# Potentials of Nigerian Bamboos for Use as Soil Reinforcement

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## Abstract

Five bamboo samples taken from five different villages in Lapai Local Government of Niger State were tested for compression, bending and tension. One of the bamboos was then used as reinforcement in a clay soil, to evaluate its effect on the bearing capacity of the soil. It was observed that, though, the bending strength and compressive strength of the tested bamboos are lower than that of other bamboos studied from other part of the world, their tensile strength compete favorably with those of the others reported in literature. The clay soil used in the study classified under A-7-6 subgroup according to AASHTO soil classification system and based on mineralogical test result, contains mainly kaolinite as clay mineral. The bearing capacity was found to increase from 435 kN/m$^2$ at 0 layer to 600 kN/m$^2$ at 2 layers of the bamboo reinforcement, after which the values reduced to 4395 kN/m$^2$ at 5 layers. Two layers of the bamboo reinforcement is therefore the number of layers that gave effective soil reinforcement in the studied clay soil.

## Keywords

Bamboo, bearing capacity, load–settlement characteristics, soil reinforcement

## 1. Introduction and Concept

Bamboo is a nickname used for a particular group of large woody grasses and belongs to the family the Andropogoneae and subfamily Bambusoideae (Scurlock *et al.* 2000). Bamboos exist in more than 1250 species most of which are fast growing, attaining stand maturity within five years. Even though few dwarf species exists which can grow to as little as 10 cm in height, most bamboo species can grow up to 15 to 40m high. According to Timothy (2015) and Panda (2011), bamboo is one of the fastest growing grasses, with growth rate of between 3 to 250 cm per day, depending on the species, climate condition and the soil condition. Bamboo is use by about 2.5 billion people across Asia (Scurlock et al., 2000).

Bamboo is wide-spread in Nigeria especially in south and middle belt states. According to (RMRDC, 2004a), bamboo is more than 10% of the natural vegetation in the south-southern states, 6-9% in the south-western states, 3-5.9% in the middle belt states and less than 3% in the northern states. It has advantage of high resistance to fire due to high silica acid, high elasticity and light weight (Klaus, 2002). According to Atanda (2015), bamboos in Nigeria are environmentally friendly and can be used to substitute wood and steel reinforcement. This will go a long way to reducing deforestation and improve environment in the country. Bamboo has advantage of being very durable and elastic. It was observed to give a tensile strength of as high as 125 MPa and can be used for culinary, paper, instruments and construction (Rottke, 2002).

A lot of soft soil deposits occur in Nigeria. The ability to place heavy structures on such soils has always proved difficult. This is because the technology of pre-consolidation with vertical drains, and use of modern geo-membranes are difficult and expensive, especially for a third world country like Nigeria. There is therefore the need for a cheaper and readily accessible technology to reduce the cost of constructing structures on these types of soils. Meanwhile, most research on bamboos has been carried out on the species in Asian countries, with a little done, using Nigerian bamboo. This study is therefore, intended to evaluate the strength properties of some selected bamboo samples in Nigeria and use one of the selected samples as soil reinforcement, which would be evaluated using small scale laboratory load bearing test.

## 2. Relevant Literature

A lot of work has been done on the use of various fibers as reinforcement in soils (Ayyar, et al., 1988; Gray and Al-Refeai, 1986; Hirao et al., 1992; McGown, 1977; Narayana, 1988; Maheshwari, et al., 2013). Sayyed (2011) reviewed both natural and synthetic fibers that have been employed for soil reinforcement. The author listed bamboo among other fibers as having high potential for use as soil reinforcement due to its resistant to attack by pests and bacteria. Francis and Paul (1966) had earlier highlighted some features to be considered for selection and preparation of bamboo for structural purposes. The researcher advised that only bamboos showing pronounced brown color should be selected since that will ensure that the bamboo is at least three years old. The longest large diameter culm should also be selected and must be seasoned for at least 3 – 4 weeks. The authors also reported that splints bamboo (split culm) are more desirable as reinforcement than the whole culm.

