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Bamboo-Reinforced Concrete Beams

Poutres en béton armées de bambous

Betonbalken mit Bambusbewehrung

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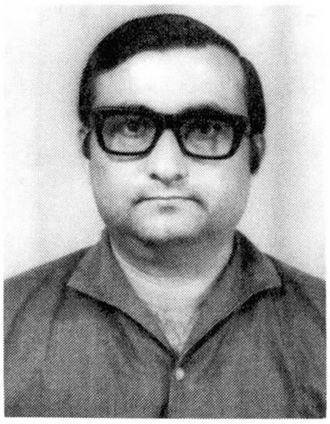

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SUMMARY

An experimental investigation to examine the effectiveness of bamboo as reinforcement in reinforced concrete Tee beams is reported. In all, eight bamboo reinforced simply supported members were tested to failure to study the effect of varying percentages of longitudinal bamboo reinforcement on the ultimate strength of beams. The effectiveness of bamboo stirrups (links) as shear reinforcement was also examined. Water-repellant treatments for bamboo reinforcement are discussed. A method based on the test results is proposed for analysing such beams.

RÉSUMÉ

Cet article présente l'analyse expérimentale menée pour déterminer l'efficacité du bambou en tant qu'armature de poutres en béton armé à section en T. Huit poutres sur appuis simples armées de bambous ont été soumises à des essais de rupture pour étudier l'effet du pourcentage variable du renforcement longitudinal en bambou sur la résistance ultime de ces éléments porteurs. On examine aussi l'efficacité offerte par des étriers en bambou prévus comme armatures de cisaillement. On donne en outre un certain nombre de traitements hydrofuges des armatures en bambou. L'article propose enfin une méthode d'analyse de ces poutres en se basant sur les résultats découlant des essais.

ZUSAMMENFASSUNG

In dieser Arbeit wird über experimentelle Untersuchungen zur Anwendbarkeit von Bambus als Bewehrungsmaterial in T-förmigen Balken aus Beton berichtet. Insgesamt wurden acht mit Bambus bewehrte einfach gestützte Balken bis zum Versagen untersucht. Der Einfluß der Längsbewehrung aus Bambus in verschiedenen Prozentsätzen auf die Traglast der Balken wurde studiert. Die Anwendbarkeit von Bügeln aus Bambus als Schubbewehrung wurde auch untersucht. Wasserabstoßendmachende Behandlungsverfahren für Bambusbewehrungen werden ebenfalls besprochen. Eine Methode zur Analyse von solchen Balken mit den Ergebnissen der Untersuchungen als Grundlagen wird dargestellt.

1. INTRODUCTION

The less developed world today faces the daunting task of providing housing for the millions who now live in grossly inadequate shelters. The situation will worsen as it is estimated that the world population will increase by the year 2000 to about six billion of which more than four billion will live in these lesser developed countries. The problem of inadequate shelters is compounded by the high cost and general shortage of reinforcing steel and other suitable construction materials. Consequently research effort is now aimed at developing various types of cement concrete reinforced with locally available natural fibres or with relatively cheap man-made fibres. One such natural fibre is bamboo.

Bamboo is an ancient building material and its use so far has been more traditional than technical. It has long served many purposes but the application of materials technology to bamboo took place only in comparatively recent years [1,2]. It is yet to be fully exploited for major engineering applications. Economics and other relative factors in developing countries now require Civil engineers to apply appropriate engineering technology to utilise bamboo as effectively and economically as possible in various construction works.

This paper examines the effectiveness of bamboo reinforcement in reinforced Concrete T-beams. In all eight bamboo reinforced simply supported beams were tested to failure under four point loading. All beams were of the same cross-sectional dimensions. Collapse occurred either due to flexural and/or diagonal tension failure of the concrete in shear span. The following parametric studies were conducted:

- the effect of varying percentage of longitudinal bamboo reinforcement on the ultimate strength of beams
- effectiveness of bamboo stirrups (links) as shear reinforcement
- types of water-repellent treatment for bamboo reinforcement and their effectiveness.

Experimental test results were compared with theoretical formulas developed based on simple bending theory. The proposed formulas predict strength of bamboo reinforced beams with reasonable accuracy.

2. DETAILS OF EXPERIMENTAL WORK

The concrete was made from ordinary portland cement, natural river sand and coarse aggregate having a nominal maximum size of 10mm. The mix proportions used were (water: cement: fine aggregate: coarse aggregate) = (0.58: 1.0: 1.26: 2.11) by weight. Along with each specimen three 100mm cube specimens were also cast.

