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Study of the Structural Behavior of Bamboo Reinforced Concrete Slabs

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Abstract. This research investigates the structural behavior of concrete slabs reinforced with bamboo as an alternative to conventional steel reinforcement. Bamboo, a renewable and eco-friendly material, offers potential benefits in terms of sustainability and weight reduction. Seven one-way concrete slabs with dimensions of 1500 × 550 × 100 mm were tested under flexural loading, with varying reinforcement configurations including 100% steel, 100% bamboo, and hybrid ratios. The experimental results revealed that while bamboo-reinforced slabs demonstrated reduced strength compared to steel-reinforced slabs, certain hybrid combinations showed acceptable structural performance. The findings indicate that bamboo can partially replace steel reinforcement in non-critical structural elements, offering an environmentally sustainable alternative. This study contributes to the development of green construction practices and supports further research into improving the mechanical and durability properties of bamboo as reinforcement in concrete structures.

Keywords: Bamboo reinforcement, Concrete slabs, Structural behavior.

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1. Introduction

Bamboo has gained attention in recent years as a potential alternative to steel reinforcement due to its availability, low cost, and sustainability. Ghavami (2005) investigated the behavior of bamboo-reinforced concrete beams, showing that bamboo could provide acceptable tensile capacity when properly treated and positioned. [1] Similarly, Terai and Minami (2012) developed guidelines for using bamboo in structural concrete elements based on experimental analysis. [2]

Agarwal et al. (2014) focused on the effects of chemical treatment on bamboo to improve its durability and bond strength with concrete, which is essential for its structural performance. [3]

Ikponmwosa et al. (2017) and Javadian et al. (2016) explored the use of bamboo in foamed and composite concrete systems, further supporting its structural viability. [4] [5]

More specifically, Haryanto et al. (2021) conducted experimental tests on bamboo-reinforced concrete slabs under concentrated loading, highlighting improvements in flexural behavior and crack resistance. [6] However, limited studies have addressed the behavior of one-way slabs with hybrid steel–bamboo reinforcement. This gap forms the basis for the present investigation, which aims to evaluate the structural performance of such slabs under flexural loading conditions.

Research Significance and Novelty

The novelty of this research lies in the experimental investigation of bamboo as partial and full reinforcement in one-way concrete slabs. While previous studies focused primarily on bamboo-reinforced beams and columns, limited data exists on the behavior of slabs reinforced with varying bamboo-to-steel ratios.

This study aims to fill this gap by presenting the flexural performance of seven slab specimens under uniform loading conditions. The use of bamboo, an organic and sustainable material, addresses the growing need for environmentally responsible construction solutions.

Furthermore, the bamboo reinforcement was treated and tested to account for its durability and structural efficiency, particularly in regions with limited access to steel. These results contribute to the ongoing development of green, low-cost alternatives in structural engineering.

2. Materials and Methodology

2.1 Materials

In this section, we will discuss the materials used in the study of the structural behavior of bamboo reinforced concrete slabs. The selection of appropriate materials is crucial to ensure the reliability and effectiveness of the experimental investigation. The materials used in this study include bamboo, concrete, steel reinforcement, and other supplementary materials.

Bamboo

Bamboo is a natural, renewable material with high tensile strength, low density, and promising durability, making it a viable alternative to steel in concrete reinforcement. In this study, locally sourced bamboo bars were selected based on quality and straightness, then cut and treated with preservatives to enhance resistance against insects and fungal decay.

Concrete

A standard concrete mix was used in this study, consisting of ordinary Portland cement (OPC), natural river sand as fine aggregate, crushed stone as coarse aggregate, and clean water. The mix proportions were selected to achieve the required strength and workability, with a controlled water–cement ratio to ensure proper hydration and consistency during casting.

Steel Reinforcement

In addition to bamboo, steel reinforcement was used to enhance the overall strength and ductility of the bamboo-reinforced concrete slabs. Mild steel deformed bars were employed, forming the bottom layer of reinforcement, while bamboo bars were placed at the top.

The steel bars used in the study were high-quality, conforming to relevant standards for concrete reinforcement. They were carefully cut and bent to the required dimensions prior to placement in the formwork, and were positioned at the tension zone of the slabs to resist tensile stresses and control cracking.

