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Bamboo as Geogrid Material for Improvement in Road Construction

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Abstract: Bamboo or its scientifically known as *Bambusoideae* is now extensively used for construction materials since they have good bending strength, durability and the speed of growth contribute to making bamboo a very popular and sustainable material for building and road construction. The aim of this study is to evaluate the performance of bamboo as geogrid material for improvement in road construction as to overcome poor soil conditions that lead to unsatisfactory performance of road pavements. The objective of this study is to study the mechanical properties of untreated bamboo by compressive strength test, to determine the shear parameter of soil sublayer with and without bamboo geogrid reinforcement using physical laboratory model and to analyse the performance layer of bamboo geogrid in the soil sublayer. Type of bamboo used for this study is *Gigantochloa Scortechinii* or locally known as *buluh semantan/buluh galah* undergone compressive strength test. The vane shear test is to determine the shear parameter of soil sublayer. Then, the performance of bamboo geogrid in the soil sublayer has been analyzed by monitoring the settlement that occur by applying a constant load of 2 kPa for controlled model, one layer of bamboo geogrid and two layers of bamboo geogrid. The results obtained shown that shear strength of peat soil was not affected by the bamboo geogrid but, an improvement for settlement occur using two layers of bamboo geogrid as reinforcement for the peat soil sample.

Keywords: Bamboo Grid, Shear Parameter And Settlement

1. Introduction

Bamboos now are extensively used for building materials since they have good bending strength, durability and the speed of growth contribute to making bamboo a very popular and sustainable building material [1]. The finding has revealed potential of bamboo geogrid since it has properties such as its mechanical resistance which is high tensile strength and the physical properties which is its openings or apertures in the bamboo geogrid help interlocking the aggregate or the soil over it. Geogrids can be described as a geosynthetic with large apertures and a high-modulus polymer material such as polypropylene and polyethylene [2]. Geogrids generally can be uniaxial or biaxial. The commercial

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geogrids that are used for soil reinforcement usually have apertures or openings that are rectangular or elliptical. The main function of geogrid is reinforcement which they are usually stiff.

In road construction nowadays, geogrids are widely used since it could provide resistance to tensile stresses transferred from the soil as reinforcement applications. Poor road pavement conditions may be a result of natural causes such as flooding, heavy rain and landslide that leads to unsatisfactory performance of road pavement and shows the sign of pavement defects or failures include potholes, cracking and uneven road surfaces [3]. This will disrupt the safety of road users. To overcome this issue, soil reinforcement using a geogrid is applied as improvement in the road construction due to the good in tension and ability to distribute load across a large area using geogrid. This will provide the road construction stronger and more stabilized. Bamboo could be used as geogrid material to be applied as soil reinforcement especially for soft subgrade since bamboo depends on its properties including its mechanical resistance which is high tensile strength and high compressive strength [4].

The aim of this study is to evaluate the performance of bamboo as geogrid material for improvement in road construction. The objective of this study is to study the mechanical properties of bamboo by compressive strength (CS) test, to determine the shear parameter of soil sublayer with and without bamboo geogrid reinforcement using physical laboratory model and to analyse the performance layer of bamboo geogrid in the soil sublayer. Type of bamboo used for this study is *Gigantochloa Scortechinii* or locally known as *buluh semantan/buluh galah* undergone CS test following standard of ASTM C39/C39M-09a. The vane shear test compliance with ASTM D-2573 is to determine the shear parameter of soil sublayer. Then, the performance of bamboo geogrid in the soil sublayer has been analyzed by monitoring the settlement for 24, 48, 72 and 144 hours that occur by applying a constant load of 2 kPa for controlled model, one layer of bamboo geogrid and two layers of bamboo geogrid. The results obtained shown an improvement for settlement occurred using two layers of bamboo geogrid as reinforcement for the peat soil sample. Since the use of bamboo as geogrid reinforcements able to create an improvement performance in soil reinforcement based on the analysis properties of sublayer soil, thus it is able to control the settlement of soil. This finding also could be used as a guidance in future research for laboratory scale physical modelling.

