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Evaluation of Bamboo Reinforcements in Structural Concrete Member

Ayesha Siddika*, Md. Abdullah Al Mamun and Md. Abu Bakar Siddique

***ABSTRACT:** This study is based on the use and performance of bamboo reinforcements in construction of low-cost structures. This study investigated the physical and mechanical properties of bamboo reinforcements. Bamboo reinforced concrete beam specimens were tested with different reinforcement ratios and observed the load capacity, deflection and failure patterns. It was observed that, flexural strength of bamboo reinforced column is sufficient higher than plain cement concrete and comparable to steel reinforced concrete beams. Bamboo reinforced concrete columns with different reinforcement ratio also tested and observed the ultimate compressive strength and failure pattern. It found, all columns failed in a similar pattern due to crushing of concrete. According to cost analysis, bamboo reinforced beams and columns with moderate reinforcement ratio showed the best strength-cost ratio among plain cement concrete and steel reinforced concrete.*

Keywords: Bamboo reinforcement; Flexural Strength; Compressive Strength; Ultimate Failure;

I. INTRODUCTION

Bamboo is a natural element and available in the rural areas as a huge quantity and easy to use in different sizes. It is very widely used in construction and housing. According to study it is estimated that one billion people in the world live in bamboo houses [1]. Recently bamboos are used as reinforcing material in concrete and to make framing, shoring, scaffolding flooring, walls, roofs and trusses.

In Bangladesh several species of bamboo are prized for their strength and cultivated in villages. These include jai (bambusa vulgaris), barua (bambusa balcooa) and mittinga (bambusa jaintiana). The mechanical properties vary with height and age of the bamboo culm. Research findings indicate that the strength of bamboo increases with age. The optimum strength value occurs between 2.5 and 4 years. The strength decreases at a later age [2].

The objective of this study is to analysis the use of bamboo as reinforcement in structural concrete member. The parameters investigated were: density, tensile strength and modulus of elasticity of bamboo reinforcements, flexural performance of bamboo reinforced beams, cracks and deflection patterns after loading and compressive characteristics of bamboo reinforced columns, strength-cost ratio of bamboo reinforced construction.

II. LITERATURE REVIEW

In the previous research it is obtained that, tensile strength of bamboo reinforcements is comparable with mild steel reinforcements. Yu et al. [3] found the values of tensile strength of bamboo vary from between 115 and 309 N/mm2. Agarwal et al. [4] observed a tensile strength of bamboo is 370N/mm2. Tensile strength of mild steel ranged between 250-415 N/mm2 in accordance with their grade. Therefore, bamboo's tensile strength lies in the range of mild steel. Bamboos can be a replacement of 40 grade mild steel without any question in tensile strength and can be used for low cost structural construction. Research efforts have also been directed towards the development of methodology for bamboo application in space structures and as reinforcement in concrete [5]. Experimental results of Sakaray et al. [6] concluded that bamboo can be used as substitute for steel reinforcement. Adom et al. [7] did a comparative study of bamboo-reinforced beams with some stirrup, to make a suggestion for the most economic low cost construction. The stirrup materials used in the study were cane, bamboo and steel stirrups with bamboo reinforcements is the most economical. Falade et al. [8] analysed the scope of bamboo reinforcement in concrete beams for low-cost housing.

Ghavami [9] showed that the ultimate load of a concrete beam reinforced with bamboo increased 400% as compared to un-reinforced concrete. It was found that, compared to steel, there was lower bonding between the bamboo and concrete, and the bamboo had a Modulus of elasticity 1/15 of steel.

The United States Naval Civil Engineering Laboratory [10] recommended that the amount of Bamboo reinforcement in concrete be 3- 4% of the concrete's cross-sectional area as the optimum amount. It concludes that bamboo reinforced concrete is a potential alternative light construction method at a low cost. Lo et al. [11] and Amada et al. [12] investigated the mechanical and physical properties of bamboo and conducted an investigation into the structure and purposes of the nodes, which they found to strengthen the bamboo culm.

Masani [13] conducted a study and found that the bamboo reinforcement area should be 5 times the typical steel reinforcement area, and that even when fine cracks develop on the surface of bamboo, the load carrying capacity of the member is not reduced. The only negative properties of bamboo given are its susceptibility to attack by insects, fungi and dried bamboo is prone to catch fire.

