Characteristic Strength of Concrete Column Reinforced with Bamboo Strips

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Abstract

This work investigated the structural strength of concrete column reinforced with bamboo strips. Experimental work includes load capacity test, deflection and failure patterns observation of eighteen concrete columns. Varying bamboo, from 4No to 12No, strips of coated seasoned bamboo of cross-section 8x10mm, were used to reinforce the concrete columns. Three other samples of column were reinforced with four length of 12mm high yield steel while the remaining was plain concrete, which served as controls. The results showed that the load carrying capacity of the column increased with increase in percentage of bamboo strip reinforcement but the increase is not proportional to the percentage of reinforcement. There was also improved post cracking ability of the concrete due to the bamboo inclusion but not as pronounced in steel reinforced column. However, all columns failed in a similar pattern due to crushing of concrete. The bamboo strips showed no sign of slippage and remain unaffected even after concrete failure.

Keywords: Bamboo strips, Concrete column, Tensile strength, Deflection, Post cracking ability, Ultimate failure

1. Introduction

Building with bamboo looks back on an ancient tradition in the regions in which the plant grows in abundance, such as in South America, Africa and, in particular, South-East Asia.

Bamboo attains its greatest strength after three years, when it assumes a brownish colour. The bending strength of bamboo depends significantly on the location of nodes, which stiffens the culms (stem) at intervals, preventing it from buckling or collapse. Specimens with a node at the loading point, in static bending tests, show a higher strength but lower stiffness than those having the load points between nodes. Akeju and Falade (2001) reported the ultimate tensile strength values as $135N/mm^2$ and modulus of elasticity as ranging from 15833 to 22843 N/mm^2. Yu et al. (2008) concluded that the mean longitudinal tensile strength of bamboo ranged from 115 to 309 MPa. These values compared favourably with that of steel of 250 - $500N/mm^2$. Lima et al. (2008) did an experimental investigation to evaluate bamboo durability to be used as concrete reinforcement. The durability was evaluated by changing the tensile strength and Young's modulus of bamboo. The results showed that the bamboo tensile strength is comparable with the best woods used in construction and even with steel. The tensile stress/strain curve of the bamboo is linear up to failure. The bamboo average tensile strength is approximately 280 MPa in the specimens without node and 100 MPa with those with node. Also, 60 cycles of wetting and drying in solution of calcium hydroxide and tap water did not decrease the bamboo tensile strength as well as the Young's modulus, attesting to the durability of in the aggressive tests.

Test results on various species of bamboo by various researchers have shown its tensile strength to vary from $38N/mm^2$ to $505N/mm^2$. Xiaobo (2004) reported a strength variation with age; the maximum compressive strength and young modulus of one-year bamboo was 51 and 2834MPa respectively while that of three-year old are 86 and 5993MPa. Bamboo thus possesses a significantly lower strength in compression than in tension.

Low bond with concrete is one of the principal problems associated with the use of bamboo as reinforcement. The tensile strength of seasoned bamboo is generally greater than that of unseasoned ones. It is thus essential to use a suitable water-repellent treatment to ensure volume constancy of the reinforcing material while encased in concrete. Seasoned bamboo possesses higher bond strength compared to unseasoned bamboo due to low water absorption and reduced swelling and shrinkage of the bamboo. In addition, the coefficient of thermal expansion of bamboo is as low as one-third that of concrete longitudinally and ten times diametrically. These differences contribute to cracking of concrete cover and loss of bond, thus, an effective moisture-proof treatment is necessary for bamboo reinforcement.

Janssen (1991) commented that the real problem in bamboo reinforced concrete is in the bonding between the bamboo and the concrete, which is never a problem with steel reinforcement. Concrete will shrink during the hardening process and these results in a firm bond of the concrete around the steel reinforcing bars while bamboo will absorb water as soon as the concrete is poured around it. During concrete hardening, bamboo will dry as well and shrink. The shrinkage of bamboo can be four times that of concrete. Clearly, this will completely break down any bonding between bamboo and concrete. This condition limits performance of the composite structure to a point far less than the yield strength of the individual materials of the composite. With a simple waterproofing agent, the swelling of bamboo can be stopped. Ghavami (2005) used a product called Negrolin, combined with wire to achieve bond. He presented the results of some of the recent studies of the microstructure of bamboo as a functional gradient material and found that bond strength increased with increase in cement content and with reduction in water-cement ratio. Jung (2006) investigated the feasibility of using bamboo as alternative reinforcement to steel in concrete structural elements. The researcher investigated bamboo's tensile strength and its pullout characteristics in concrete. Tensile test specimens were tested to failure and their deformation characteristics noted. Test results show that failure modes were (1) node failure, (2) splitting failure; and (3) failure of the end-taps. Also, the pullout test results showed that the bond strengths for bamboo was lower than those for steel.

