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Bamboo Reinforced Concrete Slabs for Fence Walls

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Abstract

The construction industry consumes large quantities of steel and emits carbon which is a dampener for sustainable growth all over the world. As an alternative to steel, bamboo and rattan cane have been tried as reinforcement in different countries on a very small scale only. This work aims at exploring the methods of adopting bamboo reinforced concrete slabs for erecting fence walls in rural parts of south-India. Presently, fence walls are erected using steel reinforced concrete (SRC) slabs which are cast as a cottage industry, without adhering to any specification. Twenty five (25) bamboo reinforced concrete (BRC) slabs of size 1000 mm by 300 mm by 50 mm (length: width: thickness) were cast in the laboratory using M20 mix ratio. The slabs were tested using (a) ultrasonic instrument and (b) universal testing machine to assess the quality of concrete and deflection values respectively. As a comparative study these tests were repeated on SRC slabs, procured from a vendor. The results reveal that the quality of concrete in BRC slabs was better than that of the SRC slabs. The BRC slabs failed at approximately 50% of the magnitude of load taken by SRC slabs at failure. The deflection and the crack width also followed the same trend. The cost analysis performed indicates that BRC slabs are cheaper by 25 to 30%. Therefore, it is recommended to adopt BRC slabs for erecting fence walls by which more bamboo will be grown, leading to a sustainable growth of the environment.

Keywords: Bamboo, concrete, cost analysis, crack width, deflection, steel, sustainable growth

1. Introduction

Bamboo is known as poor man's building material and abundantly found in Southeast Asia and in other countries. Southeast Asia is one of the most populated regions in the world and low-cost houses are increasingly in demand. Uses of bamboo in the construction industry are scaffolding, trusses, low cost dwellings in earthquake prone hilly regions and many other engineering applications since pre-history days. Recently, in many parts of the world, bamboo has been tried as an environmentally sustainable building material. The significant feature of bamboo is its immense vitality and one particular species has been known to grow over 1.25 m in 24 hours. Bamboo grows well in light-sandy soil with good draining facilities for excess water. The advantages of bamboo are:

a) Possesses high tensile strength when compared to steel, which makes it as a suitable reinforcement material.

b) It is an extremely light-weight material and the progress can be achieved without the necessity of skilled craftsmen and heavy machinery, such as cranes.

c) It is a versatile shock absorbing material which makes its application useful in the construction of lightweight houses in seismically active hilly regions.

d) It is a sustainable and renewable material due to its exceptionally fast growth.

e) The transportation costs are very minimal when compared to other construction related materials.

However, there are few disadvantages, such as:

a) Bamboo is made up of starch and this requires proper treatment with appropriate chemicals prior to using for construction purposes.

b) Bamboo is stronger only at the nodes and it does not contain cross fibres, thus becomes width-wise weaker.

c) Possesses low modulus value.

It is worthy of note that in spite of these drawbacks, the maximum advantages of bamboo can be achieved with a pretreatment of fungi. Ironically, at places where strong varieties of bamboo suitable for the construction industry are abundantly available, yet the utilization as an alternative to steel is very meagre.

1.1 Steel Reinforced Concrete Slabs for Fence walls

Concrete slabs of dimension 1000 mm x 300 mm x 50 mm (length : width : thickness) with 6 mm diameter mild (or smooth) steel as reinforcement are increasingly being used to erect fence walls replacing the traditional barbed wire or other type of fences, especially in rural and semi-urban parts of Tamil Nadu (a state in South India). A typical fence wall erected using steel reinforced concrete (SRC) slabs is shown in figure 1. The advantages of this type of slab are:

a) Reusable.

b) Skilled labour is not required, erection time is short and economical compared to other type of fences.

c) More safety and privacy for individual households.

