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Compressive Behavior of Concrete Columns Confined with Bamboo Sheet Twinning Tubes

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Abstract: *This study examines the compressive behavior of concrete columns confined with Bamboo Sheet twining tubes. Bamboo, as a natural fiber, is gaining attention as an eco-friendly alternative to synthetic materials. Bamboo sheet, is an emerging as promising materials for external confinement of concrete structures. Due to its superior strength-to-weight ratio, corrosion resistance, and durability, serves as an efficient alternative to traditional steel reinforcement in concrete structures. The objective of the project work is to assess the structural enhancement provided by Bamboo Sheet confinement under axial loading. Concrete specimens were wrapped with varying layers of Bamboo Sheet (6, 12 and 24 layers) to determine the optimal confinement configuration for strength improvement. Standard cylindrical specimens were tested under uniaxial compression using a Compression Testing Machine (CTM), and compressive strength variations were analyzed. The findings demonstrate the effectiveness of Bamboo Sheet confinement in enhancing load-bearing capacity, highlighting its potential as a sustainable and high- performance reinforcement solution for concrete columns in structural applications.*

Key Word: *Bamboo Sheet Twining Tube-Confined Concrete (BSTCC), Bamboo Composite Tube (BCT), Compressive Strength, Axial loading, Concrete Columns.*

I.INTRODUCTION

The external confinement of concrete columns using Bamboo Sheet wrapping is a highly effective technique for improving structural strength, durability, and impact resistance. This method involves the application of Bamboo sheets around concrete columns to enhance confinement, mitigate cracking, and increase energy absorption capacity. The number of Bamboo Sheet wrapping layers plays a critical role in determining the overall structural performance, including compressive strength, ductility, and resistance to high strain-rate loading. An increase in the number of Bamboo Sheet layers results in greater confinement effects, leading to enhanced load-bearing capacity and improved toughness. Recognized for its exceptional tensile strength, lightweight properties, and superior resistance to impact and fatigue. On the base of the structure of bamboo composite tube confined concrete, the mechanical behavior of bamboo sheet twining tube-confined concrete (BSTCC) under axial compression was investigated. The choice of composite significantly influences the mechanical behavior of confined concrete. Utilizing the good tensile strength of bamboo, the results presented in the study are expected to provide a new structure for confining concrete with bamboo composite tubes.

II.EXPIREMENTAL DETALIS

Material Properties of cement

The properties of materials are essential in defining the strength, durability, and overall performance of structural elements. To evaluate their physical, mechanical, and chemical characteristics, various tests are conducted on materials such as cement, and aggregates. Properties of cement are shown in table 1. These tests are for ensuring quality control.

Table 1. Material Properties of Cement.

Cement Properties	Values of Tests
Specific Gravity of Cement	3.15
Fineness of Cement	6.67
Standard Consistency of Cement	Water content required for standard consistency is 31%
Initial Setting Time of Cement	Assess workability of 45minutes

Material Properties of Aggregates

Aggregates

Aggregates occupy 70–80% of the volume of the concrete. The presence of different impurities prevents the adhesion of aggregates and hence reduces the strength of concrete. It can be classified into fine and coarse aggregates. Natural river sand is used as fine aggregate, and broken stone is generally used as coarse aggregate. Considering the local availability, the fine aggregate used in this project was M-sand. It has a grain size ranging from 600 microns to 2.36mm. It is necessary to use crushed rock of grain size 12.5mm as coarse aggregate.

