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Bearing Capacity of Soft Soil Using Bamboo-Geotextile Composite

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Abstract

Construction on soft clays is often affected by stability and settlement problems. General stabilization of these soils usually involves expensive soil improvement method in order to enhance stability suitably reducing the potential and prevailing uneven settlement. Studies on soft clay reinforced with bamboo-geotextile composite overlaid by granular layer had been carried out to determine the increase in bearing capacity of strip footing on the soft clay. The bamboos were arranged in square and parallel pattern having various ratio of distance (s) to width of footing (b), s/b = 3.0, 2.0, 1.0 and 0.5. The height of granular material (u) overlying the soft clay varies with u/b = 0.25, 0.50 and 0.75. The soft clay was made from kaolin slurry that was consolidated in square boxes of 600 mm width and 1000 mm height. The results show that there is a great increase in bearing capacity and decrease of settlement at failure for the reinforced model. The bearing capacity increment of more than 127 % was recorded for bamboos of square and parallel pattern, having the s/b = 0.50 at u/b = 0.25. However, bamboo arranged in square pattern gives better improvement of bearing capacity than the parallel pattern. It can be concluded that the bamboo-geotextile composite could be used as another alternative method in improving the bearing capacity of soft clay. This will therefore benefits the construction industry especially in highway engineering.

Keywords: Soft Clay, Bearing Capacity, Strip Footing, Bamboo-Geotextile Composite

INTRODUCTION

Soil reinforcement is considered an ideal method to strengthen soft clays and has been used in Malaysia for the rehabilitation of soft soils. In addition to its other benefits, reinforcement provides the soil with the tension force that strengthens it and makes it capable of supporting more loads than it usually can. Geotextile and bamboo were chosen as reinforcement for this type of soft soil for their availability in the market and their widespread use all over the world for soil reinforcement applications.

General stabilization of soil, especially soft soils, usually involves expensive improvement methods, to enhance stability and suitably reducing the potential and prevailing uneven settlement. In other related road structure, for example road embankments, bridges approaches and slope, extensive stabilization of wider foundation base for support is often necessary, resulting in increase in land utilization area and right of way and thus, cost. In most cases, imported backfill materials are required for those structures that will further increase the overall cost.

It is noted that the potential use of strength, inclusive of bending properties of local vegetation, like bamboo, shall be able to accommodate the improvement of stability and settlement problems of soft soil. Alongside the bamboo, another man-made product referred to as geosynthetic material (e.g. geotextile), is to be used compositely. The geotextile are either permeable or impervious sheets or strips of material, which are used in association with soil.

They are also woven and non-woven in nature. They usually made from synthethic polymers to geotextiles. Geotextile are increasingly used to improve the stability of soft soils and thus, help to reduce the cost of constructing earthworks over such soils.

The bamboo-geotextile composite is a method whereby the bamboo is first laid on soft clay and geotextile is then laid on top of the bamboo. This is because if the soil too soft, the use of geotextile alone is quite impossible as machine can't be mobilized to lay the geotextile. To further enhance the stability and settlement problems, bamboo-geotextile composite is used to provide both bending and tensile reinforcement, at the overlying fill and soft soil interface with the geotextile acting as separator and filter between the fill material and sub-grade soil, thus the increase in the soil bearing capacity.

RESEARCH METHOD

Equipment and Model

The equipment used in this study consisted of soil container, bamboo models and loading equipment. The vertical load was applied to the bamboo model using loading equipment that provided a constant rate of vertical displacement. The loading equipment was a compression-testing machine with a maximum capacity of 1000 kN. A load cell and two linear variable displacement transducers (LVDT) were used for measuring load and the displacement of the loading plate, respectively, during loading test.

The soil container was a plexiglass box with a thickness of 25 mm, 600mm long, 600 mm wide and 1000 mm height. Four small holes of about 5 mm diameter were drilled in opposite sides of the box where valves were installed in these holes to control the drainage during the consolidation stage and load test on soft soils either the soils were un-reinforced and reinforced with bamboo. The loading plate of 580 mm length, 50 mm width and 10 mm thickness was used to simulate a plane strain condition at the soil model.

The bamboo model was arranged in two patterns, namely square and parallel in nature. Figure 1 shows the sectional view of reinforced soil model and Figure 2 illustrates the bamboo model. The total length of the bamboo used was 600 mm and the width was 300 mm.