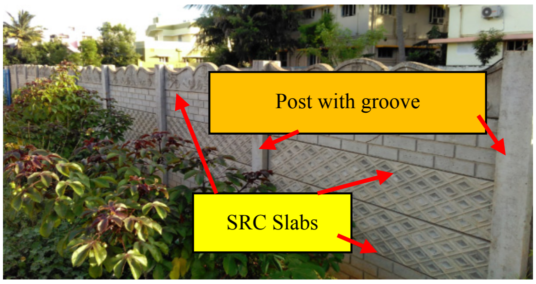


Figure 1. Fence wall with SRC slabs

Erection of fence walls using SRC slabs has become a cottage industry without adhering to any specification or quality control tests. Interestingly, the length and width of the slab vary from place to place (custom made) whereas, the thickness remains a constant (= 50 mm). A survey conducted at 25 such cottage industries, reveals that 1000 mm x 300 mm x 50 mm slabs with 6 mm diameter mild steel as reinforcement are most common and weekly production of each industry varied between 100 to 750 units, based on the facilities available for casting. This large scale fabrication and the associated depletion of fossil fuels, stimulated to investigate the use of locally grown bamboo as a replacement for steel in erecting fence walls. Casting bamboo reinforced slabs and testing them, using ultrasonic instrument and universal testing machine, after the stipulated curing period is the main objective of the present study. Also comparing the test results of BRC slabs with that of the commercially available steel reinforced concrete (SRC) slabs and cost analysis of the two types have been performed.

Several researchers have conducted investigations on bamboo as reinforcement with an intention to find a replacement for steel in the construction industry. (Glenn 1950; Francis & Paul 1966; Low 1988; Ghavami 1995; Ghavami 2005). Glenn’s pioneering work on bamboo as an alternative to steel has led to far reaching contributions on the engineering applications in the construction industry. Janssen (1991) reported the existence of weaker bonding characteristics between bamboo and concrete wherein such a behaviour is not found between steel and concrete. Bamboo starts shrinking and drying during the process of hardening of concrete, which is not encountered when steel, is used as reinforcement. Also this study confirms that the magnitude of shrinkage in bamboo is of the order of four times as that of concrete. The major disadvantage with bamboo is that as soon as concrete is poured, bamboo swells setting the concrete to dry and this restricts the performance of the composite structure. Akinyele & Aresa (2013) conducted a comparative study on short struts of dimension 150 mm x 150 mm x 300 mm using three different types of reinforcement, namely, steel, bamboo (Bambusa vulgaris) and rattan cane. The findings reported that with respect to cracking, struts with bamboo performed better than the struts made of steel and rattan. Mark & Russel (2011) made a comparative study of sixteen (16) beams. Four beams each were cast with bamboo, rattan and steel as reinforcement respectively. However, the last four beams had no reinforcement. The findings showed that bamboo reinforced beams performed better than unreinforced sections. Falade & Ikponmwosa (2006) studied the application of bamboo reinforcement in concrete beams for the purpose of constructing low-cost houses. The investigation showed that the computed deflection in beams with bamboo reinforcement was directly proportional to the applied moment and a reduction in deflection was noticed as the quantity of bamboo reinforcement was increased. Salau et al. (2012) studied the use of bamboo as reinforcement in 150 mm x 150 mm square columns with height as 1000 mm. Six (6) such columns were fabricated, out of which four (4) consisted of varying number of bamboo (4, 8 and 12) strips as reinforcement, the fifth was with steel and the last column had no reinforcement. The last two columns were used as controls for the bamboo reinforced columns. The bamboo splints were coated with bitumen to achieve better bonding. The findings showed that bamboo reinforced columns had more load carrying capacity in comparison to the column with no reinforcement. The researchers also suggested for further investigation, to determine the optimum percentage of reinforcement with bamboo. Khan (2014) studied the behaviour of eight (8) slabs of dimension 1000 mm x 1000 mm x 50 mm. The first six (6) slabs were reinforced with bamboo and the last two slabs consisted of steel as reinforcement. The shapes of bamboo reinforcement made were circular, square and triangular. Among the six (6) slabs, two slabs each were provided with circular, square and triangular shape reinforcements. The slabs were tested as simply supported with concentrated load applied at the centre. The findings showed that the load carrying capacity of slabs with square shaped reinforcement was higher than that of the slabs with other two shapes of reinforcement. Further it was reported that the deflection of the slabs reinforced with square shaped bamboo was lesser than the other two shape of reinforcements and 25% less than the slabs with steel as reinforcement. Ghavami (2005) carried out extensive research work involving bamboo as a replacement to steel. Circular and rectangular columns cast with bamboo as reinforcement were tested in a 100 kN capacity steel frame. The bamboo was treated with Sikadur 32-Gel for improving the bond. For comparison purposes, a steel reinforced column with the same concrete mix was used as controls. All the columns, including the control column failed at the same load due to crushing of concrete. The significant outcome of the research was that 3% of the bamboo reinforcement treated with Sikadur 32-Gel would be equivalent to the conventional steel reinforcement for normal concrete as per Brazilian Norms. This researcher further recommended that the awareness on using bamboo as a building material should be taught at undergraduate and postgraduate levels.

