Experimental Analysis of Bending Stresses in Bamboo Reinforced Concrete Beam

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Abstract

Bamboo has been a very fascinating natural material useful in almost all aspects of life. Bamboo is a light weight, tensile, flexible, sustainable, eco friendly, green material and its use shall be advocated in building construction for sustainable development. Researchers are working to find its suitability as a concrete composite material.

This paper evaluates bamboo reinforced concrete beam with four point bending test. The load elongation curve was plotted and the crack loads, ultimate bending moment at failure were investigated. The values of maximum bending stresses at extreme concrete fibre and the concrete surrounding reinforcement were found. Ultimate experimental stresses, design stresses were compared. This paper envisages experimental program, analytical results of bamboo reinforced concrete beam.

Keywords: Bamboo; bamboo reinforced concrete beams, bamboo composite, bending test

1. Introduction

The depletion of natural resources has posed urgent need of use of green technologies in construction industry. Bamboo is an eco friendly light weight green material having good tensile strength. The strength mass ratio of bamboo is 20 times higher than that of steel. INBAR: International Network for Bamboo and Rattan, National Bamboo Mission (India) etc organizations are working on research and development of bamboo. Various civil engineering researchers are working on use of bamboo as a structural construction material for last few years. Yet, the elaborate standards on bamboo as a structural material have not been developed in many countries. International Standards have published ISO-22156 for Bamboo Structural Design and ISO-22157 for Determination of physical and mechanical properties of bamboo (1). Indian Standards have published several codes, however, there are only few for bamboo as a structural material. None of standard has been developed yet for bamboo as a reinforcing material in concrete.

Various researchers have been studying use of bamboo in concrete. US Naval Civil Engineering Laboratory, California (2) has published its report in 1966 to assist the construction personnel in design and construction of bamboo reinforced concrete structural members. Some design charts and tables are published in the report and the BRC members are designed like RCC members.

The bamboo selected for the present work is of Dendrocalamus Strictus specie which is predominantly found in India. Various mechanical and physical tests were conducted on the samples and the same bamboo splints were used for reinforcement in beams. The beams were tested after 28 days curing and the results were verified analytically.

2. Laboratory Program

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Bamboo reinforced concrete beams of M20 concrete were cast and tested after 28 days curing. A predesigned laboratory M20 concrete mix was used for casting of beams. A bamboo from a farm 60 km away from Nagpur (India) of specie Dendrocalamus Strictus was selected for the experiment. Splints of 16-20 mm were prepared to use for reinforcement. Tensile tests (3) of these samples were conducted as per ISO 22157.

The bond of bamboo reinforcement with concrete is weak and the member fails in bond. It is due to reason that bamboo absorbs water and swells in green concrete while the member is cast and contracts after the concrete dries. The void between the reinforcement and the concrete results into weak bond. It is essential to minimise water absorption of reinforcement to increase the bond strength. Various chemicals such as Dr Fixit, Phenol Formaldehyde, Epoxy, Asphalt were tested and asphalt coating on reinforcement proved to be the most effective. The asphalt coating was applied on the reinforcement before casting the beams.

Three beams of size 750X200X200 were cast, vibrated on vibrating table and cured for 28 days. Stirrups of Fe415, 8 mm diameter were used. Behaviour of typical beam is discussed in this paper.

3. Input data and Test Results

The beam dimensions and material properties and the test observations are recorded in following table.
Table I: Four point bending test on bamboo reinforced beam data.

<table>
<thead>
<tr>
<th>SN</th>
<th>Particulars</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Specimen type</td>
<td>Bamboo Reinforced Concrete Beam</td>
</tr>
<tr>
<td>2</td>
<td>Specimen size</td>
<td>200x200x750 mm</td>
</tr>
<tr>
<td>3</td>
<td>Effective length</td>
<td>640 mm</td>
</tr>
<tr>
<td>4</td>
<td>Type of main reinforcement</td>
<td>Bamboo splints 4 numbers</td>
</tr>
<tr>
<td>5</td>
<td>Area of bottom reinforcement</td>
<td>847.62 sqmm</td>
</tr>
<tr>
<td>6</td>
<td>Area of top reinforcement</td>
<td>422.8 sqmm</td>
</tr>
<tr>
<td>7</td>
<td>Stirrups</td>
<td>Fe415, 8 mm dia</td>
</tr>
<tr>
<td>8</td>
<td>Characteristics</td>
<td>Tensile strength of bamboo reinforcement fy</td>
</tr>
<tr>
<td>9</td>
<td>Characteristic Strength of Concrete fck</td>
<td>20 MPa</td>
</tr>
<tr>
<td>10</td>
<td>Load at first crack</td>
<td>59133 N</td>
</tr>
<tr>
<td>11</td>
<td>Load at third crack</td>
<td>98283 N</td>
</tr>
<tr>
<td>12</td>
<td>Load at failure (Shear)</td>
<td>45183 N</td>
</tr>
</tbody>
</table>

Fig 3.1: Load Elongation Curve for Bending Test

4. Cracks and Failure Investigation

The beam is tested under UTM equipped with data acquisition software. The graph is as generated from the machine. The cracks and the loads were noted. After the test, the data, cracks and the graph are investigated. It was observed that the beam took to load linearly up to certain limit and a small crack generate in bottom bending zone, at this time machine stops a bit to take the load. This load is 59.13KN. This point is predominantly marked on the graph generated from the machine. After the first crack the beam starts taking load again then it moves up to maximum point and it starts dropping down. This load is the ultimate load due to bending as the cracks observed are in bending region. After ultimate load is reached, the load drops and the elongation increases rapidly, here the concrete goes into plastic stage, the reinforcement leaves the bond and again the bamboo reinforcement starts taking load, it reaches another two intermediate load points and again starts dropping down, due to failure of reinforcement. The reinforcement failure was in bending. A diagonal crack develops and widens from support and beam fails finally in shear as evident from figure 2.2.
Table II: Crack and load observations

