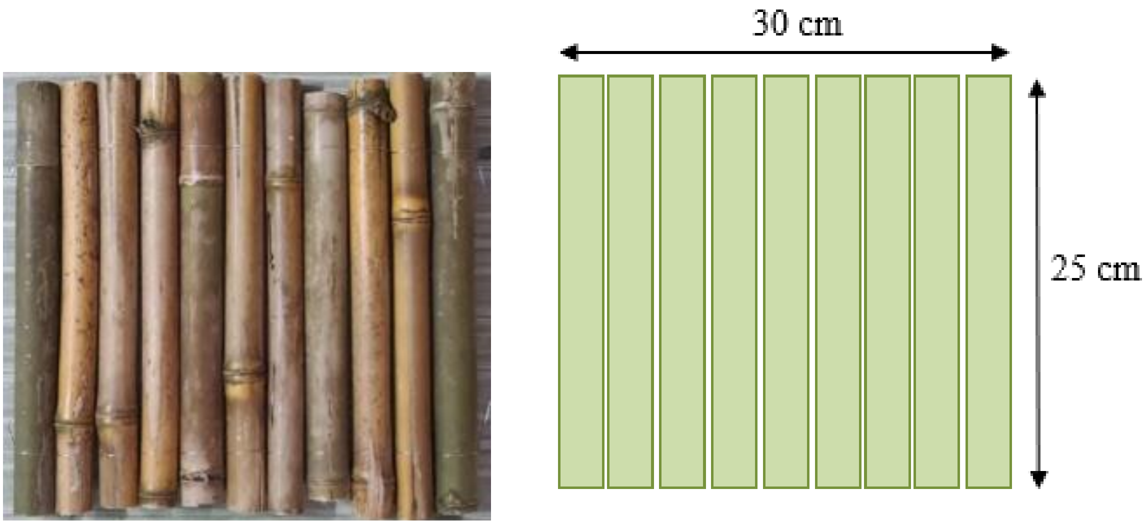


Fig. 3 - Without Bamboo

Laminated Beams of Bamboo Dendrocalamus Asper Reinforced Peat Soil

Fig. 4 shows the material that was used in this study. The bamboo types Dendrocalamus asper were arranged properly as laminated bamboo beams. The bamboo reacts as reinforcement for the soil.



(a) (b)

Fig. 4 - Laminated Bamboo Beam

Fig. 4 also, the bamboo has dimensions of 35 mm diameter (± 5 mm). The measurement that was used is 30 cm x 25 cm. Two types of physical models were conducted in this study, without bamboo, and with bamboo. The test was conducted at four different loading stages of 4 kg/cm^2, 6 kg/cm^2, 8 kg/cm^2, and 10 kg/cm^2.

Fig. 5 shows the testing with 1 layer of bamboo reinforcement in the measure used of a foundation size of 10 cm x 15 cm. It is obtained that the displacement of the settlement collapse load which resulted in 2.189 mm to 8.454 mm approximately in 27.2% to 8.9% from 1 hour to 2 hours loading.

