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Assessment of Flexural Strengths and Flexural Load Bearing Capacity of Bamboo Grids-Reinforced Soil Beam

ONYIA, ME; *OLE, SO

Department of Civil Engineering, University of Nigeria, Nsukka, Enugu State, Nigeria

**Corresponding Author Email: Solomon.ole.pg80762@unn.edu.ng*
Co-Authors Email: michael.onyia@unn.edu.ng

ABSTRACT: Soil improvement techniques have become a major solution to soil related problems. Thus, this paper aims to determine the flexural strengths and flexural load bearing capacity of bamboo grids-reinforced soil beam using standard methods and experiments at 7 days, 14 days, 21 days and, 28 days curing ages. The findings of this study showed that the mean flexural strength of uniaxial bamboo grid reinforced soil beam gave 3.50 N/mm² while flexural strength of biaxial bamboo grid reinforced soil beam gave 3.86 N/mm². The result indicates that biaxial bamboo reinforced soil beam has the tendency to maximize the flexural load bearing capacity of soil beams when compared with the use of uniaxial bamboo grid orientation technique. This paper, therefore, recommends that flexural strength and flexural load bearing capacity of inorganic clays of low to medium plasticity should be improved using biaxial grid type of bamboo grid orientation technique.

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It has never been safe to construct on clay soil because of their swell-shrink characteristics. Clay soils exhibit strange behaviour, they shrink when dry and swell when wet, damages can occur at a long duration after construction due to volume changes (Wagner, 2013). The need to improve the soil characteristics on the site such that to mitigate the menace found on earth structures, multilayer pavements and foundations as a result of differential settlement has always been civil engineering priority. The techniques to improve the engineering characteristics of soil with tensile components like strips or metal rods, non-biodegradables fabrics like granular materials, geotextiles and green natural materials such as jute, bakau or bamboo; or by little introduction of other materials in form of fibers or fibrous membrane or solid plates to resist tensile forces and interact with soil through adhesion or friction were discussed by (Das, 2004; Hejazi *et al*, 2011). Like concrete, bamboo can be introduced as reinforcement in soil, mainly to support roads, or to stabilize riverbanks or slopes (Janseen, 2000). To improve the soil characteristics and its load bearing capacity in the ancient time was done by mixing straw with mud, reinforcing with woven reeds, branches of tree and other plant materials; while the modern form of soil reinforcement was introduced by Henri Vidal in the early 1960s for constructing a retaining wall (Peter, 2015). Henri constructed the walls using galvanized steel strips with ribs to provide lateral resistance against earth pressures which is referred to as mechanically stabilized earth (MSE). Techniques for improving the mechanical and engineering characteristics of soil were broadly classified by (Saran, 2005) into five categories, such as, Soil stabilization, Reinforced soil, Soil nailing, Texsol and Fiber reinforced soil or ply soil. Douglas (1990) showed how bamboo can be used in soil reinforcement. Though, the introduction of

**Corresponding Author Email: Solomon.ole.pg80762@unn.edu.ng*

bamboo in the construction of soil structures like retaining walls and embankments can be examined. Douglas (1990); Hegde and Sitharam (2014) pointed out that current information about polymeric material provides a passage into bamboo related geotechnical research. According to Anjan (2019), the introduction of reinforcement (geosynthetic) in soil mass absorbs the tensile loads or shear stresses within the structure and its failure due to excessive deformation or shear is thus prevented. As regards to their tensile strength in different directions, Geogrids can be uniaxial or biaxial.

