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Behaviour of Laterised Concrete Columns Reinforced with Bamboo Strips

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This paper reports the results of investigation on the behaviour of bamboo strip reinforced laterised concrete columns. Seventy-five (75) No. 150 x 150 x 1000mm laterised concrete column specimens were prepared using varying percentages of laterite content in the fine aggregate and bamboo strip reinforcement, ranging from 1.92 - 7.68% of cross-sectional area. The results showed that all the columns failed due to the crushing of concrete in compression and the bamboo reinforcement did not contribute to the load carrying capacity of the columns. However, the reinforced laterised column could sustain increased deformation and strain with superior post-yielding and post-cracking behaviour.

Keywords: Bamboo strip, reinforcement, laterised concrete column, strength, lateral deflection.

1. Introduction

Concrete, an extensively used construction material, is strong in compression but weak in tension. Its weakness in tension is ameliorated by incorporation of steel bars. Steel is however costly, particularly in the developing countries where it is mainly imported. Researchers in this country and other parts of the world have therefore been investigating the possibility of replacing reinforcement steel with cheaper and locally available natural fibres such as oil palm and bamboo. Extensive research has been carried out on bamboo to determine its physical properties. **Olateju (1993)** observed that when fresh, the tensile strength of bamboo Vulgaris, a specie of bamboo, at nodal and inter-nodal sections varies from 260N/mm^2 - 500N/mm^2 and 160N/mm^2 - 275N/mm^2 respectively which compare favourably with those of steel which is between 280N/mm^2 and 500N/mm^2. **Pama (1978)** reported on the stress - strain relationship under tension of bamboo and concluded that the relationship was essentially linear and that bamboo exhibited a brittle failure in tension. Other researchers (3-7) also investigated the modulus of elasticity of bamboo and also its behaviour under compression. The summary of their results showed that the compressive strength of bamboo varies from 23.2N/mm^2 - 11.7N/mm^2, while the compressive modulus of elasticity is in the range of 4600N/mm^2 - 19350N/mm^2. **Meyer** and **Ekelund (1992)** studied bamboo and concluded that it is as strong as wood in tension and deflection but much weaker in shear. In their opinion, the shear strength of bamboo is only about 8% of its compressive strength. **Lakshmipathy** and **Santhakumar (1980)** investigated the effect of natural plant and vegetable fibre in concrete and observed that concrete reinforced with natural plant and vegetable fibre is stiffer, stronger and more ductile compared to plain concrete. **Kankam (1997)** studied the strength characteristic of raffia reinforced concrete beams and his results showed that raffia reinforcement contributed immensely to the load-carrying capacity of the beam specimen. **Salau** and **Sadiq (2001)** experimented on the use of palm firbre strips as substitute for steel reinforcement in normal concrete beams. Their results showed that oil palm fibre reinforcement increases the flexural strength of the beam compared to unreinforced normal concrete. It also increases the post-cracking behaviour as well as the serviceability performance of plain concrete. However, the failure of oil palm strip reinforced concrete beam is accompanied with wide

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cracks and large deflections, probably due to the low modulus of elasticity of the fibre and the bonding between the fibre and conrete.

In order to reduce the cost of concrete due to aggregates, extensive work has been carried out on the possibilities of replacing fine aggregate wholly or partially with laterite in concrete. **Adepegba (1975)** carried out a comparative test on normal concrete and laterised concrete, in which laterite was used as fines in place of sand and concluded that laterised concrete could be used as structural member but with reduced strength. Instead of replacing sand wholly with laterite, **Adepegba** and **Balogun (1978)** experimented on partial replacement of sand with laterite and concluded that 2:3:6 mix by weight of concrete in which the fines are composed of 25% laterite and 75% sand compares favourably in strength with normal 1:2:4 mix of concrete. **Salau** and **Balogun (1990)** investigated the shear resistance of laterised concrete without shear reinforcement and concluded that the mode of failure of the beams does not depend on the percentage of laterite content, but mainly on the shear span/effective depth ratio. They also observed that the presence of laterite in the concrete improves its post-cracking ability, serviceability condition due to high ductility, stiffness and superior crack control.

Most of the work of the earlier researchers have concentrated on the application of natural fibre on concrete beams and slabs. Not much attention has been paid to the use of natural fibre on concrete columns. The objective of this thesis, therefore, is to investigate the capacity of bamboo reinforced normal and laterised concrete short columns.