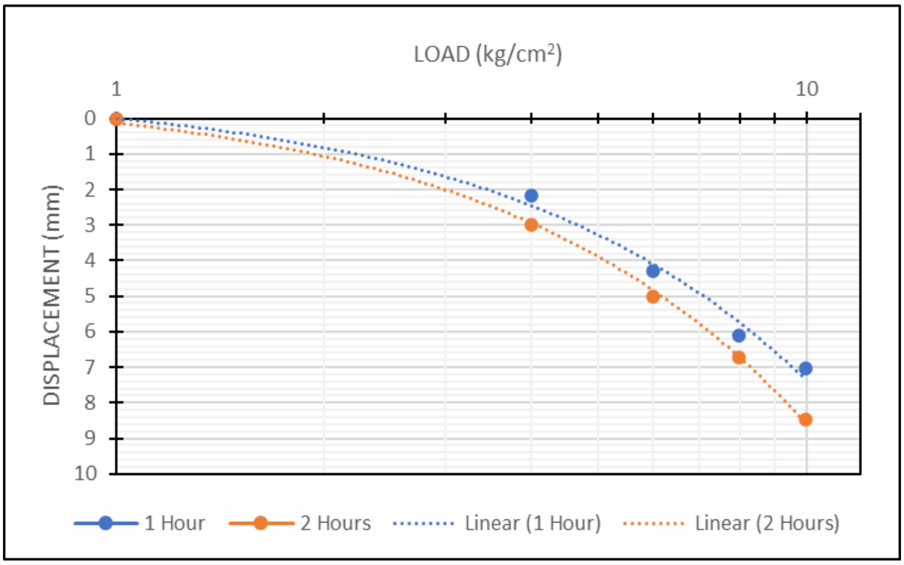


Fig. 5 - With 1 Layer Bamboo

From Fig. 5, the displacement of 2.189 mm to 3.007 mm shows in the range of 27.2% after a 4 kg/cm^2 load was applied from 1 hour to 2 hours. When the load increased to 6 kg/cm^2, the displacement of 4.309 mm to 5.024 mm shows in range a decrease of 14.2% from 1 hour to 2 hours after the applied load. The displacement of 6.125 mm to 6.727 mm shows in the range of a slight decrease to 8.9% at a load of 8 kg/cm^2. It shows the displacement 7.041 mm to 8.454 mm is slightly increased in the range to 16.7% at a 10 kg/cm^2 load after 2 hours. Even though the displacement of the settlement shows the performance of displacement decreases and increases, it doesn’t show a very excessive settlement as much as the difference of settlement between 13% to 7.8%.

Fig. 6 shows the testing with 2 layers of bamboo reinforcement in the measure used of a foundation size of 10 cm x 15 cm. It is obtained that the displacement of the settlement collapse load which resulted in 1.993 mm to 6.666 mm approximately in 19.3% to 5.8% from 1 hour to 2 hours loading.

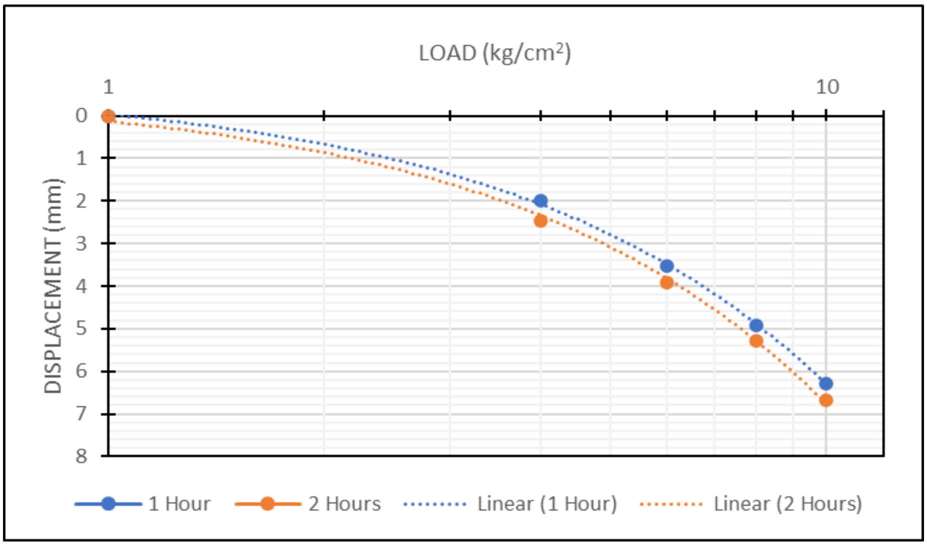


Fig. 6 - With 2 Layer Bamboo

From Fig. 6, the displacement of 1.993 mm to 2.471 mm shows in the range of 19.3% after a 4 kg/cm^2 load was applied from 1 hour to 2 hours. When the load increased to 6 kg/cm^2, the displacement of 3.527 mm to 3.913 mm shows in range a decrease of 9.8% from 1 hour to 2 hours after the applied load. The displacement of 4.921 mm to 5.282 mm shows in the range of a slight decrease to 6.8% at a load of 8 kg/cm^2 and follows the displacement 6.279 mm to 6.666 mm to 5.8% at a 10 kg/cm^2 load after 2 hours. Even though the displacement of the settlement shows the performance of displacement decreases as much as 13.5% in different 1 hours, it doesn't show a very excessive settlement.