[1] Department of Civil Engineering, Rajshahi University of Engineering & Technology, Rajshahi-6204, Bangladesh
*Corresponding Author: E-mail: ayesha.ruet@yahoo.com; Co-Author E-mail: mamun_05ce7@yahoo.com; siddique050012@gmail.com

Amada et al. [2] studied the fracture properties of bamboo and states that the tensile strength of Bamboo fibers almost corresponds to that of steel. Janseen [14] conducted her study and found that, the bonding between bamboo and concrete is considered the biggest problem due to absorption of water and smooth wall of the bamboo culm.

Therefore, investigation of locally available bamboo reinforcements in tension and compression member of concrete with cost analysis is the major concern of this study.

III. Experimental Investigations

A. *Physical and Mechanical Properties of Bamboo Reinforcements*

A-1. Selection of Bamboo and Specimen Preparation

Bambusa balcooa which is named as 'Borak Bash' in Bangladesh were used in this study for testing the performance as reinforcing material. Three- four years old defect free dry bamboos were selected for testing purpose. At first bamboos were splitted into several pieces of 14 mm diameter straight sticks of 1-1.5 m length. Then rounded with smooth diameter of 12 mm (Figure I). To compare, steel reinforcements of 12 mm diameter 40 Grade bar was also tested.

FIGURE I
Bamboo Reinforcements

A-2. Unit Weight of Bamboo Reinforcements

Unit weight of bamboo specimens were calculated by standard method of determination of unit weight. The results found is listed in Table I.

TABLE I
Unit weight of Bamboo and Steel Reinforcements

Sample No.	Length, m	Diameter of Bar, mm	Weight, kg	Unit Weight, kg/m^3	Average Unit weight, kg/m^3
Bamboo-1	0.3	12	0.027	795	770
Bamboo-2	0.3	12	0.026	780	
Bamboo-3	0.3	12	0.025	735	
Steel-1	0.3	12	0.267	7860	7870

A-3. Tensile strength of Bamboo Reinforcements

Specimens of 12 mm diameter and 0.3 m length were used to determining tensile strength properties. To eliminate gripping problem in tensile strength testing of specimens using UTM, GI wires (1 mm diameter) were bonded spirally at both ends of the specimen. Three specimens were tested to determining the yield strength and modulus of elasticity of bamboo reinforcements. The results obtained for Sample Bamboo-1, Bamboo-2 and Bamboo-3 are figured in Figure II-IV respectively.