2. Origin and Structure of Bamboo

Bamboo is a perennial grass belonging to the class of Monocotyledonae and is found growing abundantly in many developing countries of Africa and Asia. It grows in tropical, sub-tropical and temperate zones. Bamboo can be classified into two main groups according to its growth pattern, namely Sympodial and Monopodial. About 75 genera and 1250 species are obtained in different countries of the world with each specie having widely differing characteristics, thus affecting its usefulness as a building material. The woody pointed stems of bamboo, commonly called culm grows closely together in clumps. The growth of bamboo culm is rapid, about 70mm per day and can be as much as 350mm - 400mm per day. Once the maximum height is attained, lignification of the culms takes place during the subsequent two to three years. Bamboo attains its greatest strength after three years when it assumes a brownish colour.

Bamboo culms are generally cylindrical and smooth with diameters ranging from 29mm - 300mm. The culms are divided into nodes and inter-nodes. They are hollow and have transversely dividing walls at the nodes. The culm is covered on the inside and outside thus offering considerable resistance to the absorption of water particularly when dry. The mechanical properties of bamboo do not vary only with individual species but also depend upon many other factors such as age, moisture content, extent of seasoning, time of cutting, maturity, soil and climatic conditions. The node of bamboo is generally stronger in tension than the inter-node.

3. Experimental Procedure

The coarse aggregate was crushed granite of density 2740kg/m^3, 72% of which passes through 19mm BS Sieve. The fine aggregate was composed of laterite and sharp sand. The grading curves for the aggregates are shown in **Figure 1**, and it can be seen that the aggregates were well graded, with the coefficients of uniformity of granite, sand and laterite being 1.71, 2.43 and 3.87 respectively, certifying the aggregates to be good for concrete work. The bamboo size ranging from 10mm splints was cut into lengths of 950mm, providing for 25mm cover at the top and bottom of the 1000mm concrete column. After splitting and cutting each specimen, the smooth back was then hacked-off with a hand saw before water-proofing it by brushing with coal tar after which, sand is sprinkled on it to enhance adequate bonding of the bamboo bars with laterised concrete.

Preliminary investigations on bamboo strips of 10mm x 10mm rectangular strips, using the Mansato Tensometer type "W" testing machine with gauge length of 300mm, indicate that the bamboo exhibits linear relationship of stress and strain with limit of proportionality varying between 100.75N/mm^2 and 106.5N/mm^2. **Figure 2** shows the Stress-Strain relationship of the bamboo strip. For use as reinforcement in the concrete column, the bamboo splints were cut into rectangular shapes with average width of 12mm and thickness of 9mm, thus giving