Supplementary Materials

In addition to the primary materials, supplementary components were utilized to ensure proper casting and curing of the bamboo-reinforced concrete slabs. These included admixtures to enhance workability and durability, plywood and timber formwork to maintain slab geometry during casting, and curing compounds to prevent moisture loss and promote effective hydration. The careful selection and application of these materials contributed to the consistency and reliability of the experimental results.

2.2 Material Properties

Physical and Chemical Properties of Materials

Table 1. Properties of the materials used in the experimental work.

Material	Properties
Cement	Portland cement with high quality Grade 42.5 Newly produced, not 45 days before. Had been stored in a dry atmosphere in isolation from moisture. By hand insertion into the bag, it was cool, smooth and no presence of lumps. Specific gravity: 3.15 Fineness: <10% retained on 90µm sieve Setting time: Initial – 45 minutes, Final – 10 hours Chemical composition: CaO (60–65%), SiO_2 (20–25%), Al_2O_3 (4–8%), Fe_2O_3 (2–5%)
Sand	Ordinary sand composed of siliceous materials. Clean and almost free from impurities. Did not contain more than about 1% by weight of silt, clay and mica. Fineness modulus: 2.3–2.7 Specific gravity: ~2.6
Coarse aggregate	Angular crushed stone with smooth surface texture having a good quality and free from injurious materials. Big size and most of granules retained on No.4 sieve. Specific gravity: ~2.65 Water absorption: 0.5–1%
Water	Clean drinking fresh water. Free from impurities.
Steel	High-grade steel 360/520 deformed bars were used. Its yield strength (f_y = 360 N/mm²).
Bamboo	Its yield strength (f_y = 80 – 105 N/mm²). Density: approximately 600–700 kg/m³ Modulus of elasticity: ~17–20 GPa High silica content (about 2–3%) increases its resistance to decay but affects bond with concrete.

Tensile Strength Test for Steel Reinforcement

Mild steel deformed bars (360/520) were tested to verify the yield and ultimate strength before casting. The test was conducted using a universal testing machine.

Specimen No	Diameter (mm)	Yield Load (kN)	Ultimate Load (kN)	Yield Strength (MPa)	Ultimate Strength (MPa)	Failure Mode
1	10	28.8	45.5	367	580	Necking
1	10	29.2	46.1	372	587	Necking
Average				369.5	583.5	

These results confirm that the steel used meets the required yield strength (fy = 360 MPa) as per standard specification.

2.3 Methodology

The research methodology employed in this study aims to investigate the structural behavior of bamboo reinforced concrete slabs, specifically one-way slabs. This section outlines the approach and procedures followed to achieve the objectives of the study.

Experimental Design

The specimen size (1500 × 550 × 100 mm) was selected to simulate realistic one-way slab behavior under flexural loading while remaining compatible with laboratory capacity and testing equipment. The 1500 mm span allows for observable flexural response under two-point loading without introducing deep beam behavior. The 550 mm width ensures sufficient space for placing both bamboo and steel reinforcements, as well as installing instrumentation such as LVDTs. The 100 mm thickness reflects typical slab thickness used in light structural applications.

These dimensions also ensured that crack formation, propagation, and failure patterns could be clearly monitored and measured. Furthermore, the selected reinforcement ratios (ranging from 100% steel to 100% bamboo) were chosen to explore the transition in performance from traditional to fully sustainable reinforcement, which aligns with the objective of evaluating bamboo as a viable alternative to steel in structural slabs.

Material Selection

All materials were selected to ensure quality and consistency. Their physical and mechanical properties are provided in detail in Section 2.2.

Fabrication of Bamboo Reinforced Concrete Slabs

The research involved fabricating and testing one-way concrete slabs reinforced with bamboo to assess their structural performance. Bamboo bars were positioned as per the design layout, and slabs were cast under controlled conditions to ensure consistency. Concrete was poured and compacted to achieve uniformity.

Testing Procedures

Both destructive and non-destructive tests were conducted. Destructive tests assessed flexural strength, cracking behavior, and failure modes under gradually increasing loads. Non-destructive tests monitored deflection and serviceability during loading. All load-deflection responses and crack patterns were recorded.

Data Analysis

Experimental data were analyzed using standard engineering methods and compared to conventional reinforced slabs. Parameters such as flexural capacity, crack propagation, and structural response were evaluated.

Research Limitations

The study focused on one-way slabs using specific materials and reinforcement ratios. Results may not be directly applicable to other slab types or loading conditions. The limited sample size and lack of long-term durability assessment are acknowledged limitations.