Yan Xiao et al. (2008) reported in their book other favourable characteristics of bamboo which includes its strong and elastic fibrous textures that makes it exhibit high resistance to earthquake, high strength-weight ratio, lightness, natural insulation properties that would save thermal energy and high durability if treated well. Leena (2005) carried out test on bamboo reinforced concrete beams. Results showed that bamboo reinforcement enhanced the load carrying capacity by approximately 250% as compared to the initial crack load in the concrete beam. It also showed that the ultimate load carrying capacity of bamboo reinforced concrete beam was about 35% of the equivalent steel reinforced concrete beams. Falade and Ikponmwosa (2006) investigated the scope of bamboo reinforcement in concrete beams for low-cost housing. Findings showed that the computed deflection for each loading of bamboo-reinforced beams increased with increase in value of applied moment and span but reduced with increase in the quantity of bamboo reinforcement in the beams. The results also show that the optimum span for bamboo reinforcement in reinforced concrete beams based on cross-sectional dimensions of 225x450mm is 4000mm at optimum load of 60% M_u (ultimate moment of resistance). Within this limit, the requirements of ultimate and serviceability limit states were achieved. Kumar and Prasad (2003) conducted investigation on strength and deformation characteristics of six (6) bamboo reinforced conventional and blended concrete beams. Three (3) bamboo reinforced concrete beams of M.25 - grade concrete and three (3) of blended concrete containing 15% fly ash and 30% blast furnace slag as partial replacement of cement and coarse aggregate in the same mix were used. The result showed that the first-crack load and ultimate failure load were similar for both types of beams while all the beams exhibited large ductility before the final failure with 2.40 and 2.43 times their corresponding theoretical failure loads respectively.

From the above works, it can be concluded that, under appropriate conditions, bamboo splints may safely be used as substitute for steels in beams and slabs. It should be noted that in beam, steel reinforcement resisted loads approximately 1.5 times over that of bamboo; although, the local capacity of members at ultimate failure increase up to 4 or 5 times greater than that of plain concrete for bamboo reinforced concrete.

Much work has been done on beams and slabs reinforced with bamboo strips, little has been known about the possibility of using bamboo in concrete column, especially when majority of concrete column need nominal reinforcement in low rise and low cost construction. Furthermore, the cost of steel has limited the proportion of citizens in Nigeria and other developing countries who can afford their own house to about 30%. Satjapan et al. (2010) presented a paper on the structural and environmentally sustainable aspects of bamboo as a reinforcing material instead of steel reinforcement in concrete columns. Seven (7) small-scale short columns (125mm x 125mm x 600mm) with different types of reinforcements were tested under concentric loading to investigate strength capacity and ductility. The results showed that for the column reinforced by bamboo without surface treatment, strength capacity was sufficient to withstand the maximum axial force provided by the American code (ACI 318 – 05), while ductility was rather low, especially in the column reinforced by 1.6% of bamboo without surface treatment. The column showed brittle behaviour like plain concrete column. The column treated with water-repellent substance, Sikadur – 31CFN, before concrete casting, showed more strength and ductility. They concluded that the 1.6% of steel reinforcement in relation to the concrete section could be replaced by 3.2% of treated reinforcing bamboo which had the same behaviour, strength and ductility. Salau and Sharu (2004) investigated the behaviour of laterized concrete columns reinforced with bamboo strips and observed that all the columns tested failed due to the crushing of concrete in compression and the bamboo reinforcement did not contribute to the load carrying capacity of the column. This, however, may not be unconnected with the laterite content, since for constant content of bamboo reinforcement, the ultimate load reduced with increase in laterite content. It was also observed that due to visco-elasticity of laterite, the ductility of the columns increased with 25% - 75% laterite content.

This paper reports an experimental investigation on the suitability of bamboo strips as reinforcement in normal concrete column, as there is little information on the subject and taking into cognizance the need to improve bond between concrete and bamboo interface.

2. Experimental Details

2.1 Bamboo Selection and Preparation

Following the recommendations of various bamboo researchers, the selection of the bamboo was done thus:

i Only bamboos showing a pronounced brown colour are used in order to ensure that the plant is matured and at least three(3) years old.

ii Selection of the longest large diameter culms available was made while as far as possible, straight long bamboos without any deformations and cracks were selected. Bamboos used are free of any decay, fungus growth or holes due to white ants.

iii. The bamboos were not cut under wet condition because the culms are generally weaker due to increased fiber moisture content.

iv. All main reinforcements consist of bamboo splints with the nodes exposed upwards to increase bond; thus bamboo species with the greatest number of nodes were selected.

