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Feasibility Study of Using Bamboo as Reinforcement in Concrete Beams

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Abstract—*The engineering community continually strives to achieve sustainability in the concrete construction. It is an attempt to see the feasibility of using bamboo as a tensile reinforcement in the concrete beams and evaluates their flexure and shear response at various percentages of the bamboo reinforcement; the present paper presents the results from a set of 60 beams cast and tested under four point bending test conditions and their response was observed in the form of the load deflection curve, crack patterns, first crack and ultimate strength values. A comparative study was drawn between untreated bamboo strips in comparison with the steel reinforced concrete beams. The comparative study shows that it is possible to replace the conventional reinforcement in concrete beams with the bamboo strips; almost similar response was observed between the normal cast RC beams and those with bamboo strips.*

1. INTRODUCTION

The progress of science and innovation is a long lasting quest for set up in infrastructure of humankind around us. The constructions in nature are satisfactory classes for human learning. As indicated by study, it is estimated that thousand million persons on this planet reside in bamboo houses. Due to the fact that bamboo is mainly utilized in development and as of now they are selected as props, foundation, framing, scaffolding, ground, walls, roofs and trusses. Bamboos are tied collectively to back grid reinforcement and located in indulgent mud to resolve distortion problems in embankments. During the over and done years, numerous researchers have retain and set up new resources for structural purposes in civil engineering. The USA Navel Civil Engineering Laboratory (1966-2000) started the usage of bamboo as concrete reinforcement for prefabricated structural elements. They stated that the strength of the bamboo culm is optimum in both tension and compression side. The culm tangential strength is minimum and cannot be regarded and their investigation on structure with bamboo was carried out.

About 18 million hectare of bamboo are distributed in world forest ecosystems in Asia, Africa, and America. On a conservative estimate, it constitutes about 12.8% of the total area under forests in India. The annual production of bamboo in India is about 4.6 million tons, of which about 1.9 million tons is used by the pulp industries. China and India are the world's largest producers of bamboo. Between these two countries China is slightly higher producer of bamboo. The use of bamboo as reinforcement in Portland cement concrete has been studied extensively by the Clemson Agricultural College and also several methods are presented by universities and the U.S navy and has proven the validity of the use of bamboo in structural members such as columns and girders. Bamboo has been used as a building material globally by the human civilization since a very long period of time but after the Clemson study, its use as reinforcement has gained little attention. Since the use of bamboo in the ancient times for housing purposes, it has been diminishing in our world in the form of a building material despite its rich properties, strength and economical advantages. The investigation of the use of bamboo as a complimentary material with steel in RCC construction has been shown in this study with the economy, convenience and durability of application of the particular idea.

It has been initiated that certain classes of bamboo have ultimate tensile strength same as that of mild steel at yield point. Hence in this study, the methods are presented for the better strength of structure members like beam and are more applicable methods with the least compromise in strength. Methods that have been put forth in this report are not guaranteed to have the best outcomes or with any assurance of the maximum strength of a structure. The designs being presented are those which have been tested under UTM for safe working load and failure analysis. This could be very helpful and have a very good breakthrough in the field of concrete designing with prominent economical benefits over steel. Its benefits are related to the reduction of carbon emission in the atmosphere. If methods like these are applied extensively and studies for the development of a code pertaining to concrete design with bamboo reinforcements can be brought forward, it would lead to a for a promising future of economical and eco-friendly RCC construction.