Flexural behaviour of soil beams was investigated by some researchers and their findings showed that the failure of soil beams in flexure is brittle and at failure or cracking the tensile strain is a small fraction of the compressive strain (Gaind and Char, 1983). Gaind and Char (1983) found that tensile strains as a result of flexure occur in earth structures such as dams, multi-layer pavements and embankments. It would be advantageous if soil behaviour in tension is improved, since it is weak in tension and cracks occur under small tensile stresses. Gaind and Char (1983) investigation was geared towards the improvement of soil behaviour in flexure due to the introduction of reinforcement. In connection with compacted fine-grained clayey soil layer subjected to flexural condition as a result of differential settlement, soil beam tests more closely represent the tensile behaviour found in the field (Viswanadham *et al*, 2010; Ajaz and Parry, 1975). (Viswanadham *et al*, 2010) reported that several researchers have maintained a ratio of length to depth and length to width in the range of 4 to 5. Flexure test on soil shows how vulnerability of various soils to flexural cracking and also the effect of vulnerability on the moulding moisture content. The load bearing capacity of a soil can be increased when bamboo reinforcement is placed within the depth of the failure envelope (Asaduzzaman and Islam, 2014). This study therefore assessed experimentally and statistically the bamboo grid reinforcement techniques that improve the soil beam flexural strength and flexural load bearing capacity maximally.

MATERIALS AND METHODS

Materials: The materials were Clay soil; Potable water and Bamboo (strips), etc.

Soil sample: The soil sample used for this study was collected at Hilltop, behind Holy Trinity Parish, Catholic Church, Nsukka, Enugu State, Nigeria, where there is an existing borrow pit at a depth of 400mm. The soil sample was air-dried before use.

Bamboo reinforcement: The fresh green bamboo culms used for this study were purchased from timber shed, Nsukka, Enugu state, Nigeria. The fresh green bamboo culms were split into strips of various sizes, then treated using diffusion method of treatment. For the uniaxial orientation technique, the culm was split into long direction, specified thickness is as follows 500mm x 10mm x 10mm (length × width × depth) while 5 bamboo strips were placed at each layer at the distance of 10mm apart to each other. Whereas, for the biaxial orientation technique, the bamboo culm was split into two different directions, that is, long direction and short direction. Both long and short directions were tied with annealed steel wire of thickness 1mm at every intersection to make the reinforcements rigid so that they do not get displaced during deposition of the soil specimen. For the short direction, the specified dimension is as follows 80mm x 10mm x 10mm (length × width × depth) while for the long direction, the dimension is as follows 500mm x 10mm x 10mm (length × width × depth). Both short and long directions where tied at the dimension of 57mm apart to each other for 8 bamboo strips while 25mm apart to each other for 3 bamboo strips, at the intersections, respectively. Preservative such as chromate-copper-arsenate (CCA) was used for the treatment of the bamboo strips in the proportion of 4:3:1. The bamboo grid reinforcement frameworks are shown in Fig. 1 and Fig. 2.