The bamboo used in this investigation belonged to the Bambusa Vulgaris which is abundantly available in the West Indies. The bamboo culms of this species were seasoned for periods varying from 60 to 78 days. The average tensile strength based on six test specimens was 145 N/mm^2. These specimens comprised of nodes and internodes. Another set of test was conducted to estimate the tensile strength between two nodes (internodal). The average tensile strength in this case was estimated to be 200 N/mm^2. Tension bamboo reinforcement was tied into two or three layers of two splints each separated vertically by short spacer splints 10mm thick with the outer sheaths of the splints facing the zone of the greatest tensile stress (Fig. 1).

The eight test specimens were divided into four groups as given in Table 1. Each group had two beams. Except group A in which the number of layers of bamboo reinforcement was two all other had three layers.

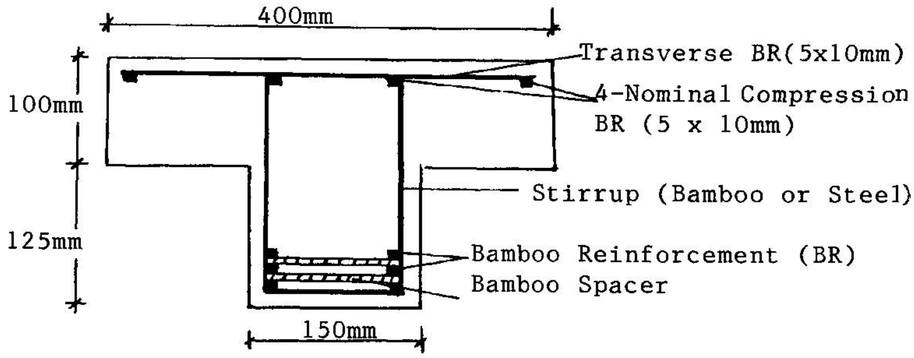

Fig. 1 Typical Cross-Section of Beam

Beam No.	Area of Reinforcement A_b (mm^2)	Percentage of Reinf.	Type of Shear Reinf.	Type of treatment of Reinf*
A2	881	2.61	Steel	WG
A3	893	2.65	Steel	BS
B4	1273	3.77	Steel	WG
B5	1302	3.86	Steel	BS
C6	1362	4.03	Bamboo	WG
C7	1361	4.03	Bamboo	BS
D8	1374	4.07	Steel	WG
D9	1367	4.05	Steel	BS

* Waterglass (WG), Bitumen + Sand (BS)

Table 1 Details of Test Beams

The reinforcement for the test specimens A3, B4, C7 and D9 were treated with two coats of bituminous paints at interval of 24 hours, dusted with sand immediately after second coat and allowed to dry for a further period of 24 hours before use. Whereas for the other beams the reinforcement was treated by plunging it into a waterglass - dipping bath for 15 mins. The density of the bath was 1.15 kg/dm³. In the C-Series beams, 5x5mm bamboo stirrups were used at a spacing of 120mm. The stirrups consisted of two horizontal and two vertical bamboo pieces [3]. Small incisions were made at the end of the pieces, then the two ends meeting at each of the four corners were tied together by means of steel wire. Before fabrication these bamboo stirrups were pretreated as indicated in Table 1. In the rest of the test specimens high yield strength steel stirrups (630 N/mm²) were provided. They had a nominal diameter of 3.4mm and 175mm x 100mm size (same as bamboo stirrups). The spacing of steel stirrups was 130mm.

The loading arrangement is shown diagramatically in Fig. 2a. Demec gage points on both vertical faces of the beam were provided as shown in Fig. 2b. At each increment of load the mid-span deflections and concrete strains were recorded. The load increments were applied until the beam failed.

3. ANALYSIS

The tensile strength of concrete can be reasonably estimated based on the cube strength [4] using