Ethical Considerations

All research activities were conducted ethically, with necessary approvals obtained. Safety and research integrity were maintained throughout the process.

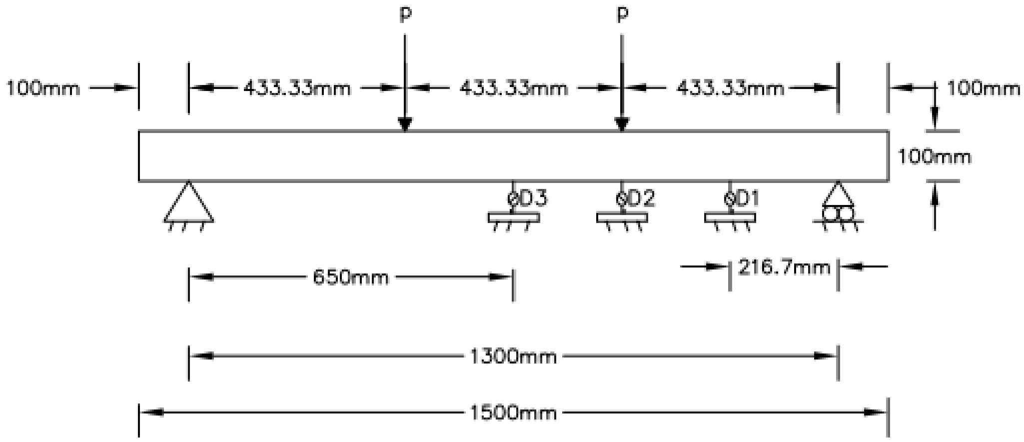


Figure 1. Arrangement LVDT.

Table 2. Details of all specimen the RFT and concrete dimension

Slab Code	Concrete Dimensions(mm)	Reinforcement		Cover
		Steel	Bamboo	
S (S100-B0) %	1500*550*100	5Ø10	0	20 mm
S (S0-B100) %		0	5Ø10	
S (S80-B20) %		4Ø10	1Ø10	
S (S60-B40) %		3Ø10	2Ø10	
S (S40-B60) %		2Ø10	3Ø10	
S (S40-B60) %		2Ø10	2Ø12	
S (S20-B80) %		1Ø10	4Ø10	