Mustapha (2008) studied the potential use of bamboo as soil reinforcement. A circular bamboo specimen of 34mm diameter was arranged in layers in a soil specimen of 38mm diameter and 76mm height. The soil specimen, containing the bamboo reinforcement was evaluated using unconfined compressive strength. Increase in stress was observed from 226 kN/m$^2$ at 0 layer of bamboo to 621 kN/m$^2$ at 3 layers.

Marto and Uthman (2011) studied 3 trial embankments on soft clay using hydrostatic profiler for settlement and inclinator for lateral movement. The first embankment was reinforced with Bamboo-Geotextile Composite (BGC), the second with High Strength Geotextile (HSG) and third one was an Unreinforced (UR) embankment. Each of these embankments was 10m long, 16m wide and about 3m high. The average moisture content of the bamboo was observed to be 20%, bending stress was 48.75 MPa, while the tensile stress was 93.55 MPa. The result of the study showed that the UR embankment gave maximum settlement of 744mm, while the (BGC) embankment gave maximum settlement of 588mm. The maximum lateral movement occurred at 4.5m depth. At this depth, BGC embankment recorded lateral movement of 9.4mm while the UR embankment recorded 13.6mm. It was therefore concluded that BGC composite reinforced embankment performed better than both the HSG and UR embankments, hence bamboo has the potential to serve as soil reinforcement.

Rolt (2008) reported range of tensile strength for bamboos between 75 and 350 MPa, poisons ratio of between 0.25 and 0.41 and modulus of elasticity ranging from 10,000 to 28000. Typical values were observed to be 130 MPa, 0.32 and 18000 for tensile strength, poison ratio and modulus of elasticity respectively. The behavior of bamboo reinforced soils was reviewed by Anusha and Emmanuel (2011) and concluded that bamboo can serve as reinforcement in soft materials like soil.

Aazokhi (2014) work on laboratory model of a structure, founded on bamboo reinforced peat soil. The study considered a plate on peat soil only, on sandy soil only and on peat soil reinforced with 1, 2 and 3 layers of bamboo specimens. The resultant load–settlement graphs were plotted and ultimate bearing capacities were obtained. It was observed that the bamboo reinforcement increased the bearing capacity by 140% for 1 layer, 224% for 2 layers and 279% for 3 layers of reinforcement.

Endra and Fico (2015) carried out a case study on three different arrangement of a combination of gridded matrass and piles of bamboo. The first was gridded matrass and piles of bamboo, the second was matrass and piles of bamboo and the third was a group of mini piles connected by H-beams with a compacted top layer to hold the top mini piles. This was done on a full scale field experimental basis. The case studies result and full-scale field work verifications showed that the three reinforcement systems worked properly, even though, each system has its own merits and demerits in terms of construction duration, cost and effectiveness.

Charles et al. (2016) argued that the mechanism of strength development in geogrid reinforced soils depends largely on the plasticity and gradation of the soil to be reinforced. The authors compacted three different soils of varied plasticity and gradation in a mold and tested for CBR, with and without geogrid reinforcement. The result shows that as plasticity increases, CBR decreases. Similarly, as proportion of course aggregate in soil sample increases, CBR increases.

Bamboo has also been considered as reinforcement in concretes especially rigid pavement concretes. Nindyawati and Baiq (2016) studied the potential of bamboo as reinforcement in light-weight concrete. The study concentrated mainly on the bonding strength of bamboo in concrete. The tensile strength of the six bamboo specimen studied ranges from 133.5 to 144.2 MPa. The pull-out strength was between 0.33 to 0.48 MPa. Based on direct tension pull-out bond test, the authors recommended bond strength reinforcement by direct tension pull-out bond test to bond strength reinforcement.