Specific gravity (IS 2286-1963)

The specific gravity of aggregates is the ratio of the weight of a given volume of aggregates to the weight of an equal volume of water. Take about 500g of sample, place it in the pycnometer, and weigh it. Pour distilled water into it until it is full. Eliminate the entrapped air by rotating the pycnometer on its side, the hole in the apex of the cone being covered with a finger. Wipe out the outer surface of the pycnometer and weigh it (W4). Transfer the contents of the pycnometer into a tray, taking care to ensure that all the aggregate is transferred. Refill the pycnometer with distilled water to the same level. Find out the weight (W2). Drain the water from the sample through a filter paper. Place the sample in an oven in a tray at a temperature of 100°C to 110°C for 240.5 hours, during which period it is stirred occasionally to facilitate drying. Cool the sample and weigh it (W3). Weight of the pycnometer is noted as W1.

$$\text{Specific Gravity} = \frac{W3-W1}{(W2-W1)(W4-W3)} \quad (1)$$

Sieve Analysis of Aggregate (IS 2386 Part 1 1963)

The aggregate, most of which passes a IS 4.75 mm sieve, is classified as fine aggregate in table 2. Fine aggregate is defined as material that will pass a 4.75 mm sieve and, for the most part, be retained on an IS 75micron sieve. For increased workability and for economy, as reflected by the use of less cement, the fine aggregate should have a rounded shape. The purpose of the aggre gate in the fine aggregate is to act as workability agents. The aggregate, most of which passes a IS 4.75 mm sieve, is classified as fine aggregate. Fine aggregate is defined as material that will pass a 4.75 mm sieve and, for the most part, be retained on an IS 75micron sieve. For increased workability and for economy, as reflected by the use of less cement, the fine aggregate should have a rounded shape. The purpose of the aggregate in the fine aggregate is to act as workability agents. The table 2.1 shows, the coarse aggregates are particulates that are greater than 4.75mm. The usual range employed is between 9.5mm and 37.5mm in diameter. Fine aggregates are usually sand or crushed stone that are less than 9.55mm in diameter.

$$\text{Fineness Modulus} = \frac{\textit{cumulative percentage of aggregate retained}}{100} \quad (2)$$

Table 2. Sieve Analysis of Fine Aggregate.

Sieve size (mm)	Weight of aggregate retained (g)	% Weight of aggregate retained (g)	Cumulative % Weight of aggregate retained =x	% of fineness =100-x
10	0	0		
4.75	4	0.8	0.8	99.2
2.36	24	4.8	5.6	94.4
1.18	166	33.2	38.8	61.2
600µ	103	20.6	59.4	40.6
300µ	101	20.2	79.6	20.4
150µ	89	17.08	97.4	2.6
Pan	13	2.6	100	0

Table 2.1. Sieve Analysis of Coarse Aggregate

Sieve size (mm)	Weight of aggregate retained (g)	% Weight of aggregate retained (g)	Cumulative % Weight of aggregate retained	% of fineness =100-x

80				
40				
20	2009	66.97	66.97	33.08
12.5	950	31.67	98.64	1.36
10	30	1.0	99.64	0.36
4.75	3	0.10	99.74	0.26
Residue	8	0.26	100	0

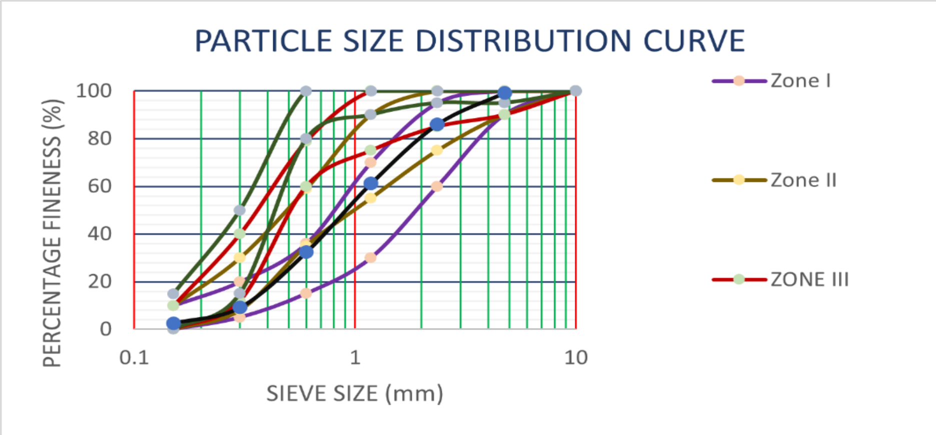


Fig.1. Particle Size Distribution Curve of Fine Aggregates.

