ABSTRACT: Bamboo is used as reinforcement in soil mainly to stabilize slopes or river banks or to support roads. Now a days treated and untreated bamboo is used along with other materials such as bitumen, geotextile etc in soft soil reinforcement. The present study attempts to review the behaviour of bamboo reinforcing elements under different loading conditions as well as in different structures. The foundation settlement of bamboo mats placed on mud deposit of break waters in Selangor, Malaysia indicated the maximum total settlement was limited to 15 cm in 2 years. No differential settlement was there in break waters which shows the integrity of the foundation mats. Laterite soil reinforced with bamboo plates placed in different layers subjected to various tests gives that the dry density of the molded specimens decreases with number of bamboo specimens. The unconfined compressive strength and modulus of rigidity increased with number of specimens. Case studies in Kualalumpur and Kuching in Malaya reveal that the bamboo mattresses along with nonwoven needle punched geotextiles increases the bearing capacity of soft sub grade and also serves as a good separator. A detailed review of the bamboo reinforced soil has been carried out in this paper.

INTRODUCTION
Reinforced earth technique has been gaining popularity in the field of civil engineering due to its highly versatile and flexible nature. It has been used in the construction of retaining walls, embankments, earth dams, foundation beds for heavy structures on soft grounds, viaduct bridges and other applications. Reinforced earth can be defined as a construction material composed primarily of soil whose performance has been improved by the introduction of small quantities of other materials in the form of solid plates or fibers or fibrous membranes to resist tensile forces and interact with soil through friction and/or adhesion [9].

Sustainable construction materials that can be inexpensively provided in bulk and simple techniques of construction are two most important aspects of a cost-effective approach that could be practical and affordable for local stakeholders and authorities. Bamboo is such a sustainable material harvested from renewable natural resources. Reinforcement of soils with natural and synthetic fibers is potentially an effective technique for increasing soil strength. The growing interest in utilizing natural materials in civil engineering applications has opened the possibility of constructing reinforced soil structure with bamboo. Bamboo, a perennial grass, belonging to the class monocotyledoneae, exists abundantly in tropical, subtropical and temperate zones of the world and have been mentioned by [5] as a potential material for reinforced earth. More than 10 million tones of bamboo are produced annually with most coming from Asia [11]. Studies have shown that bamboo posses high tensile and compressive strength and have been used as reinforcement in concrete especially when it is properly seasoned and have lasted more than 3 years [10], [13] and [12].

The aim of this paper is to carry out a review of experiments conducted in different types of soil reinforced with bamboo in different forms.

BAMBOO AS SOIL REINFORCEMENT
Among plants, bamboo has a unique structure which resembles that of a unidirectional, fiber-reinforced composite with many nodes along its length. The reinforcing fibers are orient ed along the bamboo's culm (trunk), whereas in the nodes the fibers become entangled in a complicated manner to produce nodes with isotropic properties that provide additional reinforcement for the culm. The axial strength of the bamboo's culm, specimens in the form of thin slices cut out from various locations along the culm's radius in the inner region is about 80GPa and increases parabolically with radial distance, reaching its maximum value in the outer region [6]. The fiber strength is about 600MPa which is 12 times higher than the matrix strength.

They studied the performance of reinforced gravel subbase layer with different materials, such as Bitumen Coated Bamboo Mesh (BCBM), Waste Plastics (WP) and Waste Tyre Rubber (WTR) in model flexible pavement construction laid on expansive soil subgrades. Cyclic load tests were carried out by placing a circular metal plate directly on the flexible pavement laid on expansive subgrades. The load carrying capacity was substantially increased for reinforced BCBM, which exhibits high load carrying capacity followed by WP and WTR stretches.

Alhaji Mohammed Mustapha (2010)
In this research lateritic soil reinforced with bamboo specimen were tested in the laboratory. The bamboo specimens were cutted and trimmed into a circular plate of
34mm diameter and 3mm thickness. The smooth surface of the bamboo specimens was roughened to increase the friction between the specimen and the soil. The specimens were prepared in four forms one without bamboo and others with 1, 2 and 3 bamboos.

**Unconfined compressive strength (UCS)**
The UCS increased with increase in the number of bamboo specimens as shown in figure 1 below. The value increased from 226kN/m² at 0 bamboos to 621kN/m² at 3 bamboo specimens. This is explained as due to the friction between the soil sample and the rough surface of the bamboo specimen.

![Fig. 1 Variation of UCS with the number of bamboo specimens (Source: Mustapha, 2008)](image1)

**Dry Densities**
The value of the molded dry densities decreases from 1.638Mg/m³ at 0 bamboo specimens to 1.470Mg/m³ at 3 bamboo specimens. This is explained as due to low specific gravity bamboo that substitutes a high specific gravity soil sample. The variation of the molded dry densities for UCS specimens is shown in figure 2 below.