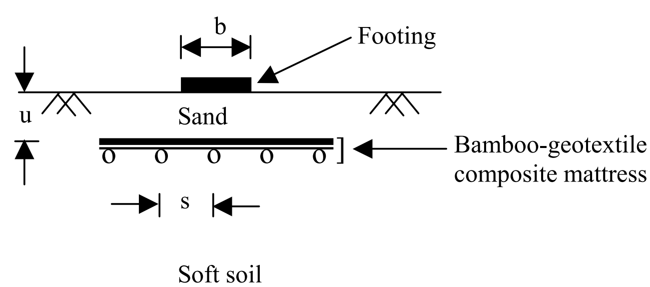
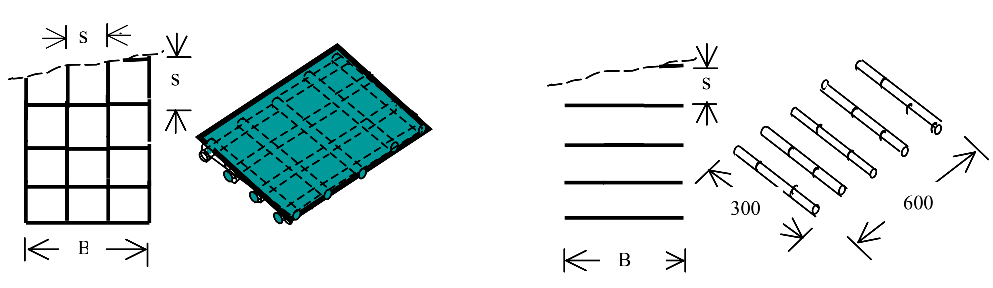


Figure 1 Geometric parameters of composite



a) Square pattern

b) Parallel pattern

Figure 2 Bamboo models

Testing Program and Experimental Procedure

The testing program includes the finding of the basic engineering characteristics of the materials used in the model tests, followed by the model tests. Each model test consists of two stages: consolidation stage and loading test stage. In the loading test, the un-reinforced and reinforced soft clay models with various thickness of sand layer overlying the soft soil were loaded until failure. The purpose of the investigation was to assess the effect of incorporating a geotextile layer and various numbers of bamboo as reinforcement, arranged in square and parallel pattern, on the behavior of the footing and sand layer over clay. The combination employed was bamboo space-distance ratio, s/b = 3.0, 2.0, 1.0 and 0.5 with a single layer of Polyfelt TS 60 type geotextile. The sand layer represents the embankment to be constructed on soft clay sub-grade. Both un-reinforced and reinforced soil were tested at embankment ratio, u/b = 0.25, 0.50 and 0.75. The notation of u, b and s can be seen in Figures 1 and 2.

Consolidation Stage

The consolidation process was performed in a special loading frame. During the consolidation stage, poorly graded sand was placed at the bottom of the soil box to serve as a drained layer followed by geotextile as a separator. Thereafter, the oven-dried kaolin powder, thoroughly mixed with the required amount of water to obtain the desired initial moisture (liquid limit condition) was placed in the soil box in three layers, each at 125 mm thick. The calculated weight of soil for the first layer was placed over a geotextile separating the soil from the sand layer. After that, an upper plate, having 580 mm long, 580 mm wide and a thickness of 15 mm, was placed on top of the soil layer.

Filter paper was placed along the sides of the soil box and between the soil and the loading plate, to quicken the consolidation process. The valves at the small holes at the sides of the box were opened and then the first load increment of 10 kPa was applied. Soil deformation was monitored and settlement readings were taken at certain time intervals until the relationship between settlement and logarithm of time became nearly horizontal. Then the second layer of soil was placed and a load of 20 kPa applied. When consolidation completed, the third layer was then placed on top of the second layer and the consolidation occurred by applying 40 kPa pressure. The settlement of the soil layer was measured by means of two dial gauges connected to the loading plate on the top of the soil layer. The consolidation for the three layers of the soil took about fifteen days to complete. During the initial stage of experimental work, vane shear test had been carried out at various positions to get the undrained shear strength (S_u) of the consolidated soil. The soil can be said as very soft since the average shear strength obtained was about 12 kN/m^2.