Table 2.2. Properties of Aggregates.

Properties	Fine Aggregate	Coarse Aggregate
Specific gravity	2.65	2.75
Grading Zone	Zone II	-

III. TEST ON MATERIALS

Concrete

The cement used for testing was Ordinary Portland Cement 53. These specimens were prepared using a specific concrete mix ratio. To evaluate the concrete strength, three 150 × 150 × 150 mm concrete cubes were prepared from each batch. All specimens were cured under identical conditions for 7 and 28 days, respectively. It can be seen from Table 3 that the average compressive strength of concrete cubes is 28 MPa at 7 days and 39.10 MPa at 28 days respectively. The cubes were tested using a compressive testing machine and results are shown in table 3.1, where the maximum load sustained by each specimen and their compressive strengths were obtained. The mix proportions of concrete are stated in Table 3.2.

Table 3. Compressive Strength of Concrete Cubes for 7 Days.

Specimen	Compressive Strength for 7 days (MPa)	Average (MPa)
M30-1	29	
M30-2	30	28
M30-3	27	

Table 3.1. Compressive Strength of Concrete Cubes for 28 Days.

Specimen	Compressive Strength for 28 days (MPa)	Average (MPa)
M30-1	38.23	
M30-2	39.78	39.10
M30-3	39.3	

Table 3.2. Mix Proportions of Concrete kg/m^3.

Cement	Water	Fine Aggregate	Coarse Aggregate	Plasticizers
370	148	1270.72	688.788	3.7

IV.EXPIREMENTAL PROGRAM

Specimen Design

Bamboo sheet twining tube-confined concrete columns (BSTCC) and with three confined concrete columns, with inner diameters of 150 mm and heights of 300 mm were designed and prepared for the universal compression testing machine. The main variation parameters included the number of bamboo sheet layers (6, 12, & 24), which is the thickness of the bamboo composite tube (BCT), and the grade of the concrete M30.

Bamboo Sheet

Bamboo sheets provided by Dongguan Jiaqiao bamboo and Wood Industry Co. Ltd. China were used to manufacture composite tubes as the confined material in the test. The bamboo sheets were prepared by slicing softened moso bamboo stem along the bamboo fiber, and the nominal thickness of each bamboo sheet was 0.5 mm. The size of bamboo sheet 2500 x 430x x 0.5 mm.

Epoxy Resin

The epoxy resin adhesives (SR-998) used in this test.

Table 4. Physical and Mechanical Properties of Epoxy Resin Adhesive.

Adhesive	Density (g/cm^3)	Tensile Strength (MPa)	Operable time (min)
SR-998	1.0	35	45

Specimen Preparation

The detailed production steps of BCT and BSTCC are shown in Figure 2. A plastic film was applied to the acrylic pipe prior to wrapping it with bamboo sheets, allowing the pipe to be reused. After the bamboo sheets were saturated with epoxy resin adhesive, a 150-mm overlap was provided for all specimens to prevent premature failure in the overlap region. Before casting the concrete, the Bamboo Confined Tube (BCT) was temporarily secured to the bottom formwork. Concrete was then poured and properly vibrated.

All specimens were cured under ambient room conditions for 28 days. Following the curing period, the bottom formwork was removed. To ensure a uniform load-bearing surface, the ends of all specimens were finished with a thin layer of high-strength, self- leveling mortar.

(a) (b)

(c) (d)

Fig 2. (a) Bamboo sheet, (b) wrapping bamboo sheet, (c) Bamboo Composite Tube (BCT), (d) Pouring Concrete.