Fig. 7 shows the testing with 3 layers of bamboo reinforcement in the measure used of a foundation size of 10 cm x 15 cm. It is obtained that the displacement of the settlement collapse load which resulted in 1.252 mm to 4.444 mm approximately in 18.9% to 5.9% from 1 hour to 2 hours loading.

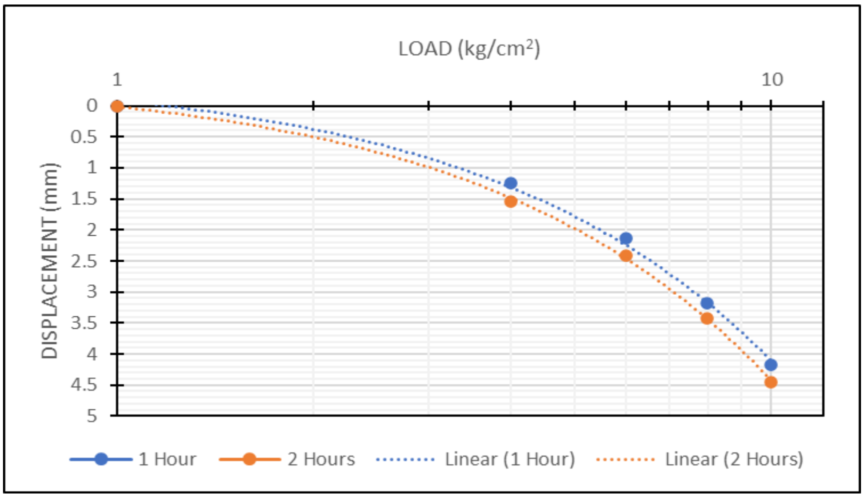


Fig. 7 - With 3 Layer Bamboo

From Fig. 7, the displacement of 1.252 mm to 1.545 mm shows in the range of 18.9% after a 4 kg/cm^2 load was applied from 1 hour to 2 hours. When the load increased to 6 kg/cm^2, the displacement from 2.143 mm to 2.413 mm shows a decrease in the range of 11.1% from 1 hour to 2 hours after the applied load. The displacement of 3.176 mm to 3.421 mm shows the range of a slight decrease to 7.1% at a load of 8 kg/cm^2 and follows the displacement of 4.181 mm to 4.444 mm in the range of 5.9% at a 10 kg/cm^2 load after 2 hours. Even though the displacement of the settlement shows the performance of displacement decreases as much as 13% in different 1 hours, it doesn't show a very excessive settlement. Model testing of foundations on top of the peat soil with the dimensions of 10 cm x 15 cm showed the value of soil bearing capacity in reduction displacement of settlement from 15.6% to 13% (from without bamboo to 3 layers reinforcement bamboo).

It can be seen in Fig. 8, the displacement of the settlement without bamboo increased from 3.052 mm to 9.969 mm after the applied load until 10 kg/cm^2 in 1 hour. It shows that around 69.3% of the settlement increased without bamboo after applying 10 kg/cm^2 in 1 hour.