1.2 Structural Properties of Bamboo

Bamboo behaves differently unlike steel when used with concrete, since it is a naturally growing plant. All other materials used for structural purposes are man-made and a quality control can always be imposed upon the production (Akinyele & Aresa, 2013). Alade et al. (2004) reported that the tensile strength of a bamboo species varied between 204 and 250 N/mm^2, which was comparable with that of mild steel. The average compressive strength values of bamboo reported by different investigators are given in Table 1.

Table 1. Average value of compressive strength reported

Sl. No.	Average value (N/mm^2)	Researcher(s) and year
1	103.0	Chung & Yu (2002)
2	108.9	Sakaray et al. (2013)
3	109.5	Baldaniya et al. (2013)

The existing literature on bamboo as used in the construction industry reveals that different types of structural elements, such as beams (Francis & Paul, 1966), columns (Ghavami, 2005), slabs and light-weight, low-cost houses (Falade & Ikponmwosa, 2006; Mark & Russel, 2011) have been tested predominantly to provide economic housing essentially for rural people. The utilization of bamboo as a replacement for steel, in erecting fence walls has not been reported in the literature. The significant observation noted from the brief review of literature studied is that bamboo is a potential alternative to steel with an appropriate treatment for bonding with concrete. In tropical and sub-tropical areas, chemically treated bamboo is an ideal material to construct light-weight structures and low-cost dwellings, especially in Southeast Asia, due to its dense population.

2. Experimental Investigation

The different phases of testing involved in the present study are shown in the flow chart. The type of bamboo used was Bambusa balcooa which is a genis of tropical and subtropical clamping variety, usually giant, with numerous branches at a node. The other important characteristics: the maximum height and diameter are 18.3 m and 0.1524 m respectively. The minimum temperature it could withstand is (minus) -7.8 degree Celsius. It is very strong, difficult to harvest and more suitable for engineering applications. Based on the recommendations of many researchers, bamboo showing yellow (or dark brown) colour, with at least 3 to 5 years of age, having the largest diameter was identified. The bamboo was harvested in a farm in March 2015, using a saw to avoid any damage. Subsequently, the whole bamboo was further cut into the required number of pieces of suitable length. Splints of size 960 mm x 16 mm x 8 mm were prepared by splitting the bamboo in order to achieve continuous fibres as shown in figure 2. The splints were air-dried for a period of four weeks, without exposing to direct sunlight. Figure 3 depicts the arrangement of splints. The bent splints were straightened by anchoring them to steel rods as shown in figure 4.

Bamboo in its natural state consists of starch and using it as reinforcement without any preservative, absorbs water from concrete leading to reduction in the bond strength. Also, bamboo if untreated it can easily be destroyed by fungi. Coal tar creosote has been used as the preservative not only to overcome fungi but also to achieve: (a) better performance, (b) corrosion resistance and (c) good protection from termites. Coal tar creosote was mixed with fuel oil in the ratio of 50:50. The air-dried splints were soaked in this mixture in a large tray for 30 minutes approximately. Subsequently, the splints were kept in a vertical position, to drain out the excess preservative, if any. To increase the bonding strength between bamboo and concrete, sand passing through 2.36 mm sieve with a fineness modulus between 3.0 and 3.2 was sprinkled on the chemically treated splints, using a glass funnel with a long stem. The velocity of the falling sand was controlled with a finger. Finally, the bamboo reinforcement was allowed to dry at the room temperature for a period of 24 hours.

The conventional method used in the construction of reinforced concrete was adopted for casting BRC slabs as mentioned by Francis & Paul (1966). The specifications prescribed in IS: 456-2000 and IS: 10262-2009 have been scrupulously followed. The concrete slump should be as low as workability is feasible. Excess water leads to swelling of bamboo. Therefore, high early strength cement was used, with the aim of minimizing swelling. Clean river sand after sieving was used as fine aggregate and for coarse aggregate, crushed granite of 10 mm (maximum) size was chosen. Potable water was used for mixing of the concrete. The details of the concrete mix design are given in Table 2.

Bamboo reinforcement should be placed providing at least 20 mm cover from the outer face of the concrete. For securing better bonding strength between concrete and bamboo, the nodes of the splints were staggered evenly and the outer (smooth) surface was scratched gently using emery paper. This arrangement was to ensure the availability of a uniform cross-section of the bamboo. Further the wedging effect achieved at the nodes simultaneously increased the bonding strength. Bamboo reinforcement was evenly spaced and tied together using binding wire on short sticks placed at right angles to the main reinforcement. The clear spacing provided between any two bamboo splints was equal to the maximum size of aggregate plus 6.35 mm (=25.4/4). This worked out to be 16.35 mm with the maximum size of aggregate used was 10 mm.