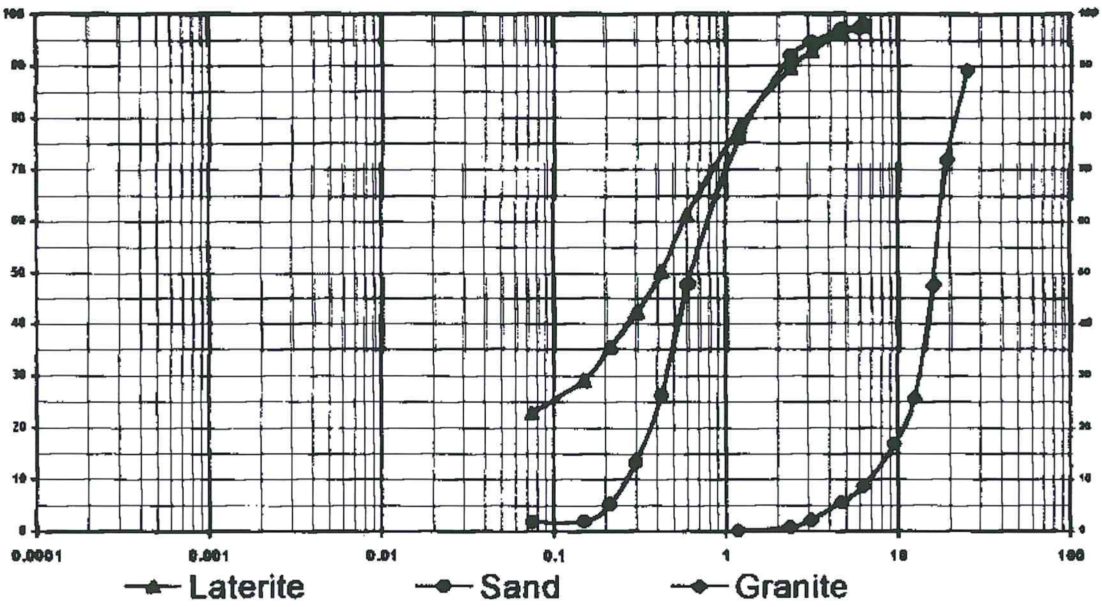

FIGURE 1: *Particle Size Distribution*

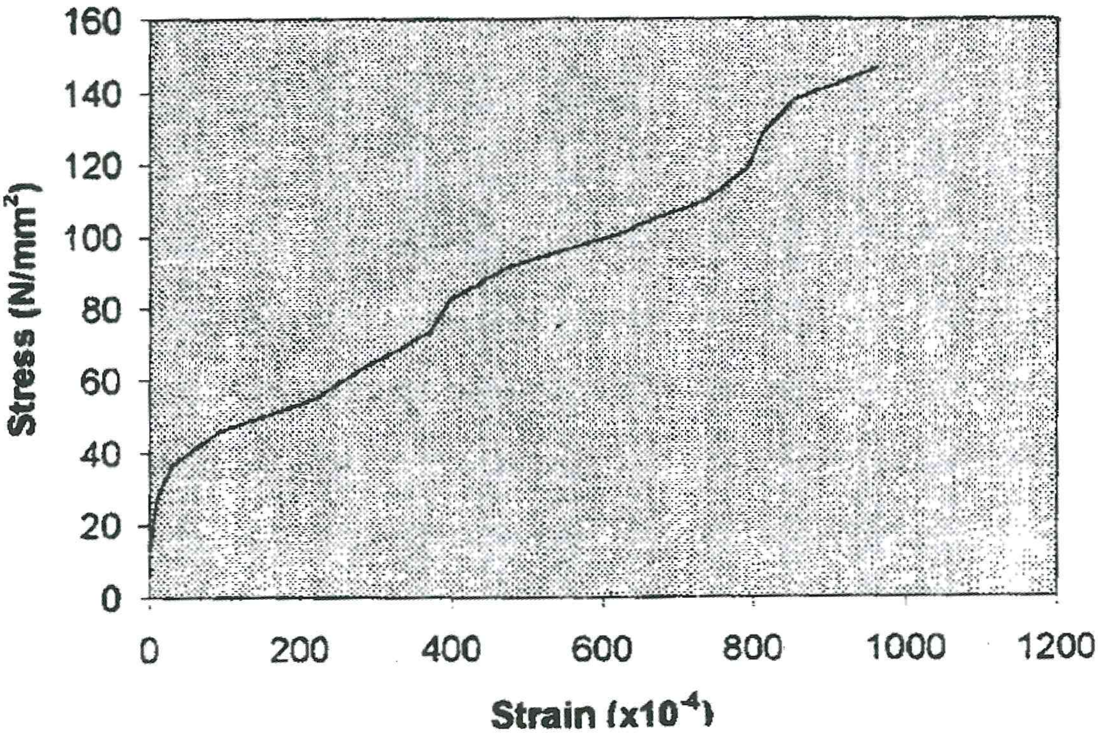

FIGURE 2: *Typical Stress-Strain Relationship of the Bamboo*

an average area of each splint to be 108mm^2. Column speciments of size 150 x 150 x 100mm were prepared with mix ratio 2:3:6 (cement: fine aggregate: coarse aggregate) by weight and water/cement ratio of 0.65. The proportion of laterite in the fine aggregate was varied from 0 - 100% of weight of fine aggregate in a step of 25%. For each proportion of laterite, the percentage of bamboo strips longitudinal reinforcements provided in the column specimen ranged from 1.92 - 7.68% of the gross area of the column section. The number of 12mm x 9mm bamboo strips corresponding to percentage reinforcements is shown in **Table 1**. The links are also provided using 10mm thick bamboo strips tied with binding wire to the longitudinal reinforcement at 300 - 325mm centre-to-centre. **Figure 3** shows the details of arrangement of the bamboo-strip reinforcement in the different columns tested. All columns were cured under damp sand after demoulding for three days and kept in the laboratory environment until the 28th day, when they were tested. For each combination of laterite and bamboo reinforcement, three samples were tested.