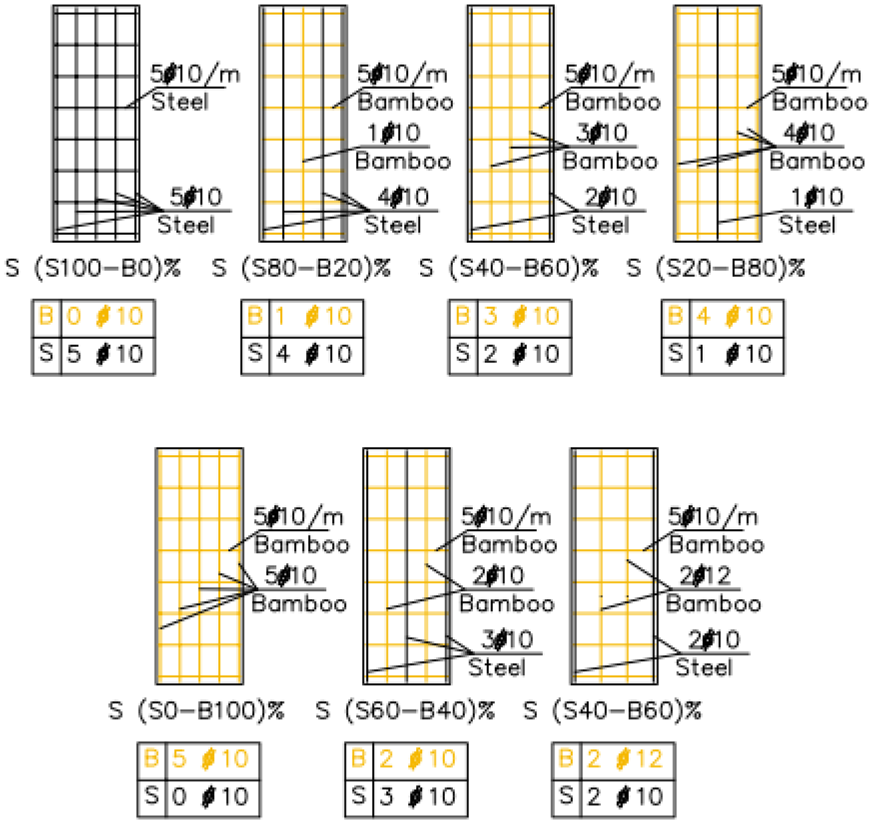


Figure 2. Different type of RFT in Slabs

Main Test Program

A total of seven one-way concrete slabs with dimensions of 1500 × 550 × 100 mm were cast and tested under two-point loading to investigate their flexural behavior. The specimens incorporated different steel-to-bamboo reinforcement ratios and were labeled using the code S(X–Y), where X and Y represent the percentages of steel and bamboo reinforcement, respectively. The reinforcement configurations for all specimens are summarized in Table 2.

Moreover, light distribution reinforcement (Ø10 mm @ 200 mm spacing) was provided in the transverse (short) direction of the slabs (550 mm) to control shrinkage and temperature-induced cracking. This secondary reinforcement was kept consistent across all specimens and was not considered a study variable, as the main investigation focused on the flexural behavior along the longitudinal axis.

3. Results and Discussion

The primary focus of this study was to evaluate the flexural performance of bamboo-reinforced concrete slabs. To ensure the accuracy and reliability of the main slab tests, several preliminary tests were conducted on the constituent materials, including bamboo tensile strength, concrete compressive strength, and concrete tensile strength. These material tests provide essential baseline data for interpreting the structural behavior of the tested slabs. The results of these tests are presented below, followed by a detailed discussion of the flexural performance of the slab specimens.

3.1 Tensile Strength Test of Bamboo Specimen.

The tensile tests were conducted for several samples of both bamboo specimens. Their failure pattern, ultimate and yield strength will be discussed in the following section. Tension tests were performed for specimens with different conditions of gripping.

Figure 3. splitting and Grip Failure (sample-1)

Figure 4. Splitting and Grip Failure (sample-2)

Figure 5. Splitting and Grip Failure (sample-3)

Figure 6. Splitting and Grip Failure (sample-4)

Figure 7. Splitting and Grip Failure (sample-4)

Table 3. Results of Tension Test for Bamboo Reinforcement.

Specimen No	Avg. Area (mm2)	Failure Load (KN)	Stress at Failure (MPa)	Strain	Failure type
1	19.5	9.419	483.03	0.002	Splitting and Grip Failure
2	15.51	3.396	219	0.0045	Splitting and Grip Failure
3	12	4.406	367	0.0027	Splitting and Grip Failure
4	9.5	2.505	260	0.0038	Splitting and Grip Failure
5	9.5	1.605	169	0.0059	Splitting and Grip Failure
6	12	5.147	428.916	0.0023	Splitting and Grip Failure

Table 4. Stress –Strain curve For Bamboo (Sample – 1).

Load (KN)	Area(mm)	Stress (MPa)	Length (mm)	Elongation (mm)	Strain (x10^{-3}) (mm/mm)
0	19.5	0	500	0	0
0.88	19.5	45.128	500	1.5	0.003
1.32	19.5	67.69	500	2.5	0.005
1.76	19.5	90.26	500	3	0.006
2.64	19.5	135.38	500	3.5	0.007
3.52	19.5	180.51	500	6	0.012
5.28	19.5	270.76	500	6.75	0.0135
7.48	19.5	383.58	500	7.75	0.0155
7.92	19.5	406.15	500	8.75	0.0175
9.419	19.5	483.03	500	10	0.02