Loading Test Stage

After the consolidation of soil had been completed, the consolidating load was removed and the soil box was moved to the loading frame. Bamboo models, when needed, were placed at the surface of the soil layer. Sand, with uniform grading, was later poured onto the soil or bamboo surface using the raining technique to get the desired maximum density of 1704.5 kg/m^3, up to the thickness (u) specified.

The loading plate of 50 mm width was then located centrally and extends the full width of the box model. The load was then applied to the plate through a compression-testing machine at a constant rate of deformation of 1 mm per minute. A load cell was used to measure the applied load and the displacement was measured by LVDT, connected to a data logger. Figure 3 shows the schematic diagram of the laboratory model test set-up.

RESULTS AND DISCUSSIONS

Basic Test on Material

The materials used in this research were kaolin powder, obtained from local supplier to form soft soils and sand from nearby quarry for the fill and drainage layer. The test of soil had been carried out according to BS 1377 (1990) and the results are shown in Table 1. The tests on the geotextile had been carried out by the supplier, Polyfelt Industries, Shah Alam, Selangor, Malaysia, and the results are shown in Table 2. The bamboo used in this research has the outer diameter between 3mm – 10 mm and the inner diameter ranging from 2 mm – 7 mm.

Model Test

The load-settlement curves obtained from all tests show no obvious point of failure. Therefore, for the purpose of discussions, the ultimate bearing load, Q_{ult}, defined by Shin, *et al* (1993) and Dash, *et al* (2001) was used. It is the load at the point where the systems reinforced with planar reinforcement fail as settlements equal to about 20% of the width of the footing that is at 10 mm settlement. This concept was employed for all models tested in the present investigation for the purpose of comparison and revealed a unique value for the ultimate bearing load for each load-settlement curve.