In all, 75 columns and 15 cubes were investigated. The column specimens and the 150mm cubes were tested on Dension Universal testing machine with maximum capacity of 10 tonnes (98kN). The load at which the first crack appeared and the collapse load were noted. The central lateral deflections of the column were measured using a dial gauge placed at the mid-height of the column. **Figure 4** shows the set-up of the bamboo-reinforced laterised concrete column under loading.

4. Test Results and Discussion

4.1 Density and Compressive Strengths of Laterised Concrete Cubes

The density of laterised concrete, as shown in **Table 2** reduces with increase in the laterite content. However, the density of lateritic concrete (concrete in which the fine is wholly laterite) is just 9% less than the normal concrete. This confirms that laterised concrete can be used in normal concrete work where the density is not below 2350kg/m^3.

Table 2 also shows the variation of 28-day concrete, 150mm cube strengths with laterite contents. It is observed in **Figure 5**, which shows the relationship of cube strength and density with laterite content, that the cube strength reduces as the laterite content is increased from 0% - 100%. For plain concrete (i.e., concrete with no laterite), the cube strength is 29.73N/mm^2 while that of laterised concrete with 25% laterite is 27.33N/mm^2 representing a reduction of 8.78%.

This is a comparatively small reduction which makes 2:3:6 laterised concrete with 25% laterite suitable for structural use as concluded by **Balogun** and **Adepegba (1975)**. The cube strength for lateritic concrete (concrete with 100% laterite) is 15.29N/mm^2, representing a reduction of about 50%, indicating that the rate of reduction in the cube strength is higher than that of the density. This also shows that laterised concrete in which the sand is fully replaced with laterite is not suitable for structural concrete. Laterite aggregate itself has generlly low strength characteristics and thus should be used in concrete of lower strength as the lateritic aggregates will fail prior to failure of the cement matrix. It may be useful for non-structural members and for block-making and this will reduce the cost of such elements made from sand only.

TABLE 1: *Percentage Reinforcement with Corresponding Area and Number of Bamboo Strips*

No. of Bamboo Strips	Corresponding Area (mm^2)	Percentage Reinforcement %
4	432	1.92
6	648	2.88
8	864	3.84
10	1080	4.80
12	1296	5.76
16	1728	7.68

TABLE 2: *Variation of Density and Cube Strength of Concrete with Varying Laterite Content*

% Laterite	Density (kg/m^3)	Crushing Load (kN)	Cube Strength (N/mm^2)
0	2570	669	29.73
25	2490	615	27.33
50	2460	487	21.64
75	2440	417	18.53
100	2350	344	15.29

TABLE 3: *Variation of Collapse and First Crack Load (kN) with Percentage of Bamboo Reinforcement*

% Laterite Content	No. of Bamboo Reinforcement (Percentage Reinforcement)													
	0 (0%)		4 (1.92%)		6 (2.88%)		8 (3.84%)		10 (4.80%)		12 (5.76%)		16 (7.68%)	
	FCL*	UFL*	FCL	UFL	FCL	UFL	FCL	UFL	FCL	UFL	FCL	UFL	FCL	UFL
0	404	404	130	150	154	179	217	226	193	201	188	200	142	157
25	350	382	105	135	142	173	185	206	189	202	126	135	139	151
50	200	218	98	142	117	159	121	150	77	90	121	136	103	132
75	178	193	64	106	87	112	50	100	46	66	94	120	80	118
100	80	100	10	42	28	88	16	78	21	54	48	88	10	40