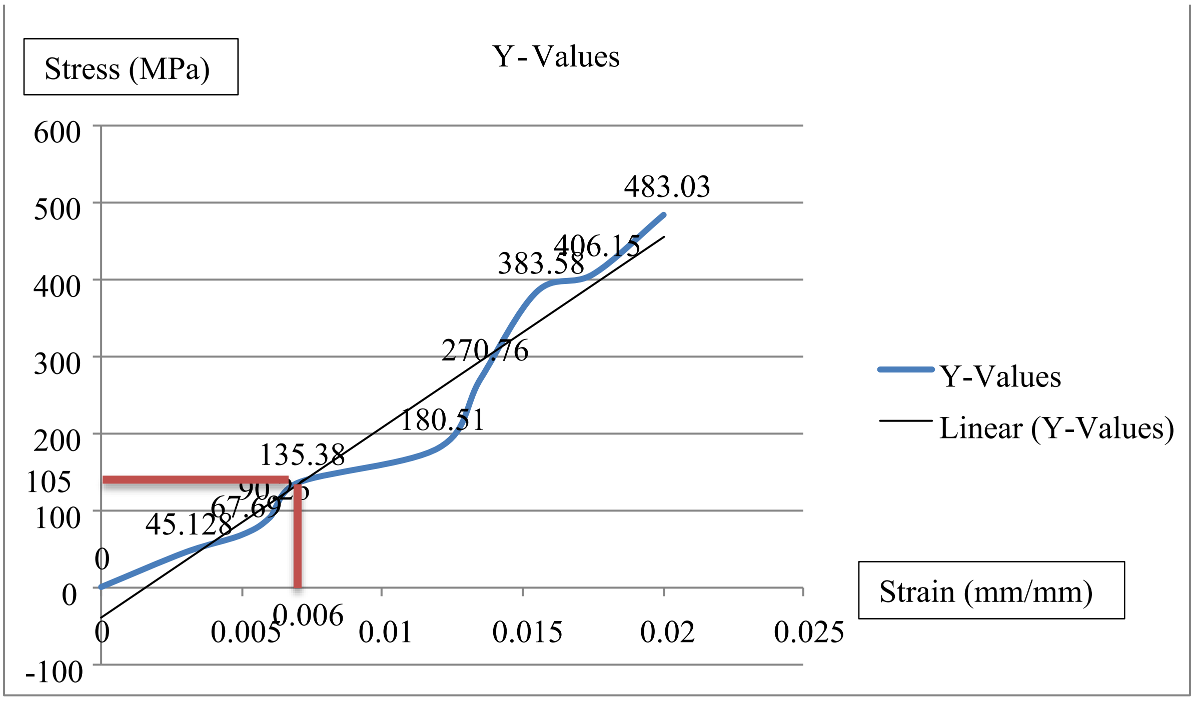


Figure 8. Stress - Strain Curve of Bamboo Samples -1.

From this curve, the yield strength has been calculated by offset method. The offset is the horizontal distance between the initial tangent line and any line running parallel to it. The value of the offset for a given material is usually expressed this way: Yield Strength, 0.1% Offset. Therefore, from this method, the yield strength fy = 105 MPa.

3.2 Compression Test of Concrete Cylinders.

Three cylinders (150 mm Diameter & 300 mm height) were constructed, cured and tasted after 28 days (the day of testing of the slabs). The results are shown in Table 5.

Table 5. Results of Concrete Compressive Tests.

Specimen	Area (mm2)	Load (KN)	Concrete Compressive Stress (MPa)
1	1766.2	401	22.7
2	1766.2	420	23.7
3	1766.2	435	24.6
		Average	23.66

So, the compressive strength of concrete is taken 25 MPa

3.3 Tensile Strength Test of Concrete Cylinders.

Three cylinders (150 mm Diameter & 300 mm height) were constructed, cured and tasted after 28 days (the day of testing of the slabs). The results are shown in Table 3.4. Shown in figure 9.

Figure 9. Concrete Tensile Strength Tests Cylinder.

Table 6. Results of Concrete Tensile Strength Tests.

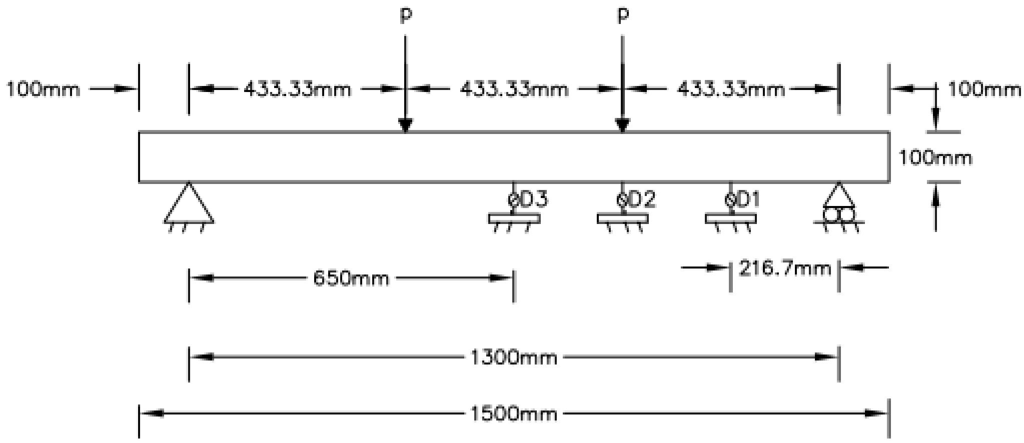
Specimen	Load (KN)	Concrete Tensile Strength (MPa)
1	181.3	1.28
2	206.5	1.46
3	199.1	1.41
	Average	1.38