Some other fibers were tried for use as soil reinforcement to improve some geotechnical properties of soils. Akhtar et al. (2015) studied the use of jute fiber for reinforcement of sub-grade. The authors prepared the soil samples at maximum dry densities corresponding to optimum moisture content in a CBR mold with and without reinforcement. The amount of fiber, by weight of the dry soil, used for the reinforcement, was 0.3, 0.6, 0.9 and 1.2%. The length of the jute fibers considered was 15mm and 30mm, while the diameters were 4mm and 8mm. The result showed that for 15mm long fiber, the CBR increased from 5.22% at 0% fiber to 7.38% at 1.2% fiber, while for 30mm long fiber, the CBR increased from 5.22% at 0% fiber to 9.36% at 1.2% fiber. These represents 41.38% and 79.31% increase in CBR for 15mm length and 30mm length fibers respectively. Nilo et al. (2002), worked on the possible use of plastic waste fiber to reinforced sand soils with and without addition of cement. The plastic fiber was obtained from recycling waste plastic bottles. The separate and joint effect of fiber and cement were studied using experimental design and multiple regression analysis. The result showed marked increase in the stiffness and peak strength and change the soil behavior from ductile to brittle. Extensive study was also carried out by Philipus and Hairulla (2016) on the possible use of bus wood as soil reinforcement. The author used a model laboratory experiment on soft clay, reinforced with the bus wood at varied layers. Load–settlement test was conducted on the soft soils, reinforced with the bus wood at varied depths. The moisture content of the bus wood was observed to be 21.58%, the tensile strength was 18.51 MPa, while the bending strength was 5.0 MPa. The results showed marked decrease in settlement with increase in the bus wood reinforcement.

## 3. Materials and Methodology

The materials used for this research are five bamboos, collected from five different places in Lapai Local Government Area of Niger State, Nigeria. Strength properties tests were carried out on specimens collected from each of the five bamboos. The bamboos were reduced to splint as recommended by Francis and Paul (1966), and tested for tensile and compressive strengths (Figure 1 and 2). The tests were carried out in National Centre for Agricultural Mechanization (NCAM), Ilorin, Kwara State, Nigeria.

Figure 1: Bamboo culm in compression

Figure 2: Bamboo splint in tension

A reddish fine lateritic soil collected from a borrow pit along Birgi-Lapai Gwari road in Minna, Niger State, Nigeria, was prepared using the method of disturbed sampling. The sample was air-dried and prepared according the procedure highlighted in part 1 of BS 1377 (1992). X–Ray diffraction (XRD) test was carried out on the lateritic fine to determine the nature of the minerals contained in the soil sample. Index properties test and compaction tests were carried out on the soil based on the specifications highlighted in BS 1377 (1997), to characterize the soil and obtain compaction characteristics (Maximum Dry Density-MDD and Optimum Moisture Content-OMC) to be used in molding specimens for load-bearing tests.

The bamboos were formed into small strands of averagely 1.5mm thickness (Holtz, 2001) and netted into 20mm rectangular apertures, and the resulting net cut to form 148mm diameter (Figure 3). The number of blows required to achieve standard proctor compaction in the test tank (CBR mold) was recalculated and the number of layers readjusted to six layers instead of the normal five layers. This was to allowed placement of the bamboo reinforcement in five layers (Figure 4). The first load-settlement test was carried out on the unreinforced compacted soil base at predetermined moisture content. The second test was on a similar compaction energy level and the same predetermined moisture content, but with one reinforcement layer placed after the fifth layer of compaction. In the third load–settlement test, one bamboo reinforcement layer each was placed after the fourth and fifth compaction layers. This process was continued down to the fifth reinforcement layer.