The incorporation of bamboo in concrete as a replacement of conventional steel can be important practice towards economy and if pretreated well can provide strength almost same as that of steel. Research is basically directing on to how to diminish the resources value which are consumed for structure purpose predominantly steel. Steel is the substantial which is mainly selected for all varieties of reinforcement in column, beam and slab. Bamboo as reinforcement is incorporated in concrete beam with certain percentage viz. 25%, 50%, 75% and 100% and flexure response was observed. After the trial ends, it was related with control beam in flexural strength, deflection and their crack pattern and it was noted that 25% bamboo replacement beam obtain optimum strength than other. P. R Mohan Rao et.al (2018). The properties of friction in the beam of bamboo which is a concrete beam can be increased by providing a layers of sand with G.I wire and the coir on bamboo rods. The web of beam essentially consists of stirrups which is root of resisting shear strength in beam. Flexural strength of different specimen were checked on varying period of curing, it has been noted beam with maximum percentage of reinforcement and curing period gives optimum result Abhijeet Deya et.al (2016). The various layers of coating are put on to verify the bonding behavior between the concrete and the newly established reinforcement of composite-bamboo, and the properties of newly bonding reinforcement were determined by the pull-out test. A technology has been made that the mechanical properties of bamboo can be preserved and to increase the physical characteristics of bamboo composite structures A. Javadian et.al (2016). Tensile test of locally acquired bamboo strips are led for assessment of its ultimate strength and designing properties. Mixtures of adhesive, for example, Tape Crete P-151, Sikadur 32 Gel, Araldite and Anti Corr RC have been utilized for the treatment bamboo to inspect their impact on bond strength. It is observed from pull out test that, the bonding strength at the interface of the bamboo concrete composite is highest for Sikadur 32 gel among the adhesives compared. It is observed from two-point load test that, the load carrying capacity of the beam increased up to 29.41% by using merely 1.49% by area of treated bamboo as reinforcement A. Agarwal et.al (2014). The shear behavior of bamboo reinforced Self-compacting concrete (SCC) beams without stirrups is taken into consideration with vibrated beams (VC). The deformation capacities of tested SCC beams are comparatively higher than VC beams. Shear provisions from four design standards were considered to evaluate their applicability to bamboo-reinforced self-compacting concrete beams without stirrups M. Adom-Asamoah (2018).

In this paper the aim of the study is to investigate the Structural performance of bamboo reinforced concrete beam in flexure and shear and their response was observed in the form of the load deflection curve, crack patterns, first crack and ultimate strength values under four point bend test at different shear span to depth ratio.

2. EXPERIMENTAL PROGRAMME

An experimental study was carried out on a set of 75 beam specimen to evaluate the shear and flexure behavior of bamboo reinforced concrete beams at varying shear span to depth ratio (a/d) and the percentage of bamboo reinforced (pt.). The main parameters investigated were the failure modes of beam specimen, while changing behavior from shear to flexure at shear span to depth ratio 1.25 to 3.5.

2.1 Materials and test specimen

Portland Pozzolana Cement conforming to IS 1489:1991 having specific gravity 3.14 , fine aggregate (grading zone II, specific gravity of 2.64, fineness modulus of 2.63 and water absorption of 1%) and coarse aggregate (specific gravity of 2.94, fineness modulus of 6.98 and water absorption of 0.599%). The coarse aggregate selected for experimental work were retained on 16mm sieve and 20 mm passing guidelines followed from BIS 383 were used to prepare the mix.

Details of the longitudinal bamboo reinforcement used in the beam specimen are shown in Table 1. All bars have tensile strength 100 N/mm^2 to 120 N/mm^2 of varying sizes. Further details of different specimen used in this study are also given in Table 1.

2.2 Mix proportion and test specimen preparation

Design mix selected for work was M25 and the guidelines were taken from BIS 10262 (BIS 2009). The final mix proportion is shown in Table 2. The various batches of concrete were prepared in a revolving drum type concrete mixer of 0.06 m^3 capacity. Mixing was carried out, initially the sand and coarse aggregate were mixed together with half of the total water content. After that cement and remaining water were then added to the mixture. The material were properly mixed to obtain the homogeneous concrete mix. No such signs of segregation were observed in the concrete and good homogeneity were exhibited during slump test. The slump value of concrete mix for M25 was 85mm.