So, the Tensile strength of concrete is taken 1.38 MPa

3.4 Results of Slab Tests.

After establishing the properties of the constituent materials, the primary experimental program focused on the flexural behavior of the bamboo-reinforced concrete slabs. All slab specimens were tested under two-point loading to simulate bending conditions and evaluate their structural performance in terms of crack patterns, load-deflection response, and ultimate load capacity. The following subsections present the observations and results for each reinforcement configuration.

Figure 10. Arrangement LVDT.



Slab with 100 % Steel Reinforcement

Flexural Behavior

Figure 11. Failure mode for the SLAB 100% Steel (S100-B0) %.

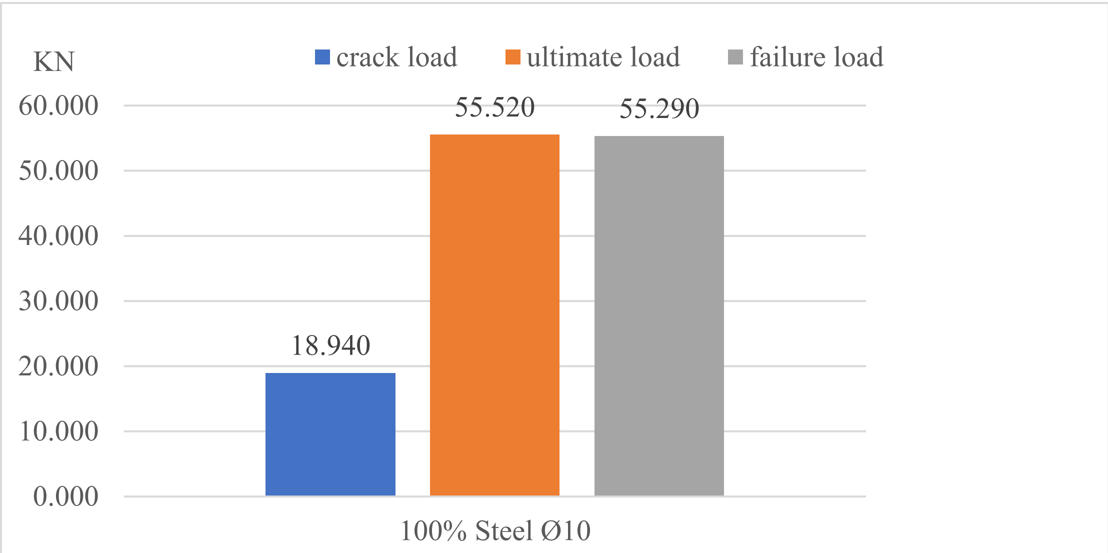


Figure 12. Comparison of the cracking, ultimate and failure loads for the Slab (S100-B0) %.

Cracking Behavior

The first crack was observed in the mid-span at 18.940 KN. Upon increasing the load, more flexure cracks appeared in the bottom of the tension zone and expanded vertically upward. The cracks propagated at the maximum tension zone during the sequent loading stages up to failure shown in figure 13.

Figure 13. Final Crack patterns for 100% Steel Reinforced Slab (S100-B0) %.