Test Setup and Instrument

A Compression Testing Machine (CTM) is a versatile testing device used to determine the mechanical properties of materials under various loading conditions. it is widely used in material testing laboratories to evaluate properties like compressive strength and bond strength. The compression tests were conducted on a high-stiffness testing machine with a capacity of 3000 kN. Prior to the test, the top and bottom surfaces were ground smooth to ensure that the load was applied uniformly across the cross-section. The compressive loads of specimens wrapped with 6, 12, and 24 layers of bamboo sheets were tested using a Compression Testing Machine (CTM) as shown in Figure 3.

Fig 3. Compressive Test Instrument.

Failure Mode

All the specimens had serrated cracks throughout the axial direction. However, the bamboo sheet layers had an influence on the failure pattern. However, the internal aggregates remained relatively intact, indicating that the failure primarily affected the surface and near-surface layers of the specimen. All the specimens had serrated cracks that due to shear failure, throughout the axial direction of the BCT. However, the number of bamboo sheet layers had an influence on the failure pattern. When the number of bamboo sheet layers was less than 18, the fracture of the crack initiated at the middle of the BCT and then propagated towards the two ends of the specimen along its longitudinal direction resulting in the development of a major crack. When the load reaching the ultimate bearing capacity of the specimen, with a crisp sound, the mid-height region of the BCT was stripped destructively. The typical failure mode of the BSTCC specimens with different parameters is shown in Figure 4.

Fig 4. Typical failure modes of the BSTCC specimens.

V.RESULTS AND DISCUSSION

The test results P_{max} is the maximum axial load. the number of bamboo sheet layers on the axial load-bearing capacity of concrete columns. Here nf is the Number of Layers and tf is the Thickness of the Layers. Here M30B6-1, M30 is the concrete Mix and B6 is the number of layers of first specimen, likewise M30B12-2, M30B24-3**.** These theoretical results confirm that the addition of more bamboo layers progressively improves the column ability to withstand axial loads. The test results are shown in Table 4.1.

Table 4.1. Test Results of the Specimens.

Specimen	Aramid Fibre Reinforced Polymer		P_{max} (kN)
	n_f	t_f (mm)	
M30B6-1	**6**	**3.0**	**458**
M30B12-2	**12**	**6.0**	**485**
M30B24-3	**24**	**12.0**	**510**

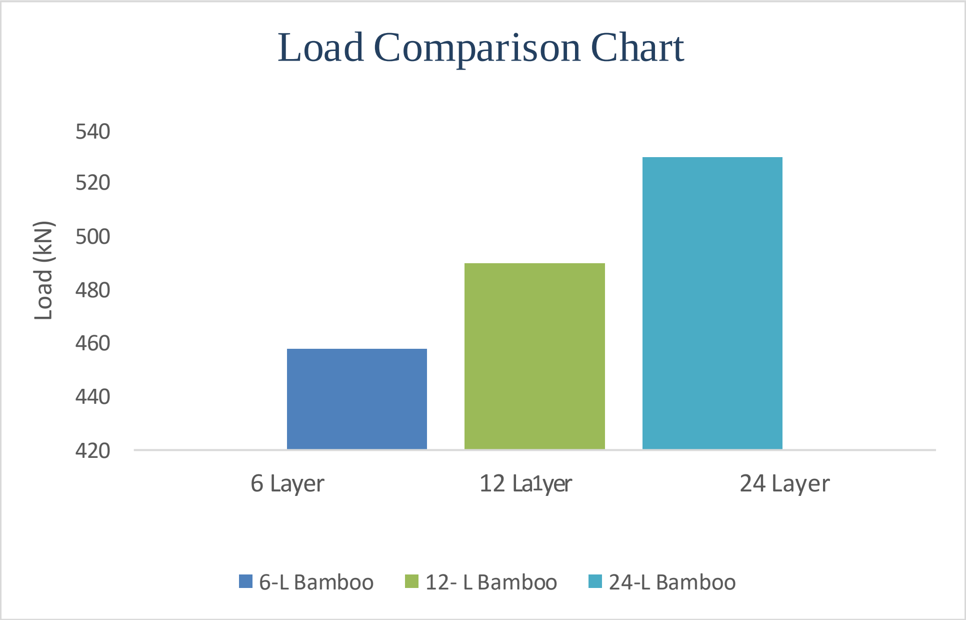


Fig. 5. Load Comparison Chart of 6, 12, 24, Layers of Bamboo Sheet.