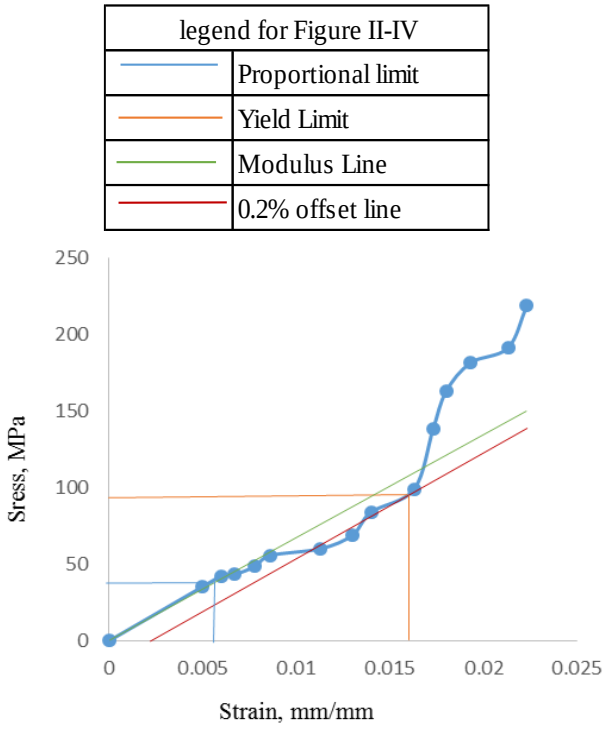

FIGURE II
Stress-strain relationship of sample 1

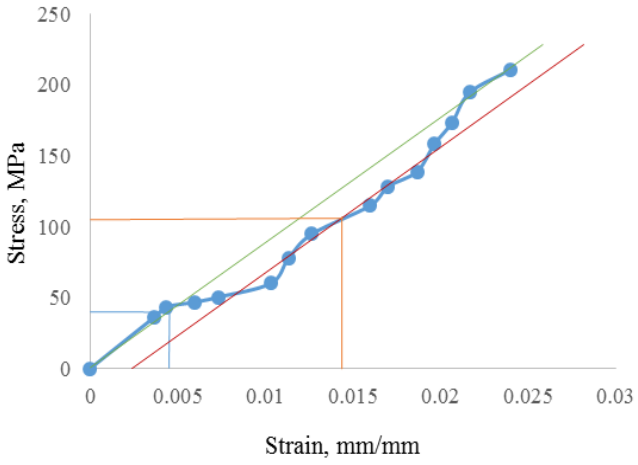

FIGURE III
Stress-strain relationship of sample 2

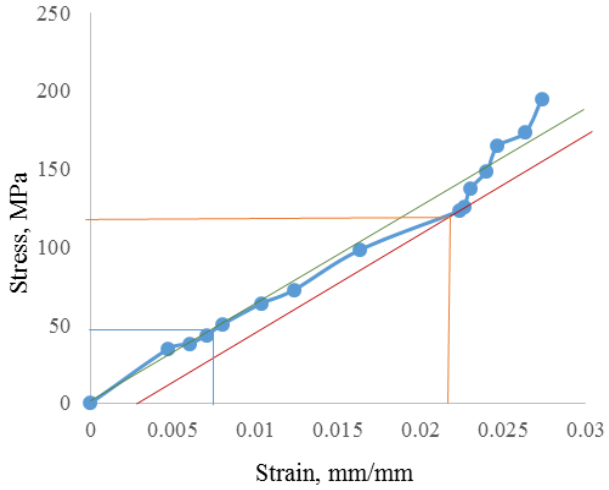

FIGURE IV
Stress-strain relationship of sample 3

From Figure II, III and IV by offset of 0.002 strain yield strength and modulus of elasticity of samples were estimated and listed in Table II.

TABLE II
Modulus of Elasticity of Bamboo Reinforcements

Sample No.	Yield Strength, Mpa	Average Yield Strength, Mpa	Modulus of Elasticity, Mpa	Average Modulus of Elasticity, Mpa
Bamboo-1	95	105	5920	6500
Bamboo-2	105		8000	
Bamboo-3	117		5600	
Steel-1	300	300	200000	200000

A-4. Compressive strength of concrete

Cylindrical specimens were tested under compression (Figure V) to measure the compressive strength of used concrete. The mixing proportion of concrete mix and the results found in compressive strength is listed in Table III and Table IV respectively. Modulus of elasticity of concrete was calculated from the empirical formula Ec = 4700√fċ in MPa.

TABLE III
Mixing Proportion of Concrete

Concrete Specimen M20 (1:2:3) w/c= 0.50		
Cement, kg/m^3	Sand, kg/m^3	Brick Chips, kg/m^3
185	371	555

TABLE IV
Compressive Strength of Concrete

Specimen	Compressive strength after curing , N/mm^2			Modulus of Elasticity, N/mm^2
	7 Days	14 Days	28 Days	
Concrete M20	15.3	18.2	23.9	22977

FIGURE V
Compressive Strength Testing of Concrete

B. Experimental Investigation of Bamboo Reinforcements
B-1. Flexural Strength of Bamboo Reinforced Concrete Beam

Plain cement concrete beam, bamboo reinforced concrete beam and steel reinforced concrete beams were casted to test their flexural strength. 2 mm diameter mild steel wires were used to bind the reinforcements for each type of beam as stirrup with spacing 150 mm. Constitutes and properties of beam sections are listed in Table V.

After casting all the specimens hardened and cured for 28 days and the flexural test were performed in accordance with IS: 516-1959 [15] only the span of beam kept different. Preparation of reinforcement for beam and column specimen is given in figure VI.

FIGURE VI
Bamboo Reinforcement binding for Beam and Column Specimens

In the test, with the help of loading gauge and deflection dial gauge which was fitted on center of beam, deflection of beams under each load were recorded. After that load deflection curve has been plotted and maximum bending moment and flexural strength calculated. The load deflection curve obtained for the beam specimens were shown in Figure VII. From the test results and the graphical representation the maximum load on center of each beam specimens and the maximum deflection at failure load is listed in Table VI. The maximum bending moment at the center of beam and flexural strength corresponding maximum load was calculated and listed in Table VI.