2. Literature Review

2.1 Bamboo

Bamboo or its scientifically known as *Bambusoideae* is categorized as a type of grass which is woody in nature with a hard outer layer and a hollow centre. Bamboo is also known to be perennial and it is evergreen where it does not only grow on only specific season because bamboo can be found in many climates from cold mountains regions to tropical regions. Bamboo belongs in the true grass family called *Poaceae* [5]. Based on recent studies by [1], stated that the benefit of bamboo is its physical properties. Bamboo is known to be a lightweight material while still being flexible and tough as bamboo can withstand high tensile. Therefore, it must be taken into consideration to be used more widely in any construction. Past researchers [6], stated that the most common type of bamboo that is used in Malaysia is *Gigantochloa Scrotechinii*. Experiment has conducted to determine the moisture content and compression strength of the bamboo using treated and untreated bamboo which collected from Hulu Langat, Selangor with diameters in the range of 45 to 60 mm and height of bamboo culm is 3m [6]. From the CS test results for untreated bamboo, it shows that top section with the larger cross-sectional area of 2290.24 mm^2 and bigger wall thickness of 27.30 mm resulted the highest compression strength of 22.33 MPa. For treated bamboo CS test result, it is shown that top section with the larger cross-sectional area of 1893.55 mm^2 and bigger wall thickness of 19.25 mm resulted the highest compression strength of 34.35 MPa. To summarize, the moisture content of bamboo is higher at the bottom section and the thicker wall thickness of bamboo, the higher its compression strength.

2.2 Geogrid

Geogrids is one type of geosynthetic materials that with large apertures and a high-modulus polymer material which is polypropylene and polyethylene [2]. Geogrids generally can be uniaxial or biaxial. The main function of geogrid is reinforcement. Geogrids are relatively stiff and its large apertures or openings allow interlocking with surrounding soil or rock as to perform the function either reinforcement or segregation [2]. The technique of soil improvement with geogrid reinforcement may increase the stiffness and load carrying capacity of the soil through fractional interaction between the soil and the geogrid. Geogrids are widely used in pavement construction to help in the case of the subgrade being too soft which may lead the service life of the pavement to decrease due to problems such as cracking [7].

2.3 Bamboo Geogrid

Bamboo geogrid as reinforcement have been modelled in a study of reclaimed asphalt pavement (RAP) reinforced with bamboo geogrid and bamboo geocell and its performance have been evaluated [8]. The bamboo geogrid for this study was made with 10 mm wide bamboo strips with square apertures. The RAP layer was reinforced with bamboo geogrid which have been placed at different levels as this study was to analyse its effects on load-settlement behavior. It is observed that the most effective location for single layer of bamboo geogrid placement is one-third from the top of the total thickness of RAP layer (150 mm) for maximum improvement of bearing pressure. [9] has studied the use of bamboo in soft-ground engineering and its performance comparison with geosynthetics. It is concluded that using bamboo in the form of a grid called bamboo geogrid and bamboo cell had better performance compared to geogrid. The result from this study showed that the settlement of the reinforced clay bed was reduced 97% due to the placement of the combination of bamboo geogrid and bamboo cell compared to unreinforced clay bed.

2.4 Soft Soil Characteristics

Excessive settlement is one of the major concerns of soft soil due to its high compressible characteristic [10]. Peat soils considered as soft soils as it is very soft, highly compressible and has very low shear strength [11]. Also stated that organic matter content in peat soil is often greater than 10%, with some containing as much as 98% of organic matter. Peat is naturally highly organic substance which mostly made up of plant material [12]. Peat can be described brownish-black or dark brown in appearance with distinct odour. Peat is also described highly spongy, very compressible since organic matter is the major component. It is reported that moisture content, MC (%) for the peat obtained in Parit Nipah [11] was 635% which complies with [12] which mentioned that the moisture content (%) of peat soil, typically range from 260 to 1600%. Other than that, the amount of organic matter in peat has a significant impact on its index parameters such MC (%), density and plasticity [13]. As a result, it has an influence on peat's engineering behaviour, making proper determination of this parameter useful for engineering projects.