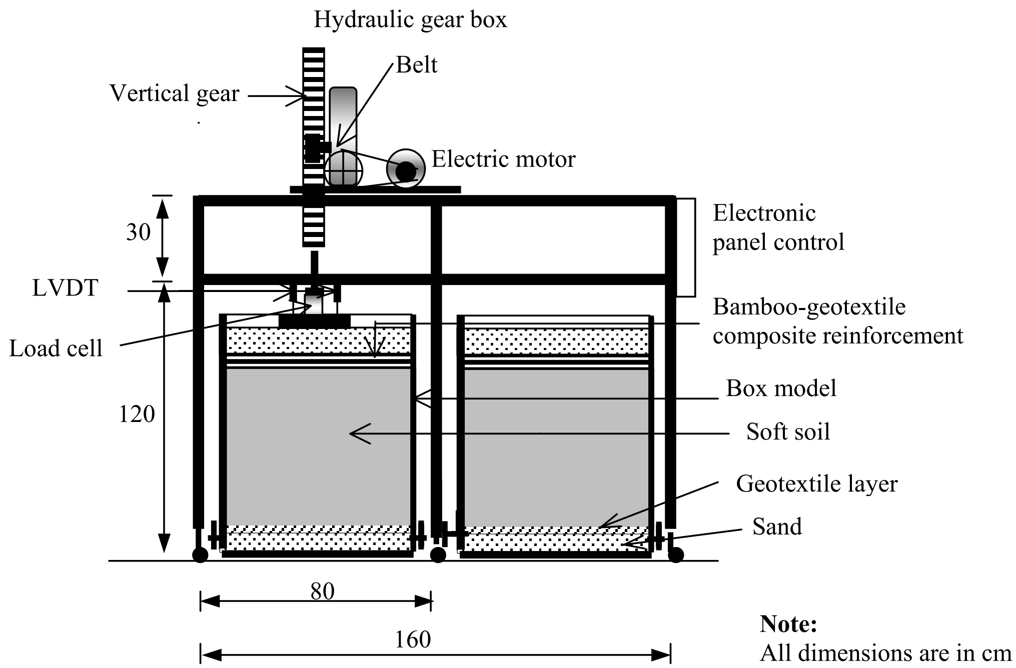


Figure 3 Schematic laboratory test setup

Table 1 Properties of sand and kaolin

Soil parameters	Sand	Kaolin
Specific gravity (G_s)	2.64	2.52
Maximum void ratio (e_{max})	0.81	-
Minimum void ratio (e_{min})	0.58	-
Coefficient of uniformity $C_u = D_{60}/D_{10}$	4.14	-
Effective size D_{10}	0.29mm	-
D_{30}	0.50mm	-
D_{60}	1.20mm	-
Dry density		
$\rho_{d\ min}$ (kg/m^3)	1225.6	-
$\rho_{d\ max}$ (kg/m^3)	1704.5	-
Atterberg limit		
Liquid limit, w_L (%)	-	62
Plastic limit, w_P (%)	-	45
Plastic index, I_P (%)	-	17
Shrinkage limit (%)	-	11
Vane shear test, S_u (kPa)	-	12

Table 2 Properties of geotextile

Parameters	Value
Mass per unit area (g/m^2)	204
Thickness under a 2 kN/m^2 load (mm)	3.40
Peak wide-width tensile load (kN/m)	31.0
Elongation at maximum load (%)	60.6
Secant modulus at 10% elongation (kN/m)	39.2
Elongation at 50% peak strength (%)	29.0
Geotextile-kaolin interface friction angle (^{o})	22

Un-reinforced Models

Figure 4 shows the load-settlement curves from load tests on un-reinforced model. This figure illustrates the influence of a different embankment ratio, u/b, for un-reinforced soil. It shows that the greater the embankment ratio, the higher the ultimate bearing capacity and hence the lower the settlement. Table 3 summarizes the results for the ultimate bearing load and the increase of ultimate bearing capacity at various embankment ratio. From the results in Table 3, it can be seen that without the reinforcement to the soft soil, the ultimate load increase as the height of the sand layer (embankment) increase. The ultimate load for load test on the surface of the soil is 170 N. As the embankment ratio increased to 0.25, the ultimate bearing capacity increased to 220 N (29.4 % increase). When the embankment ratio was 0.5, the ultimate load improved to 330 N or increase of 94.1 %. Finally while the embankment ratio at 0.75; the ultimate load is 440 N, or the ultimate bearing capacity improvement to 158.8 %. The evidence shows that, the increasing of embankment ratio (u/b) has significance effect towards the contribution of increasing the ultimate bearing capacity.

Reinforced Models

Table 4 summaries the results of loading tests on soft clay model, reinforced with bamboo-geotextile composites. The discussions will be given on the effect of embankment ratio, u/b, bamboo pattern and bamboo distance ratio, s/b, on the ultimate bearing load, Q_{ult} achieved from the reinforcement of the composites. The increase in ultimate load was calculated by comparing the results with the ultimate load obtained from un-reinforced condition, and noted as Q_o.

Effect of Bamboo Ratio

The effect of embankment ratio could be seen clearly from the plot of Q_{ult} vs u/b as shown in Figure 5. The results show similar trend with un-reinforced model that is the ultimate load

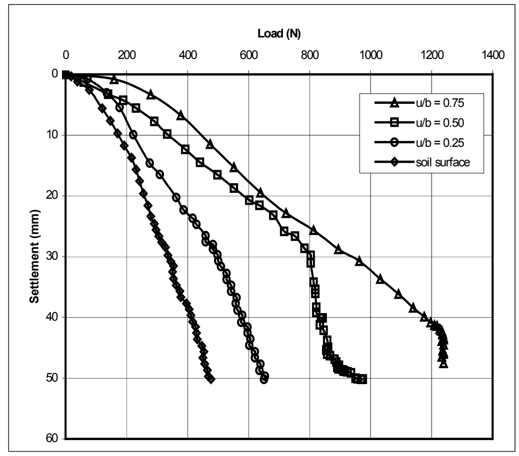


Figure 4 Load-settlement curves for un-reinforced model at various u/b ratio

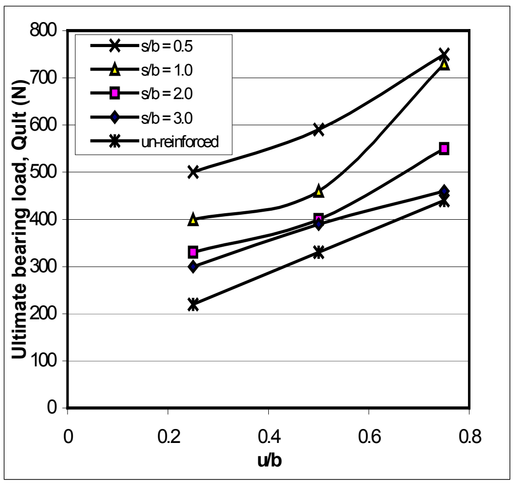
Table 3 The ultimate bearing load for un-reinforced model