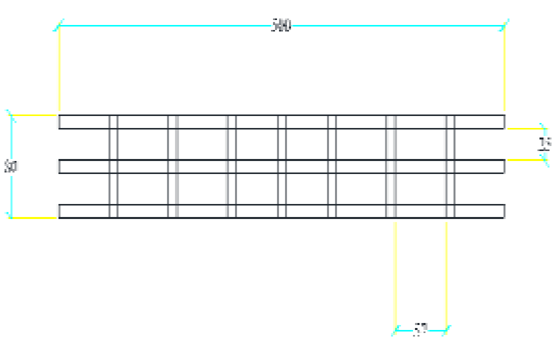

Fig. 1. Biaxial bamboo grid framework

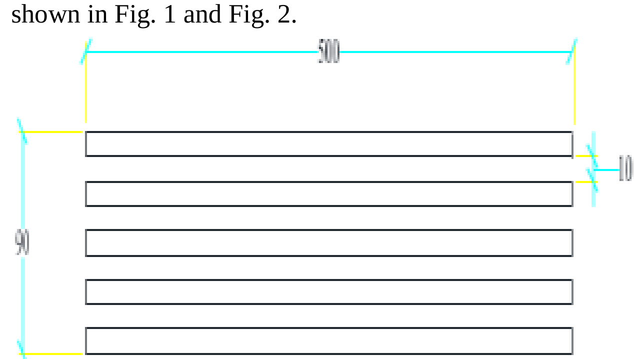

Fig. 2. Uniaxial bamboo grid framework

Methods: This section gives an elaborate description of the materials and methods employed for the purpose of this present study, the experiments performed to determine both mechanical and physical properties of the materials used and the flexural test determination. The properties of the soil were tested by applying the techniques described in BS 1377 – 1990 (British Standard Methods of Tests for Soils for Civil Engineering Purposes), the bamboo strips were treated by applying the Indian Standard (IS 401, 2001; IS 9096,1976), the reinforced soil beam test conducted under flexure conforms with (ASTM C78/C78M-16) and the soil beam was prepared according to the methods employed by (Gaind and Char. 1983; Vivi *et al*. 2017). All the laboratory experiments performed in this study were carried out at Soil and Structural laboratories of Civil Engineering, University of Nigeria, Nsukka.

Specimen preparation and Test procedure: To prepare the specimen, moisture content closer to the optimum moisture content (OMC) was used to mix the soil specimens, then stored for 24 hours in a closed container for proper hydration. Each specimen prepared with a unique moisture content was compacted in four layers. From simulation studies as was observed by (Gaind and Char, 1983) that the rammer and height of drop used gave 95% of Standard Proctor compaction. Briefly, equivalent of the compaction effort used by (Gaind and Char, 1983) expressed in Eqn. 2 was replicated in this study. 52 blows for each layer of compaction was adopted for this present study. However, a control specimen of the soil beam was prepared without reinforcement, using the same moisture content for the soil beam mix. The bamboo grids (uniaxial orientation and biaxial orientation) reinforcements were placed at each layer, at interval spacing, in the soil beam horizontally. For uniaxial orientation technique, 5mm was provided for soil specimen cover at all the edges before compaction, while for the biaxial orientation technique, 10mm was provided for soil specimen cover at the long direction edges. The conditions of the bamboo strips were kept constant (air-dried, chemically treated and at constant length). A customized flexural test beam setup of dimensions 510mm x 100mm x 100mm (length × width × depth) were used to make the soil beam.

Compaction of the specimen was carried out using 4.5kg rammer, falling freely from a height of 450mm and compacted in four layers. The specimen was removed from the mould after 24 hours of compaction, weigh the specimen and wrap it with plastic bags (curing process) for 7 days, 14 days, 21 days and 28 days prior to the test date. The specimens were each placed under third-point loading on a flexural testing machine as shown in the Fig. 3 for flexural strength and flexural load bearing capacity determination.

Fig. 3: Specimen placed on Flexural testing machine

Calculations:
Flexural strength, FS, is expressed as shown below. If the crack initiates in the tension surface within one-third of the span length, flexural strength can be calculated as thus (ASTM C78/C78M-16):

$$\mathrm{FS} = \frac{\mathrm{PL}}{\mathrm{bd}^2} \qquad (1)$$

Where FS is Flexural strength (N/mm^2), P is Maximum applied load indicated by the flexural testing machine (N), L is Span length (400 mm), b is Width of the specimen (100 mm) and d is Depth of the specimen (100 mm).
Compaction effort,CE, in an impact compaction test is expressed as thus (Das, 2014):

$$\mathrm{CE} = \frac{h \times w \times N_L \times N_b}{V} \qquad (2)$$

Where CE= Compaction effort ($KN\text{-}m/m^3$), h is Drop of hammer (mm), w is Weight of hammer (Kg), N_L is Number of layers andN_b is Number of blows.

RESULTS AND DISCUSSIONS

Experimental analysis: Summary of some specific properties of soil sample used in this study are listed as follows: Specific gravity (G_s) = 2.21, Liquid limit (W_l) = 39.25%, Plastic limit (W_p) = 18%, Plasticity index (I_p) = 21.25%, Optimum moisture content

(OMC) = 21.43%, Maximum dry density (MDD) = 1.73 g/cm^3 and Soil classification = CL. On the plasticity chart, the Atterberg limit plot falls above the A-line, that is, the soil is inorganic clays of low to medium plasticity. The physical properties of the fresh green bamboo strips used for this study are as follow: flexural strength of the bamboo strip was found to be 25.699 N/mm^2, the tensile strength was found to be 127.47 N/mm and the modulus of elasticity (MOE) was found to be 523.334 N/mm. The results obtained from the physical test investigation on the fresh green bamboo strips, which is relatively high, makes it attractive in tensile loading application according to (Ghavami, 1995).For simplicity, summary of the results obtained from the soil beam types investigation for unreinforced, uniaxial and biaxial orientation techniques are presented on Table 1 while the charts are plotted in the subsequent pages.