While [14] reported in the study for comparison of shear strength properties for undisturbed and reconstituted Parit Nipah peat, shear strength properties for reconstituted peat samples show a cohesiveness of 21 kPa. At the same time, shear strength properties for undisturbed peat samples show a cohesion of 10 kPa. Reconstituted peat samples and undisturbed peat samples resulted of moisture content 328% and 545% respectively. This obviously shows that MC (%) could affect the behaviour of peat soils. For this reason, improvement of soft soils or peat soils is necessary for any structures or pavement to be constructed onto it.

Table 1: Index properties of Parit Nipah peat [11]

Parameter	Parit Nipah Peat
MC, %	635
Liquid limit, %	252
Specific gravity, SG	1.34
Bulk density, kN/m^3	10.45
Organic content, %	95.5
Fiber content,%	37.8
Compression Index, Cc	1.48
Von Post Scale	H6

2.5 Settlement in Soft Soil

It is stated that peat has a high compressibility due to its high void ratio [11]. Also stated that due to its permeable nature peat, it has a high preliminary settlement and short settlement period usually days. Pore water is forced out of the peat under the weight during primary concsolidation, causing the peat fibres to compress and fill the space left by the pore water dissipation. After this, the secondary compression will begin, with a considerably slower settlement rate. A study [15], physical modelling is used to evaluate and to analyse the deformation behaviour of peat soil and compare with dry sand. The physical modelling is used to gain fundamental understanding of how peat soil deforms when a load is applied onto it. It has been observed that punching shear was occurred in the peat soil model due to its high compressibility and general shear failure is observed in the dry sand model. When load is applied onto the soil, it is observed that the settlement happened immediately in peat soil model. Overall, settlement in peat occurred higher compared to dry sand when the same load was applied onto the soil surfaces.

3. Materials and Methods

3.1 Preparation of Materials

Materials used for this study is local bamboo sample named *Gigantochloa Scortechinii* or locally known as *buluh semantan* and *buluh galah* that was collected near Parit Hj. Rais, Batu Pahat, Johor since it was reachable. Soil sample of peat soil was taken at Parit Nipah Darat, Batu Pahat, Johor nearby oil palm and pineaple plantations. Then, the soil was filled until 400 mm into the laboratory scale model with volume of 1.0 m x 0.5 m x 0.53 m.

3.2 CS Test

To determine mechanical properties of bamboo which is compression strength, three of bamboo samples with different in size are collected. Bamboo A with diameter 70mm, thickness 10 mm while bamboo B with diameter 60mm, thickness 20mm and bamboo C with diameter 70mm, thickness 15mm. The main objective of compression strength test is to the determine the behaviour of bamboo sample used for this study under compressible load using Universal Testing Machine (UTM Instron). The load applied was continuously till the samples experienced failure. The failure mode by compression strength test were analyzed either end bearing or splitting. Parameter obtained for this testing are load (kN) and strength (MPa). The standard use for operating the equipment for this testing comply with ASTM C39/C39M-09a.

Figure 1: Bamboo samples A, B and C (all samples were cut with height, h = 150 mm)

3.3 Soil Sample

Samples of peat soil then was sent to Research Center for Soft Soil (RECESS) UTHM to determine its physical index which is MC (%). MC (%) was tested to the peat soil sample following MS 1056-2:2005. From observation, peat soil at the mentioned location was dark brown in colour, quite moist, spongy and noticed to have high retention when was stepped onto its surface.

Figure 2: Peat soil Parit Nipah

3.4 Preparation of Model

Preparation of model included of controlled model which is without bamboo geogrid reinforcement (model A), one layer of bamboo geogrid reinforcement (model B) and two layers of bamboo geogrid reinforcement (model C). Bamboo sample is cut into strips with width size of 13 to 15 mm each and arranged in grid positions refering to biaxial geogrid to be used as soil reinforcements. Rib dimensions, aperture size and thickness of the bamboo geogrid were measured.