The selected bamboos were air dried for over 30days (seasoning in air) and then cut into strips size of 8x10x1000mm. To determine the ultimate stress of the seasoned strip, 8x10mm strip of 300mm gauge length was axially loaded in tension on a 500kN Avery Denison tensile testing machine. The specimens were tested to failure. For the reinforcement, the bamboo strips were lightly scratched to induce roughness on the surface. To reduce water absorption and increase the bond with concrete matrix, bamboo strips were coated with bitumen and wound round with 1mm diameter coir rope at a pitch of 100mm along the strip from end to end. The coir rope was also dipped in hot bitumen before being wound round the bamboo strip. This gave a surface similar to a ribbed steel surface. The ribbed surface was expected to improve the bond considerably and the structural behaviour of the bamboo reinforced concrete. Also, fine sands were sprinkled over the coats of bitumen on its surface.

The fine aggregate used is sharp river sand having grains with a lower size limit of 70 or 60 μm and not larger than 4mm, with quartz being the major mineral constituent, while the coarse aggregate is crushed granite which comprises material with 12mm maximum size and in which the granite dust were thoroughly sieved out, leaving no grains less than 9mm in the materials used. Portable water with no impurities was used for the concrete mixing.

2.2 Experimental Procedure

The concrete mix proportion adopted for this work was 1:2:4 (cement: sand: granite) with water/cement ratio of 0.65 so as to have a true slump and greater movement of concrete around the bamboo strips.

The test specimens were rectangular columns of 150mm x 150mm cross section and height of 1000mm. In the absence of any standard specifications for incorporating bamboo in concrete, reference was made to clauses 3.12.5 and 3.12.6 in British Standard BS 8110, which stipulate a minimum of 0.4% and a maximum of 8% gross sectional area for reinforcement in column. Five different reinforcement volume fractions were considered. The volume fractions are 0; 1.42; 2.13; 2.84; 4.27 expressed as percentages of gross-sectional area (150x150mm) of the column and corresponding to 0; 4No; 6No; 8No and 12No of splints respectively. The other control beams in addition to the zero percent bamboo reinforcement was one set cast with 4No high yield steel of 12mm diameter. For shear reinforcement, 8mm diameter mild steel was provided at 175mm centre-to-centre throughout the height of the column. For each type of longitudinal reinforcement, three columns were cast. Figure 1 shows the various arrangements of the bamboo strip reinforcements in the column.

The concrete constituents, which were batched by weight, were mechanically mixed in a mobile rotating drum mixer. Compaction was done by the use of mechanical rotating device (vibrator), which was immersed in the mould during placement of concrete at different depths. The moulds were tapped to ensure the dislodgement of trapped air and better compaction. Meanwhile, the reinforcements were well positioned by the use of 12.5mm thick concrete biscuits tied round them. 150x150x6mm thick plate was cast at each end of the column to ensure concentric loading during the test. 150mm concrete cubes specimens were also cast in order to determine the concrete strength.

The prepared specimens in the moulds were stored for 24hours after which they were demoulded and transferred into a curing tank containing clean water. The specimens were cured until 28th day.

Compression tests were carried out on the specimens (both cubes and columns) after 28 days of curing. The specimens were tested in accordance with BS 1881 Part 120, using a 1000kN Avery Universal testing machine. Dial gauges that measure the value of buckling (central horizontal deflection) were fixed at 250mm mark from both end of the column and at the centre.

The readings of the dial gauges were taken before and after every load increment. During the testing, the central, first quarter and third quarter deflections were recorded while the development of cracks and mode of failure were monitored as the load increases for each type of column.

3. Results and Discussion

3.1 Preliminary Tests on Materials

Based on the preliminary tests on the concrete cubes, the obtained average density of the concrete was 2556kg/m^3. The compressive strength, from the testing of the cube, cast in two different batches, gives the average 28-day strength of the concrete as 26.18N/mm^2, in consonance with the estimated design strength of 25N/mm^2. The results of the preliminary tests, carried out on the untreated seasoned bamboo strip, showed the average moisture content of the bamboo strip to be 14.8%. The tensile test gave the ultimate load of 5.75kN, corresponding to a maximum stress of 71.88N/mm^2. This is about one-third of the average tensile stress of steel reinforcement of 200kN/mm^2. The results further showed that the response of the bamboo strip to direct tensile loading is a manifestation of its low ductility compared to steel. The strips were unable to sustain loading beyond 5.75kN at which the bamboo strips literally pulled apart with a total elongation of 10mm for the 20cm initial length, indicating a total strain of 5%, compared to that of steel of about 12 -20%.