Table 1: Soil Beam Test Results (Average)

Age of Soil Beam (Days)	**Soil Beam Type**	**Weight of Beam Before Curing (Kg)**	**Weight of Beam after Curing (Kg)**	**Flexural Force (Load) (N)**	**Flexural Strength (N/Mm²)**
	Unreinforced	10.12	9.97	573.00	0.229
7	Biaxial	9.65	9.57	1337.50	0.535
7	Uniaxial	9.63	9.56	1329.80	0.532
14	Biaxial	9.64	9.53	1925.25	0.770
14	Uniaxial	9.64	9.50	1830.00	0. 732
21	Biaxial	9.62	9.45	2061.15	0.825
21	Uniaxial	9.63	9.44	2049.85	0.820
28	Biaxial	9.63	9.40	2020.00	0.808
28	Uniaxial	9.64	9.40	2000.00	0.800

Flexural force, Flexural strength and Age of beam (days): Flexural force (P) is regarded as the maximum applied force (load) indicated by the flexural testing machine specimen ASTM C78/C78M-16. The charts in Fig. 4 and Fig. 5 describe the relationship between flexural force, flexural strength and age of the reinforced soil beams. The maximum flexural force and flexural strength occurred at 21 days before decreasing or losing of strength at 28 days for both bamboo grid orientation techniques as a result of moisture content present and crack formations on surfaces or edges of the soil beams (Thusyanthan *et al*, 2007). For all the soil beam types, the biaxial bamboo grid orientation technique gave a higher flexural force (load) and flexural strength values when compared with uniaxial bamboo grid orientation technique as the day progresses.

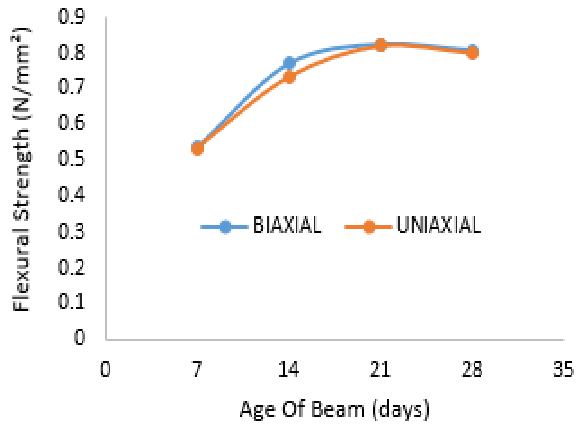

Fig. 4: Flexural strength characteristics of bamboo grids reinforced soil beam with respect to age of soil beam.

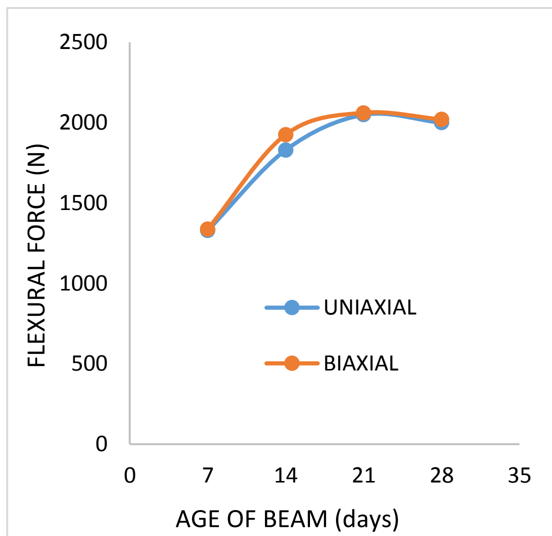

Fig 5: Flexural force (load) characteristics of bamboo grids reinforced soil beam with respect to age of soil beam.