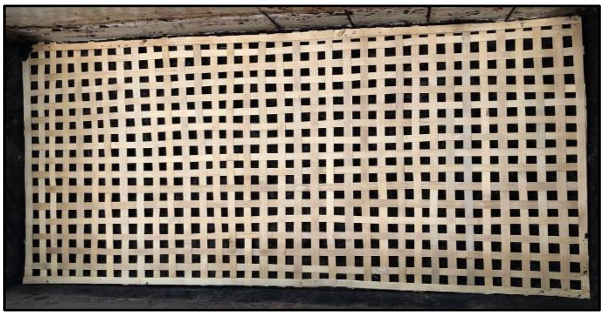

Figure 3: Bamboo geogrid prepared

Table 2: Properties of bamboo geogrid prepared

Properties	Value
Aperture (mm x mm)	15 x 15
Thickness (mm)	2
Area (m x m)	0.95 x 0.45

3.4.1 Vane Shear Test (VST)

In this study, field vane shear test was to determine the shear parameter soil sublayer. Test performed followed ASTM D-2573. The field vane shear used was rectangular vane with vane height of 50 mm and vane diameter of 25 mm due to its sensitivity since peat soil has high water content and compressibility as the selection of vane size is related to the consistency of the soil being tested.

3.4.2 Monitoring of Settlement

Monitoring of settlement had done by conducting laboratory physical modelling. This testing conducted for all three models prepared to monitor their settlements. A constant load of 2 kPa or 102 kg was applied on the soil layer for all the models prepared. Then, the settlement readings for all models prepared occured were measured using dial gauge and have been monitored for 24, 48, 72 and 144 hours. The laboratory scale set up for model A shown in **Figure 4**. To monitor the performance of the bamboo geogrid, the bamboo geogrid was placed in the sub layer of soil about 0.1 m from the surface of soil layer for model B in **Figure 5.** For model C shown in **Figure 6**, the second layer of bamboo geogrid was placed 0.05m from the surface of soil.