Table 1. Detail of test specimens (beam width= 100mm, overall depth=100mm, and length = 1000mm)

Beam	Effective Length: mm	a/d	Pt:%	Longitudinal steel arrangement : mm
B3.9A1.5 B5.5A1.5 B6.9A1.5	450	1.25	3.92 5.52 6.98	2×10×15 2×15×15 2×20×15
B3.9A1.5 B5.5A1.5 B6.9A1.5	530	1.75	3.92 5.52 6.98	2×10×15 2×15×15 2×20×15

B3.9A1.5 **B5.5A1.5** **B6.9A1.5**	**610**	**2.25**	**3.92** **5.52** **6.98**	**2×10×15** **2×15×15** **2×20×15**
B3.9A1.5 **B5.5A1.5** **B6.9A1.5**	**730**	**3**	**3.92** **5.52** **6.98**	**2×10×15** **2×15×15** **2×20×15**
B3.9A1.5 **B5.5A1.5** **B6.9A1.5**	**810**	**3.5**	**3.92** **5.52** **6.98**	**2×10×15** **2×15×15** **2×20×15**

In above Table Bamboo reinforcement was provided only in tension side

Beam specimen of 100 mm width were cast on flat surface using concrete mix shown in Table 2. The specimen were designed as such that premature failure should not develop to affect the strength parameter of specimen. Accordingly bamboo as longitudinal reinforcement strips were provided on the tensile side with a bottom clear cover of 25 mm and side cover of 20mm. A minimum clear spacing of 25mm was kept between the two adjacent strips shown in Table 1.

Concrete was poured into the metallic mould and filled up to 20-25mm from the bottom then reinforcement is provided maintaining the clear cover from bottom as well as side cover. Figure 1(a) shows the typical reinforcement provided in a test specimen and Figure 1(b) depicts a partially filled test specimen during concrete procedure, 1(c) depicts the slump test. After that beam specimen was completely filled up to the top followed by vibration. Finally, the top face of the beam specimen was levelled using a trowel and levelling bar. Finally 1(d) illustrates beam specimen under testing.

Table 2: Concrete mix proportion adopted in the study

Mix	**Cement Kg/m^3**	**Coarse aggregate Kg/m^3**	**Fine aggregate Kg/m^3**	**Water Kg/m^3**	**Slump value (mm)**
M25	394	968.4	551.76	197.16	85

1(a)

1 (b)

1(c)

1(d)

Figure 1. Typical details of (a) longitudinal bamboo strips, (b) concrete poured, (c) slump test, (d) the test setup.

2.3 Test procedure

After the curing period of 28 days, the beam specimen were tested under four point-point loading. Five different shear span to depth ratio (a/d= 1.5, 1.75, 2.25, 3 and 3.5) were considered in the investigation. Figure 1(d) illustrates a typical test setup used in this study. All the beam specimen were instrumented and the load carried by them at different displacement were observed followed by first crack strength, crack pattern, modes of failure and ultimate load strength. An identical procedure was followed for all tests. The test specimen were first preloaded and this allows specimen to settle and the instrumentation to be checked to ensure it was operating correctly. The load was applied gradually with a rate of 0.2mm/min over the top face of the specimen until the first visual crack appeared. At the first sign of cracking, the load increment was reduced to approximately 1.5kN.

The bottom and the side faces of the specimen were examined to check the any possible cracking and any other unexpected behavior. The load at which the mid-span deflection started at a very high rate or the test specimen failed to take further load was taken as the ultimate load. The shear capacity of beam specimen was then computed by dividing the ultimate load by the effective beam cross-sectional area (B×d).

3. ANALYSIS OF RESULTS

All the test specimen were prepared and tested under the following procedure described in the previous chapter. The specimen of bamboo strips were initially exhibited for tensile strength test and bond strength test between concrete and bamboo as shown in Table 3 with fig 2(a).

Further beam specimens initially shows a non-linear elastic response, followed by the appearance of very fine flexure crack, that we say the first crack strength. With further increase in load, some more fine cracks are appeared. The beams with a higher longitudinal bamboo reinforcement percentage (3%) directly develops inclined cracks in their shear zone with one or more fine cracks in the middle of the beam. In these beam specimens, failure occurred shortly after the inclined flexure shear crack penetrated into their compression zone.