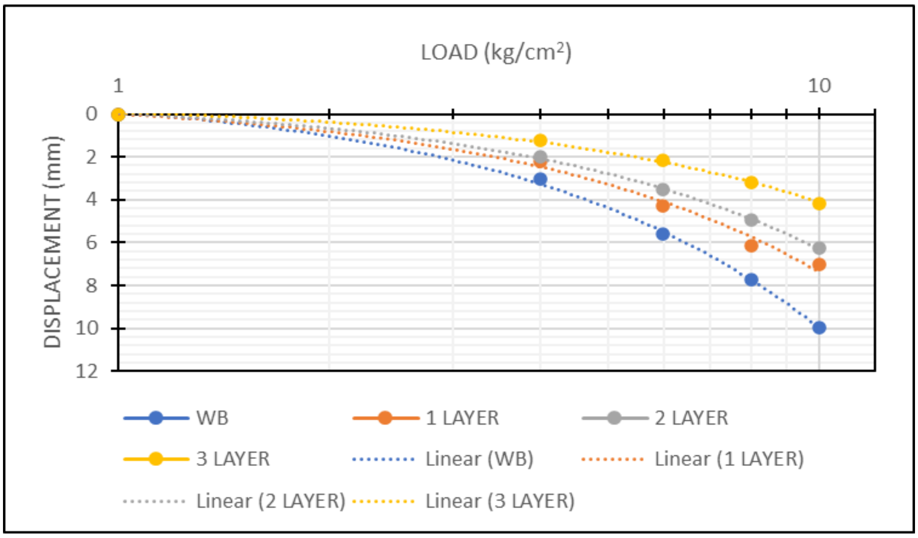


Fig. 8 - Displacement of the Settlement Performance in 1 hour

In 1 hour, the changes load from 4 kg/cm^2 to 6 kg/cm^2 give a displacement of 45.5%. After the load increases from 8 kg/cm^2 to 10 kg/cm^2 the displacement of the settlement decreases to 22.5%.

Fig. 8 also shows the displacement of the settlement for reinforcement bamboo in 1 layer from 2.189 mm to 7.041 mm after applying a load of 10 kg/cm^2 in 1 hour. It shows that around 68.9% of the settlement increased with 1 layer of bamboo after applying 10 kg/cm^2 in 1 hour. In 1 hour, the changes in load from 4 kg/cm^2 to 6 kg/cm^2 give a displacement of 49.1%. After the load increases from 8 kg/cm^2 to 10 kg/cm^2 the displacement of the settlement decreases to 13%.

For reinforcement bamboo in 2 layers the displacement of the settlement was in the range of 1.993 mm to 6.279 mm after applying a load of 10 kg/cm^2 in 1 hour as shown in Fig. 8. It is shown that around 68.2% of the settlement increased with 2 layers bamboo after applied load 10 kg/cm^2 in 1 hour. In 1 hour, the changes in load from 4 kg/cm^2 to 6 kg/cm^2 give a displacement of 43.4%. After the load increases from 8 kg/cm^2 to 10 kg/cm^2 the displacement of the settlement decreases to 21.6%.

While for reinforcement bamboo in 3 layers, the displacement of the settlement was in the range of 1.252 mm to 4.181 mm after applying a load of 10 kg/cm^2 in 1 hour as shown in Fig. 8. It is shown that around 70.1% of the settlement increasing with 3 layers bamboo after applied load 10 kg/cm^2 in 1 hour. In 1 hour, the changes in load from 4 kg/cm^2 to 6 kg/cm^2 give a displacement of 41.5%. After the load increases from 8 kg/cm^2 to 10 kg/cm^2 the displacement of the settlement decreases to 24%.

It is shown that the ultimate bearing capacity values at the foundation increased after being given reinforcement layer 1. Significant increases occurred in the number of reinforcement layers 2 layers and layers 3 layers in 1 hour performance.

It can be seen in Fig. 9, the displacement of the settlement without bamboo increased from 3.934 mm to 10.706 mm after the applied load until 10 kg/cm^2 in 1 hour. It shows that around 63.2% of the settlement increased without bamboo after applying 10 kg/cm^2 in 1 hour. In 1 hour, the changes load from 4 kg/cm^2 to 6 kg/cm^2 give a displacement of 37.7%. After the load increases from 8 kg/cm^2 to 10 kg/cm^2 the displacement of the settlement decreases to 21.6%.

Fig. 9 also shows the displacement of the settlement for reinforcement bamboo in 1 layer from 3.007 mm to 8.454 mm after applying a load of 10 kg/cm^2 in 1 hour. It shows that around 64.4% of the settlement increased with 1 layer of bamboo after applying 10 kg/cm^2 in 1 hour. In 1 hour, the changes in load from 4 kg/cm^2 to 6 kg/cm^2 give a displacement of 40.1%. After the load increases from 8 kg/cm^2 to 10 kg/cm^2 the displacement of the settlement decreases to 20.4%.