3.2 Crack Pattern and Mode of Failure

The first crack load corresponds to the loads at which micro cracks appeared on the column, which is dependent mostly on the strength of the concrete, while the ultimate failure is the load at which the column refused to take more load due to the failure of the composite materials, that is, additional load after the cracking is taken by the reinforcement (Bamboo strips).

In the tested columns, the first cracks started from top or bottom of the column, depending on the critical position due to punching effect of point load. The cracks extended toward the centre of the columns as shown in Figure 2a and 2b, suggesting a compression failure of the concrete in the columns. Some columns, especially those with large volume of bamboo strip reinforcement have their cracks starting from about one fourth of its height and extended to the centre and their failure loads were accompanied with wide cracks as shown in Figure 2(b).

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Furthermore, as the load was increased from the first crack load, the inclined cracks extended further with multiple cracks appearing until it got to a stage where a further increase in load did not affect the concrete but was having effects on the bamboo and steel reinforcement.

Since, similar pattern of failure was observed in all columns, it follows that the failure modes were independent of the materials used as reinforcement in the concrete matrix. However, the propagation of the cracks depends on the strength of the reinforcement/concrete matrix interface. Therefore, it may mean that wide cracks seen in the 12No. bamboo-strip reinforced column is as result of poor reinforcement/concrete matrix bond in the section.

3.3 Effects of Loading on Bamboo Reinforced Columns

Table 1 shows the average values of loads obtained from three samples of each column type tested, while Figure 3 shows the effect of bamboo reinforcement on the load carrying capacity of the concrete column. Based on the results, the capacity of the column (strength) is depended on the bamboo reinforcement volume fraction.

The bamboo reinforced columns show ductility since there is remarkable difference between the cracking load and the ultimate failure load in all the different percentages of bamboo strip reinforcement, as against the unreinforced (plain) concrete, which has both its cracking and failure load as 160kN. Furthermore, the increase in the percentage volume of bamboo strips in the concrete section resulted in reduction in initial cracking load though not proportionally. There is reduction from 276kN in 4No-strips reinforced concrete column to 240kN, 227kN, and 200kN in 6no-, 8no- and 12no-strips reinforcement respectively, corresponding to 12.14%, 17.26% and 27%.

As the volume of bamboo strips continues to increase, that of concrete reduces as well as the bond between the two materials, thus resulting to lower cracking load. The crack loads decrease with increase in bamboo strip reinforcement. This might be as a result of the composite material strength being dependent mostly on concrete strength, a similar behaviour to that of oil palm fibre reinforced concrete reported by Salau and Sadiq (2001).

A comparison of the first crack loads with the ultimate failure loads showed that the bamboo imparted post-cracking strength to the columns. For example, the first crack loads are 276kN, 240kN, 227kN, and 200kN for 4No., 6No., 8No. and 12No. bamboo strips reinforced concrete columns respectively, while the corresponding ultimate loads are 332kN, 357kN, 270kN and 243kN. This shows increase of 20.3%, 48.8%, 28.9% and 21.5% above the first crack loads. This increase manifested mostly in 6No. bamboo strips reinforced column, sharing more ductility of the concrete section. However, steel reinforced column has crack load of 280kN and the ultimate load of 428kN, about 52.9% increase in the load, meaning that inclusion of bamboo in the column as reinforcement has induced ductility in the section which is an advantage over the unreinforced column but the ductility is less than that produced by the steel reinforcement.

Figure 3 shows that there is a sharp increase in the crack and the ultimate load with 4No bamboo strips compared to unreinforced concrete. With 6no bamboo strips, the cracking load reduced since it depends on the reduced concrete section (reduced) but the ultimate load, corresponding to the post-cracking effect of the additional bamboo strip increased. Thereafter, the load carrying capacity of the section with further increase in the bamboo reinforcement reduced.

3.4 Lateral Deflection Characteristics

The average values of central deflections of the tested columns with increase in loading are shown in Table 2. Figure 4 shows the load-deflection curves of concrete columns reinforced with different numbers of bamboo strips and steel bars.