<table>
<thead>
<tr>
<th>SN</th>
<th>Particulars</th>
<th>Load in KN</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>First crack</td>
<td>59.133</td>
<td>A minute crack developed in left bending region near the centre of span</td>
</tr>
<tr>
<td>2</td>
<td>Second crack</td>
<td>86.503</td>
<td>A crack in right bending region</td>
</tr>
<tr>
<td>3</td>
<td>Third crack</td>
<td>98.283</td>
<td>A crack developed in bending region on right side of centre, the crack widens, bending failure, ultimate load</td>
</tr>
<tr>
<td>4</td>
<td>Fourth load point</td>
<td>60.103</td>
<td>Bamboo reinforcement takes load and drops again</td>
</tr>
<tr>
<td>5</td>
<td>Fifth load point</td>
<td>77.273</td>
<td>Bamboo reinforcement takes load and fibres fail, load drops</td>
</tr>
<tr>
<td>6</td>
<td>Sixth Load Point</td>
<td>76.383</td>
<td>Bamboo reinforcement takes load and fibres fail, load drops</td>
</tr>
<tr>
<td>7</td>
<td>Shear failure</td>
<td>45.183</td>
<td>Shear diagonal crack from the support developed and widened, beam fails in shear due to crushing of concrete.</td>
</tr>
</tbody>
</table>

3.1 Experimental results

Ultimate Bending Moment (experimental) = \( \frac{WL}{6} = 98283 \times 640/6 = 10483520 \) N.mm = 10.48352 KN.m
Bamboo material undefined and properties are variable hence material safety factor is considered as 1.5

Ultimate Design Moment of resistance of a beam \( M_u = 0.67 \cdot f_y \cdot A_b \cdot d \left( 1 - \frac{A_b f_y}{f_c k} \right) \)

\[
\begin{align*}
\text{...} & = 0.67 \times 95.8 \times 847.62 \times 170 \left( 1 - \left( \frac{847.62}{200 \times 170} \right) \right) \\
& = 8144337 \text{ N.mm} = 8.144 \text{ KN.m}
\end{align*}
\]

The experimental ultimate moment is 10.48 KN.m and the designed ultimate moment is 8.144 KN.m. Thus the design load is less than the actual ultimate load.

3.2 Stress Calculations

Concrete beam of width \( b \) and depth \( D \); effective depth \( d \) is reinforced with bamboo splints. The strains in compression and tension are proportional. The neutral axis is located at \( x \) from the top. The stress for compression is parabolic.

![Fig 3.2: Stress and strain distribution in a beam subjected to bending.](image)

Modulus of Elasticity of M20 concrete = \( 5000 \sqrt{20} = 22360 \) MPa

Modular Ratio \( n = \frac{E_b}{E_c} = \frac{18600}{22360} = 0.832 \)

Equivalent change in concrete area in tension zone = \( (0.832-1) \times 847.42 = -142.53 \)

Equivalent change in compression area = -142.53

\[ Ay = a1y1 + a2y2 + a3y3, \quad y = 99.874 \text{ mm} \]

Moment of Inertia \( I = \sum I_c + a d^2, \quad I = 1.3119426 \times 10^8 \)

For Experimental value of Bending Moment 10.48352 KN.m

Maximum compressive stress in concrete = \( \frac{My}{I} = 7.98 \) MPa
Stress in concrete surrounding tension reinforcement = 5.60 MPa

Stresses in bamboo reinforcement: 
\[
\frac{10576586}{(170-99.87\times416)(847.62)} = 97.139 \text{MPa}
\]

For Design value of Bending Moment 8.144 KNm responses are shown in Table II

5. Discussion of Results

The experimental and the design responses are compared below. The designed responses are within limit of actual responses.

<table>
<thead>
<tr>
<th>SN</th>
<th>Particulars</th>
<th>Design</th>
<th>Analytical</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bending Moment</td>
<td>8.144 KNm</td>
<td>10.484 KNm</td>
</tr>
<tr>
<td>2</td>
<td>Maximum Compressive stress in concrete</td>
<td>6.20 MPa</td>
<td>7.98 MPa</td>
</tr>
<tr>
<td>3</td>
<td>Stress in concrete surrounding bamboo</td>
<td>4.35 MPa</td>
<td>5.60 MPa</td>
</tr>
<tr>
<td>4</td>
<td>Stress in Bamboo</td>
<td>75.46 MPa</td>
<td>97.139 MPa</td>
</tr>
</tbody>
</table>

6. Conclusion

The design method used for design RCC members can be used to design BRC beam as the stress strain curve for bamboo reinforcement is linear up to a certain limit. The load elongation graph of bending test shows well defined pattern of displacement. The beam fails due to bending and it is visualised from load elongation curve. The beam fails slowly as the bamboo reinforcement are flexible in nature, giving prior intimation of failure. Final failure is observed in shear developed near the support. Bamboo material has uncontrolled properties like that of concrete. IS 456 uses 1.15 as a material safety factor for the steel. However, the tensile strength of bamboo reinforcement varies on various factors such as type of species; land type of cultivation, environmental conditions, therefore material safety factor of 1.5 can be used for design of BRC members. It is recommended to test the bamboo samples for tensile strength before use. Similarly, high water absorption of bamboo degrades the bond strength, care should be taken to coat bamboo reinforcement with appropriate water sealant such as asphalt and provide antifungal treatment before use.

References