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The Potential Use of Bamboo as Green Material for Soft Clay Reinforcement System

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Abstract— **The stability problems of embankment on soft clay always occur due to high compressibility and low shear strength of the soil. However, as development proceeds further, the construction of embankment especially for road construction on this type of soil is unavoidable. The aim of this paper is to evaluate in term of settlement and lateral movement the potential use of bamboo as reinforcement of soft clay in embankment construction. This paper presents the results obtained from the monitoring of trial embankments on soft clay using Hydrostatic Profiler (settlement) and Inclinometer (lateral movement). Three embankments had been constructed and monitored; (i) Embankment on Bamboo- Geotextile Composite (BGC) reinforced, (ii) Embankment on High-Strength Geotextile (HSG) reinforced and (iii) control or un-reinforced (UR) embankment, constructed without any reinforcement to the soft clay. These three embankments were each 10m long, 16m wide and about 3m in height. 5m long of buffer zones separated each embankment. The completed height of BGC reinforced embankment was 2.97m, 2.968m for HSG reinforced embankment and 3.071m for UR embankment. All three embankments had been monitored from the start of the construction day until about 419 days. Results show that UR embankment settled about 744mm while for BGC reinforced embankment, the settlement was about 588mm only. The maximum lateral movement occurred at 4.5m depth. At 4.5m depth, BGC reinforced embankment experienced 9.4mm movement while for UR embankment, the movement was 13.6mm. The results show that the performance of the BGC was better compared with HSG embankment and also UR embankment at the end of monitoring works.**

Keywords- Soft clay; Reinforcement; Embankment; Settlement; Lateral Movement

I. INTRODUCTION

In Peninsular Malaysia, soft clays are usually found throughout the coastal area such as Johor, Melaka, and several areas in Terengganu and Kedah. Generally, soft clay has shear strength less than 40 kPa and it can be physically moulded by light finger pressure [1]. Due to high compressibility and low shear strength, it results with high settlement and deformation to structure such as embankment, if constructed on soft clay. Stability, deformations and time required for consolidation are the major concerns in the design and construction of embankments over soft foundations. There are methods to improve soft soil such as electro osmosis, lime stabilization, stone columns, grouting and preloading with vertical drains. The methods mentioned are mostly very costly and require a lot of time to strengthen the soft foundation soil. To overcome these difficulties, soil reinforcement has been introduced as one alternative method in embankment construction over soft clay which seemed to be more efficient than other methods. Soil reinforcement is a technique where soils are strengthened by tensile elements such as metal rods or strips, non-biodegradable fabrics such as geotextile, granular materials and green natural materials like jute, 'bakau' or even bamboo [2].

Bamboo is widely known as traditional sources for construction material and it grows in abundance in the tropical and sub-tropical regions of the world. Major part of bamboo can be used in daily living such as shoots for food, bamboo culms for floor mat and often used to produce joss papers and toilet papers. Bamboo is known as rapidly grown trees and according to [3], bamboos start to mature in two to five years of planting. Known as renewable natural resources and biodegradable, bamboo was seen as an efficient material to adopt in decreasing the global warming effects and to save the environment from chemical waste.

[4] reported that the mechanical properties of bamboo culms are affected by their anatomical characteristics. Bamboo culm can be considered as a composite material, reinforced axially by aligned cellulose fibres embedded in a lignin matrix. The distribution of the fibres in the cross section of a bamboo shell varies across the thickness of the culm, increasing from the inner surface to outer surface. The mechanical properties of bamboo also depend on the species or types, age, moisture content, density and culms height. These situations had been confirmed by the research conducted to evaluate the mechanical properties on selected Malaysian bamboo by [5] in 1995. The result shows that the different specimen of different types of bamboo gives different value in static bending strengths. [6] used three different types of Indonesian bamboos where the age was more than three years. They found that bamboo has more strength in tension compared to bending strength.

Issues related to the use of bamboo as a green material have been addressed by [1][7]. They tried to use the system consisting of bamboo as a pile combined with bamboo mattress on soft clay in Indonesia. Their findings suggest that bamboo can distribute embankment load uniformly and at the same time it can alter the critical failure surface, besides providing upward buoyancy pressure. The use of bamboo had also been experienced by [8] in which they claimed that it could give saving of up to 45%-65% compared with using high strength geotextile alone and conventional filling method.

[1] investigated the bearing capacity of BGC with the bamboo laid in parallel and square pattern (Fig. 1). He reported that the bamboo-geotextile composite as reinforcement system tend to spread load further so as the stress transferred to the underlain soft clay will be much smaller than using geotextile alone or bamboo alone. When bamboo is laid in a square position, they forms an interlock or 'pocket' that creates an increase stiffness of bamboo, which distributed vertical pressure evenly and could minimize differential settlements. Its central portion supports the embankment against downwards displacement by mobilizing tensile resistance of horizontal ribs and compressive resistance of vertical ribs of bamboo that could prevent a catastrophic failure. For the geotextile, it is not only act as a separator and filter between the backfill material and soft clay layer, it also acts locally as a "tension membrane" between the bamboo interlocks, thereby reducing localised stress in the soft foundation clay.