2.1 Preparation of Bamboo Reinforced Concrete (BRC) Slabs

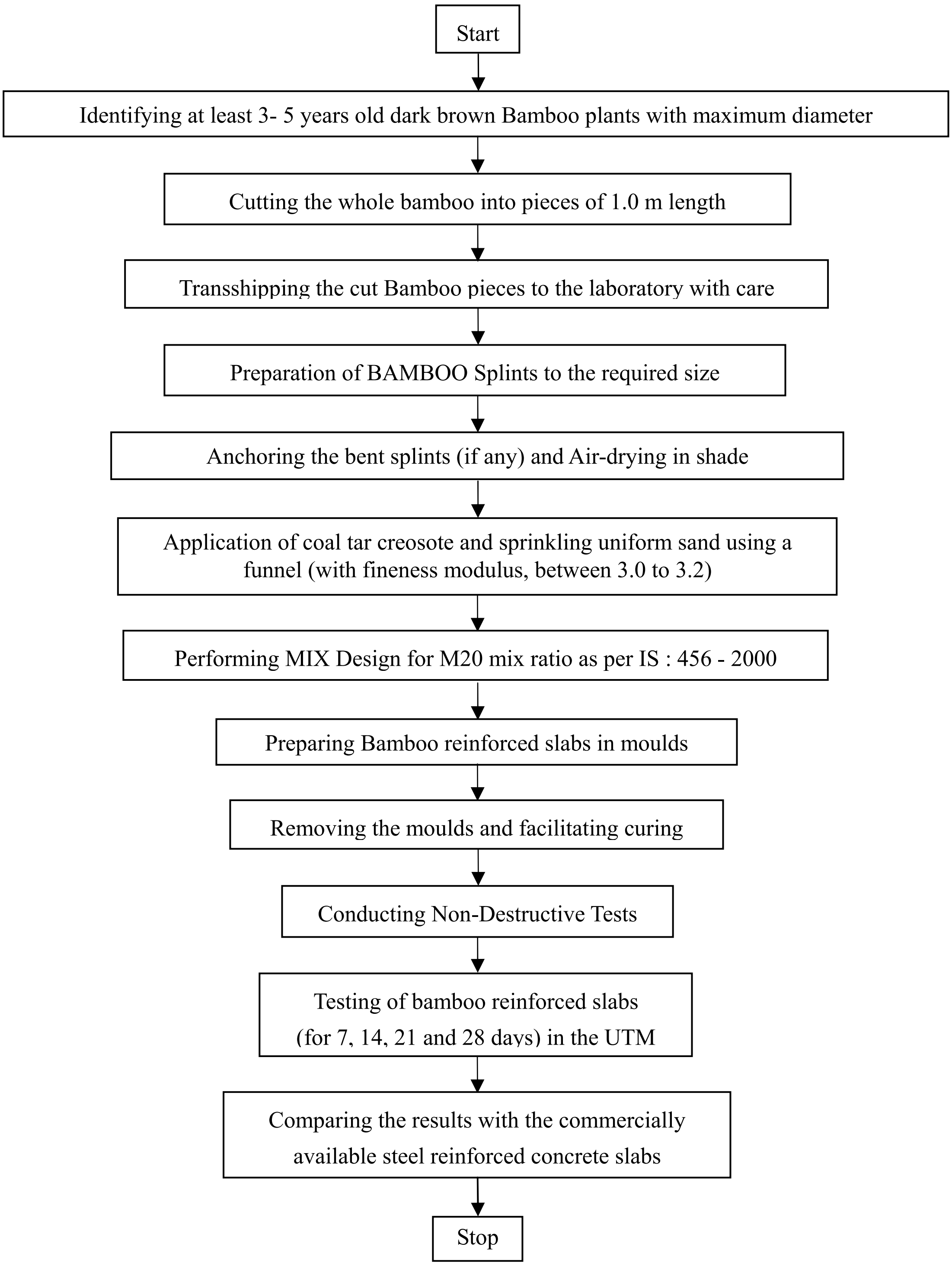
The inner surface of the moulds, were greased with waste engine oil for easy removal of the slab, after setting. Figure 5 shows the preparation of BRC slabs. After 24 hours of casting, they were placed in a curing tank as shown in figure 6.