Fig 3. Shows a typical set of load-displacement responses of the beam specimen cast using M25 concrete; the first flexural cracking load was marked by the first step or a slope change in the load displacement response. At first peak, slope-displacement dip indicates failure of concrete, further reinforcement simultaneously resists the further load with changing peak, signifies formation of single diagonal crack especially for the beams tested at lower a/d ratio. The beam tested under higher a/d ratio shows several peak in load-displacement response, this corresponded to initial fine flexural cracking in the section followed by formation of cracks and crack widening. The ratio of the loading at first cracking to the ultimate load were follow a specific trend: an average value of 1/2 was found for the test specimen tested at a/d= 1.5 (pt. = 3.92). Further it was observed that 20% of shear strength was increased at a/d= 1.5 (pt. =5.52%) and slightly increment of shear strength up to 30% more than second one at a/d= 1.5 (pt. = 6.98).

3.1 Effect of shear span to depth ratio (a/d)

The development of shear crack is actually based on magnitude of shear force and bending moment at any given point in the beam span; if the magnitude of shear force is more than bending moment shear cracks can develop in shear zone inversely mechanism followed with flexure cracks. The shear span to depth ratio used in testing generally controls the relative magnitude these stresses. Therefore, this parameter plays a vital role in controlling the shear capacity and failure mode of member. Figure 4 and 5 illustrates the effects of a/d on shear capacity of beams, a reduction in shear capacity was observed for the beam specimen tested at higher a/d.

Figure 6. Indicates the existence of different shear mechanism in the beam specimen depending on a/d adopted. Testing at a/d less than 2.5, a shear failure was observed because the beam was strong in flexure and magnitude of bending moment was less due to part of concrete below loading confine the load laterally towards the support and shear cracks were formed. At a/d > 2.5, the loading point with respective to effective span is small so direct transfer of load to the support could not take place. While the beam specimen contribute to main equilibrium by mobilizing the bars present in the tension zone. Where in the rate of change of tensile force in reinforcing bars contributes towards the beams shear capacity. At smaller values of a/d (<2.5), the beam generally failed in shear due to inclined crack, which led to formation of inclined strut. In other case a/d (>2.5) final failure was due to formation of cracks along longitudinal reinforcing bars, when inclined cracks moved downwards and joined the rebar's.

Table 3.2 Strength Parameters of Bamboo

Tests	Bamboo	Steel
Specific gravity	0.59	7.75-8.05
Average weight	540 kg / m^3	7850 kg / m^3
Modulus of elasticity	1.5-2×10^5 kgf/cm^2	2.1×10^6 kgf/ cm^2
Bond stress	1.4 N/mm^2	1.55 N/mm^2
Tensile strength	113.3 N/mm^2 (pt. = 3.92 %)	417.8 N/mm^2 (8mm bar)
	120 N/mm^2 (pt.= 5.52)	434.22 N/mm^2 (10 mm bar)
	100 N/mm^2 (pt.= 6.97)	433.25 N/mm^2 (12 mm bar)

Note: Bamboo strips are selected according to tensile strength compared with different size of HYSD bars respectively shown above.

2 (a) Tensile test of bamboo strip in UTM

Table 4: Shear and flexure response of beam specimen

Pt: %	a/d	Shear stress: Mpa At first crack	Shear stress: Mpa At ultimate load	Mode of failure
3.92	1.25	1.31	2.52	Shear
5.52	1.25	1.61	2.87	,,
6.98	1.25	2.26	3.55	,,
3.92	1.75	0.9	1.87	Shear
5.52	1.75	1.26	2.2	,,
6.98	1.75	1.96	2.86	,,
3.92	2.25	0.71	1.56	Flexure
5.52	2.25	1.01	1.81	,,
6.98	2.25	1.55	2.25	,,
3.92	3	0.66	1.28	Flexure
5.52	3	1.07	1.9	,,
6.98	3	1.15	1.88	,,
3.92	3.5	0.46	0.97	Flexure
5.52	3.5	0.55	1.07	,,
6.98	3.5	0.95	1.57	,,
Steel: %				
1.96	1.25	5.02	8.6	Shear
1.96	1.75	3.93	6.5	Shear
1.96	2.25	3.26	4.73	Shear
1.96	3	2.51	4.47	Flexure
1.96	3.5	1.96	3.9	Flexure