*FCL - First Crack Load
*UFL - Ultimate Failure Load

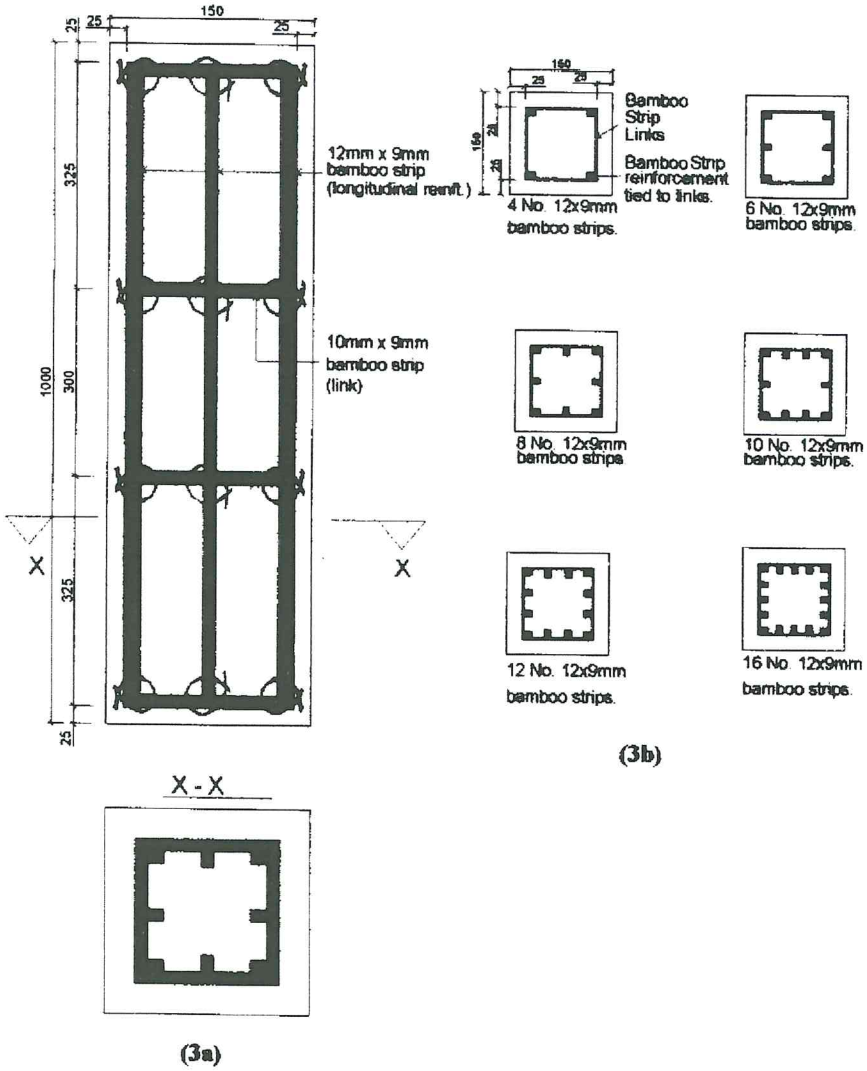

FIGURE 3: *(a) Column Longitudinal Section;*
(b) Arrangement of Bamboo Strips in Columns

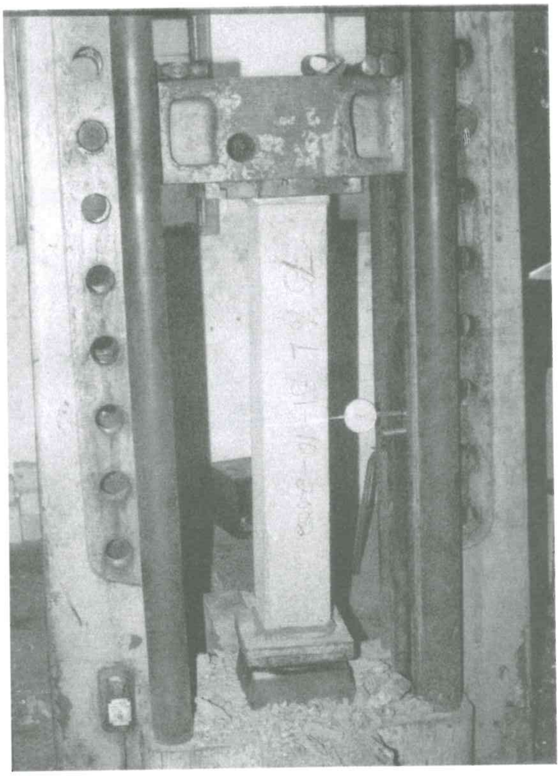

FIGURE 4: *Bamboo-Reinforced Laterised Column under Loading*

4.2 Strength Capacity of Laterised Concrete Columns

Table 3 shows the average values of the cracking ultimate loads with the varying percentages of bamboo-strip reinforcement in different laterised concrete columns. The reults showed that the first cracking load in all cases is lower than the ultimate load except in unreinforced normal concrete (i.e., without laterite fine and bamboo reinforcement). In unreinforced laterised concrete, there is general increase in the ultimate failure load compared to the load at crack formation. However, there is drastic reduction in crack and failure loads due to bamboo reinforcement for low percentage reinforcement but with constant laterite content. This may likely be due to the reduced concrete area and ineffectiveness of the bamboo reinforcements in this case.