2.2 Laboratory Tests on BRC Slabs

Two different types of test were carried out on the bamboo reinforced concrete (BRC) slabs, namely Non-destructive test (NDT) using ultrasonic instrument to assess the quality of concrete used and universal testing machine (UTM) to determine the deflection values respectively.

2.2.1 Non-Destructive Test

In the first phase, pulse velocity test was conducted on the bamboo reinforced slabs to assess the quality of the concrete using PUNDIT (Portable Ultrasonic Non-Destructive Digital-Indicating Tester) ultrasonic instrument. Three types of transducer arrangement, namely, direct, semi-direct and indirect or surface methods are available. Generally, the direct method is adopted since this ensures the maximum signal transmission between the transducers (Proceq, 2011). Figure 7 depicts this arrangement and the ultrasonic pulse velocity measured across the length is shown in figure 8.



Flow chart: Steps Involved in preparing Bamboo Reinforced Slabs

Figure 2. Preparation of bamboo splints

Figure 3. Stacked bamboo splints

Figure 4. Removal of bents by anchoring

Table 2. Concrete mix ratio

Sl. No.	Parameter	Results
1.	28-day Compressive strength (N/mm^2)	21
2.	Cement (Kg)	350
3.	Fine aggregate (clean river sand, Kg)	950
4.	Coarse aggregate (crushed granite, Kg)	1060
5.	Water / Cement ratio	0.50
6.	Mix ratio	1:1½:3
7.	Unit weight of Bamboo reinforced concrete (Kg/m^3)	25.5

2.2.2 Compression Test

The bamboo reinforced slabs were tested using a TUN 400, Universal Testing Machine, at the end of 7th, 14th, 21st and 28th day of curing. The computed strength (load divided by area) values shown in figure 9, correspond to average values of 3 tests each. However, 3-day strength could not be established, since the slabs got disintegrated while removing from the curing tank. This emphasizes that at least a 7-day period is required for developing adequate bonding strength between bamboo and concrete. The compression test on every slab was conducted considering it as a simply supported case with equal spacing between the two supports. The nature of the loading was single point load applied at the centre and the deflection was measured using a dial gauge fixed at the bottom centre of the slab as shown in figure 10.

Figure 5. Preparation of BRC slabs

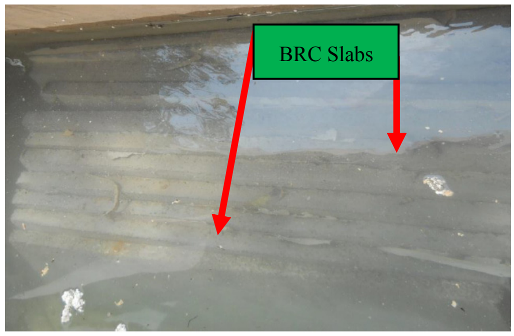


Figure 6. BRC slabs stacked for curing

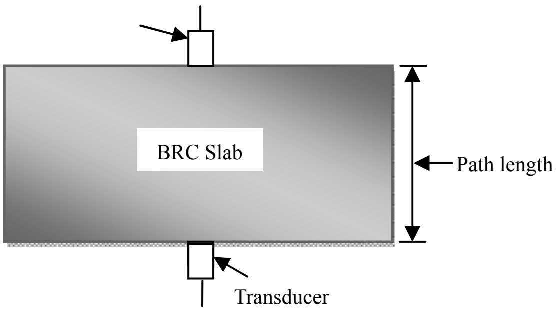


Figure 7. NDT for ‘Direct’ measurement

Figure 8. Ultrasonic test in progress

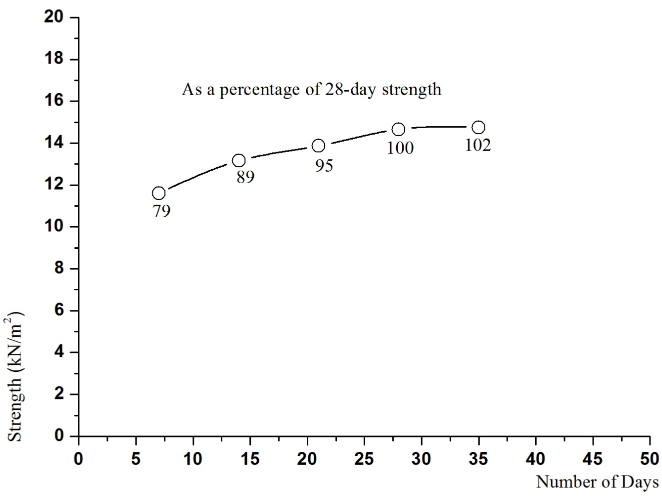


Figure 9. Strength *vs* number of days; BRC slabs

2.3 Laboratory Tests on SRC Slabs

All the tests conducted on BRC slabs were repeated on the SRC slabs, to investigate the relative behaviour of the two types. For this purpose, as many as 25 number of SRC slabs were procured from a vendor. A similar graph as shown in figure 9 could not be drawn due to unavailability of the strength of SRC slabs at the end of 7th, 14th, 21st and 28th day of curing.