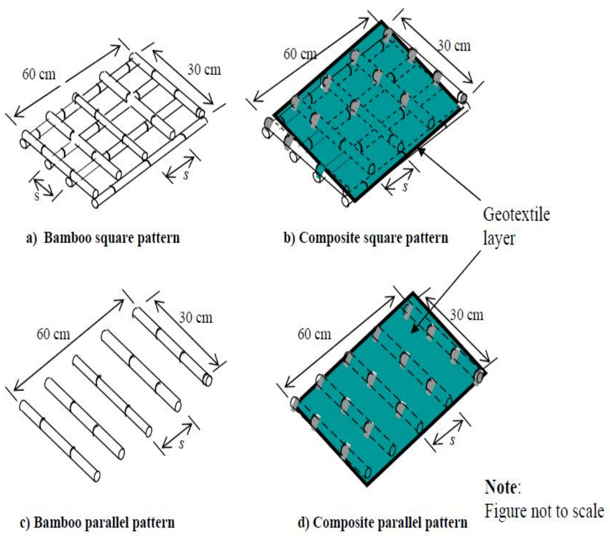

Figure 1. Bamboo and bamboo-geotextile composite reinforcement models (Khatib, 2009)

This paper discusses the performance of bamboo-geotextile composite reinforced embankment (BGC embankment) constructed clay compared with high strength geotextile einforced embankment (HSG embankment) and UR embankment in order to see the potential use of bamboo as reinforcement of soft clay. The field performance of the embankments had been monitored during and at the post construction phases using instrumentations installed at the soft clay and also at the embankments.

II. FULL-SCALE TEST

Three full-scale instrumented embankments namely the BGC embankment, HSG embankment and UR embankment had been constructed to determine the actual performance of the embankments, in particular the BGC embankment. This is to evaluate the potential use of bamboo as reinforcement of soft clay in embankment construction. The embankments was constructed at the designated site, consisting of soft clay, in UTHM campus.

A. Soil properties

The site where the embankments were constructed generally consists of soft soil, deposited to about 22.5m thick. The top soil, consisting of desiccated crust and vegetations, lies from 0 to 0.5m depth. This layer had been removed prior to the construction of the embankments. The ground water level laid between 0.2m to 0.5m below ground level. The soil layer below the topsoil consists of very soft clay (c =15 kPa, ϕ=2°) to the depth of about 4.5m. Below this layer, another very soft clay layer (c=17 kPa, ϕ=1°) occurred between 4.5m to 13.5m followed by the layer of silty clay to clay (c=37.3 kPa, ϕ=4.9°) to about 22.5m depth. The bedrock layer lies over 30m depth below ground level.

B. Mechanical properties of bamboo

Forest Research Institute of Malaysia (FRIM) supplied the bamboo used in this research. The type of bamboo used was known as *Semantan* Bamboo (*Gigantochloa scortechinii*). The requirements of the selected bamboo are based on the FRIM report and research done by [6]. Before bamboo was installed on site, bending and tensile tests had been carried out in the laboratory. All tests were in accordance with ASTM A370. TABLE I summarizes the condition of bamboo before tests were carried out.

From the results of both tests on bending and tensile strength (TABLE II), it can be said that the strength at internode of *Semantan* bamboo is much better compared with at node. For engineering and construction purposes, the node and internode of bamboo have a significant effect to give influences on the strength of bamboo. The bamboo also had the tendency to give a buoyancy effect, contributed by the air trapped in the bamboo culms.

TABLE I. GENERAL CHARACTERISTICS OF SEMANTAN BAMBOO

Type of Bamboo	**Age**	**Average Moisture Content**	**Node length**	**Outer Diameter**	**Inner Diameter**
Semantan Bamboo	3 years and above	20%	300mm to 500mm	80mm	68mm

TABLE II. TABLE II SUMMARIZES ON PROPERTIES OF *SEMANTAN* BAMBOO AT NODE AND INTERNODE CONDITION.

Properties	**Node**	**Internode**
Bending Strength, ó$_b$	43.41 MPa	48.75 MPa
Tensile Strength, ó$_t$	48.23 MPa	93.55 MPa
Bending Modulus of Elasticity, E_b	16.06 GPa	22.81 GPa
Tensile Modulus of Elasticity, E_t	2.42 GPa	3.80 GPa

Tensile, EA	342.00 kN	348.04 kN

C. Construction method

The embankment fill was constructed in 8 layers with the thickness of the first layer (after installation of the reinforcement) was about 900mm and the rest about 300mm each until 3m height. Each layer was compacted to 90% of maximum dry density. The cohesion of fill soil was 136.8kPa and the friction angle 23.54°. The construction of the embankment was completed in 18 days for HSG embankment and 17 days for BGC embankment and UR embankment. The layout of the embankments is shown in Figure 2.

