BEARING CAPACITY OF SOFT SOIL REINFORCED WITH CHEVRON PATTERN BAMBOO-GEOTEXTILE COMPOSITE

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Abstract

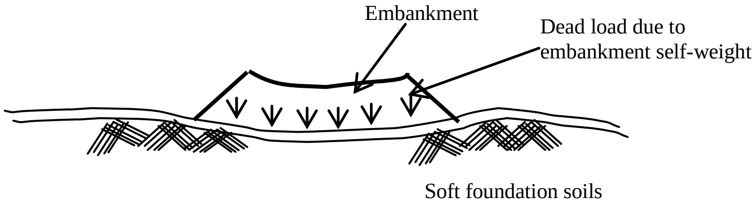
The problem of soft soil is associated with low shear strength and high compressibility, hence low bearing capacity and high settlement. This paper presents the results of the laboratory-model tests on the bearing capacity of a strip footing laid on different thickness (u) of sand layer underlain by soft soil reinforced with bamboo-geotextile composite mattress at the interface. The width (b) of the footing was 50 mm. Bamboo poles of about 5 mm inner diameter (d) were arranged in chevron grid pattern, at various distance (s) between the poles. The embankment ratio (u/b) was limited to 0.25, 0.50, 0.75 and 1, while the bamboo distance ratio (s/d) was set to 5, 10, 20 and 30. The soft soil was prepared in a soil container, from kaolin powder mixed with water of twice its liquid limit, and consolidated in three layers to achieve an undrained shear strength of about 12 to 14 kPa. The loading test was carried out by applying the vertical load slowly to the strip loading plate, placed centrally on top of the sand surface of the soil model assembly. Results show that the chevron grid pattern bamboo-geotextile composite system has the potential to become an alternative cost-saving method for soil stabilisation or improvement, especially in highway construction. The charts developed in this study allows the engineer to use them in the design of embankment over soft soil.

Keywords:*bamboo-geotextile composite; bearing capacity; laboratory-model test; soft soil*

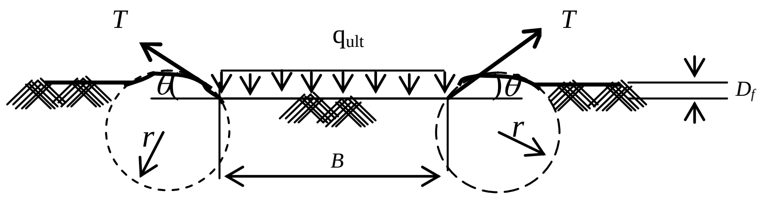
Introduction

The more recent advancement of reinforced soil is to provide three-dimension confinement to the soil by using bamboo mattress. The bamboo foundation mattress is a series of interlocking cells, constructed from bamboo poles and geotextile reinforcement, which contains and confines the soft soil layer at the base of the footing. It intersects potential failure planes and its rigidity forces them deeper into the foundation soil, thereby increasing the bearing capacity. Several investigations have been reported highlighting the beneficial use of bamboo poles such as Yusuf, *et al*. (1989); Low and Tey, (2000) and Marto, *et al*., (2005a and 2005b).

In a normal condition when an embankment is constructed on soft soil, the settlement will occur beneath the embankment and heave occurs at its edges (Figure 1a). In-situ monitoring and testing are usually employed to control construction activities. However, when a reinforcing material, such as geotextile is to be laid at the interface between the embankment and the soft soil, the load from the embankment will be taken by the tensile strength of the reinforcing material (Figure 1b).