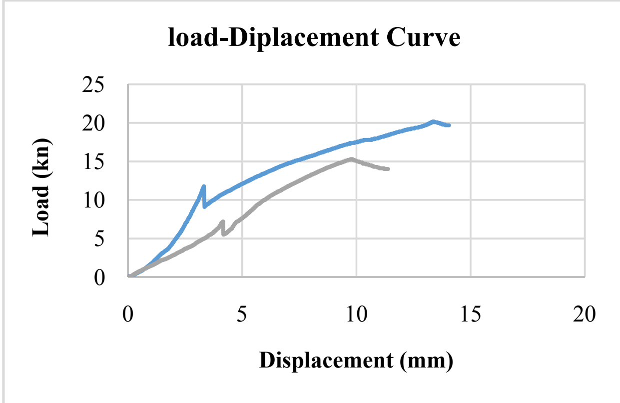
4. DISCUSSION

The below Table 4. Illustrates the shear stress of beams at the first crack and also the stress at ultimate load with varying shear span to depth ratio (1.25, 1.75, 2.25,3 and 3.5) and a varying percentage of bamboo reinforcement as 3.92%, 5.52% and 6.98 compared with percentage of steel reinforcement as 1.96%.

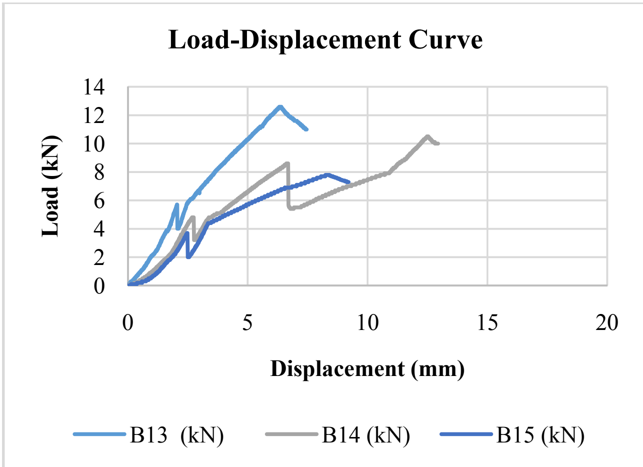
The results indicate with increase in shear span to depth ratio, the ultimate load carrying capacity of beam decreases. Also the mode of failure changes from shear to flexure failure from a/d 1.5 to 3.5. At shear span to depth ratio 1.25 to 1.75 of bamboo reinforced beam shear crack was observed at a distance of'd' from support and from 2.25 to 3 beam specimen were failed under flexure cracks occurred below the loading points. While in case of steel reinforced concrete beam percentage of steel 1.96% was incorporated and its behavior at a/d 1.25 to 1.75 pure shear cracks were occurred near the shear zone and at 2.25 shear cracks was occurred again but at some distance from support. In case of a/d > (2.5 to 3.5) the beam specimen failed under flexure and cracks were occurred below loading points.

Figure 4. Load-Displacement curves of beams

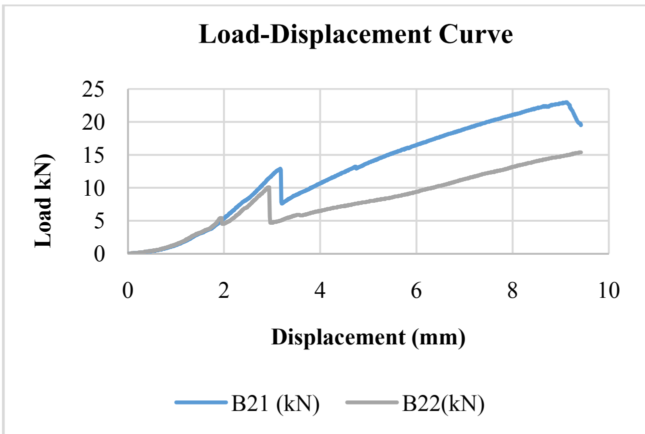
4(a) Pt.: 3.92 (a/d= 1.25 & 1.75)