TABLE V
Constitutes and Properties of Beam Specimens

Types of Beam	Plain Concrete (PCC-B)	Steel Reinforced Concrete (SRC-B)	Bamboo reinforced concrete	
			BRC-B1	BRC-B2
Size of Beam	150 mm ×150 mm× 1000 mm	150 mm ×150 mm× 1000 mm	150 mm ×150 mm× 1000 mm	150 mm ×150 mm× 1000 mm
Grade of Concrete	M20 (1:2:3) w/c = 0.50	M20 (1:2:3) w/c = 0.50	M20 (1:2:3) w/c = 0.50	M20 (1:2:3) w/c = 0.50
Reinforcement types	No Reinforcements	No 4 bar 40 Grade Steel	Bamboo sticks of 12 mm diameter	Bamboo sticks of 12 mm diameter
Percentages of Reinforcement	0	1%	1%	1.5%
Total Reinforcement	0	2 reinforcements	2 reinforcements	3 reinforcements
Clear Cover	25 mm	25 mm	25 mm	25 mm

TABLE VI
Flexural Strength of Beam Specimens

Types of Beam	Maximum load on center of Beam, kN	Maximum deflection at Centre of Beam, mm	Flexural Strength, MPa	Bending Moment, kN-m
PCC-B	25.0	1.9	6.67	3.75
BRC-B1	33.12	3.5	8.8	4.97
BRC-B2	45.33	3.8	12.08	6.8
SRC-B	54.38	4.2	14.5	8.2

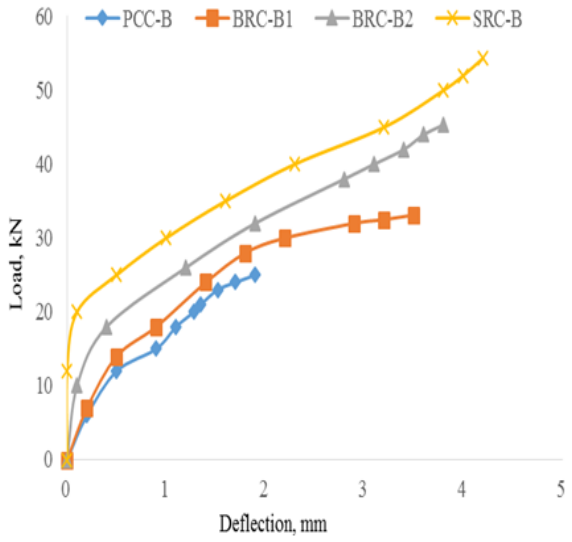

FIGURE VII.
Load-Deflection Curve of Beam Specimens

B-2. Ultimate Load Capacity of Bamboo Reinforced Concrete Column

Plain cement concrete column, bamboo reinforced concrete column and steel reinforced concrete column were casted to test their compression carrying capacity. 2 mm diameter mild steel wires were used as tie bar with spacing 150 mm for each type of reinforcement. Constitutes and properties of beam sections are listed in Table VII.

The casted specimens in the moulds were stored for 24 hours for hardening and then cured until 28th day. Compression tests of specimens were done in accordance with BS 1881 Part 120 [16], using Universal testing machine. Dial gauges used to measure central horizontal deflection. The readings of the dial gauges were recorded before and after every increment of load. During the testing, deflections at center of column were recorded while the pattern of cracks and mode of failure were monitored with the increased load for each type of column. The load deflection relationship of each column specimens can be shown using Figure VIII and listed in Table VIII.

TABLE VII
Constitutes and Properties of Column Specimens

Types of Column	Plain Concrete (PCC-C)	Steel Reinforced Concrete (SRC-C)	Bamboo reinforced concrete	
			BRC-C1	BRC-C2
Size of column	150 mm ×150 mm× 1000 mm	150 mm ×150 mm× 1000 mm	150 mm ×150 mm× 1000 mm	150 mm ×150 mm× 1000 mm
Grade of Concrete	M20 (1:2:3) w/c = 0.50	M20 (1:2:3) w/c = 0.50	M20 (1:2:3) w/c = 0.50	M20 (1:2:3) w/c = 0.50
Reinforcement types	No Reinforcements	No 4 bar 40 Grade Steel	Bamboo sticks of 12 mm diameter	Bamboo sticks of 12 mm diameter
Total Reinforcement	0	4 reinforcements	4 reinforcements	6 reinforcements
Clear Cover	12.5 mm	12.5 mm	12.5 mm	12.5 mm

TABLE VIII
Compressive Strength of Column Specimens

Types of Column	Cracking Load, (kN)	Ultimate Failure Load (kN)	Maximum Deflection at failure load (mm)	Ultimate Compressive Strength, MPa
PCC-C	205	205	2	9.1
BRC-C1	245	298	8	13.2
BRC-C2	288	321	9	14.3
SRC-C	284	410	15	17.3