On the charts, the control (unreinforced) soil beam type gave the least flexural force and strength values. From the flexural force and flexural strength results obtained, it can be found that the introduction of bamboo grid orientation techniques improved the flexural load bearing capacity and the ductility of the soil beams (Gaind and Char, 1983; Chaudhari and Char, 1985). It can be found that the soil beams of bamboo grid biaxial reinforcement orientation technique resisted more load than the uniaxial reinforcement orientation technique, and the biaxial reinforcement helps in distributing forces over a large area by reducing shear failure and maximizing the flexural force (load) bearing capacity of the soil beams (Kariuki *et al*, 2014).The tensile stress failure due to crack formation, even at the point of vulnerability, that tries to reduce the mass strength of the soil beams, at 28 days, were enhanced using bamboo grid orientation techniques to reduce the effect of crack formations on the soil beams. The introduction of the bamboo grid biaxial soil beam type showed a better flexural force (load) bearing capacity resistance than the uniaxial orientation and the unreinforced soil beam type. Improvement on the load bearing capacity of the soil as a result of introduction of reinforcement has been discussed by (Das, 2004; Hejazi *et al*, 2011), which are in line with the result discussions of this study.

Statistical analysis: The statistical analysis was performed using Statistical Package for the Social Sciences (SPSS) software. A Cornbrash's alpha reliability test as shown in Table 2 was conducted on bamboo grid (uniaxial and biaxial) orientation techniques to assess if bamboo grid can be used to improve the flexural strength and flexural load bearing capacity of a soil beam. The result gave an overall reliability index of 0.96 which shows that the use of bamboo grids to enhance the flexural strength of soil beam is highly feasible.

Table 2: Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N
0.960	0.960	2

Where N is the number of items, X is the mean, S.D is the standard deviation, SIG is the significance and S/N is the serial number.

Hypothesis 1 (HO 1): There is no significant mean difference between the load bearing capacity of beams reinforced uniaxially and those reinforced biaxially using bamboo.

Table 3: Summary of the Statistics Item Result

S/N	Soil Beams Reinforced With Bamboo Grid Improves The Following:	X	S.D	Decision
1	Flexural strengths of the soil beam (N/mm^2)	3.33	1.33	Agree
2	Flexural force (loads) of the soil beam (N)	3.28	1.41	Agree

The summary of the statistics item result is shown in Table 3. Table 3 shows that flexural strengths and flexural loads have means of 3.33 N/mm^2 and 3.28 N, respectively, which is above the decision rule of the 5-point Likert scale set for this study. It therefore implies that soil beams reinforced with bamboo of either grids orientation technique improves the load bearing capacity and flexural strength of any soil beam. Note that the decision rule implies that any means above 2.5 should be accepted otherwise reject.

Table 4 shows a T-test with a significant value of 0.273 which is greater than (0.05) level of significant set for this study. The null hypothesis of no difference is therefore not rejected. The result indicates that there is no significant mean difference between the load bearing capacity of soil beams reinforced with biaxial grid orientation and those reinforced with uniaxial grid orientation using bamboo-grids reinforcement. The result elicited from the Independent Samples T-Test shows that soil beams reinforced with biaxial grid orientation technique produces higher flexural strengths when compared with those reinforced using uniaxial orientation technique. The observed mean and flexural strength differences between the two categories occurred by chance according to Table 4.

Table 4: Independent Samples T-Test

Reinforced Soil Beam Type	n	x	Sig.	Decision
Uniaxial reinforced	8	3.50		
Biaxial reinforced	8	3.86	0.273	Do not reject HO 1

Conclusion: It is evident from this study that the introduction of bamboo grids in both biaxial and uniaxial orientation techniques can be used to improve and maximize the flexural strength and flexural load bearing capacity properties of inorganic clays of low to medium plasticity.

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