(a)



(b)

Figure 1: Design concept for embankment construction: a) ground deformation under embankment; b) modeling of ground deformation (Ochiai, et. al, 1996)

According to Ochiai, *et al*. (1996), if reinforcement is introduced to the soft soil, the ultimate bearing capacity of the soft foundation soil is assumed to comprise of four components: (i) bearing capacity due to the shear strength of the existing ground, q_1; (ii) bearing capacity developed by tensile forces generated at both ends of the geotextile reinforcement, q_2: (iii) restraining effect of geotextile on ground deformation, q_3; and (iv) the surcharge effect due to settlement and heave, q_4. These four components can be expressed mathematically as:

$$q_1 = c_u N_c \tag{1}$$

$$q_2 = 2T \sin\frac{\theta}{B} \tag{2}$$

$$q_3 = T\frac{N_q}{r} \tag{3}$$

$$q_4 = \gamma D_f \tag{4}$$

where: c_u = undrained cohesion of the soft foundation soils; N_c and N_q = bearing capacity factors; T = tensile force generated in the geotextile; θ = angle between the surface of geotextile and the horizontal at the edge of the loaded area; B = loaded width; r = radius of the circle approximating the deformation pattern of the ground adjacent to the loaded area: γ = unit weight of the soft foundation soils; and D_f = settlement of the soft foundation soils.Therefore, the ultimate bearing capacity, q_{ult}, may be expressed as follows:

$$q_{ult} = q_1 + q_2 + q_3 + q_4$$

$$= cN_c + 2T\sin\frac{\theta}{B} + T\frac{N_q}{r} + \gamma D_f \tag{5}$$

with$H$ as the height of the embankment, JSSMFE (1986) has produced a relationship between D_r/H, θ, r and c_u as shown in Figure 2. However, with the inclusion of bending element such as bamboo, it will greatly change the system such that presently available analytical techniques are inapplicable. Thus, a method of estimating the bearing capacity will require to be developed for this reinforced condition.

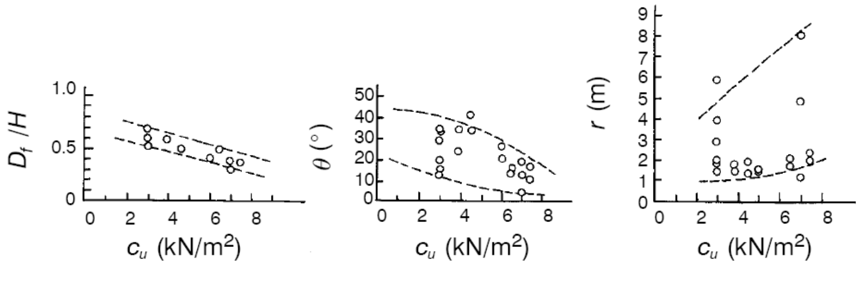


Figure 2 Parameters for calculation of ground bearing capacity (JSSMFE, 1986)

A review of literature shows that, this novel technique of bamboo reinforcement, though has successfully been applied in many fronts but in the avenue of foundation it remains scarcely explored. Therefore, the present study deals with an experimental investigation on the bearing capacity performance of the soft soil overlaid by sand bed and reinforced with bamboo-geotextile composite mattress at the interface. The purpose of the investigation was to assess the effect of incorporating a geotextile layer and bamboo poles (termed as "bamboo-geotextile composite"), on the bearing capacity of the soft soil. In particular, this paper reports on the performance obtained when using bamboo poles, arranged in chevron grid pattern. Results on the use of parallel and square pattern bamboo-geotextile composite reinforced soft soil, has been reported in Marto, *et al*. (2005b).

Material, Equipment and the Model

The materials used in this research were kaolin powder, sand, bamboo poles and geotextile. The kaolin powder, used to serve as soft soil, was obtained from a local supplier and the sand for fill and drainage layer was obtained from a nearby quarry. The geotextile used was a single layer of Polyfelt TS 60, supplied by Polyfelt Asia Sdn. Bhd., Malaysia. The physical and mechanical properties of the geotextile, tested by the manufacturer are shown in Table 1.