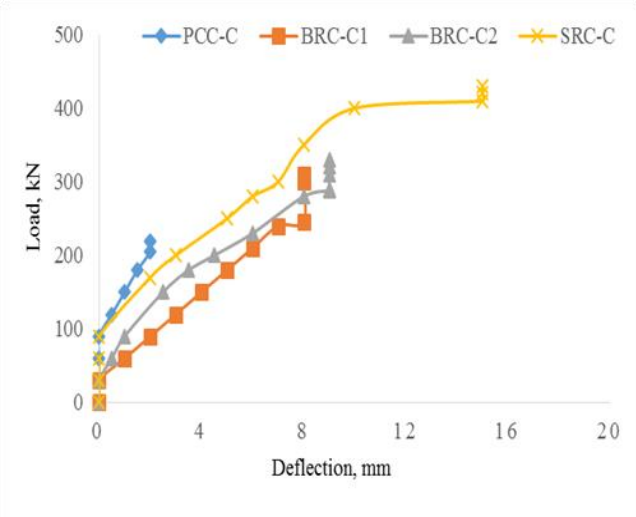

FIGURE VIII
Load-Deflection Curve of Column Specimens

IV. BAMBOO AS REINFORCEMENT IN STRUCTURAL MEMBER

1. Bamboo reinforcement in flexural member

According to flexural test results, the beam of plain cement concrete can carry maximum 25 kN load at center and failure occur at 1.9 mm deflection at center of beam specimen. But for same condition when the beam reinforced with two bamboo reinforcements of 12 mm diameter it got 32% more strength and failure occur at deflection 3.5 mm. When using three bamboo reinforcements, it got 80% more flexural strength. It is previously studied that cost of bamboo reinforced beam is relatively low as per strength requirements with comparing plain cement concrete beam with small span. Steel reinforced concrete beam is superior to than other in terms of strength but, when low cost and low self-weight construction needed, it reminds bamboo reinforced construction. The failure mode of specimens are shown in Figure IX.

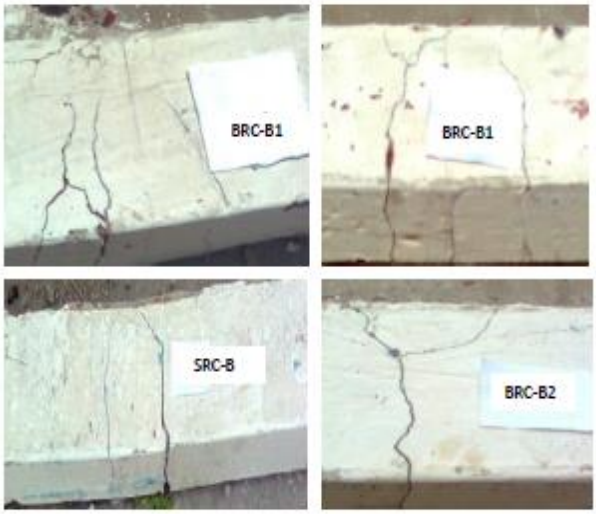

FIGURE IX
Cracked Beam Specimens after Application of Maximum load

2. Bamboo reinforcement in compression member

Compression test of column specimens shows that, the plain cement concrete column can withstands a very small deflection and fails immediately after cracks generates. But when it can be reinforced with four bamboo strips of 12 mm diameter with tie of 2 mm mils steel wire it can withstands a large deflection and can carry 45% more compression. By increasing bamboo reinforcements in column, it can be acquire more strength as per requirements in construction. It is practically proved that

steel reinforced column can withstands large deflection due to its high modulus of elasticity, but cracking starts in bamboo reinforced column and steel reinforced column at nearly same compressive load. Failure mode of columns depends on the properties of concrete not the types of reinforcements, but the post cracking behavior is different.

3. *Strength-Cost Analysis of Bamboo Reinforced Member*

The strength to cost ratio of each specimen is listed in Table IX-X. It shows that, the highest strength obtained from beam BRC-B2 in respect of cost. Strength to cost ratio is higher than steel reinforced beam also, therefore to obtain high strength cost ratio bamboo reinforced beam is superior to the others.