No	u/b	Q_{ult} (N)	Load increase (%)
1	0.00	170 (Q_o)	-
2	0.25	220	29.4
3	0.50	330	94.1
4	0.75	440	158.8

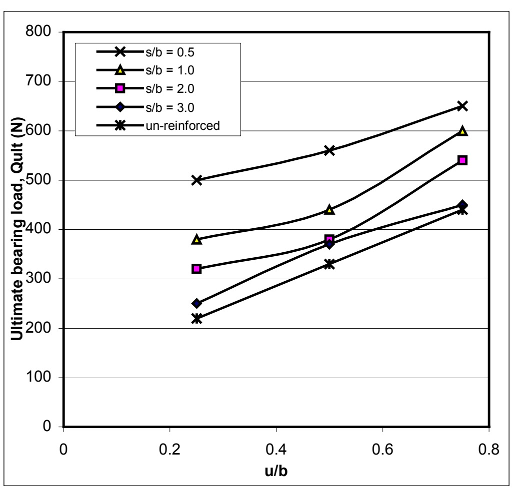
Table 4 The increase on ultimate bearing load for square and parallel pattern at various s/b ratio and various u/b ratio

No.	u/b	s/b	Q_o (N)	Q_{ult} (N) for square pattern	Load increase % for square pattern	Q_{ult} (N) for parallel pattern	Load increase % for parallel pattern	Load increase between Parallel and Square pattern (%)
1	0.75	3.0	440	460	4.5	450	2.3	2.2
		2.0		550	20.0	540	22.7	1.9
		1.0		730	39.7	600	36.4	21.7
		0.50		750	70.5	650	47.7	15.4
2	0.50	3.0	330	390	18.2	370	12.1	5.4
		2.0		400	21.2	380	15.2	5.3
		1.0		460	39.4	440	33.3	4.5
		0.50		590	78.8	560	69.7	5.4
3	0.25	3.0	220	300	36.4	250	13.6	20.0
		2.0		330	50.0	320	45.5	3.1
		1.0		400	81.8	380	72.7	5.3
		0.50		500	127.3	500	127.3	-

increases with the increase in embankment ratio. The largest ultimate bearing load of 750 N was achieved with the reinforcement of bamboo-geotextile composite with square pattern bamboo having distance ratio of 0.5, at embankment ratio of 0.75. However, the maximum increase in ultimate load of 127.3% was obtained from bamboo arranged both in square and parallel pattern, at distance ratio of 0.50, and at an embankment ratio of 0.25. The evidence shows that the embankment ratio, u/b has significance effect towards the contribution of increasing the bearing capacity.



(a) Square pattern



(b) Parallel pattern

Figure 5 The effect of embankment ratio on the ultimate bearing load

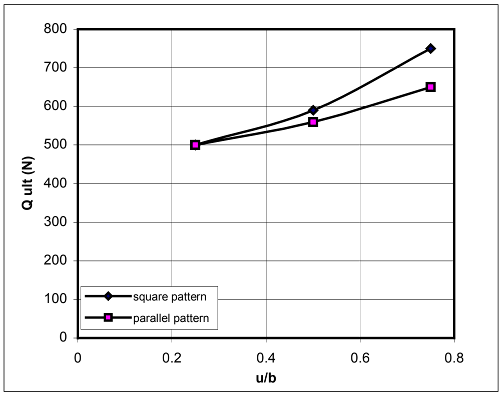
Effect of Bamboo Pattern and Distance Ratio