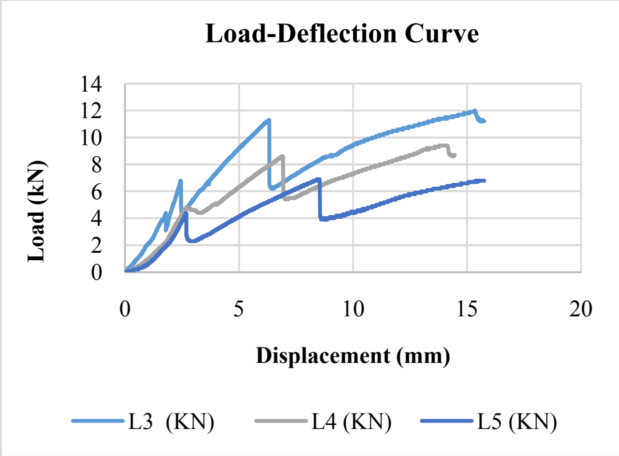
4(b) Pt.: 3.92 (a/d= 2.25,3 & 3.5)



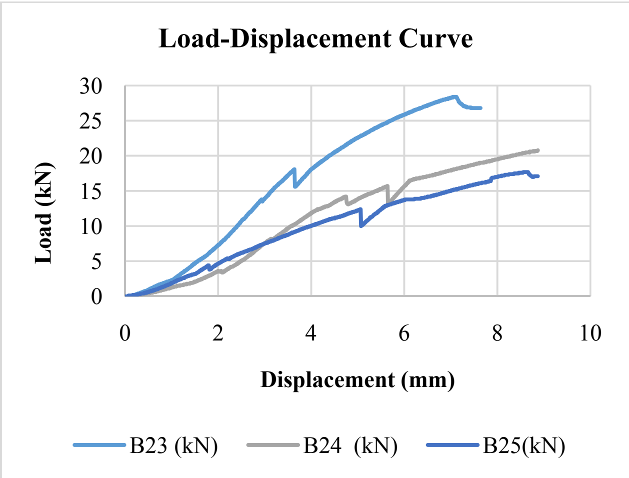
4(c) Pt.: 5.52 (a/d= 1.25 & 1.75)



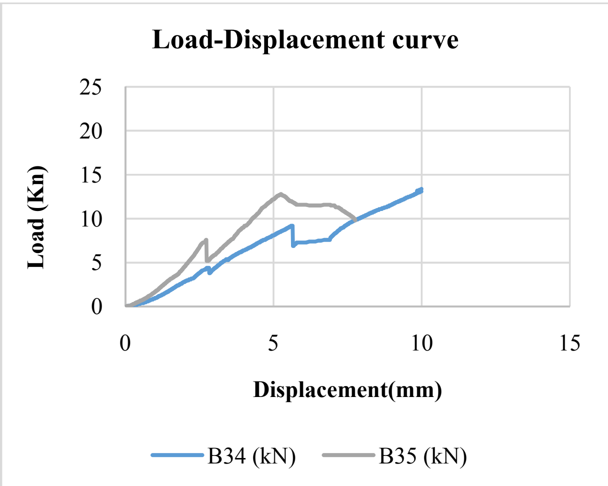
4 (d) Pt.: 5.52 (a/d= 2.25, 3 & 3.5)



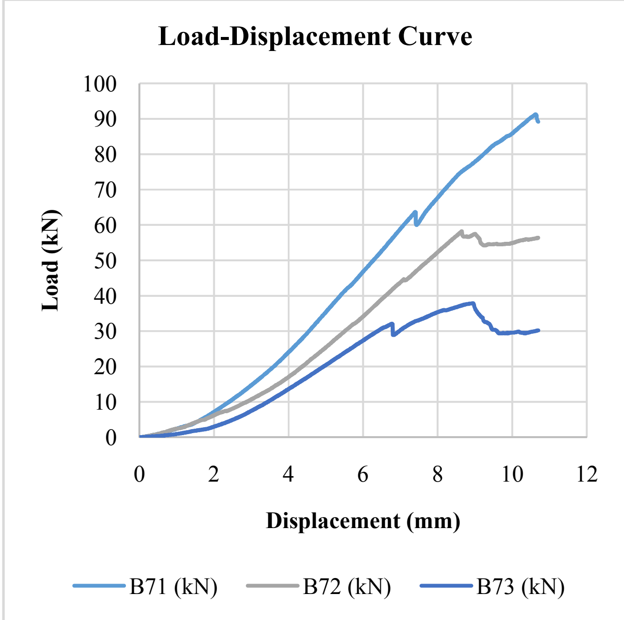
4(e) Pt.: 6.98 (a/d= 1.25, 1.75 & 2.25)