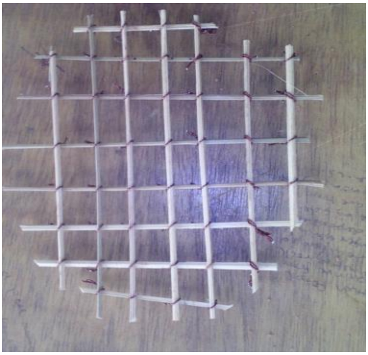

Figure 3: A typical layer of the bamboo reinforcement

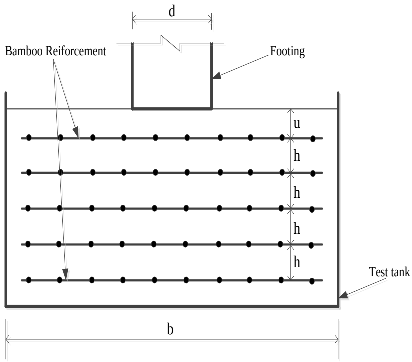


Figure 4: Arrangement of layers the bamboo reinforcement

In modeling the bases, the clay soil was compacted in the mold at predetermined MDD and OMC with inclusion of the bamboo nets (reinforcement). In accordance with the studies on reinforced soil bases, by Binquet and Lee (1975), Guido et al. (1986), Khing et al. (1992), Puri et al. (2009) and Alhassan and Boiko (2013), u/d and h/d (u is depth of the first layer of reinforcement from the foundation base, h is the vertical spacing of the reinforcement layers and d is the diameter of footing) were both kept below 0.65 for the arrangement of reinforcement layers under all the respective foundation base models. In this regards, and with a footing plate of 38mm diameter, used to transfer the load to the compacted soil, the bamboo reinforcements were inserted at vertical spacing of 21.2mm within the molded base, which gave u/d and h/d of 0.56. Considering the diameter of the test tank, 38mm diameter footing was chose so as be in agreement with b/d = 4 (b is width of the base surface), as recommended by Puri et al. (2009). The load-settlement test was carried out on the modeled bases at unsoaked condition.

# 4. Results and Discussions

## 4.1 Bamboo Strength

The result of the strength properties of the bamboos are shown on Table 1 to 3. The tensile strength test was carried out on a bamboo splint of width 8.00mm and thickness of 8.00mm.

The compression test on the five bamboo specimen showed that the compressive strength at peak ranges from 10.5 to 38.0 N/mm$^2$, with mean value of 26.0 N/mm$^2$ and standard deviation of 12.2 N/mm$^2$. The bending strength of the five bamboo specimens, studied ranges from 2.64 N/mm$^2$ to 11.62N/mm$^2$. These values are lower than the bending stress of 48.75 N/mm$^2$, reported by Marto and Uthman (2011). This may be attributed to the higher length of the bamboo culm used. The bending modulus of the specimen ranges from 60.97 to 464.21 N/mm$^2$, while the tensile strength of the bamboo splint used, ranges from 92.75 to 134.42 N/mm$^2$.

These values are within the range, observed by Rolt (2008), Marto and Uthman (2011), Rottke (2002), but slightly lower than the values recorded by Nindyawati and Baiq (2016).

Table 1 Result of compression test on the bamboo culm

| Test No. | Inner Diameter (mm) | Outer Diameter (mm) | Pipe Length (mm) | Force at peak (N) | Force at Yield (N) | Force at Break (N) |
|---|---|---|---|---|---|---|
| 1 | 62.8 | 82.8 | 410.0 | 86830 | 78960 | 66450 |
| 2 | 75.3 | 94.6 | 450.0 | 45060 | 45060 | 45060 |
| 3 | 44.5 | 77.0 | 335.0 | 97250 | 97250 | 97250 |
| 4 | 60.8 | 74.8 | 470.0 | 48620 | 47070 | 40250 |
| 5 | 77.5 | 97.8 | 370.0 | 29450 | 29450 | 29450 |
| Min | 44.5 | 74.8 | 335.0 | 29450 | 29450 | 29450 |
| Mean | 64.2 | 85.4 | 407.0 | 61442 | 59558 | 55692 |
| Max | 77.5 | 97.8 | 470.0 | 97250 | 92750 | 97250 |
| S.D | 13.2 | 10.3 | 55.6 | 29082 | 27702 | 26847 |