These results as a consistent increase in load-bearing capacity with the number of bamboo layers, confirming the effectiveness of bamboo wrapping in enhancing structural confinement and axial strength. The increase from 6 to 24 layers resulted in an overall improvement of 11.4% in load capacity. The column wrapped with 24 bamboo layers exhibited the best performance, bamboo wrapping as a sustainable and efficient technique for retrofitting or enhancing reinforced concrete structural elements.

VI. STRUCTURAL BEHAVIOR OF RC COLUMN CONFINED WITH BAMBOO SHEET UNDER COMPRESSIVE LOAD GENERAL

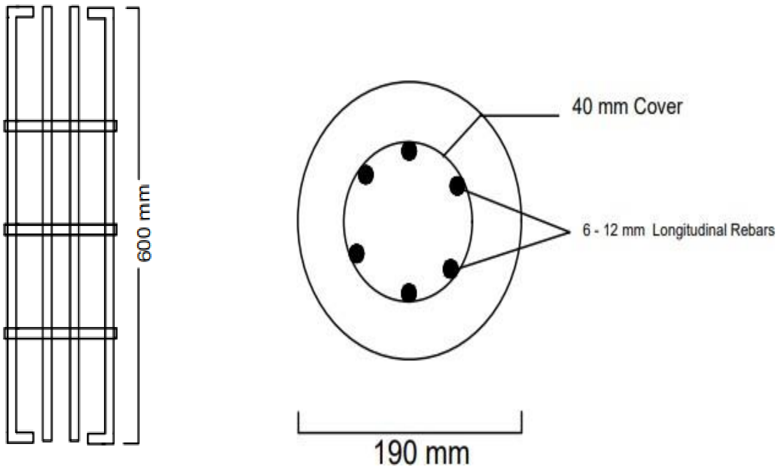
The structural behavior of reinforced concrete (RC) columns can be significantly enhanced through external confinement, and the use of bamboo sheets as a confining material presents a sustainable and cost-effective alternative to synthetic fiber-reinforced polymers. When subjected to axial compressive loads, RC columns confined with bamboo sheets improved strength, and energy absorption capacity. As the number of bamboo layers increases, the column exhibits greater resistance to deformation and higher ultimate load capacity. Overall, the use of bamboo as a confining material not only improves the structural performance of RC columns but also contributes to sustainable construction practices by utilizing a renewable and environmentally friendly resource.

Experimental Program

Specimen Design

The columns were cast in three batches, utilizing Ordinary Portland Cement (OPC) 53 grade and coarse aggregates with a maximum size of 12 mm. In this study, M30 grade concrete and Fe500 steel were employed, conforming to IS456-2000 standards. A nominal mix ratio of 1:1.86:3.43, as per IS456-2000, was adopted to ensure concrete's compressive strength. For each batch, three cubes (150 mm × 150 mm × 150 mm) and three cylinders (150 × 300 mm) were cast to verify the average compressive strength of the columns and the split tensile strength of the cylinders. the main variation parameters included the number of Bamboo Sheet layers 6, which is the thickness of the Bamboo Sheet.

The RC circular columns were fabricated, each specimen having a 190 mm diameter and standing at a total height of 600 mm. The columns were tested under an axial compression load using loading Frame. Fig. 6 shows the reinforcement detailing of RC column. This consisted of 6-12 mm longitudinal bar reinforcement and stirrups of 3- 6 mm were used as a minimal requirement to minimize the additional confinement effect from the stirrups. the stirrup spacing of 150 mm. The reinforcement specifications for the reinforced concrete columns are depicted in Fig. 6. Following the column casting, they were placed in a curing tank for 28 days.



(a) (b)

Fig 6. (a) Reinforcement Detailing RC Circular Column Longitudinal, (b) Cross Section.