![Fig. 2 Change in dry density with number of bamboo specimen (Source: Mustapha, 2008)](image2)

**Modulus of Rigidity**
The modulus of rigidity values increased with increase in the number of bamboo specimens. The variation of the modulus of rigidity at 0.5, 1.0 and 1.5% with the number of bamboo specimens are shown in figures 3.

![Fig. 3 Variation of modulus of rigidity with No. of Bamboo specimen (Source: Mustapha, 2008)](image3)

**Babak Kamali and Roslan Hashim (2010)**
In this study, bamboo culms which were strong, light weight and durable was used to make foundation mats. Rubble mound break water was constructed with bamboo mats placed on the sea floor first, and the gabion baskets were set up on the mats and filled with stones. The armour units were placed on the sea ward side of the structure to form the seaward slope. The armour units were granite quarry rocks.

Field monitoring was conducted quarterly for 2 years just after completion of construction to investigate the foundation settlement. The maximum total settlement was limited to 15.0 cm, no settlement was observed after 16 months after completion of construction which indicates the primary settlement was completed by that time. No differential settlement was observed in the breakwater which shows the integrity of the foundation mats.

In this study, laboratory pullout tests were used to investigate the bond coefficient of bamboo reinforcement embedded in weathered Bangkok clay to compare the pullout resistance of the reinforcement with or without transverse members.

Three pullout tests were done in each test setup The applied normal pressures for each of the three series were: 10, 30, 50; 50, 70, 90 and 90,110, 130 kPa, respectively. Four large scale direct shear test were made in each setup with applied normal pressures of 10, 50, 90,130 kPa. The pullout rate and the direct shear rate of 1mm/min were adopted for all tests. Figure 4 show typical pullout resistance curve for bamboo at applied normal pressure of 10, 50 and 90 kPa.

In this study onsite load test was carried out against the bamboo net with every different binding material and interval of bamboo net to evaluate the stress per condition deformation behaviour. Maximum load of bamboo net was measured to be in the range of 2.10 kN -11.02 kN depending on its interval, showing bigger maximum load at
shorter interval—the typical tendency, when the displacement was in the range of 181mm-604mm.

**Fig. 4** Pullout resistance curves for bamboo grid (20 mm bar width, 152 mm x 225 mm mesh) (Source: Bergado et al., 2008)

In the test under the same interval of bamboo net (1.0x1.0m) but with different binding material used for the joint, it was measured to be 3.66kN, 268 kN and 2.10 kN in case of steel wire, tie cable and polypropylene band showing less binding force, resulted from the area jointed with bamboo member getting loose at the time of loading.

**CASE HISTORY**

**Case 1**
The first geotextile-bamboo construction was stabilisation and reclamation of 30000m$^2$ slime pond at Sungei Besi, Kuala Lumpur, Malaysia in 1991. The thickness of slime was about 20m with undisturbed vane shear strength of about 5 kPa the geotextile used was nonwoven continuous filament needle punched with tensile strength of only 18kN/m and elongation at break of 50-80%. Approximately 3000 m$^2$ of geotextiles with bamboo fascine mattress was laid in a 10 h working day.

To facilitate geotextile installation, bamboo rods were laid and tied in crisscross direction to form a safe working platform. The geotextiles were unrolled over the bamboo mattress and adjacent panels of geotextiles were sewn with flat seam using a portable hand sewing machine. The designed initial fill thickness of about 500 mm was adopted and this thickness was maintained throughout the filling process. To minimise mud wave, berms were constructed along the edges of the geotextile to anchor the geotextile in place. Once the required level of fill placement was reached, prefabricated vertical drains were installed and surcharge load applied for foundation soil treatment.

**Case 2**

This case history is given to illustrate the importance of UV stabilised geotextile in local construction situation. Earth filling operations of geotextile bamboo fascine mattress over peat at 5km ring road, Kuching, Malaysia Delay in the commencement of earthwork resulted in the geotextiles resulted in the geotextiles being exposed to direct sunlight for about 3 months. Tensile test were carried out on the geotextile to determine the residual strength after exposure. The test results showed high retention of tensile strength in the geotextile (>90%) [7]. This retention was attributed to the UV stabilizer added to mitigate UV degradation effects. An initial sand fill of 300mm was placed over the geotextile-bamboo fascine before placement of compacted residual fill. Minimal heave was reported throughout the filling process.

**CONCLUSIONS**

Based on the literature study on the behaviour of bamboo as a reinforcing material in soil it can be summarised as follows.

1. Bamboo is a structurally smart plant having fiber strength as 600 Mpa.
2. UCS value increased tremendously with inclusion of bamboo. The percentage increase in UCS value is 175% compared with the unreinforced soil.
3. The dry density value decreases with the inclusion of bamboo. Percentage decrease is 11%.
4. The modulus of rigidity values increased with increase in the number of bamboo specimens.
5. The maximum total settlement of rubble mound break water reinforced with bamboo mat was limited to 15 cm and there was no differential settlement.
6. Case histories reveal that the geotextile bamboo composite construction has been successfully used for stabilization and reclamation of deep soft soils.

**REFERENCES**