Table 1 contd

| Test No. | Deformation at peak (mm) | Deformation at yield (mm) | Deformation at break (mm) | Stress at peak N/mm$^2$ |
|---|---|---|---|---|
| 1 | 6.593 | 5.460 | 7.589 | 38.0 |
| 2 | 5.926 | 5.926 | 5.926 | 17.5 |
| 3 | 4.379 | 4.379 | 4.379 | 31.4 |
| 4 | 3.478 | 3.166 | 4.529 | 32.6 |
| 5 | 2.527 | 2.527 | 2.527 | 10.5 |
| Min | 2.527 | 2.527 | 2.527 | 10.5 |
| Mean | 4.581 | 4.292 | 4.990 | 26.0 |
| Max | 6.593 | 5.926 | 7.589 | 38.0 |
| S.D | 1.683 | 1.451 | 1.890 | 12.2 |

Table 2 - Result of bending test on bamboo Culm

| Test No. | Bending Strength At yield (N/mm$^2$) | Bending Strength At peak (N/mm$^2$) | Bending Strength At break (N/mm$^2$) | Bending modulus (N/mm$^2$) |
|---|---|---|---|---|
| 1 | 7.029 | 7.029 | 7.029 | 280.2 |
| 2 | 2.638 | 2.638 | 2.637 | 61.0 |
| 3 | 11.618 | 11.618 | 11.618 | 464.2 |
| 4 | 3.607 | 3.921 | 3.921 | 72.0 |
| 5 | 3.793 | 3.793 | 3.788 | 63.8 |
| Min | 2.638 | 2.638 | 2.637 | 61.0 |
| Mean | 5.737 | 5.800 | 5.798 | 188.3 |
| Max | 11.618 | 11.618 | 11.618 | 464.2 |
| S.D | 3.680 | 3.638 | 3.638 | 180.1 |

Table 2 c0ntd

| Test No. | Deformation at Yield (mm) | Deformation at peak (mm) | Transverse rupture strength (N/mm$^2$) |
|---|---|---|---|
| 1 | 3.703 | 3.703 | 7.029 |
| 2 | 6.027 | 6.027 | 2.638 |
| 3 | 4.023 | 4.023 | 11.618 |
| 4 | 9.447 | 10.971 | 3.921 |
| 5 | 9.137 | 9.137 | 3.793 |
| Min | 3.703 | 3.703 | 2.638 |
| Mean | 6.467 | 6.772 | 5.800 |
| Max | 9.447 | 10.971 | 11.618 |
| S.D | 2.730 | 3.192 | 3.637 |

Table 3- Result of Tensile test on bamboo flint

| Test No. | strain At yield (%) | Strain at break (%) | Stress at peak (N/mm$^2$) | Stress at yield (N/mm$^2$) | Stress at break (N/mm$^2$) | Young Modulus (N/mm$^2$) |
|---|---|---|---|---|---|---|
| 1 | 1.013 | 6.832 | 100.4 | 50.6 | 100.4 | 8079 |
| 2 | 1.125 | 5.615 | 99.1 | 52.4 | 96.5 | 7138 |
| 3 | 2.193 | 3.261 | 109.0 | 96.6 | 106.5 | 7075 |
| 4 | 1.533 | 10.508 | 92.8 | 44.8 | 82.3 | 4404 |
| 5 | 2.759 | 4.440 | 134.4 | 116.3 | 115.9 | 7449 |
| Min | 1.013 | 3.261 | 92.8 | 44.8 | 82.3 | 4404 |
| Mean | 1.725 | 6.131 | 107.1 | 72.1 | 100.3 | 6829 |
| Max | 2.759 | 10.508 | 134.4 | 116.3 | 115.9 | 8079 |
| S.D | 0.740 | 2.784 | 16.3 | 32.2 | 12.5 | 1413 |

## 4.2 Index and Mineralogical Properties of the Clay

The result of the index properties and compaction characteristics of the lateritic fine used for this study is shown on Table 4. The soil was compacted at Standard Proctor energy level and was observed to fall under A-7-6 subgroup according to AASHTO soil classification system. The result of the mineralogical test conducted on the lateritic soil is shown on Figure 5. The result showed predominantly Orthoclase, Osumilate and Hematite minerals. This is an indication that the clay contains predominantly kaolinite minerals.