For reinforcement bamboo in 2 layers the displacement of the settlement was in the range of 2.471 mm to 6.666 mm after applying a load of 10 kg/cm^2 in 1 hour as shown in Fig. 9. It is shown that around 62.9% of the settlement increased with 2 layers bamboo after applied load 10 kg/cm^2 in 1 hour. In 1 hour, the changes in load from 4 kg/cm^2 to 6 kg/cm^2 give a displacement of 36.8%. After the load increase from 8 kg/cm^2 to 10 kg/cm^2 the displacement of the settlement decreases to 20.7%.

While for reinforcement bamboo in 3 layers, the displacement of the settlement was in the range of 1.545 mm to 4.444 mm after applying a load of 10 kg/cm^2 in 1 hour as shown in Fig. 9. It is shown that around 65.2% of the settlement increased with 3 layers bamboo after applied load 10 kg/cm^2 in 1 hour. In 1 hour, the changes in load from 4 kg/cm^2 to 6 kg/cm^2 give a displacement of 35.9%. After the load increases from 8 kg/cm^2 to 10 kg/cm^2 the displacement of the settlement decreases to 23%.

It is shown that the ultimate bearing capacity values at the foundation increased after being given reinforcement layer 1. Significant increases occurred in the number of reinforcement layers 2 layers and layers 3 layers in 2 hours performance.

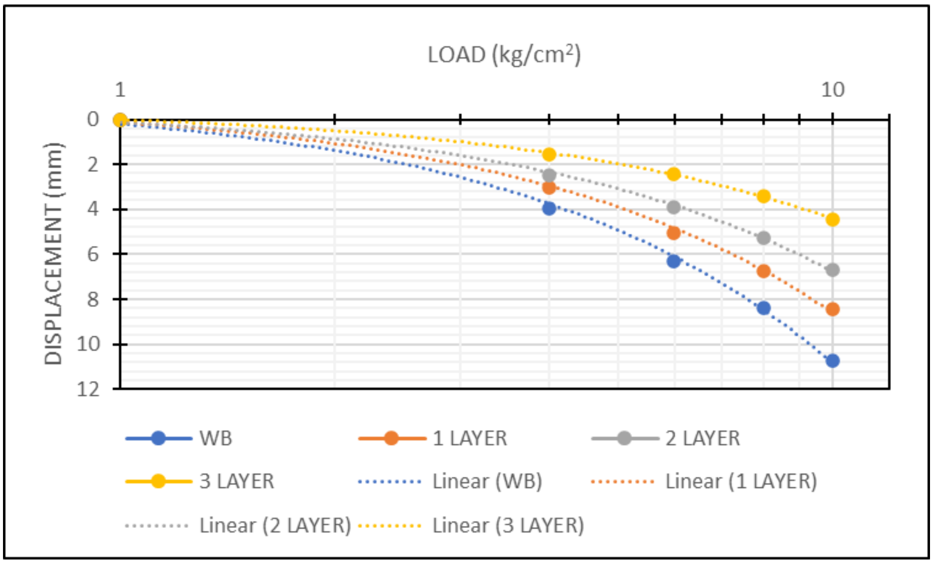


Fig. 9 - Displacement of the Settlement Performance in 2 hours

The bearing capacity value on the settlement loading is shown in Fig. 10 for loads 4 kg/cm^2 to 10 kg/cm^2. After 2 hours, the displacement of the settlement reduces by increasing the 3 layers of bamboo from 15.6% to 13% overall.