Table 1: Properties of Geotextile

Property	Test Standard	Unit	Value
Tensile strength (ave)	ISO 10319	kN/m	119
Tensile elongation (md/cd)	ISO 10319	%	80/35
Performance energy*	Calculated	kN/m	5.5
CBR puncture strength	ISO 12236	N	2900
Dynamic drop cone puncture (diam)	ISO 13433	mm	20
Effective opening size (O_{90})	ISO 12956	mm	0.09
Vertical water flow 50mm head	ISO 11058	$l/m^2/s$ (mm/s)	72
Horizontal water flow(20kPa)	ISO 12958	l/m.h	13
(200kPa)	ISO 12958	l/m/h	3.0
Nominal mass	ISO 9864	g/m^2	250
Thickness (20 kPa)	ISO 9863	mm	2.2
Apparent opening size (O_{95})	ASTM D 4751	mm	0.19
Permittivity	ASTM D 4491	s^{-1}	2.0

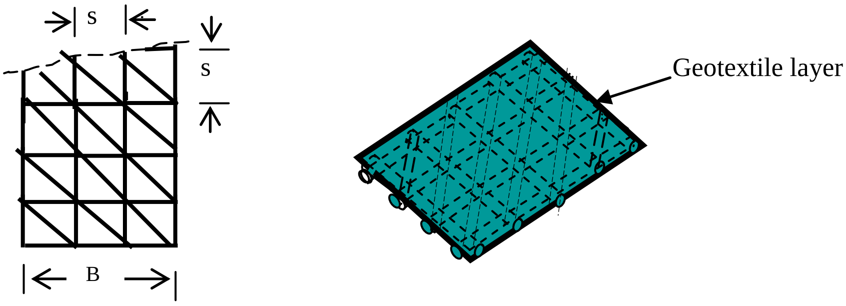
Performance energy indicates the ability of the geotextile to absorb construction stress

* Performance energy = ½ (energy md + energy cd) where

Energy md = ½ (tensile strength md x elongation md)
Energy cd = ½ (tensile strength cd x elongation cd)

The equipment used in this study includes soil container, bamboo models and the loading assembly. To expedite the work, four soil containers had been used simultaneously in this research. The container is a box, made of plexiglass, of thickness 25 mm and has a dimension of 600 mm long, 600 mm wide and 1000 mm in height. The long sides of the soil container were braced with mild steel angle iron to avoid lateral yielding during the tests. To minimise side friction, the inside surface of the box was lubricated by petroleum jelly.

For loading test, a steel plate of about 580 mm long, 50 mm wide and 10 mm in thickness was used to represent a strip footing. The compression testing machine with a capacity of 1 MN was the source to provide the vertical load to the loading plate. A load cell and two linear variable displacement transducers (LVDT) were used for measuring load and the displacement of the loading plate, respectively. The bamboo poles used in model test were obtained from around the campus of Universiti Teknologi Malaysia, Skudai, Johor. The bamboo has the average outer diameter of 6 mm and the average inner diameter (d) of 5 mm. Each poles is 600 mm long (l), therefore on average l/d ≈ 120. In this study, the bamboo was arranged in chevron grid pattern, whereby the square pattern bamboo of various space distance (s), was inserted with another layer of bamboo poles connecting two of the corners, as illustrated in Figure 3. Figure 4 shows the laboratory test setup for model testing.