Table 4 - Physical properties of the soil

| Description | Quantity |
|---|---|
| Gravel (%) | 0 |
| Sand (%) | 49.0 |
| Silt (%) | 43.0 |
| Clay (%) | 8.0 |
| Liquid Limit (%) | 50.0 |
| Plasticity Index (%) | 11.0 |
| Specific Gravity | 2.50 |
| Maximum Dry Density ($g/cm^3$) | 1.397 |
| Optimum Moisture Content (%) | 25.3 |
| Color | Pinkish brown clay soil |

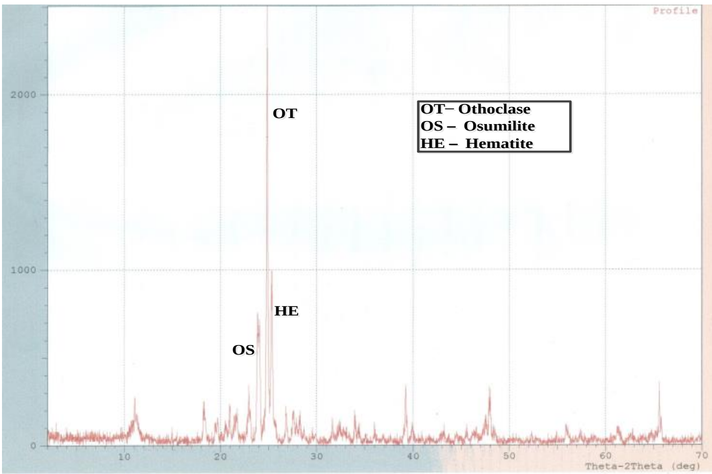


Figure 5: Result of mineralogical test on the clay soil

### 4.3 Load–Settlement Characteristics

The result of the load-settlement characteristics is shown on Figure 6. From the figure, it is possible to evaluate the effect of reinforcement on the settlement and bearing capacity of the soil bases. Studies have shown that for small-scale shallow footings, the maximum settlement at which the bearing capacity is considered allowable is taken as 10 % of the footing width (diameter) (Cerato and Lutenegger, 2007; Briaud and Jeanjean, 1994; Al-Mosawe et al. 2009; Jahanandish et al. 2010; Budhu, 2012). Thus, the maximum permissible settlement of the studied footing model was taken as 10 % of the width of the footing, which corresponds to 3.8mm settlement.

Using the maximum permissible settlement, ultimate bearing capacity of the footing at the various number of bamboo reinforcement layers were estimated (Figure 7). From the figure, it is observed that the ultimate bearing capacity of the footing increased from 435 kN/m$^2$ at 0 reinforcement layer to 600 kN/m$^2$ at 2 layers of reinforcement, after which the value decreased to 495 kN/m$^2$ at 5 layers of reinforcement. This trend represents 13.8, 37.9, 23.0, 19.5 and 13.8% increase in bearing capacity for the 1, 2, 3, 4 and 5 bamboo reinforcement layers respectively.