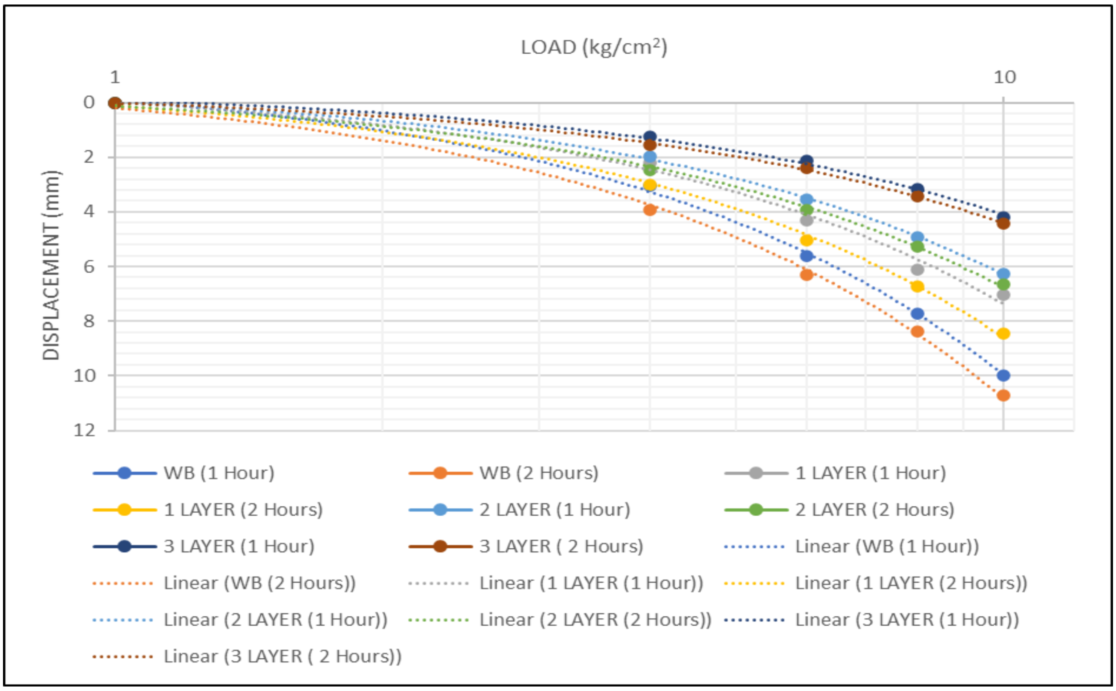


Fig. 10 - Different Displacement of the Settlement Performance within 1 hour

Fig. 10 also shows the trend of reduction for the displacement of settlement. This reduction of the displacement in settlement gives the meaning that the burden that can be borne by the foundation on the peat soil can increase with increasing the load. It is also can saved by increasing the foundation size and improving peat soil reinforcement stability. This is also supported by [12 & 14] in their study mentioned that the same foundation size or the same load can save the approximate foundation size.

4. Conclusion

The construction of any structure on the peat soil can collapse anytime. The use of reinforcement bamboo is one of the alternatives to avoid collapse. From this study, the physical modeling presents the characteristics performance value of the foundation with and without bamboo laminated beams dendrocalamus asper for improving the peat soil stability. Without the reinforcement bamboo, the foundation of any structure can be a failure. The utilization of the reinforcement bamboo of the laminated beam decreases the displacement of the settlement and increases the bearing capacity by 13% to 7.8% for 1 layer of reinforcement, 13.5% for 2 layers of reinforcement bamboo, dan 13% for 3 layers of reinforcement bamboo. This reduction of the displacement in settlement gives the meaning that the burden that can be borne by the foundation on the peat soil can increase with increasing the load. It is also can saved by increasing the foundation size and improving peat soil reinforcement stability.

Acknowledgement

This research was supported by Universiti Tun Hussein Onn Malaysia (UTHM) through Tier 1 (vot Q133). This research was made possible by the help of staff RECESS UTHM. The authors also wanted to thank friends from UTHM for their support.

References

[1] Yusof, Z. M.; Zain, N. H. M. Engineering properties of hydrated lime - pond ash treated peat soil. *AIP Conference Proceedings*. **2021**.

[2] Yusof, Z. M. Strength characteristics of pond ash - hydrated lime admixture treated peat soil. *IOP Conference Series: Materials Science and Engineering*. **2020**, 932.