The cracking and ultimate loads of unreinforced normal concrete is 404kN while the unreinforced 25% laterised concrete has the cracking and ultimate loads of 350kN and 382kN respectively; an increase of about 9.1% in the cracking load before failures. It shows that the laterite content also contributed to the ductility of the concrete specimen.

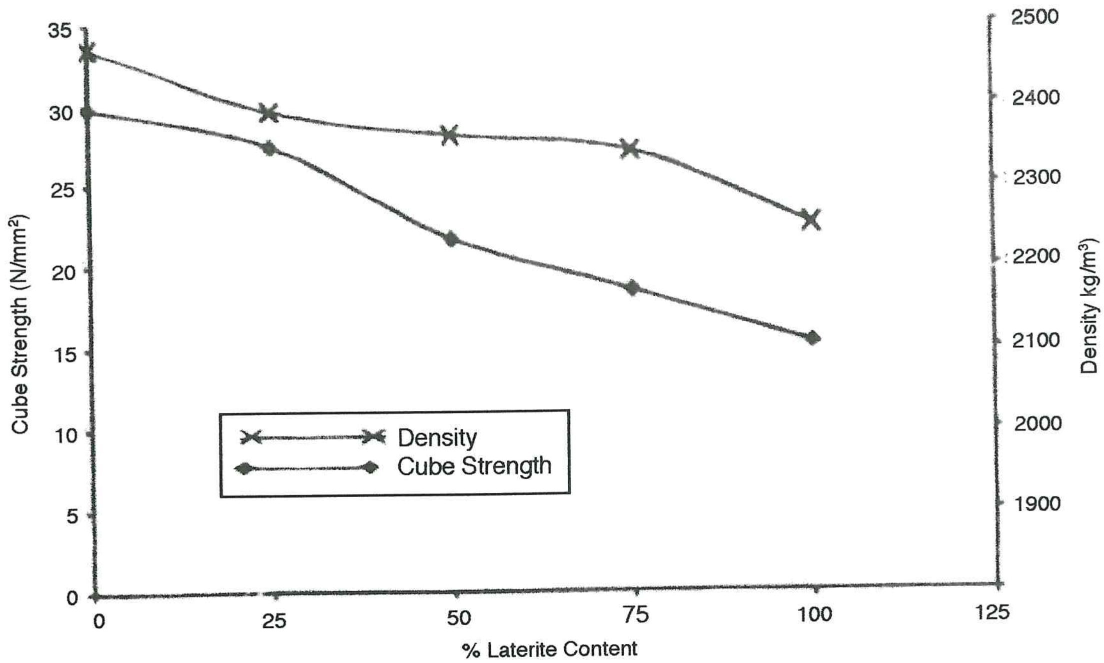

FIGURE 5: *Relationship of Cube Strength and Density with Laterite Content*

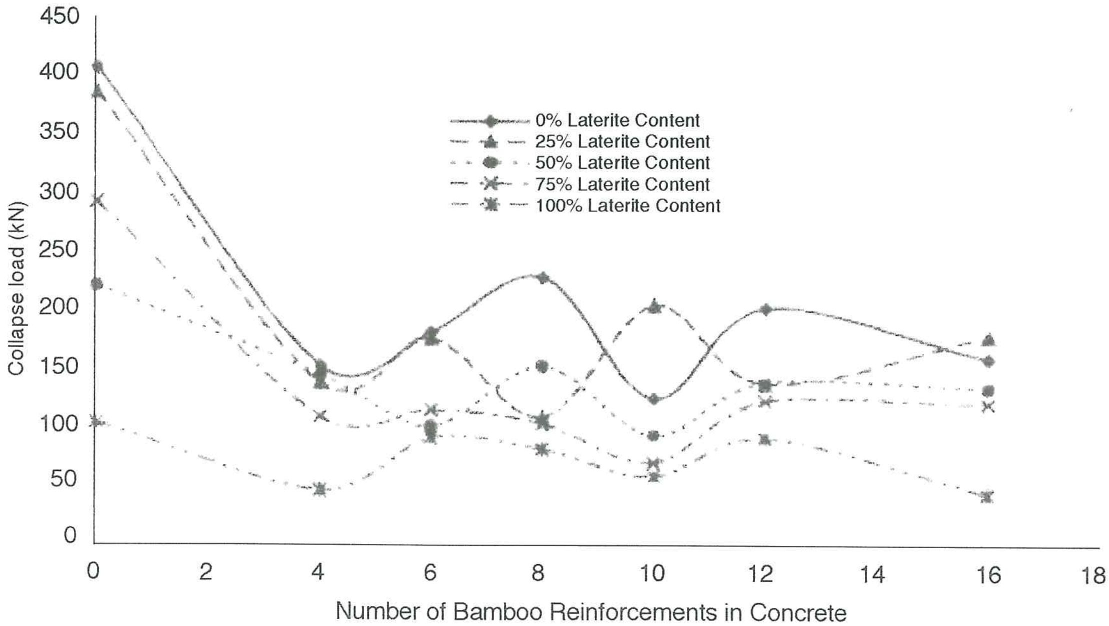

FIGURE 6: *Relationship of Collapsed Load with Bamboo Reinforcement Proportion*

Figure 6 shows graphically, the strength variation of fibre-reinforced laterised concrete columns with different percentages of bamboo reinforcement. It could be observed that the variation of collapse load with increase in the number of bamboo reinforcement does not follow any particular pattern. For example, in the case of normal concrete (no laterite fine), there is increase in the ultimate load from 150kN - 266kN between four and eight bamboo-strip reinforced columns and later reduced to 201kN and 157kN for 10 and 16 bamboo-strip reinforced columns respectively. In the case of 50% laterite concrete beam, the ultimate loads are respectively 142kN, 159kN and 150kN for four, six and eight bamboo-strip reinforcements.

For each percentage of bamboo reinforcements, the ultimate load reduced with increase in laterite content. For example, for six bamboo-strip reinforcement, an ultimate failure load of 179kN was obtained in normal concrete (0% laterite) while the failure load of lateritic concrete (100% laterite) was 88kN, a reduction of 50%. The unreinforced normal concrete (no laterite) had the highest ultimate failure load of 404kN while the lowest of 40kN load was obtained in 100% laterised concrete with 16, 12mm x 9mm bamboo-strip reinforcements.

This behaviour, the effect of laterite content on strength, is in conformity with the case of normal steel reinforced laterised concrete beams observed by **Salau** and **Balogun (1990)**. The results further showed that the bamboo reinforcement did not contribute to the load-carrying capacity of the column, likely due to its low modulus of elasticity as well as its uncohesiveness between fibre in which shear plays a role. The ineffectiveness of the bamboo reinforcement may also be due to its low bond with concrete, which is associated with its initial swelling when bamboo absorbs water from wet concrete. As the bamboo is ineffective, there would be loss of cross-sectional area, resulting in loss of strength. This may account for the highest ultimate failure load obtained in unreinforced normal concrete.