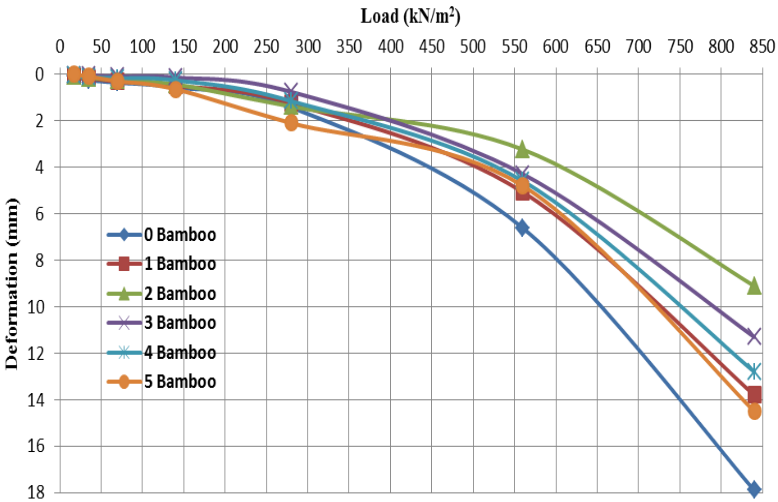


Figure 6: Load-settlement test result

The observed trend is mainly due to the stress bulb originating from the loading plate to the layers of bamboo reinforcement. The first layer is closer to the loading plate and is therefore, fully located within the stress bulb, thereby fully helping to resist load deformation and hence increasing the bearing capacity of the soil base. The second bamboo layer is also within the stress bulb, which further increase the bearing capacity. However, the third layer is outside the stress bulb and only the combined effort of the first and second bamboo layers contributed into the bearing capacity value obtained with three bamboo layers.

This assertion is shown on the graph (figures 6 and 7) of the third bamboo reinforcement layer, which showed higher bearing capacity at lower loads compared to two bamboo layers after which the bearing capacity values reduced at higher loads. The fourth and fifth bamboo layers showed no much advantage, since the pressure bulb does not cut across them completely.

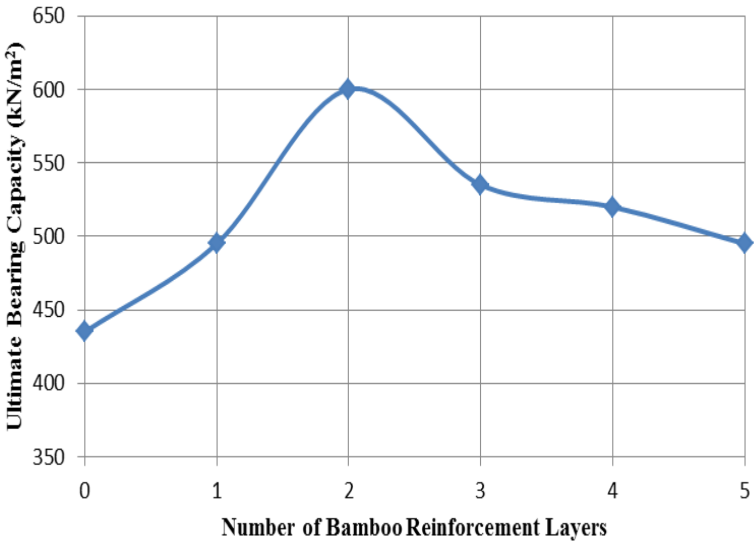


Figure 7: Variation of ultimate bearing capacity with increase in number of reinforcement layers

## 5. Conclusions

Although, the bending strength and modulus of elasticity are below the values obtained for bamboos from other parts of the world, the values of the tensile strength, which is the main property required for material to be used as soil reinforcement, was observed to in agreement with those reported for other bamboos. The clay soil used in this study contains predominantly kaolinite mineral and classified under A-7-6 subgroup according to AASHTO soil classification system. The ultimate bearing capacity of the bamboo reinforced clay soil increased from 435kN/m$^2$ at 0 bamboo layer to 600 kN/m$^2$ at 2 layers after which the values reduced to 495 kN/m$^2$ at 5 layers. Two bamboo layers is therefore the optimum layers required for effective reinforcement of the clay soil.

This study was carried out on kaolinite clay soil. The same test on other types of soil may give different results. Nigerian bamboos can be used as reinforcement for kaolinite clay soils.

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