The BGC technique uses the combination of bamboo and geotextile as a composite system (Fig. 3). *Semantan* Bamboo with about 80mm outer diameter (tensile strength of 93.55 MPa at internode and 48.23MPa at node) and Geotextile of TS40 type (product of Tencate Geosynthetics Sdn. Bhd.) with tensile strength of 13.5 kN/m length, had been used in this research. The bamboo was first laid in a square pattern, spaced at 1m x 1m and the geotextile then laid on top of the bamboo to form BGC reinforcement. As for the HSG embankment, the high tensile strength PEC100 (tensile strength of 100 kN/m length) was laid and installed at the interface between the embankment and the soft soil. UR embankment was not reinforced but only used TS40 geotextile as a separator between the soft clay and embankment.

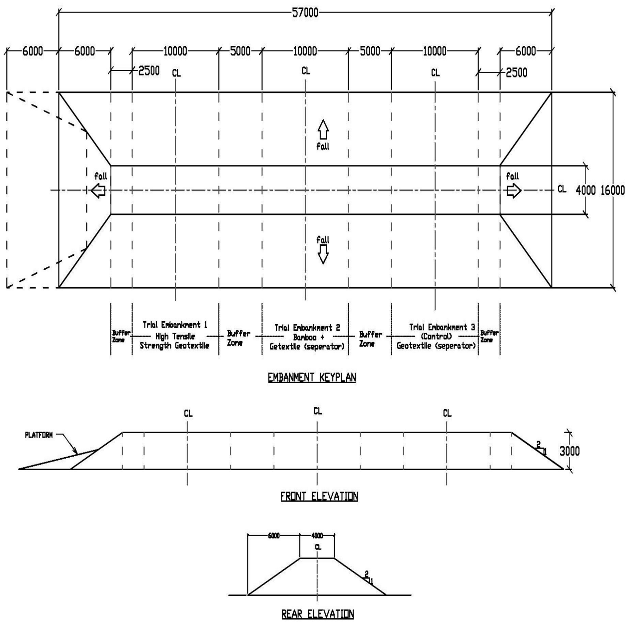

Figure 2. Layout of full-scale test embankments

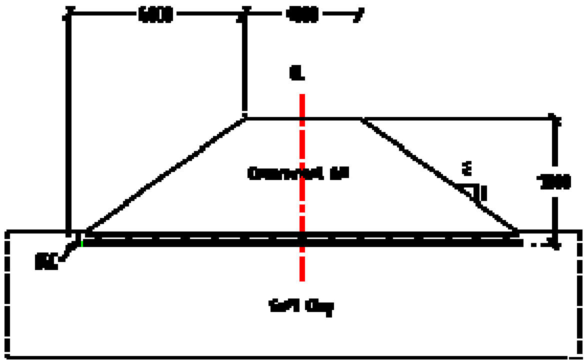

Figure 3. Placement of bamboo-geotextile composite (BGC) system

Fig. 4 shows the layout of the embankments with different reinforcement methods.

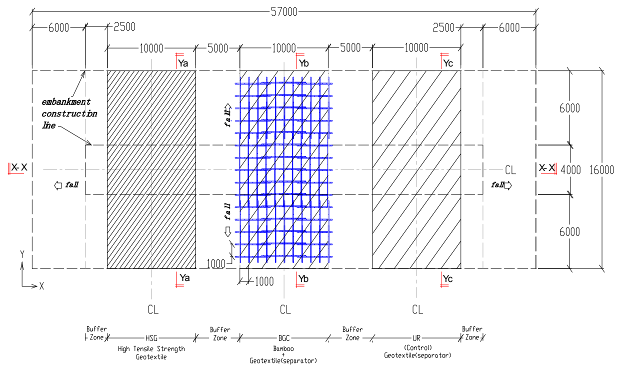

Figure 4. Layout of reinforcement installation for the embankments

III. RESULTS AND DISCUSSION

The embankment construction began on the 13th of May 2009 and finished on 31st May 2009. For embankments reinforced with HSG, the construction began on 13th May 2009 while the BGC and UR embankments it began on 14th May 2009. The completed height of BGC embankments was 2.97m while the HSG embankment was 2.968m and UR embankment was 3.071m. The monitoring results of up to 418 days after construction for BGC embankment and UR embankment and up to 419 days for HSG embankment were evaluated.