The influence of the type of bamboo pattern (square and parallel) on the footing performance was studied in the model test. The variation of the bearing capacity improvement with increasing u/b ratio and decreasing s/b ratio for different bamboo pattern are shown in Figures 6 and 7, respectively. It could be observed that the results of both the pattern give almost identical trend. As being seen earlier, there is a slight improvement in load carrying capacity when u/b was increased from 0.25, 0.50 and 0.75. The slight increase in performance improvement with u/b may be due to the effect of the pattern of bamboo. Overall, the square pattern gives higher bearing capacity than the parallel pattern. For example, at embankment ratio u/b=0.5 with s/b=0.5, the ultimate bearing capacity of square pattern is 590 N while the parallel pattern 560 N giving the increase of ultimate load between parallel and square pattern of 5.4 %. However, in general it is found that the increase between the two patterns does not exceed 10 % except at high embankment ratio. At higher settlement, the performance with square pattern is much better because of its higher stiffness and deflection. At this stage, the sand starts moving out of the bamboo and geotextile layer and hence the stiffness of the composite reinforcement has influenced on the overall behaviours.

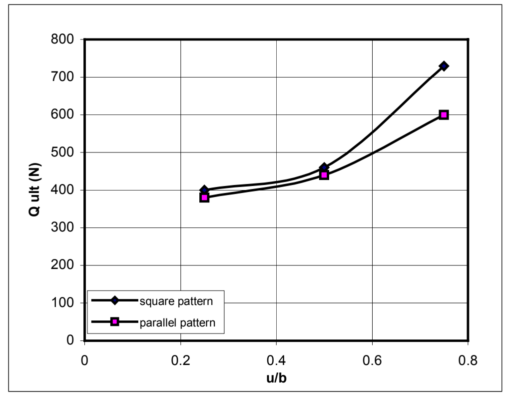
Figure 7 shows the variations effect of bamboo distance ratio, s/b on different pattern of bamboo, at various embankment ratio. The bearing capacity increases with decreasing bamboo distance ratio. A significant increase of bearing capacity was achieved when the bamboo distance ratio decreases from 1.0 to 0.5. For square pattern, the increase in bearing capacity gives almost similar values at embankment ratio of 0.25 and 0.5. However, an abrupt increase of bearing capacity could be seen with the increase of embankment ratio from 0.5 to 0.75. In general, it can be said that the bamboo distance ratio has significance effect towards the contribution of increasing the bearing capacity of soft soil.

Figure 8 illustrates clearer picture on the effect of bamboo arrangement in the bamboo-geotextile composites. As pointed earlier, there seems to be no significant different on bearing capacity obtained from both square and parallel patterns at embankment ratio 0.5 and greater. At embankment ratio 0.25, the curves widen when bamboo-distance ratio becomes less than 2.0. At this range, the increase in ultimate bearing load of square pattern shows a value of up to 100 N greater than the value obtained in parallel pattern.

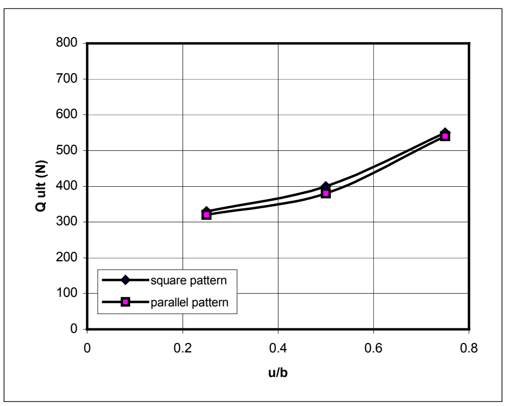
Figure 9 compares the increase of ultimate bearing capacity at a decreasing bamboo-distance ratio, at various embankment ratio, both for square pattern and parallel pattern. The increment rate is quite similar when bamboo-distance ratio decrease from 3.0 to 2.0 and then to 1.0 for embankment ratio of 0.25 and 0.75. At embankment ratio 0.5, there seems to be a negligible increase in bearing capacity at high bamboo-distance ratio but increase in ultimate load increase tremendously as the ratio become smaller.