Deflection was not noticed in the plain concrete up till loading of 160kN and it has the lowest values for deflection of 2mm. The maximum deflection values of 4No.-, 6No.-, 8No.-, and 12No.-strips reinforced columns were 6mm, 11mm, 11mm, and 22mm respectively. Generally, Deflection increased with increase in percentage volume reinforcement. The deflection values for all the bamboo-strip reinforced columns types (except 12No. strip types) were seen to be constant after the values obtained at first crack. Further loading beyond crack load resulted in no increase in deflection, because loadings at this stage were solely carried by the reinforcement (bamboo-strips), indicating the post-cracking strength of bamboo-strip reinforcement. It, therefore, follows that plain concrete (unreinforced) inability to sustain further loading on cracks formation is connected with failure of the concrete. The steel-reinforced column has a high deflection value of 17mm and failure is gradual with only a change of slope after the first crack, depicting good ductile behaviour. The post cracking behaviour of the bamboo-strip reinforced columns is similar to the behaviour of steel-reinforced column. The low modulus of elasticity of the bamboo account for the excess deflection of the bamboo-strip reinforced column over steel-reinforced column, as seen in Figure 4. This is most pronounced in the 12no.-strip reinforced column, which shows large deflection at failure, accompanied by wide cracks as shown in figure 5.

4. Conclusion and Recommendations

In this work, strips of coated seasoned bamboo of cross-section 8x10mm were used as reinforcement in concrete column. Different percentage volume of the bamboo reinforcement was considered with unreinforced and steel reinforced column.

Based on the experimental observation, the following can be deduced:

i The tensile stress of seasoned bamboo is about 70N/mm^2, about one-third of that of steel, with low ductility and a total strain of 5% compared with an average strain in steel of 12%.

ii The use of bamboo-strip as reinforcement in concrete column increased the load carrying capacity of the column compared to unreinforced concrete. It also improves the post cracking ability of the concrete but not as pronounced as in steel-reinforced column. Increase in volume content of bamboo strip reinforcement in the concrete section does not correspond to increase in the ultimate strength but only enhanced the ductility of the section.

iii Failure mode is independent of the materials used for reinforcement but rather on the strength of the reinforcement/concrete matrix. Hence, attention should be on enhancement of the reinforcement/concrete matrix bond.

iv The bamboo-strip reinforced column shows excessive cracking and deflection especially those with 12No.-strips.

In conclusion, the use of bamboo strips as reinforcement in column should not be for the purpose of imparting compressive strength but rather to induce elasticity in the concrete section, which in turn guide against sudden failure.

Secondly, bamboo strips lack grips in concrete and deteriorate with age. The application of impervious surface coating like bitumen makes it more resistance to deterioration and sand coating further increase the bonding, which in turn translates to good strength. Therefore, the bamboo reinforced concrete column is recommended for lightly loaded structures and low rise constructions. However, it may not be suitable in water retaining structures because of the large deflection accompanying its failure.

It is recommended that further investigation be carried out on bamboo strip reinforced concrete design, focusing on the determination of the optimum percentage of reinforcement.

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Table 1. Average cracking and ultimate loads of bamboo reinforced concrete columns

COLUMN CHARACTERISTICS	Types of Reinforcement					
	No reinforcement (Plain)	Bamboo Reinforced Concrete				Steel Reinforcement
		4No. Bamboo Strips	6No. Bamboo Strips	8No. Bamboo Strips	12No. Bamboo Strips	4No. 12mm Steel reinforcement
Cracking Load (kN)	160	276	240	227	200	280
Ultimate Failure Load (kN)	160	332	357	270	243	428
Central Defl. at cracking load (mm)	2.0	6.0	11.0	11.0	16.0	8.0
Central Defl. at failure load (mm)	2.0	6.0	11.0	11.0	22.00	17.0

Table 2. Load-deflection values for unreinforced, bamboo reinforced and steel reinforced column

Load (kN)	Average deflection (mm) at centre of column					Unreinforced Concrete
	Bamboo strip reinforced concrete with				Steel reinforced concrete with 4Y12	
	4No. strips	6No. strips	8No. strips	12No. strips		
20					-	
40	2.0				-	
60	2.0	6.0	1.0		-	
80	3.0	6.0	4.0	7.0	4.0	
100	3.0	6.0	8.0	10.0	5.0	
120	3.0	7.0	10.0	12.0	5.5	
140	3.0	7.5	10.5	14.0	6.0	-
160	4.0	9.0	10.5	14.0	6.5	-
180	4.0	9.0	11.0	14.0	7.0	-
200	4.0	9.0	11.0	15.0	7.0	-
220	4.0	10.0	11.0	15.0	7.5	-
240	4.5	10.5	11.0	16.0	8.0	1.0
260	5.0	11.0	11.0	16.0	8.0	1.5
280	6.0	11.0	11.0	22.0	8.0	2.0
300	6.0	11.0	11.0	22.0	10.0	
320	6.0	11.0	11.0		12.0	
340	6.0	9.0			15.0	
360		9.0			17.0	
380					17.0	
400						