3. Results and Discussion

3.1 Ultrasonic Pulse Velocity

The ultrasonic pulse velocity test results obtained on the BRC slabs are given in Table 3. ‘Direct’ measurement of pulse velocity was made at three locations each, across the width and length of each slab. The results showed that with the average velocity values varied between 3883 and 4565 m/sec. This reveals that the concrete used in the bamboo reinforced slabs are of ‘good’ quality (Shetty, 2012).

The ultrasonic pulse velocity values recorded on SRC slabs are given in Table 4. The average values lie in the range of 3140 to 3509 m/sec, showing that the quality of concrete was ‘questionable’ (Shetty, 2012). This confirms that no specification has been followed.

Table 3. Ultrasonic pulse velocity values for BRC slabs

Slab No.	Time taken across x 10^{-6} (sec)		Velocity value across (m/sec)		Remarks
	width (= 300 mm)	length (= 1000 mm)	width	length	
1.	68.1*	257.5	4405*	3883	*Sensors placed*
	70.5	249.8	4255	4003	*for ‘Direct measurement’ [Refer*
	66.5	253.8	4511	3940	*Figs.7 and 8]*
2.	68.25	250.0	4395	4001	*(1)Mean velocity across the width =*
	70.30	252.4	4265	3962	*4351 m/sec.*
	66.50	253.2	4510	3950	
3.	73.2	250.3	4100	3996	*(2)Mean velocity across the length =*
	72.3	245.1	4152	4080	*3980.6 m/sec.*
	65.7	249.4	4565	4010	

*Specimen calculation:

Width of the slab : 300 mm

Time taken to travel across the width : 68.1 μ Sec. $= 68.1 \times 10^{-6}$ Sec.

Therefore, Velocity, V : $\frac{\text{Distance}}{\text{Time}} = \frac{300 \times 10^{-3}}{68.1 \times 10^{-6}}$ m/sec = 4405.28 m/sec

= 4405 m/sec (say)

In a similar way the other values have been arrived at.

Table 4. Ultrasonic pulse velocity values for SRC slabs

Slab No.	Time taken across x 10^{-6} (sec)		Velocity value across (m/sec)		Remarks
	width (= 300 mm)	length (= 1000 mm)	width	length	
4.	85.5	312.6	3509	3199	*Sensors placed*
	86.2	314.8	3480	3177	*for ‘Direct measurement’ [Refer*
	85.8	316.5	3498	3160	*Figs.7 and 8]*
5.	87.2	317.4	3440	3151	*(1) Mean velocity across the width =*
	87.4	317.8	3432	3147	*3465.2 m/sec.*
	86.8	318.1	3456	3144	
6.	86.8	318.5	3456	3140	*(2)Mean velocity across the length =*
	86.4	317.9	3472	3146	*3156.4 m/sec.*
	87.1	318.1	3444	3144	

3.2 Compressive Load

The compression testing phase indicated that all the slabs failed in a similar pattern with cracks emanating from one corner and extending towards the centre. Formation of a crack during testing of a BRC slab is shown in figure 11. The width of the crack corresponding to each increment of load in the UTM was simultaneously measured using a digital caliper as shown in figure 12. The significant advantage of this type of caliper is that the width of a crack can be continuously measured. Table 5 shows that the maximum width of the crack in BRC slabs was 3.15 mm corresponding to a failure load of 4.4 kN. However, in the case of SRC slabs the maximum width of the crack observed was 6.0 mm in which the failure load was 8.2 kN. This value is approximately, twice as that of the value observed in BRC slabs. However, the unit weight of BRC slab was more than that of the unit weight of the SRC slab. Interestingly, ultrasonic tests conducted on SRC slabs also confirm that the quality of concrete is poorer than that of the values achieved on BRC slabs. The presence of steel in SRC slabs has taken more load and proportionately the crack width was larger. The maximum width of first crack formed was less than 2 mm in the BRC and SRC types of slab, which is within the permissible limit. Further it was noticed that cracks ran parallel to the reinforcement in both the types of slab. This was an indication that reinforcement has not participated in forming the crack pattern. Similar observations based on experiments conducted on struts using bamboo, steel and rattan as reinforcement have been reported by Akinyele & Aresa (2013).