Strengthening with Bamboo Sheet

The Strengthening of the RC columns involved the application of Bamboo Sheet wrapping techniques. The process of strengthening reinforced concrete (RC) elements using Bamboo Sheets sheet involves a series of carefully executed steps to ensure effective bonding and long-term performance. Bamboo sheets are then applied directly onto the adhesive layer and firmly pressed using rollers to eliminate air voids and ensure uniform contact. In cases where multiple layers are required, each layer is bonded with additional epoxy. This strengthening method significantly enhances the structural integrity, load-carrying capacity of RC elements. The step- by-step process for reinforcing with Bamboo Sheet is depicted in Fig. 7.

Fig 7. Strengthening of RC Column wrapping with Bamboo Sheet.

Test Setup and Instrument

The experimental set up consists of a loading frame, hydraulic jack, hydraulic Pump, load cell, LVDT and indicators to measure the load and deflection. The loading frame of 100ton capacity which is available in our lab is shown in Figure 8. The platform has a length of 3.1 m and a width of 0.35 m. A chain and pulley arrangement present in the frame to raise or lower the horizontal face of the frame. The hydraulic jack and load cell are attached to this horizontal face. Large sized nails are used to hold the horizontal face in position.

The loading was done through a hydraulic jack of 20ton capacity, with the help of a hydraulic pump of 100ton capacity. The hydraulic pump is a hand operated one and has a lever of adjustable length. It is filled with oil. The loading was done by raising and lowering the lever. Pipes are connected from the hydraulic pump to the hydraulic jack for moving the oil. When the lever is lowered, the oil is pumped to the hydraulic jack through the pipes. The hydraulic jack is capable of providing normal load as well as cyclic load. The normal loading was used for the project work.

A 40ton capacity load cell was used to measure the applied load which is attached to the bottom of hydraulic jack as shown in Figure 8. The magnitude of the applied load can be seen from the digital indicator. The digital indicator expresses the load in tons with a least count of 0.01 ton. The deflections at the mid-span were measured through two linear variable differential transducers (LVDT) connected at the mid-span and the average values were selected. The LVDTs were placed in a height adjustable stand.

Fig 8. Loading Frame and Hydraulic Jack and Load Cell.

Failure Mode

All the specimens exhibited serrated cracks along the axial direction of the bamboo-confined columns. However, the number of bamboo sheet layers influenced the failure pattern. Despite the visible surface damage, the internal aggregates remained largely intact, suggesting that the failure was primarily limited to the surface and near-surface regions of the specimens. The crack initiated at the middle and then propagated towards the two ends of the specimen along its longitudinal direction resulting in the development of a major crack. failure modes are shown in Fig. 9.

Fig 9. Mode of failure of the specimen.

VII.RESULTS AND DISCUSSION

The columns were subjected to axial compression testing until failure occurred. The Load Deflection Graph of bamboo sheet as shown in Fig. 10 and RC Column as shown in Fig. 11.

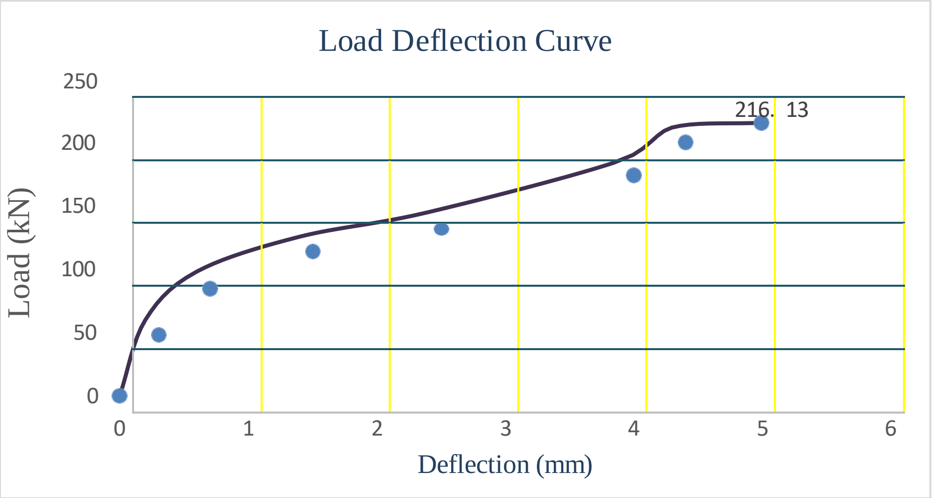


Fig. 10. Load v/s Deflection Curve 6 Layer Bamboo Sheet.