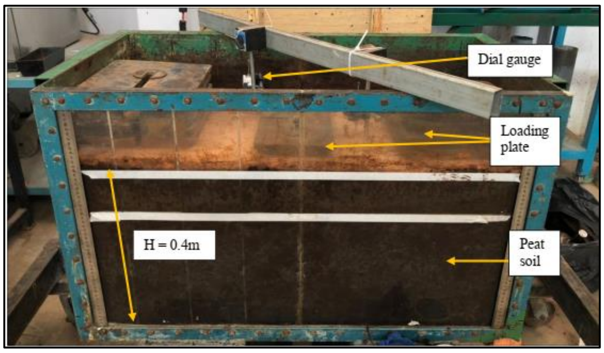

Figure 4: Model A, full laboratory scale set-up

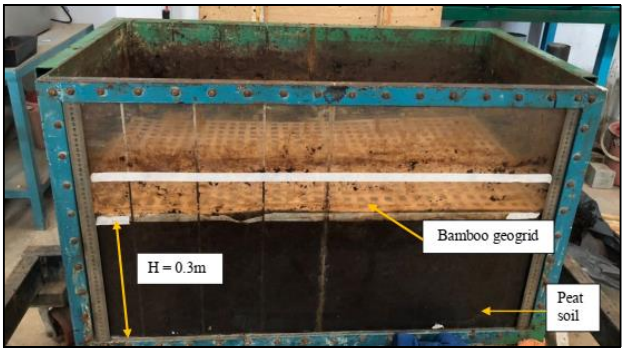

Figure 5: Model B

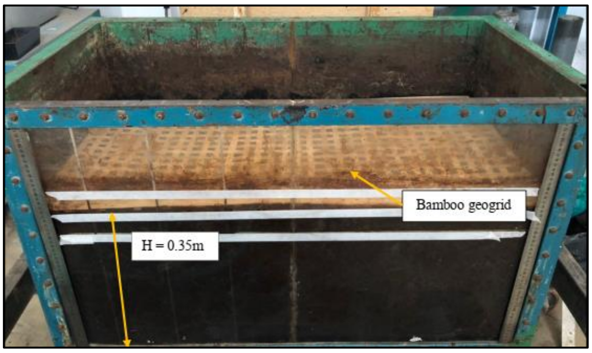

Figure 6: Model C

4. Results and Discussion

4.1 CS Test of Bamboo

In order to study the properties of bamboo, mechanical characteristics of bamboo obtained have been analyzed. The samples are all undergone end bearing failure mode since it is found that the top where the load was applied are cracked. **Table 3**, **Table 4** and **Table 5** shown the result of CS test that has been conducted for Bamboo A, Bamboo B and Bamboo C.

Table 3: CS test result for bamboo A

Bamboo A (D = 70 mm, t= 10 mm)	Strain (%)	Load (kN)	Strength (MPa)
1	4	12.9	18.0
2	7.3	20.7	29.0
3	9.5	14.8	21.0
Average		**16.13**	**22.67**

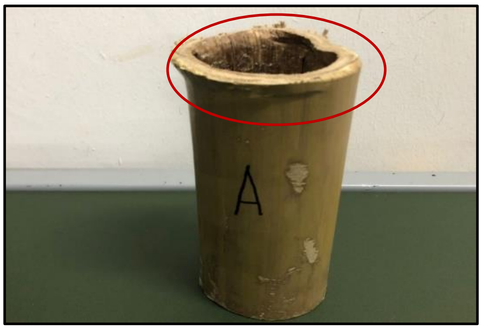

Figure 7: Bamboo A after CS test has done, end bearing failure observed (in red)

Table 4: CS test result for bamboo B

Bamboo B (D = 60 mm, t = 20 mm)	Strain (%)	Load (kN)	Strength (MPa)
1	2.11	20.5	14.8
2	4.63	32.2	22.0
3	6.47	31.4	21.5
4	8.01	28.0	20.0
Average		**28.025**	**19.58**

Figure 8: Bamboo B after CS test has done, end bearing failure observed (in red)

Table 5: CS test result for bamboo C

Bamboo C (D = 70 mm, t = 15 mm)	Strain (%)	Load (kN)	Strength (MPa)
1	1.48	1.14	2.0
2	4.22	21.4	31.0
3	5.0	24.4	34.8
4	6.94	16.5	24.0
Average		**15.86**	**22.95**

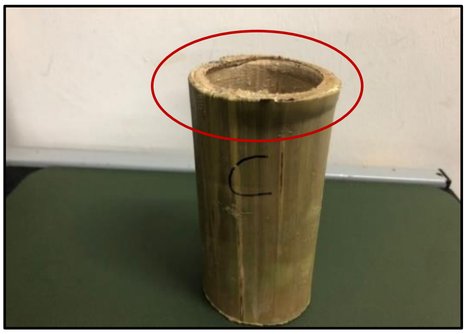

Figure 9: Bamboo C after CS test has done, end bearing failure observed (in red)

Bamboo A and Bamboo C had the same diameter, but different thickness which are 10mm and 15mm respectively. Bamboo C recorded slightly higher compression strength which is 22.95 MPa compared to bamboo A which is 22.67 MPa. Meanwhile, bamboo B, had the smallest diameter than bamboo A and bamboo C but bigger thickness, t = 20 mm than bamboo A and bamboo C resulted of 19.58 MPa for compression strength. Overall, bamboo C has the highest compression strength compared to the other samples. In a study of mechanical properties of bamboo [6], resulted bigger thickness and diameter of bamboo have the highest compression strength of 22.33 MPa and 34.35 MPa for treated bamboo and untreated bamboo respectively. Therefore, it can be concluded that bamboo with bigger diameter and higher thickness have the highest compression strength under an axial load.