(a) Chevron grid pattern bamboo (b) Bamboo-geotextile composite

Figure 3: Bamboo models

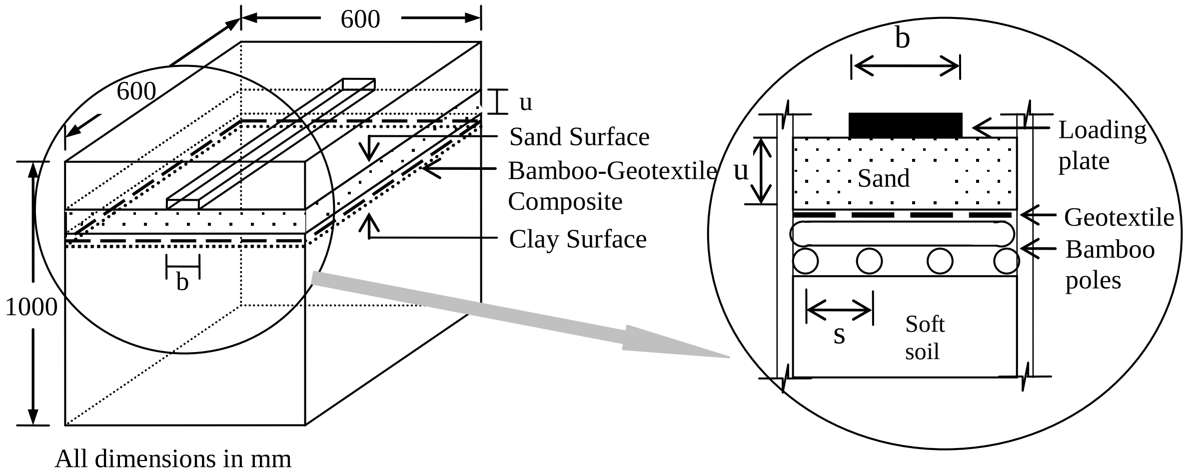


Figure 4: Laboratory test setup(Figure not to scale)

The maximum dry unit weight of sand was found to be 16.95 kN/m^3 and the minimum dry unit weight was 14.84 kN/m^3. The values were achieved in the densest and loosest state sand packing, respectively. Table 2 shows the sand properties which were used in this research work

Table 2 : Properties of sand

Parameter	Value
Specific gravity G_s	2.62
Effective size D_{10}	0.16 mm
Diameter finer than 30 % D_{30}	0.28 mm
Diameter finer than 60 % D_{60}	0.60 mm
Coefficient of uniformity $C_u = \frac{D_{60}}{D_{10}}$	3.75
Coefficient of gradation $C_u = \frac{D_{30}^2}{(D_{60})(D_{10})}$	0.82
	14.83 kN/m^3
Minimum dry unit weight $\gamma_{d(min)}$	16.95 kN/m^3
Maximum dry unit weight $\gamma_{d(max)}$	16.4 kN/m^3
Unit weight in model test γ	9%
Natural water content w	

From the Atterberg limits obtained for kaolin, the soil could be classified using the plasticity chart, according to Unified Soil Classification System, the soil is classified as silt of high plasticity with MH symbol. According to AASHTO soil classification system, the soil is classified as A-7-5. The basic properties of kaolin are summarised in Table 3.

Table 3 : Basic properties of soft clay (Kaolin)

Parameter	Value
Colour	Greyish white
Specific gravity, G_s	2.59
<u>Consistency test</u>:	
Liquid limit, w_L(%)	62
Plastic limit, w_P (%)	45
Plasticity index, I_P (%)	17
Linear shrinkage, L_s (%)	11

Classification : Unified Soil Classification System AASHTO classification	 MH A-7-5

Properties of Bamboo

The tensile load stiffness values of nodes and internodes of bamboo material obtained from a series of laboratory tests are summarized in Table 4.

Table 4 **:**Tensile test results of bamboo at node and internode condition

Type	Specimen label	Failure Load (N)	Tensile strength, σ_t (Mpa)	Tensile strength σ_t representative (Mpa)	Average of tensilestrength σ_t (Mpa)
Node	N - 1	1106.30	1106.30	88.08	98.21
	N - 2	1442.00	1442.00	114.81	
	N - 3	1152.07	1152.07	91.73	
	N - 4	183.11	183.11	-	
Inter-node	IN - 1	1052.89	83.83	-	164.56
	IN - 2	2082.89	165.84	165.84	
	IN - 3	2050.74	163.28	163.28	

After analysing the data statistically, the average results of tensile load are found to be quite distinct between internode and node conditions. The average tensile failure load at internode conditions is 164.56 Mpa while at the node conditions it is 98.21 N only.