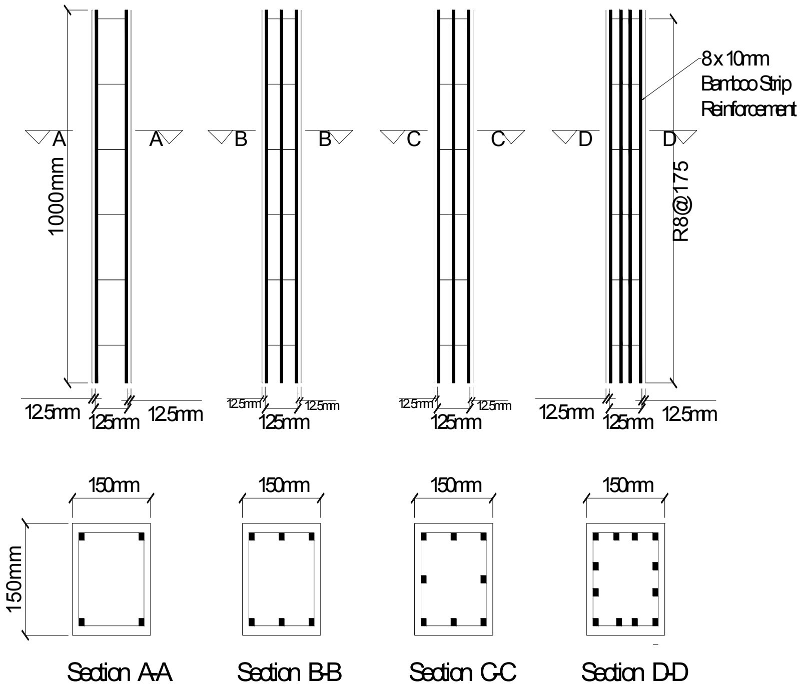


Figure 1. Longitudinal and cross-section of column with varying bamboo strips reinforcements

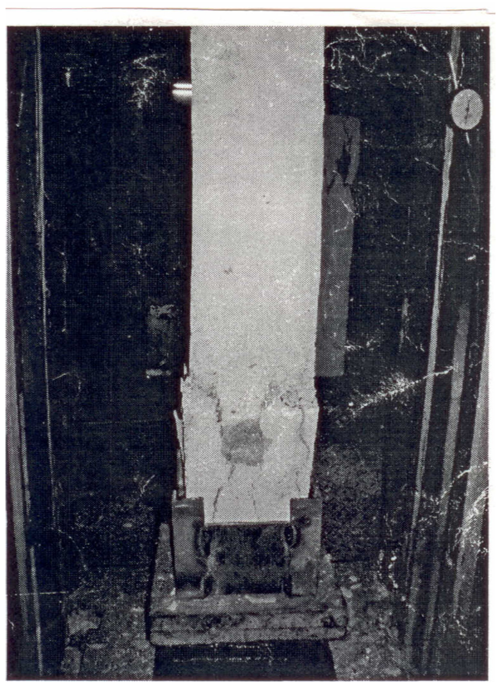
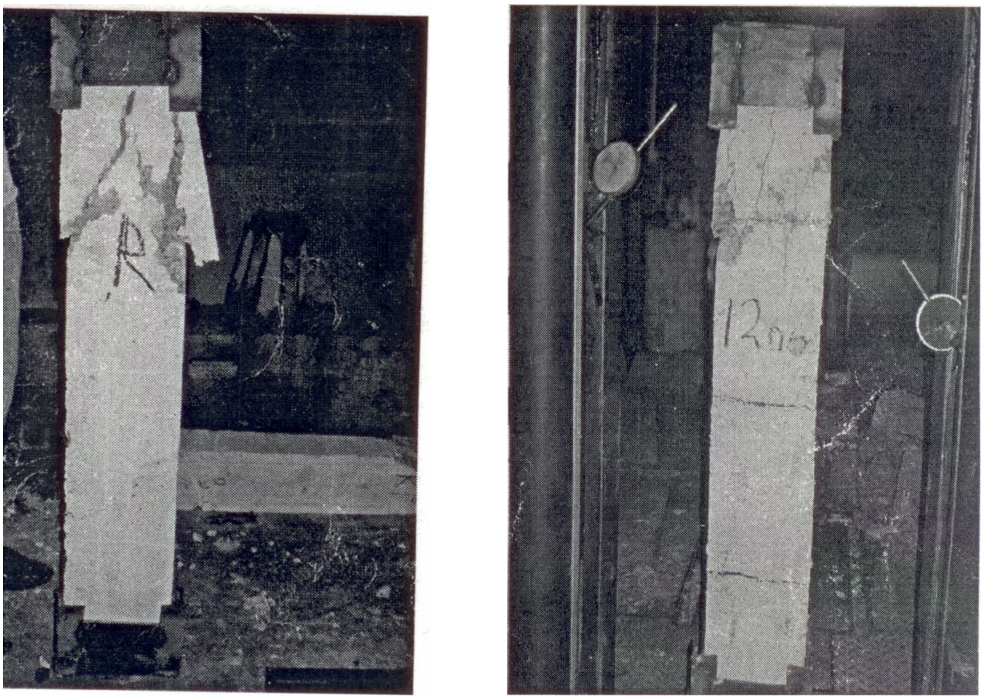