4.2 Soil Properties

According to, sample specimens of peat can be oven-dried over 16 hours at 105°c to verify their natural MC (%) the result of MC (%) obtained.

Table 6: MC (%) of peat soil obtained

Sample No	1	2	3
Mass of empty container (g)	17.50	17.30	7.50
Wet soil and container (g)	52.50	55.00	24.80
Dry soil and container (g)	24.60	26.60	11.40
Mass of solid (g)	7.10	9.30	3.90
Mass of water (g)	27.90	28.40	13.40
Moisture content, MC (%)	393.0	305.38	343.59
Average MC (%)		347.31	

From visualization, the peat soil sample obtained are moist and saturated. After drying, the peat soil sample were cracked in texture and darker in colour. From the data obtained, the average MC (%) of the peat soil sample is 347.32%. This result is satisfied with [12], which mentioned that the MC (%) of peat soil, reported as a percentage of dry weight are typically range from 260 to 1600% in view of the fact that peat deposits are commonly waterlogged and is high in water content.

4.3 Vane Shear Test

The result of field VST performed are recorded in **Table 7** and **Table 8.**

Table 7: Field VST performed before bamboo geogrid reinforcement placement

Location	Shear strength, Cu (kPa)
Left	20
Middle	20
Right	20
Average	20 kPa

Table 8: Field VST performed after bamboo geogrid reinforcement placement

Location	Shear strength, Cu (kPa)
Left	21
Middle	20
Right	21
Average	21 kPa

From the tabulated results, average value of shear strength, Cu before bamboo geogrid reinforcement placement recorded was 20 kPa. Meanwhile, the average value of Cu performed after bamboo geogrid reinforcement placement to be slightly increase which was 21 kPa. However, the bamboo geogrid did not change the properties of the peat soil in terms of shear strength but, the bamboo geogrid could reduce deformation occur when load was applied onto it. Past research by [14] recorded the Cu for undisturbed peat soil sample with 545% of MC obtained at the same location was 10 kPa while Cu for reconstituted peat recorded 20 kPa with 328% of MC. Hence, this lead to the conclusion that the MC (%) of soil, could affect the shear strength of soil and slightly improvement resulted using the bamboo geogrid reinforcement.

4.4 Monitoring of Settlement

In summary, for the first 4 hours, the soil in model A, model B and model C experienced pre-consolidation or immediate settlement phase as the recorded settlement data increasing rapidly after the loading plates were applied on top of it. This phase was fast and completed quickly. Then, the soil continuously to experienced primary consolidation settlement and followed by secondary consolidation settlement. Model A as controlled model resulted total settlement of 0.335 cm, model B with settlement of 0.253 cm and model C with settlement of 0.201 cm.

Overall, the results shown an improvement occurred using bamboo geogrid as reinforcement for the peat soil sample. Model with bamboo geogrid reinforcement provided better results than the model without bamboo geogrid reinforcement. This proven that bamboo geogrid could provide function as geogrid where geogrid distributes loads uniformly across a greater area by increasing the stiffness of the base to resists deformation. The presents of bamboo geogrid allow to increase the load distribution. As a result, the pressure applied to the soil layer is decreased, thus reducing the settlements and deformations. Model C with 40% difference settlement than the model A had recorded the better performance of settlement than model B. Meanwhile, model B recorded 24.5% difference in settlement than the model A. Therefore, two layers of bamboo geogrid able to give improvement in the soil sublayer. **Figure 10** shows the summary results of settlement (mm) vs time (min) for all models prepared.