[3] Yusof, Z. M.; Mohamed, K. Strength of treated peat soil with pond ash – hydrated lime subjected to soaking time. *Proceedings of the International Civil and Infrastructure Engineering Conference (InCIEC 2015)*. **2015**, 319-329.

[4] Yusof, Z. M., Zainorabidin, A., Suliman, M. A. O. and Osba, O. E. O. A. Effect of Palm Fiber – Hydrated Lime Composition on the Permeability of Stabilised Sandy Soil. *International Journal of Sustainable Construction Engineering and Technology*. **2023**; 14 (2):1-6.

[5] Yusof, Z. M., Al-Adhami, A. M. Y. and Matore, M. E. E. M. Compressive Strength of Stabilised Granitic Residual Soil Using Mixture of Pineapple Fibre – Hydrated Lime. *Sustainability (Switzerland)*. **2022**, 7 (14), 3826.

[6] Waruwu A., Susanti R. D., Endriani E and Hutagaol S., Effect of Loading Stage on Peat Compression and Deflection of Bamboo Grid with Concrete Pile, Int. J. of GEOMATE, Vol. 18, Issues 66, **2020**, pp. 150 – 155.

[7] Maulana, Azwar, Susanti R.D., and Waruwu A., Potential of Bamboo Pile as Reinforcement of Peat Soil under Embankment, ARPN Journal of Engineering and Applied Sciences, Vol.13, No.1, **2018**, pp. 52-56

[8] Maulana M., Hanova Y., Waruwu A., and Putra E.R., Simplified Method for Prediction of Settlement in Bamboo Piles-Reinforced Peat under Embankment, Journal of Applied Engineering Science, Vol.17, No.1, **2019**, pp. 35 – 42.

[9] Faizah Md Talib1, Habib Musa Mohamad, Muhammad Nursyahrain Mustafa. Peat Soil Improvement with Bamboo Reinforcement Technology: A Review. International Journal of GEOMATE, Dec., **2021**, Vol.21, Issue 88, pp.75-85

[10] Dewi R., Hastuti Y., Sutejo Y., Iqbal M. M. and Arfan M., Peat Soil Improvement Method using Woven Bamboo and *Cerucuk*, Int. J. on Adv. Sci. Eng. Inf. Tech., Vol. 10, No. 4, **2020**.

[11] Dewi R., Borgan W., Zunita I., Yulindasari, and Iqbal M.M., Effect of Deep Soil Mixing to Increasing Bearing Capacity on Peat Soil, International Journal of GEOMATE, Vol.17, No.63, **2019**, pp. 126-132.

[12] Waruwu A., Halim H., Nasution T., and Hanova, Y., Bamboo Grid Reinforcement on Peat Soil under Repeated Loading, Journal of Engineering and Applied Sciences, **2018**, Vol.13, No.8, pp. 2190-2196.

[13] Waruwu A., Susanti R.D., and Buulolo J.A.P., Effect of Dynamic Loads on The Compressibility Behaviour of Peat Soil Reinforced by Bamboo Grids, Journal of Applied Engineering Science, Vol.17, No.2, **2019**, pp. 157 – 162.

[14] Teodoro A. Amatosa, Jr., Michael E. Loretero, Romeo B. Santos and Marnie B. Giduquio. Analysis of Sea – Water Treated Laminated Bamboo Composite for Structural Application. Vol.8, No. 1, pp.307 – 312, **2019**. Nature Environment and Pollution Technology an International Quarterly Scientific Journal.

[15] Maulana, & Azwar, & Susanti, R.D. & Waruwu, Aazokhi. Potential of bamboo pile as reinforcement of peat soil under embankment. ARPN Journal of Engineering and Applied Sciences. 13. 52-56, **2018**.

[16] Jingwei Z., Jia L., Julong W and Shuaiqi X., Characteristics of the Interface between Bamboo Grids and Reinforced Soil of High-Filled Embankments in Loess Areas, Hindawi Adv. In Civil Eng., **2021**, pages 13.