Figure 2a. Cracks generating from ¼ height of column to the centre



(i) (ii)

Figure 2b. Cracks in the (i) bamboo reinforced column over the (ii) steel reinforced

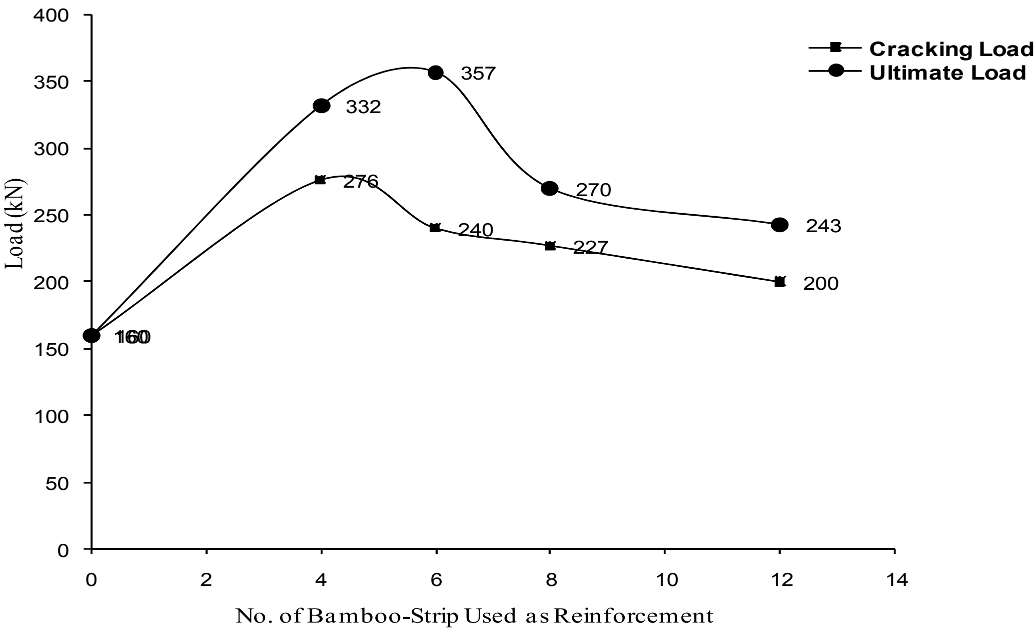


Figure 3. Load capacity-bamboo percentage reinforcement