Table 9: Summary results for model A, model B and model C

Settlement for controlled model (model A), mm	Settlement for one-layer bamboo geogrid (model B), mm	Settlement for one-layer bamboo geogrid (model C), mm	Difference settlement of model A and model B (%)	Difference settlement of model A and model C (%)
3.35	2.53	2.01	24.5%	40%

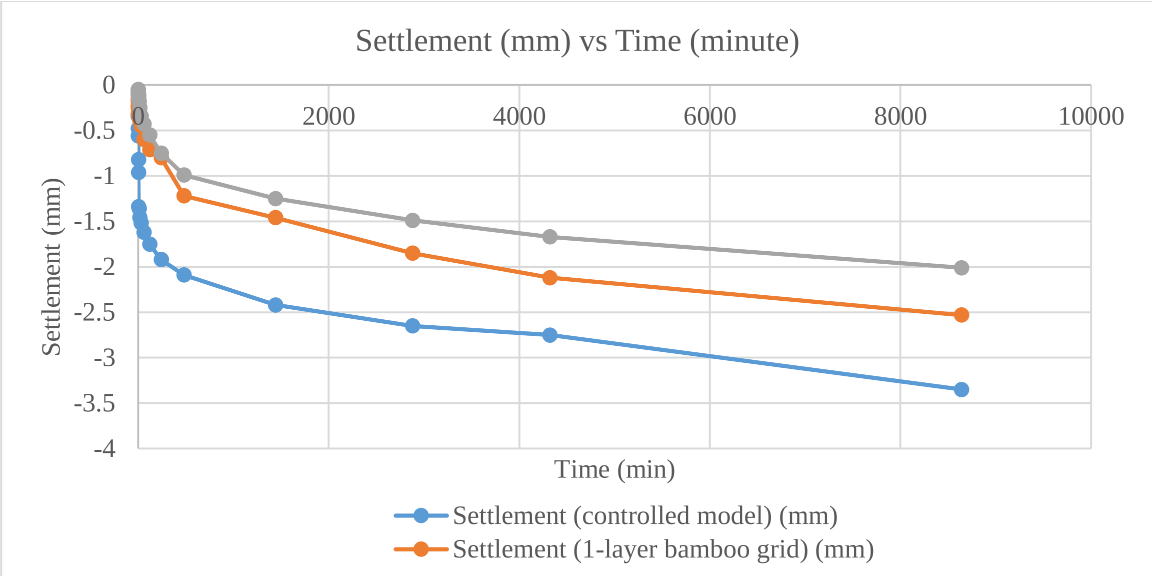

Figure 10: Settlement results for model A, model B and model C

5. Conclusion

The objective of this study which to study the mechanical properties of untreated bamboo by CS test has been achieved. It is obtained that the bamboo with larger diameter and bigger thickness have the highest compression strength under an axial load. The data obtained is one of the useful information about using bamboo for structural purposes. However, the bamboo geogrid did not change the properties of the peat soil in terms of shear strength since the shear parameter of soil sublayer with bamboo geogrid shown a slightly increase compared to shear parameter of soil sublayer without bamboo geogrid reinforcement using field VST but, the bamboo geogrid could reduce deformation occur when load was applied onto it. It can be deduced that MC (%) of peat soil, could affect the shear strength of soil. Through that, objective of this study which to determine the shear parameter of soil sublayer with and without bamboo geogrid reinforcement using physical laboratory model has been acquired. The performance of bamboo geogrid reinforcement is analysed by monitoring settlement shown that model with 2 layers of bamboo geogrid recorded better performance than model with 1 layer of bamboo geogrid. The presents of bamboo geogrid allow to increase the load distribution. Since the pressure applied to the soil layer is decreased, settlements and deformations could be reduced.

5.1 Recommendations

Based on the result, there are several suggestions for improvements should be given in this study for bamboo as geogrid material for improvement in road construction.

i. It is recommended that further study should be carried out by using another testing to obtain other properties of bamboo. For instance, to conduct tensile strength test to obtain other mechanical properties of bamboo and determine its moisture content to obtain physical properties of bamboo.

ii. To model bamboo geogrid by using treated bamboo strip since the condition of bamboo geogrid model using untreated bamboo were moist after it is placed in the peat soil sublayer.

iii. To extend the period of monitoring settlement behavior for peat soil to attain better and obvious result of settlement.

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