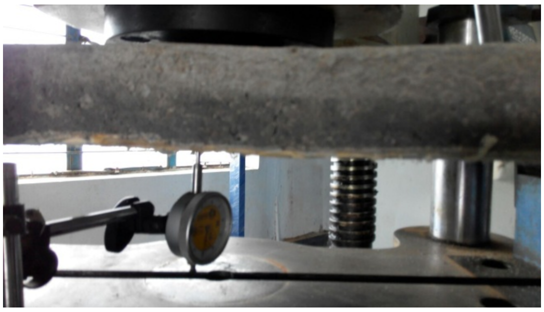


Figure 10. Measuring the deflection

Figure 11. Formation of crack – BRC slab

Figure 12. Measuring the crack width

3.2.1 Load versus Deflection

The load versus deflection curves for the BRC slabs are presented in figure 13 and that for the SRC slabs in figure 14. A comparison of the two types of slab is shown in figure 15, from which it is observed that the SRC slabs failed almost at twice the magnitude of the load at which the BRC slabs failed. In both the cases, the deflection curves also follow the same trend. It is worthy of note that the SRC slab is stronger than BRC slab and capable of undergoing more deflection due to the presence of steel, irrespective of the quality of concrete used.

4. Cost Analysis

Monetary savings in using bamboo as an alternative to steel have been evaluated by comparing the cost analysis of the two types of slab. The cost analysis is given in Table 6(a) to 6(c). The parameters considered in the cost analysis are:

Table 5. Maximum crack width in BRC and SRC slabs

Sl. No.	Slab type	Weight (kg)	Unit weight* (kg/m^3)	Maximum crack width (mm)	Load at maximum crack (kN)	Remarks
1.	BRC	37.60	2506.7	3.05	4.00	*Volume of each slab = 1000 mm x 300 mm x 50 mm = 0.015 m*^{3}.
2.	BRC	36.90	2460.0	3.15	4.40	
3.	BRC	38.20	2546.7	3.10	4.40	
4.	SRC	35.25	2350.0	5.74	7.70	** Unit weight = Weight of slab divided by volume of the slab.*
5.	SRC	33.00	2200.0	5.90	8.00	
6.	SRC	33.75	2250.0	6.00	8.20	