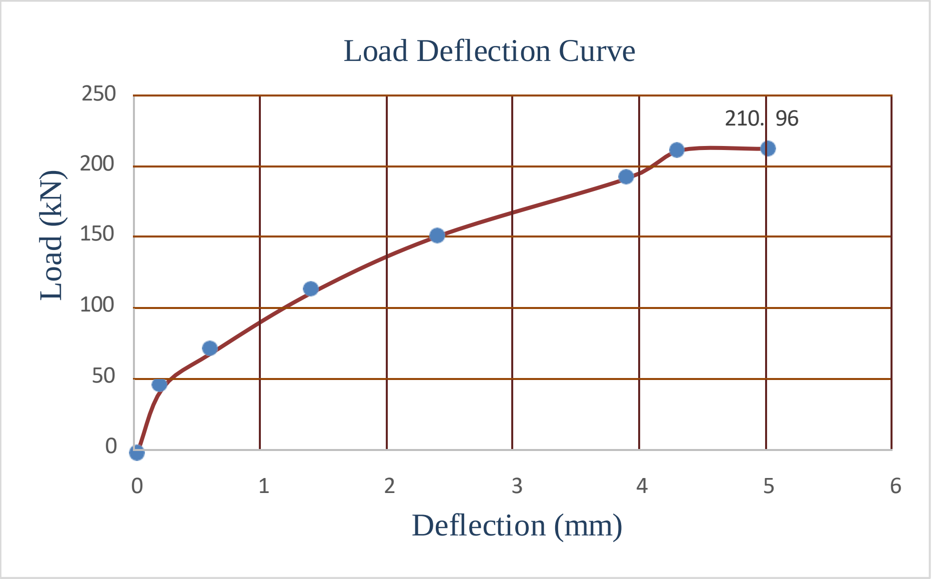


Fig. 11. Load v/s Deflection Curve of RC Column.

This section presents a detailed discussion on their load-carrying capacity, observed failure modes of shear failure accompanied by cracking that extended from the top to the bottom of the concrete columns, and a comparative analysis of their load–deflection behavior. Among the specimens, the reinforced concrete (RC) column wrapped with six layers of bamboo sheets reached a peak load-carrying capacity of 216.13 kN. The RC column (control specimen) achieved a maximum load of 210.84 kN, indicating a moderate improvement due to bamboo confinement.

VIII.CONCLUSION

This study investigated the Compressive Behavior of Concrete Columns Confined with bamboo sheet Twinning Tubes through a series of tests, whose major parameters were the concrete strength and the Bamboo Sheet thickness. Based on the test results and analysis, the following conclusions can be drawn:

- The failure mode of Bamboo Sheet-confined Concrete specimens is characterized by the formation of serrated cracks, which originate the specimen and progressively extend towards its both ends along the longitudinal axis. The presence of Bamboo Sheet wrapping significantly enhances the structural integrity of the specimens by providing strong lateral confinement, thereby restricting excessive deformation and delaying failure.
- Out of the two combinations, the column wrapped with six layers of Bamboo Sheet showed a more substantial increase, reaching a peak load, the Bamboo Sheet has a better performance with an increase of 7.15% Strength compared to conventional column.
- The application of Bamboo Sheet layers significantly improves the compressive strength of concrete specimens. As the number of Bamboo Sheet layers increases, the confinement effect becomes more effective, leading to higher resistance against axial loads.

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