4.3 Failure Pattern and Failure Mode

Cracks were observed to be formed before total failure in the specimens with laterite and bamboo reinforcement. For normal unreinforced concrete (no laterite and no bamboo-strips reinforcements), the failure is sudden and there was no crack formation before the ultimate failure. When the bamboo-reinforced laterised concrete column is loaded, the micro-cracks propagated under the loading plate

FIGURE 7: *Failure Patterns of 50% Laterised Concrete with Varying Percentages of Bamboo*

diagonally, terminating at vertical or straight edge of the member, with more cracks from adjacent faces terminating at the same point. Pieces of concrete can be observed chipping off rapidly, thus reducing the load-carrying capability of the member and afterwards the member fails.

Figure 7 shows the failure patterns of 50% laterised concrete with varying percentages of bamboo reinforcement while **Figure 8** shows those of fixed bamboo reinforcement but varying laterite contents. It was observed that due to visco-elasticity of laterite, the ductility of the columns increased in 25% - 75% laterite content, which was evident in the crushing pattern of the columns. While the columns with lateritic content exhibited multiple cracks at the top gradually reducing to one, thus splitting the column into two towards the mid-height, the normal column (0% laterite) exhibited sudden snapping due to its brittleness. It can be concluded that the bamboo-reinforced laterised concrete columns can sustain increased deformation and strain with superior post-yielding and post-cracking behaviour.

It was also observed that the bamboo reinforcement had not yielded in the concrete, as they are still intact after failure on inspection. This further confirms that the failure of the columns were due to crushing of the concrete in compression and the bamboo may not have contributed in load-carrying capacity of the laterised concrete.

FIGURE 8: *Failure Patterns of Bamboo Columns with Varying Laterite Content*

Cracks and eventual failure were generally observed to be similar for each case of laterite content but with varying percentages of reinforcement and occurred mainly around the top-loading plate of the specimen with only insignificant failure occurring around the mid-height. This further indicates that buckling has no effect on the failure of the bamboo-strip, reinforced, laterised short column investigated.