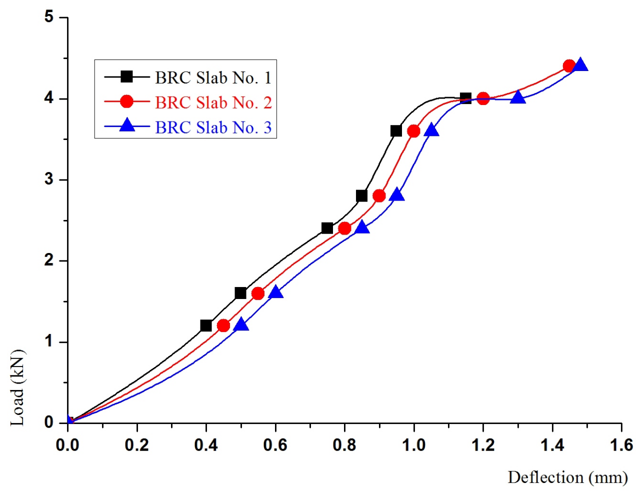


Figure 13. Load versus deflection of bamboo reinforced slabs

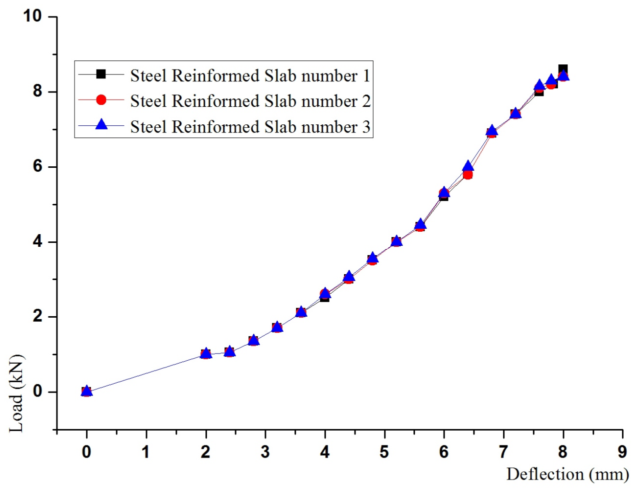


Figure 14. Load versus deflection of steel reinforced slabs

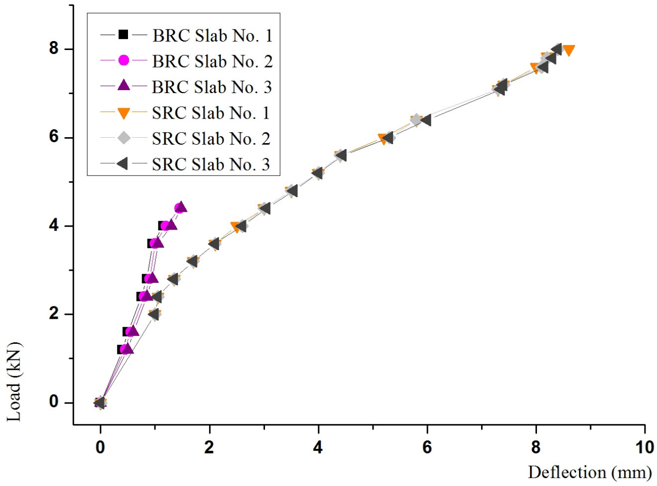


Figure 15. Load *vs* deflection; comparison between BRC and SRC slabs

(i) Material Cost:

The items considered are:

- Steel bar of 8 mm diameter of 6000 mm length 1 No.
- Bamboo of 6000 mm length 1 No.
- Creosote (used for treatment of bamboo)

(ii) Freight (Transportation) Charges:

- Cost involved in transporting the materials by a truck

Table 6 (a). Cost of materials

Sl. No.	Particulars	Rate $ (US)
1.	Steel bar, 8 mm diameter, 6 m long (Fe415 Grade)	1.50
	(Unit weight of Steel = 7860 kg/m^3)	
2.	Bamboo, 6 m long cut into 6 pieces of 1.0 m each.	4.70
	(Unit weight of Bamboo = 800 kg/m^3)	
3.	Freight charges (Transportation) per 1000 kg	9.40

Table 6 (b). Cost of steel reinforcement

Sl. No.	Description	Rate $ (US)
1.	Steel bar, 6 m long	1.50
	(Thickness = 8 mm and width = 16 mm)	
2.	Freight charges (Transportation)	0.22
	Total Cost	1.72

Table 6 (c). Cost of bamboo reinforcement

Sl. No.	Description	Rate $ (US)
1.	Bamboo, 1 m long piece (6 splints per piece) Thickness of one splint = 8 mm Width of one splint = 16 mm	0.80
2.	Treatment of 6 splints with creosote	0.24
3.	Freight charges (Transportation) for 6 splints	0.02
	Total Cost	1.06

Difference in cost = Total cost in Table 6(b) - Total cost in Table 6(c)

= (1.72-1.06) $ (US) = 0.66 $ (US) = 38%

The cost analysis shows that bamboo reinforcement is cheaper than the conventional steel reinforced slabs. The saving is of the order of 35 to 38 per cent.

5. Conclusion

In the present study, bamboo treated with coal tar creosote has been used as reinforcement in casting slabs of size 1000 mm x 300 mm x 50 mm. The performance of BRC slabs has been compared with the commercially available steel reinforced concrete slabs.

Based on the experimental investigations the following conclusions are drawn:

1) Bamboo with an appropriate chemical treatment can very well be used as a replacement for steel in erecting fence walls.
2) The quality of concrete in bamboo reinforced slabs is better than the concrete used in the commercially procured steel reinforced slabs.
3) The bamboo reinforced slabs failed approximately at 50% of the load at which the steel reinforced slabs failed.
4) The width of the first crack was less than 2.0 mm in both the types of slab. However, at failure, the crack width of bamboo reinforced concrete slab was approximately half the width of the steel reinforced concrete slab.
5) The cost of bamboo reinforced slab was cheaper than the commercially procured steel reinforced slabs. The savings can be of the order of 35 to 38 per cent.

Future Work

In the present investigation, individual slab has been tested in the laboratory. The actual erection of fence wall involves stacking of more number of slabs, vertically through the grooves provided in the posts (figure 1), up to a height varying between 1500 to 1800 mm. Therefore, it is suggested that the strength of vertically stacked, 5 to 6 BRC slabs shall be evaluated using a loading frame.

Acknowledgement

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