Testing Programme and Experimental Procedure

The testing programme includes tests on the materials, followed by model testing. Each model test consists of consolidation stage and loading test stage. In the loading test the un-reinforced and reinforced soft soil, overlain by sand layer at embankment ratio (u/b) of 0.25, 0.5, 0.75 and 1.0, were loaded until failure. In the reinforced soft soils programme, the soil was reinforced with geotextile alone, bamboo alone and bamboo-geotextile composite. The bamboo poles were arranged to have bamboo distance ratio (s/d) of 5, 10, 20 and 30. The notation of u, b and s can be seen in Figures 3 and 4.

Consolidation Stage

The consolidation process of the soil has been carried out in a special loading frame. The process has been explained elsewhere in Marto *et al*. (2005b). At the end of the consolidation, the soft soil has an undrained shear strength of about 12 to 14 kPa, measured using vane shear test.

Loading Test Stage

Upon the completion of soil consolidation, the consolidating load was removed and the soil box was transferred and moved to the loading test frame. Bamboo models, when needed, were placed at the surface of the soil layer. Then, the fill, consisting of uniformly graded quarry sand was poured on the soil surface up to the desired height, by using raining technique. The loading plate was then placed at the central, right angled to the edge of box, extending to the full length of the box to simulate a plane strain condition. Compressive load was then applied to the footing through a compression machine at a constant rate of 1 mm per minute.

Result and Discussions

Un-reinforced Model

The load-settlement curves, obtained from the load tests on un-reinforced models are shown in Figure 5. From this figure, it can be seen that there is no obvious point of failure for all curves since the foundation soil is soft type and the sand fill is medium dense. This mode of failure is termed "local shear failure". For the purpose of comparisons and discussions, the failure point is taken as the point where the settlement equals to 20% of the width of footing as defined by Shin, *et al*. (1993) and also found by Dash *et al.* (2001). The load corresponds to this settlement is taken as the ultimate bearing load, Q_{ult}. This failure criteria is also used to find Q_{ult} for reinforced models.

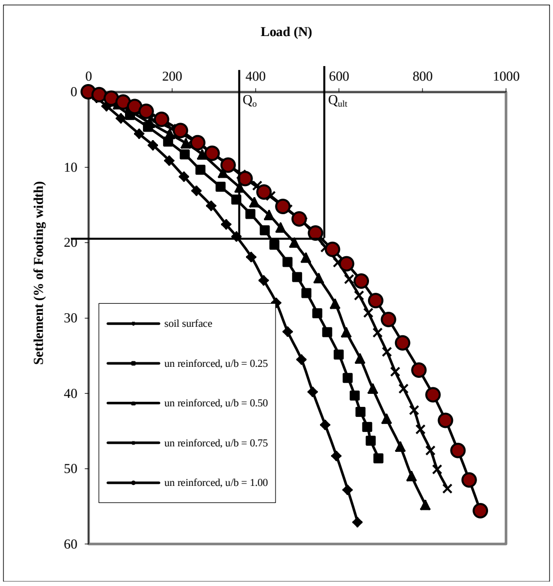


Figure 5: Load-settlement curves for un-reinforced models

Table 5 summarises the results of the ultimate load and the increase in ultimate bearing capacity at various embankment ratio. As expected, without the reinforcement, the ultimate bearing capacity increases as the height of the sand fill increases. This is because, as the distance from the soft soil increases, the distribution of the load to the soft soil surface decreases. Hence, larger load is needed at the top of sand fill to mobilise the ultimate capacity of foundation soil. The ultimate load for test directly on the surface of soft soil is found to be 364 N. The increase of embankment ratio to 0.25 increases the bearing capacity to 21%. However, it can be seen that further increase in the ratio reduced the increase in the bearing capacity of the soil.