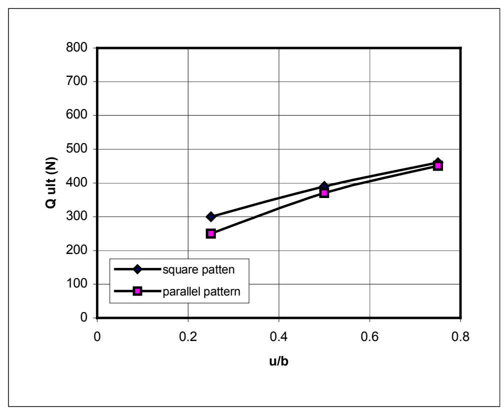
(a) s/b = 0.5



(b) s/b = 1.0

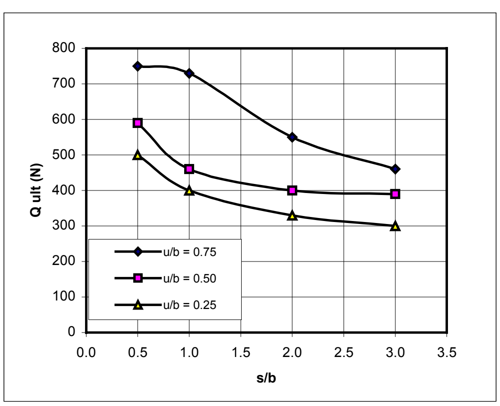


(c) s/b = 2.0

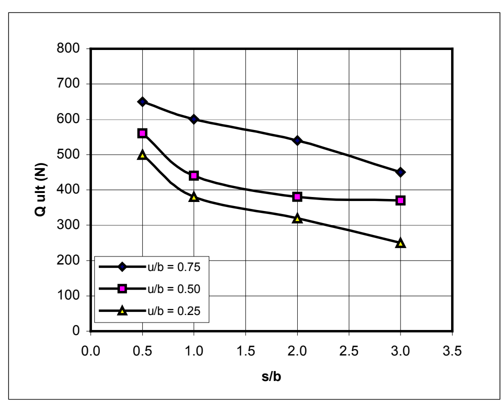


(d) s/b = 3.0

Figure 6 The effect of bamboo arrangement pattern on the ultimate bearing load at various u/b ratio

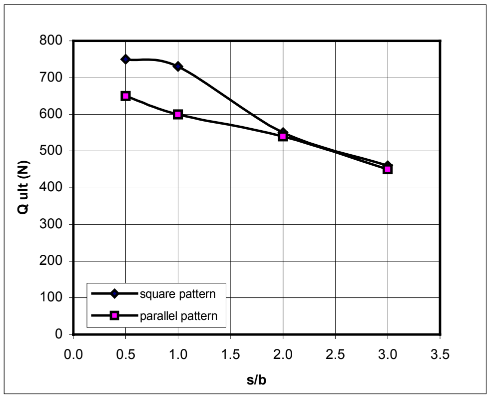


(a) Square pattern

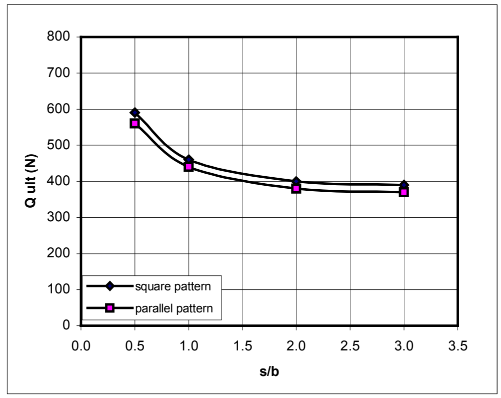


(b) Parallel pattern

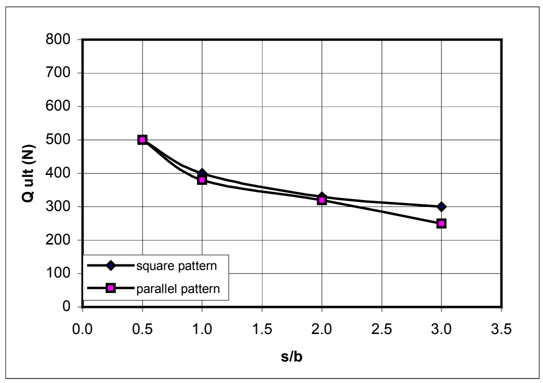
Figure 7 The effect of s/b ratio on the ultimate bearing load