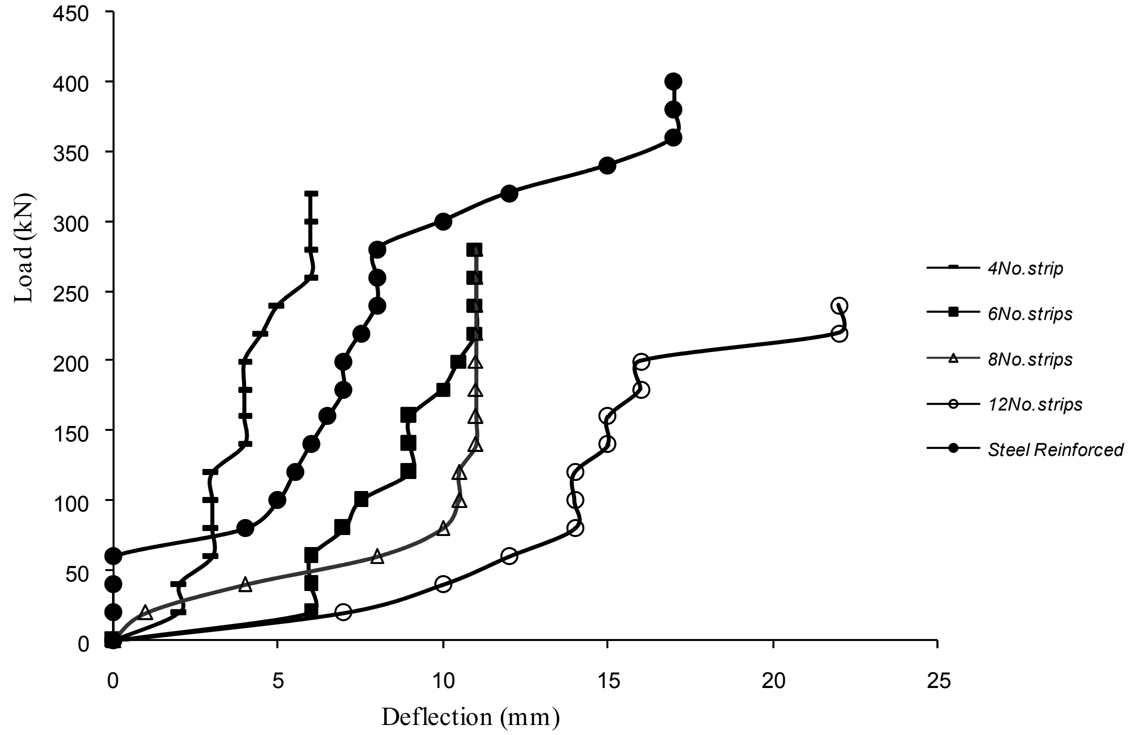


Figure 4. Load-deflection behaviour of different bamboo-reinforced concrete column

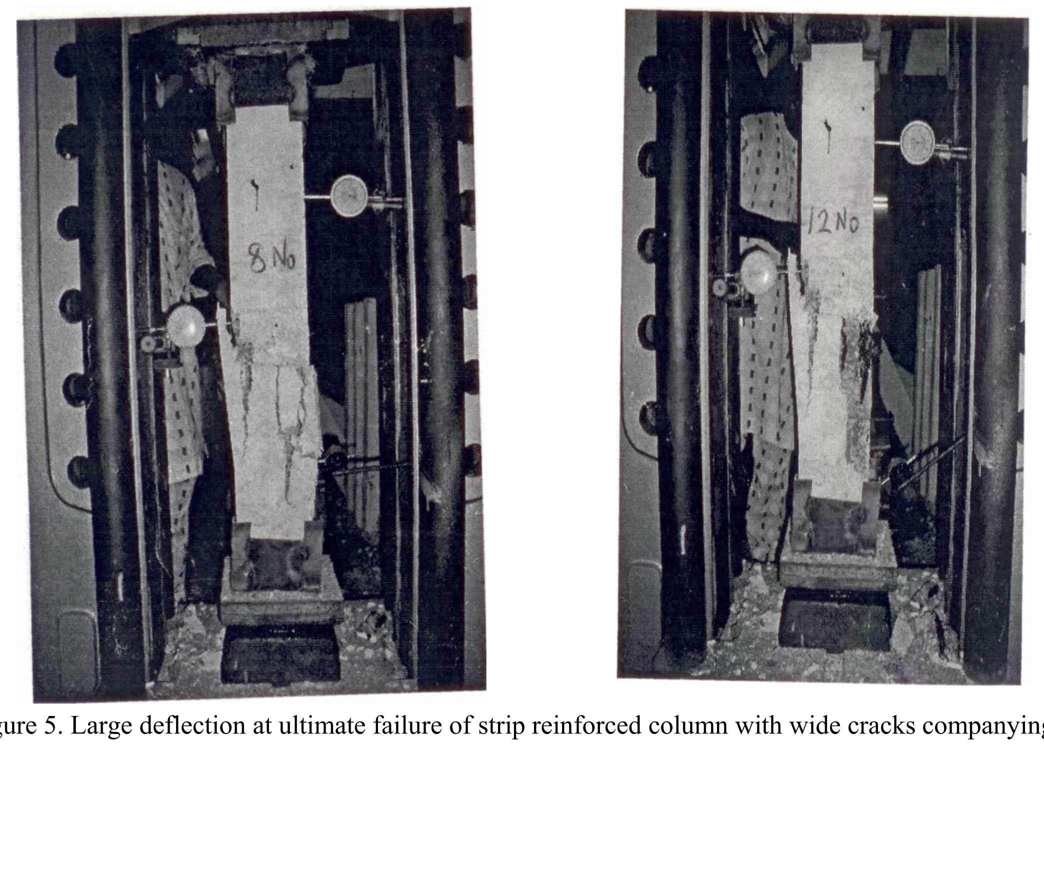


Figure 5. Large deflection at ultimate failure of strip reinforced column with wide cracks companying the failure