$$f_{tc} = 2/3 + f_{cu}/15 - f_{cu}^2/2600 \qquad \text{. . . . . (1)}$$

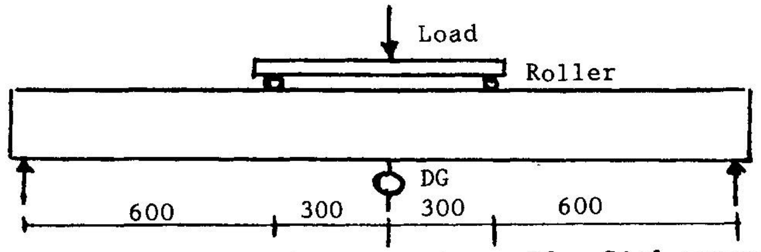

Fig. 2a Loading Arrangement DG - Dial gauge

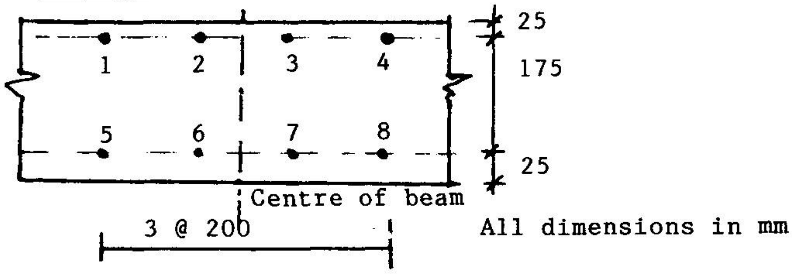

Fig. 2b Part Elevation of Test Specimen

in which f_{tc} is the tensile strength of concrete in N/mm² and f_{cu} is the cube strength in N/mm².

The cracking moment (M_{cr}) of an unreinforced concrete T-beam can be expressed as

$$M_{cr} = f_{tc}.Z \quad . . (2)$$

in which Z is the section modulus of the test specimen. And the ultimate moment of resistance of beam can be calculated using BS 8110 [5]. Neglecting compression reinforcement the ultimate moment of resistance M_u is given

$$M_u = f_b . A_b . Z \quad . . . . . (3)$$

in which f_b is the tensile strength of bamboo (estimated to be 145 N/mm²), A_b is the area of tension reinforcement and Z is the lever arm equal to 0.775 times the effective depth (d) of the test specimen.

The cracking or ultimate load on the beam can be calculated using equation (4):

$$P = 6M/L \quad . . . . . (4)$$

The shear strength of the beam was calculated based on BS8110. Total shear strength (P_{us}) of the beam equals

$$P_{us} = (\upsilon_c + \upsilon_s)\, bd \quad . . . . . (5)$$

in which b and d are the web width and effective depth of the beam respectively, υ_c is the shear strength of plain concrete and υ_s is the shear stress contributed by stirrups and is calculated using equation (6):

$$\upsilon_s = \frac{A . f}{b . S_\upsilon} \quad . . . . . (6)$$

in which A is the cross-sectional area of the vertical legs of stirrup, f is the tensile strength of stirrup (bamboo-internodal strength) and S_υ is the spacing of stirrups.

4. TEST RESULTS AND DISCUSSION

4.1. Modes of Failure

The collapse of the beams was observed to have following distinct failure mode:

- Flexural Mode (Beams A2 and A3)
- Flexural and shear Mode (Beams B4 and B5)
- Shear Mode (Beams C6, C7, D8 and D9)

The flexural failure was characterized by substantial cracking emanating from the tension face and penetrating deep into the compression zone (flange) of the beam. Whereas, shear failure (diagonal tension failure) was characterized by extensive cracking in the shear zone of the beam. The cracking was about 45° to the axis of the beam and extended from the supports to the load points.

4.2 Test Results and Comparison with Theory

The principal test results and their comparison with theory is given in Table 2. The mean P_c/P'_c is 1.135 with a standard deviation of 23.6%. The large variation could be attributed to the difficulty in ascertaining visually the initial cracks. The first four beams failed in flexure. The test results were compared with Eq.(3). The mean P_u/P'_{uf} was 1.065 with a standard deviation of 7.2%. The last four beams which were designed to fail in shear failed as predicted. The test results were compared with Eq. (5).

Beam No.	Average * Compressive Strength (N/mm²)	Expt. Load First crack P_c (kN)	Expt. Load Ultimate P_u (kN)	Theoretical Strength First crack P'_c (kN)	Theoretical Strength Ultimate Flexure P'_{uf} (kN)	Theoretical Strength Ultimate Shear P'_{us} (kN)	$\frac{P_c}{P'_c}$	$\frac{P_u}{P'_{uf}}$	$\frac{P_u}{P'_{us}}$
A2	37	17.5	62.5	13.7	60.4	-	1.28	1.03	-
A3	29	20.0	62.5	12.1	61.2	-	1.65	1.02	-
B4	41	12.5	84.0	14.7	82.0	-	0.85	1.02	-
B5	37	15.0	100.0	13.7	83.9	-	1.09	1.19	-
C6	30	12.5	50.0	12.1	-	53.6	1.03	-	0.93
C7	35	12.5	68.4	13.1	-	55.7	0.95	-	1.23
D8	29	15.0	65.0	12.1	-	54.4	1.24	-	1.19
D9	31	12.5	60.0	12.6	-	55.4	0.99	-	1.08
						Mean	1.135	1.065	1.107
						Standard Dev.	0.236	0.072	0.116

* Based on 3-100mm cubes

Table 2 Comparison of Experimental and Theoretical Results

The mean P_u/P'_{us} was 1.107 with a standard deviation of 11.6%

4.3 Effect of Percentage of Reinforcement

It was observed that an increase of bamboo reinforcement up to 3.8% increased the load carrying capacity of the beam. The load-deflection characteristics of bamboo reinforced beams (Fig. 3) are found to be similar to that of conventional steel reinforced concrete beams.