Table 5: The ultimate bearing capacity increase on un-reinforced condition

Embankment Ratio (u/b)	Ultimate load Q_{ult} (N)	Increase in bearing capacity $(Q_{ult} – Q_o)/Q_o$ x 100 (%)
0 (soil surface)	364 (Q_o)	-
0.25	442	21.43
0.50	493	35.44
0.75	555	52.47
1.00	585	60.71

Reinforced Models

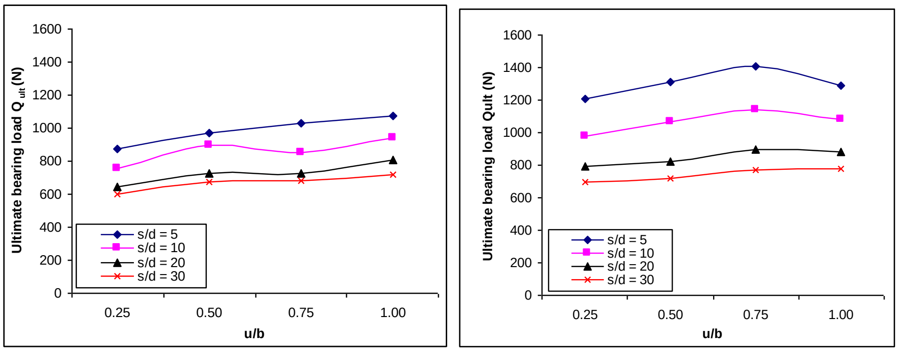
Table 4 summarises the results of loading tests on reinforced models. The discussions will be given on the effect of embankment ratio, bamboo distance ratio and reinforcement system on the ultimate bearing load, Q_{ult} and the increase in bearing capacity. The increase in bearing capacity was calculated by comparing the results with the ultimate load obtained from un-reinforced condition, and noted as Q_o.

Effect of Embankment Ratio

The effect of embankment ratio could be seen from the plot of ultimate bearing load against embankment ratio, at various bamboo distance ratio shown in Figure 6. The trend is about the same as in un-reinforced models whereby the ultimate bearing capacity increases with the increase of embankment ratio, for both chevron pattern bamboo reinforced (CB) as well as bamboo-geotextile composite reinforced (BGC). The increase in bearing capacity for CB ranges between 20 to about 100 %. As expected, the BGC shows much better increase in bearing capacity (range between 20 to nearly 200 %) especially at a lower bamboo distance ratio. The maximum increase in ultimate bearing capacity of 192 % was obtained for BGC, at a combination of bamboo distance ratio 5 and embankment ratio 0.25. It is also observed that for BGC, the ultimate bearing capacity tends to come to its peak at the embankment ratio of 0.75 and decrease beyond the value. The embankment ratio of 0.75 could be the threshold for this reinforcement system. However, in general it can be said that the embankment ratio has a significance effect towards the contribution of increasing the bearing capacity of the foundation soil.

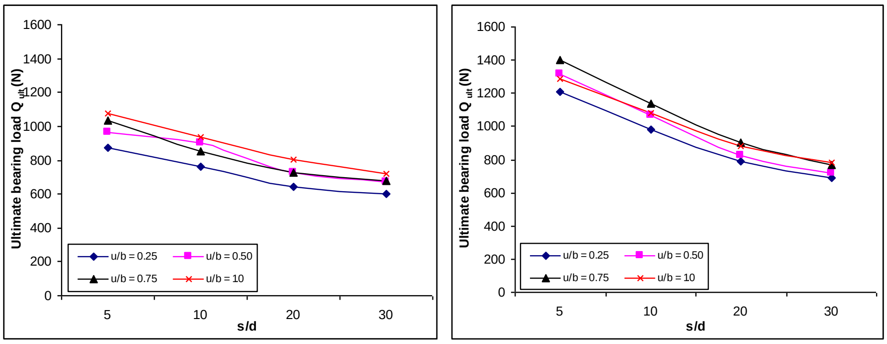
Effect of Bamboo Distance Ratio

The influence of bamboo distance ratio was also found to be obvious. As can be seen in Figure 7, the higher the ratio, the smaller the ultimate bearing capacity. The trend is the same for all embankment ratio tested on CB and BGC. However, the change in CB is not that marked, in compared with BGC. At embankment ratio of 0.25, the ultimate load of CB decreases from 873 N at distance ratio 5 to 603 N at distance ratio 30. At the same condition, the ultimate load at BGC decreases from 1290 N to 780 N.