TABLE IX
Strength to Cost Ratio of Beam specimens

Types of Beam	Flexural Strength, MPa	Cost Per Specimen, Tk.	Strength to Cost Ratio	Percent of PCC-B
PCC-B	6.67	150	0.044	1
BRC-B1	8.8	170	0.052	1.18
BRC-B2	12.08	180	0.067	1.52
SRC-B	14.5	225	0.064	1.45

For column specimens the total compressive strength greatly depends upon property of concrete, not the types and quantity of reinforcement primarily. Therefore for the short span column strength cost ratio of column specimens is not very high than PCC-C. It is noticeable that, the strength cost ratio of steel reinforced concrete is lower than that of plain concrete, because only a small part of reinforcement is carrying compression.

TABLE X
Strength to Cost Ratio of Column Specimens

Types of Column	Ultimate Compressive Strength, MPa	Cost Per Specimen, Tk.	Strength to Cost Ratio	Percent of PCC-C
PCC-C	9.1	150	0.061	1
BRC-C1	13.2	185	0.071	1.16
BRC-C2	14.3	195	0.073	1.2
SRC-C	17.3	310	0.056	0.91

4. *Recommended use of Bamboo Reinforcements*

According to study by researchers in world, in next 60 years steel production will be reduce hence a utilization of natural and ecofriendly options like bamboo should be used [1]. Compression strength of round bamboo ranges from 47.9 to 69.9 Mpa and they are weak in shear [1]. Plain concrete and untreated bamboo columns showed brittle behavior in which, tiny cracks occurred at the surface of the column at about 80% of maximum axial force [4, 17]. Use of bamboo as reinforcement may lead to economy as compared to structures reinforced with steel; thereby overall cost of construction can be reduced (10-20%) [18]. Strength-Cost ratio of bamboo is more than nine times higher than that of steel [19]. From these recommendations of researchers it is cleared that, bamboo reinforced structures is safe and economical for moderate strength construction.

5. *Limitations of Bamboo Reinforcements and Their Probable Remedies*

The main problem associated with using bamboo reinforcements in concrete structure is high water absorption of bamboo and minimize continuous water absorption waterproofing agent is recommended [1]. The increase in volume of bamboo is found after absorbing water in the concrete, which progressively caused loss in bond strength [20]. Actually bond strength of bamboo reinforcements with concrete is very lower comparing to mild steel reinforcements. Therefore, it cannot be used in high rise structures where heavy imposed loads present [21]. Resistance to seismic forces in bamboo housing system is very less as compared to the modern housing system [22]. Because it possesses low stiffness compared to mild steel reinforcements. Bamboo has a low modulus of elasticity compared to steel, which will caused cracking in concrete in short time. Therefore design life of bamboo reinforced concrete is much less than steel reinforced concrete.

Bamboo reinforcements can be used by painting some waterproofing paint having sufficient bonding capacity with concrete to reduce the water absorption. For improving bond strength gripping with steel wire was recommended by researchers previously.

Bamboo needed to dry after cutting for seasoning purpose about 3-4 weeks [23], which cannot allows always to prevent constructional delay. If seasoning was not done properly, it will possesses lower strength in structure.

Although bamboo is vulnerable to environmental degradation and attacks by insects and moulds [5]. One major shortcoming of bamboo reinforcements is fire susceptibility. Therefore, bamboo reinforced concrete elements is suitable for low rise economic structures.

V. CONCLUSIONS

This study gives bamboo as a potential material to be used as reinforcement for low load bearing structures. Based on the experimental observation, the following can be concluded:

1. The yield strength of bamboo reinforcements is about 105 N/mm^2, about one-third of that of steel, with low modulus of elasticity.
2. The load carrying capacity and flexural strength of the BRC beams are found much better with respect to plain cement concrete beam. It was found 32% more strength than PCC beam when using only two bamboo reinforcements of 12 mm diameter.
3. Deflection of PCC beams is higher with respect to BRC beams at same loading condition and after

initial crack BRC beams can withstands a large deflection than PCC beams before failure.

4. Compression carrying capacity depends greatly on properties of concrete and bonding between reinforcements and concrete. BRC column can resist more compression than PCC.
5. PCC columns cannot resist deflection after cracking, but BRC columns withstands a large deflection after cracking starts.
6. Steel reinforcements has a great bond strength with concrete than BRC, therefore SRC structures can resist more deflection and compression than others.
7. Gaining better strength with low cost rate BRC is superior to the others at same conditions. For moderate loaded structures BRC construction is more economical.

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