4(f) Pt.: 6.98 (a/d= 3 & 3.5)



4(g) St.: 1.96 (a/d= 1.25 & 1.75)



4(h) St: 1.96 (a/d= 2.25, 3 & 3.5)

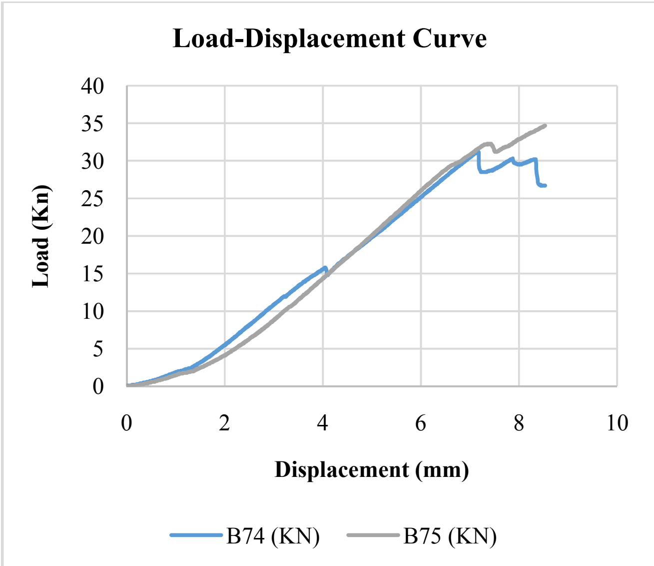
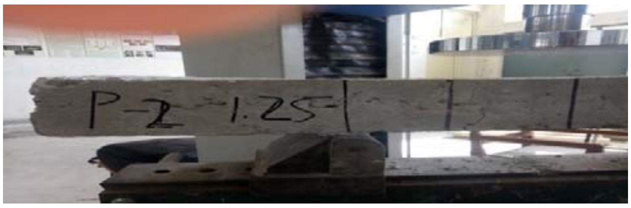


Figure 5. Modes of failure of beam and crack pattern

5(a) shear crack in beam specimen pt: 3.92(a/d=1.25)

5(b) shear crack in beam pt: 5.52(a/d =1.25)



5(c) shear crack in beam pt: 6.98 (a/d= 1.25)

5(d) flexure crack in beam pt: 3.92(a/d=1.25)

5(e) flexure crack in beam specimen pt: 3.92(a/d=1.25)

5(f) flexure crack in beam specimen pt: 3.92(a/d=1.25)

5. CONCLUSIONS

The primary conclusions made from this investigation are as follows.

The Deformation capacity of higher percentage bamboo reinforced concrete beam was slightly nearer to steel reinforced beam. The contribution from dowel action of bamboo reinforcement and surrounding concrete to ultimate shear capacity may be quite significant, and bamboo reinforced concrete shows good agreement with comparison to steel reinforced beams With the increase in the shear span to depth ratio the mode of failure changes from shear to shear-flexure and shear to flexure, up to a/d of 1.75 the beam fails in shear but after 2.5 the beam fails mostly in flexure. At a/d of 2.5 the beam fails in shear as well as flexure that may be due to slippage bond between concrete and bamboo. The behavior of pull out test of cube casted with bamboo is almost same as that of plain steel bar having a numerical value of 1.4 N/mm^2 in bamboo and steel having 1.55 N/mm^2. The results indicate with the increase in the percentage of bamboo reinforced, enhancement of strength occurs i.e. the strength is higher at 6.97 % regardless of other bamboo reinforcement. The strength parameter both flexure and shear for bamboo reinforced beams were nearly equal to conventional steel reinforced beam, thus can be adapted for the construction purpose.

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