(a) Chevron grid pattern bamboo (b) Bamboo-geotextile composite

Figure 6: The effect of embankment ratio on the ultimate bearing capacity

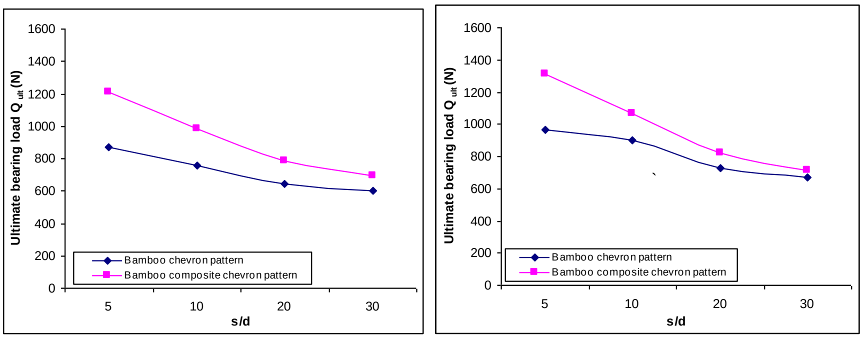


(a) Chevron grid pattern bamboo (b) Bamboo-geotextile composite

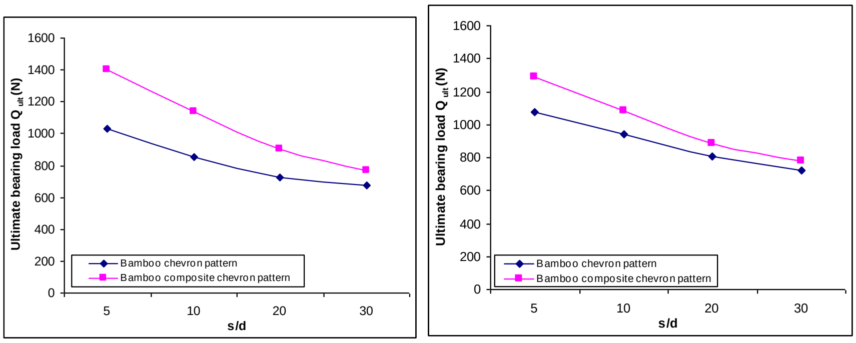
Figure 7: The effect of bamboo distance ratio ratio on the ultimate bearing capacity

Effect of Reinforcing System

The performance of bamboo, arranged in chevron pattern, alone as the reinforcing material and the combination of bamboo arranged in chevron pattern with geotextile, is shown in Figure 8. There appears to be a remarkable difference in the ultimate bearing capacity achieved. It is apparent that the bamboo-geotextile composite system performed much better whereby the difference in the ultimate bearing capacity achieved from both system is so pronounced. This is especially true at bamboo distance ratio of smaller than 10. Although the results indicate that the bamboo alone could be used as a reinforcing material but the use of geotextile is needed as a separator between the embankment fill and the soft soil foundation. At large strains, the geotextile will also have a reinforcement function.



(a)u/b = 0.25 (b)u/b = 0.5

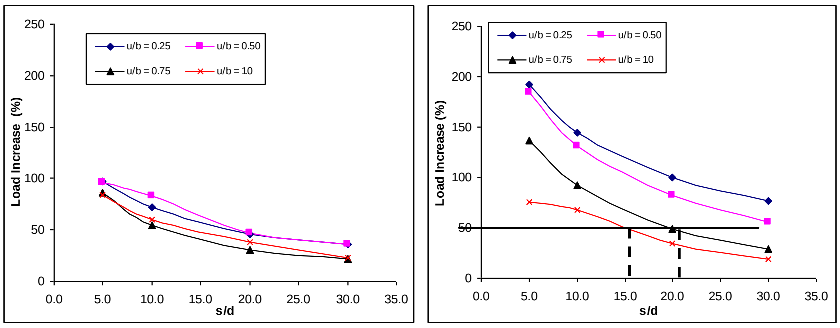


(c)u/b = 0.75 (d)u/b = 1.00

Figure 8: The effect of reinforcing system on the ultimate bearing capacity of soft soil at various bamboo distance ratio and various embankment ratio