4.4 Lateral Deflection at Failure

The values of the maximum deflection at the mid-height of the column for varying percentages of laterite content and area of reinforcement under the ultimate load are shown in **Table 4**. The results showed that the maximum mid-height deflection value of 3.6mm was obtained for column sample of 75% laterised and 7.68% bamboo reinforcement while the least of 0.10 was for 75% and 100% laterised concrete columns with 5.76% and 4.80% reinforcement respectively. There was no definite pattern of increase or decrease of the deflection with increase in laterite content or percentage of bamboo reinforcement, just as the case in the strength capacity.

Generally, columns with 50% and 100% laterite content, recorded values around 1.00mm while the 25% and 75% content had average deflection less than 1.00mm. This may not be unconnected with the weak bonding forces between the bamboo strips and concrete as a result of the coating of the strips with bitumen. The bonding forces might have collapsed as stress developed within the member due to compressive forces from the loading plate. Furthermore, as the failure is due to compression of concrete, short columns and not bending, it may be difficult to ascertain the contribution of the bamboo reinforcement in the tension zone.

5. Conclusion and Recommendations

From the results of the investigation on the behaviour of laterised concrete columns reinforced with bamboo strips, the following could be concluded:

(1) The density and cube strength of laterised concrete reduce with increase in laterite content in the concrete. However, the rate of reduction in the cube strength is higher than that of the density. Generally, the laterised concrete with 25% laterite content could be used for normal concrete work with density not below 2350kg/m^2 and characteristic strength below 25N/mm^2.

(2) The bamboo reinforcement did not contribute to the load-carrying capacity of the concrete columns, likely due to its low modulus of elasticity and shear capacity. The failure is due to crushing of concrete in compression. The variation of cracking and collapse load with increase in percentage reinforcement does not follow any particular pattern. However, for each percentage of bamboo reinforcement, the ultimate load reduced with increase in laterite content.

TABLE 4: *Variation of Mid-height Lateral Deflection (mm) of Laterised Concrete Columns with Percentage Reinforcement and Laterite Content*

% Laterite Content	No. of Bamboo Reinforcement (Percentage Reinforcement)						
	0 (0%)	4 (1.92%)	6 (2.88%)	8 (3.84%)	10 (4.80%)	12 (5.76%)	16 (7.68%)
0	0.70	1.25	0.81	0.97	1.90	0.21	0.67
25	0.88	0.89	2.76	4.49	1.58	0.28	0.30
50	0.76	0.95	1.00	0.58	0.60	0.50	1.00
75	0.29	0.90	0.60	2.20	0.80	0.10	3.60
100	0.50	0.75	1.00	1.10	0.10	0.80	0.60

(3) Cracks and eventual failure of bamboo-reinforced laterised concrete columns were generally observed to be similar for each case of laterite content but with varying percentage of reinforcement and occurred mainly around the top-loading plate with only insignificant failure occurring around the mid-height, thus indicating that the failure of the columns are due to crushing of the concrete in compression.

(4) The bamboo reinforcement as well as the laterite content contributed to the ductility of the column as the ultimate load is always higher than the first-cracking load. The laterised concrete column can thus sustain increased deformation and strain with superior post-yielding and post-cracking behaviour.

(5) Bamboo-reinforced columns with 50% and 100% laterite content recorded mid-height lateral deflection higher than 1.00mm while the 25% and 75% had average deflection less than 1.00mm. No definite pattern of lateral deflection behaviour was noticed with increase in the percentage bamboo reinforcement for any definite concrete column.

In view of the results obtained, bamboo strips cannot be recommended for reinforcement in laterised concrete columns.

The initial seasoning and treatment of the bamboo strips with coal tar and sprinklilng with sand may not have been very effective. The suggestion of **Frang** and **Melita** (15) of sulphur treatment to reduce the water absorption potential significantly during the concrete-curing process may be given consideration.

Attention can also be focussed on more slender columns to determine the contribution of the bamboo strip reinforcement to deter sideway deflection and buckling failure in such columns.

Since the failure zone is mainly close to one end, it is necessary to consider the end-effect and size-effect phenomena as contributing factors. The former could be mobilised by the lack of a cap on the ends of the specimen while the latter may be due to reduction in the laterised, concrete, cross-sectional area from increase in the number of bamboo strips embedded.

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