(a) u/b = 0.75

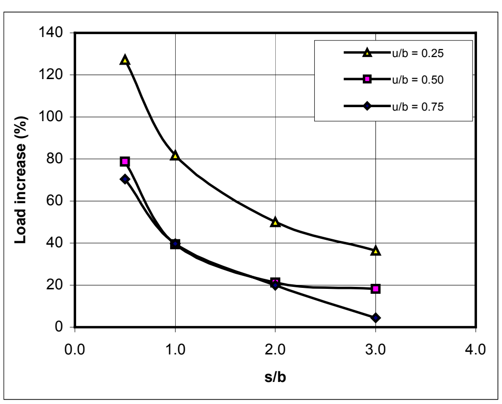


(b) u/b = 0.5

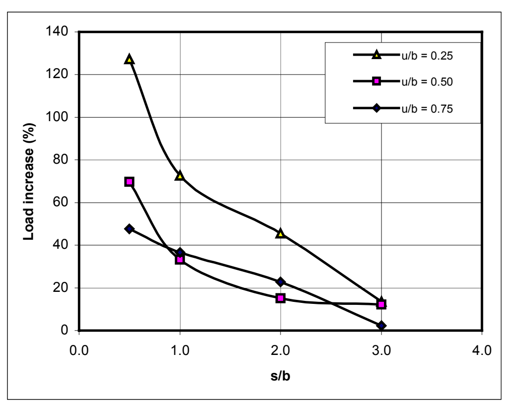


(c) u/b = 0.25

Figure 8 The effect of bamboo arrangement on the ultimate bearing load at various s/b ratio



(a) Square pattern



(b) Parallel pattern

Figure 9 The increase of ultimate bearing capacity at various s/b ratio

CONCLUSIONS

This study has confirmed the findings of a number of previous investigations by showing that the bearing capacity of a sand layer over a soft clay sub-grade is somewhat increased at large strains by the incorporation of layer of geotextile at the soil-clay interface. However, it has also been shown by Marto *et. al*, (2004) that by using bamboo, which possesses both tensile and bending stiffness, then a much greater increase in bearing capacity could be achieved even at low deformations which is quite different from the case where only a geotextile is used, as reported by Miki (1996).

Where the geotextile is used on its own, it is only when it strained significantly that sufficient tension is developed to modify the applied load-settlement behavior of the system. Thus, the principle functions of the geotextile layer at operational strain level, will be separation and filtration, although at large strains it will have a reinforcement function which will modify the failure mechanism. Since the bearing capacity theories used to analyze such systems are generally based on failure conditions, this calls into question the applicability of these theories.

Where bamboo reinforcement with tensile and bending stiffness are used in conjunction with the geotextile, it is clear that the strain behavior of the system is greatly modified. Observations to date suggest that the bamboo reinforcement will provide both tensile and bending reinforcement of the sand, while the geotextile will principally act to separate and filter the sand and clay. However, it also acts locally as a "tension membrane" between the bamboo and a "cushion" beneath the poles thereby reducing localised stress in clay. Perhaps new mathematical models of this reinforcement mechanism need to be built up to allow a design method to be developed. This will then have to be tested with data obtained from full-scale field trials on unpaved unbound roads. When developed and proven against full-scale trials, they will provide the engineer with the opportunity to make considerable savings in the depth of aggregate in unpaved, unbound roads or to greatly increase the function life of the roads.

Based on the results obtained from the present investigation, the following conclusions can be made on the behavior of strip footings resting on sand layer and bamboo-geotextile composite reinforced soft clay.

a. The bamboo-geotextile composite reinforced models show higher bearing capacity and better settlement characteristics than the un-reinforced.models.
b. The square pattern for the formation of bamboo is more beneficial than the bamboo in parallel pattern.
c. The embankment ratio and bamboo distance ratio have significance effect towards the contribution of increasing the bearing capacity of soft clay.
d. The increase in ultimate load decreases with the distance of bamboo. The maximum increase in ultimate load of 127.3% was obtained from bamboo of square and parallel pattern, having the bamboo-distance ratio of 0.5 and embankment ratio of 0.25.
e. The end product of this research may be economically scaled towards cost reduction, in embankment construction, particularly when using locally available materials. This will probably give another alternative for new type of soil stabilization methods to be adopted especially in highway construction.
f. The stress distributions on the soft soil layer with the bamboo-geotextile composite reinforced were measured with increases in footing pressure in order to assess the load dispersion angle over the soil layer. The predicted load dispersion angle could be used to estimate the bearing capacity factors of the soil layer with increases in footing deformation.

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