A. Settlement across base of embankment

During construction, foundation soil of BGC embankment settled 258 mm and UR embankment settled 331mm, which is 22 % difference. On the other hand, HSG embankment settled 141mm. The high tensile strength geotextile in HSG embankment took the load from the backfill material and hence, reduced the settlement. The same situation also occurred to BGC reinforcement.

A measurement using hydrostatic profiler at the bottom of the embankments shows that the settlement at the centre of BGC embankment was 588mm, UR embankment 744mm while for HSG embankment, it was 599mm. It shows that the total settlement occurred at BGC embankment was small compared with the total settlement occurred at UR embankment and HSG embankment. The settlement-time relationship during and after construction for all embankment are shown in Fig. 5.

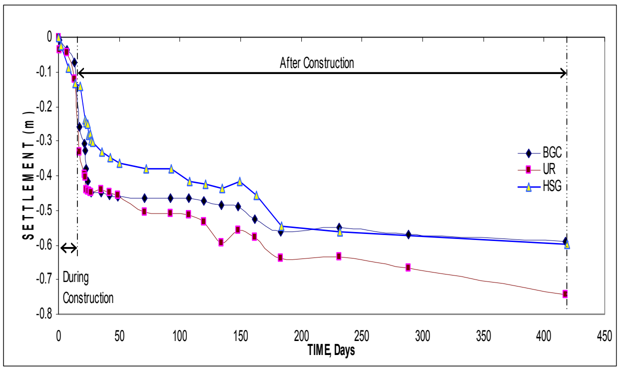

Figure 5. Settlement across base of embankment versus time

B. *Lateral movement*

The lateral movements of the embankments are measured by inclinometer. The comparison of lateral movements at depth 4.5m for all embankments is shown in Fig. 6. During construction, there was no significant movement for all three embankments. However, it increased rapidly after day 13 until the end of construction (day 18). The smallest lateral movements measured occurred on HSG embankment that was 0.957mm, for BGC embankment it was 1.738mm while the biggest deflection occurred on UR embankment that was 3.9mm.

Throughout the post-construction monitoring process (until day 418 for BGC and UR embankments, and only day 232 for HSG embankment due to the inclinometer casing was unreached to read), the maximum lateral movement recorded for all embankments occurred at the same depth, that is at 4.5m with the value of 9.414mm for BGC embankment, UR embankment recorded 13.585mm and 5.338mm for HSG embankment. Based on the results obtained, it shows that the lateral movement occurred much higher at UR embankment compared to the lateral movement occurred at HSG and BGC embankments. This is due to the fact that lateral movement, induced by imposed load of fill soil had been carried by the high tensile strength geotextile used in HSG embankment and the bamboo at BGC embankment.

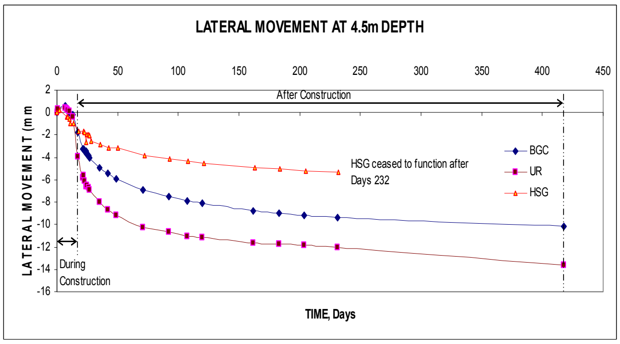

Figure 6. Lateral movement of embankment 4.5m depth

IV. CONCLUSION

The deformation performance of all three embankments with two respectively reinforced by bamboo-geotextile composite and high strength geotextile, but another one was un-reinforced embankment constructed on soft clay had been monitored for about 419 days after start of construction. Comparison of the embankment performance has been made on the settlement across the base centre of the embankments and the lateral movement. The final settlement of BGC embankment shows that the BGC gave much better improvement to the soft soil compared to UR embankment and also HSG embankment. The highest settlement occurred at UR embankment, followed by HSG embankment and BGC embankment. For BGC system, it implicates that the bamboo square pattern takes the load from the backfill material and hence, reduced the settlement much better compared to others. On the other hands, the square pattern of bamboo formed an interlock to resist horizontal shear stress and increase the stiffness of bamboo, hence distributing vertical pressure evenly. As a result, low lateral movement was observed. Another contributing factor was due to the hollow section nature of the bamboo. The trapped air inside bamboo gave the buoyancy effect and therefore distribute small embankment load to the soft clay layer.

The results show a significant improved in the deformation of foundation soil reinforced with BGC system compared to UR embankment and also the HSG embankment. Hence, the use of bamboo as green material for soil reinforcement purposes installed at the interface between the embankment and the soft clay could increase the stability and reduced the deformation of the embankment.

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