4.4 Type of Treatment

In all cases the performance of the beams treated with bitumen plus sand was better than the beams treated with waterglass. In general, the beams with former treatment gave a higher load carrying capacity.

4.5 Bamboo Stirrups

Based on the limited test data in this investigation, there are indications that steel stirrups can be replaced by bamboo stirrups. Proper care must be taken in tying the horizontal and vertical bamboo pieces. To increase the tensile strength of bamboo stirrups the pieces of bamboo should be free of nodes.

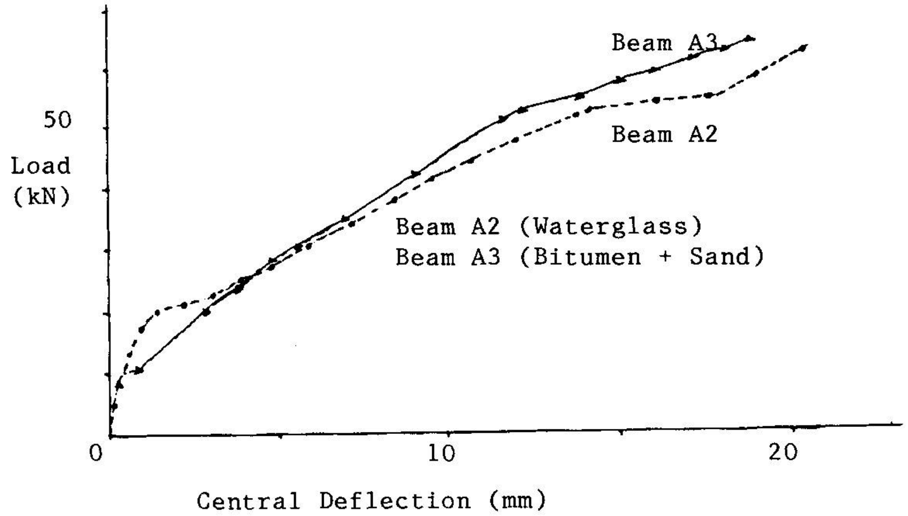

Fig. 3 Load-Deflection Curves

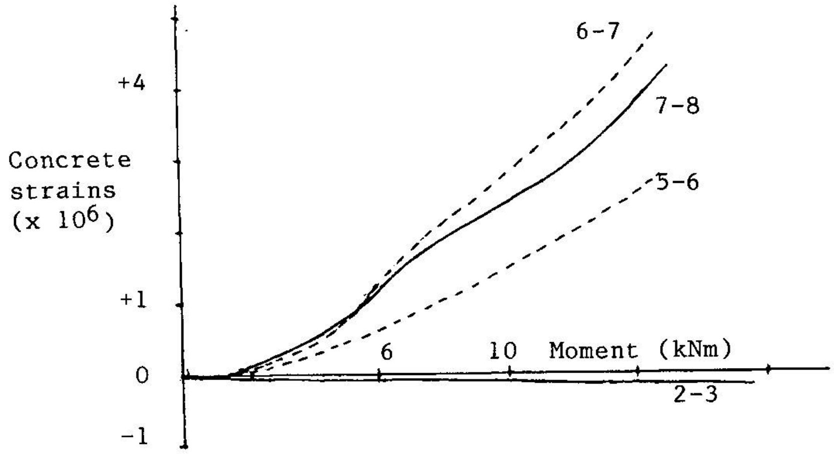

Fig. 4 Concrete strain vs Bending Moment in Beam C6

4.6 Concrete Strains

Concrete strains for a typical beam is shown in Fig. 4. The strain curves are found to be similar to the conventional steel reinforced beams .

5. CONCLUSIONS

Based on the tests reported in this investigation following conclusions can be drawn:

(a) The load carrying capacity of the bamboo reinforced concrete beams increased with increase in percentage of bamboo reinforcement. The optimum percentage range upto which the load carrying capacity increases is between 3.5 - 4.0 percent of the gross cross-sectional area of the member.

(b) 'Bitumen plus sand' water-repellant treatment was found to be suitable for bamboo reinforcement.

(c) Structural behaviour of bamboo reinforced concrete T-beams was found to be similar to that of conventional steel reinforced beams.

(d) The bamboo stirrups performed creditably well, however more tests are required before definite conclusions can be drawn.

(e) The theory proposed based on BS8110 gives reasonable estimate of the ultimate strength of bamboo reinforced concrete beams.