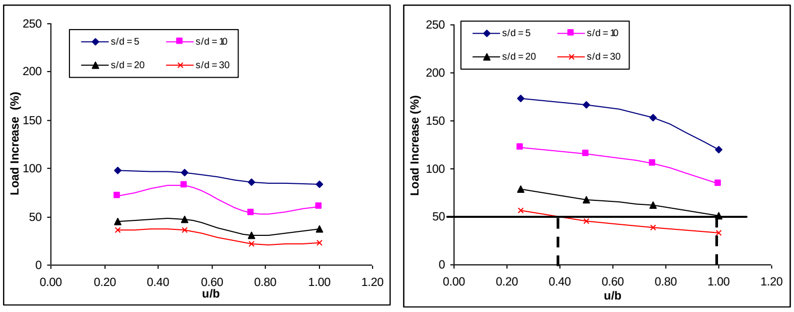
The Use of Charts for Design

The percentage of increase in bearing capacity plotted against various bamboo distance ratio and embankment ratio shown in Figures 9 and 10, respectively, could be used as a guideline in choosing the embankment fill height for construction on soft soils, or the amount of bamboo to be used as the reinforcing materials. For an example, if one considers using chevron pattern bamboo-geotextile composite as the reinforcing material and to expect a 50 % bearing capacity increase, there will be two choices: (i) use Figure 9(b) to choose a predetermined embankment ratio, then determine the bamboo distance ratio from the chart, (ii) use Figure 10(b) to choose a predetermined bamboo distance ratio, then determine the embankment ratio from the chart. From the chart in Figure 8(b), if one chooses embankment ratio 1.0 then the bamboo distance ratio to be used should be 15. On the other hand, if one chooses embankment ratio 0.75 then the bamboo distance ratio can be larger, i.e. 20. Using both the charts in Figures 8 and 9, allows the engineer to design the embankment based on which level of bearing capacity increment is expected.



(a) Chevron grid pattern bamboo (b) Bamboo-geotextile composite

Figure 9: The effect of bamboo distance ratio on the increase in ultimate bearing capacity



(a) Chevron grid pattern bamboo (b) Bamboo-geotextile composite

Figure 10: The effect of embankment ratio on the increase in ultimate bearing capacity

Conclusion

From this study, it can be concluded that the bearing capacity of a sand layer over a soft soil sub-grade increased significantly by the incorporation of bamboo at the sand-soft soil interface. The addition of the geotextile layer over the bamboo poles, arranged in chevron grid pattern, further increase the bearing capacity. The amount depends on how close the poles are laid together, and also the height of the sand fill layer. Both the bamboo distance ratio and the embankment ratio give significant effect towards the contribution of increasing the bearing capacity of soft soil. The combination use of bamboo, as reinforcement with tensile and bending stiffness, and geotextile for separation and filtration seems to modify the strain behaviour of the system, thus the failure mechanism. A new mathematical models of this reinforcement mechanism need to be built up to allow a design method to be developed which then have to be tested with data obtained from full-scale tests. The results will provide the engineer with the opportunity to make considerable savings in the embankment fill materials inclusive of the depth of aggregate in unpaved, unbound road. The bamboo-geotextile composite system has the potential to become an alternative cost-saving method for soil stabilisation or improvement, especially in highway construction. The charts developed in this study allows the engineer to use them in the design of the embankment based on which level of bearing capacity increment is expected to be achieved.

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