Slab with 20 % Bamboo Reinforcement

Flexural Behavior

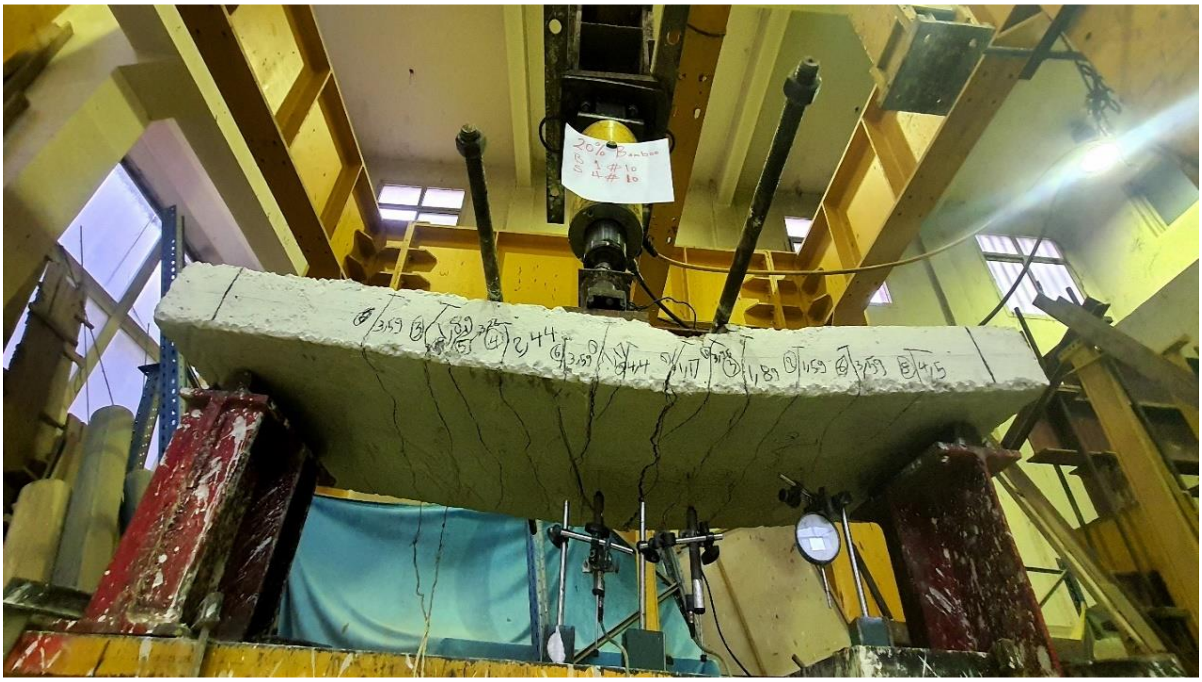


Figure 1. Failure mode for the Slab 20% Bamboo (S80-B20) %

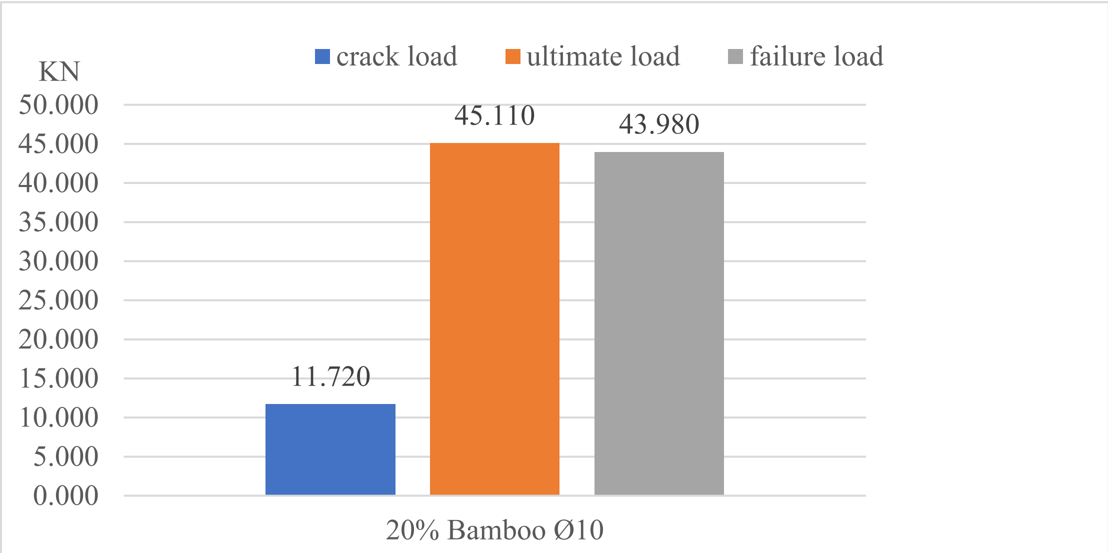


Figure 15. Comparison of the cracking, ultimate and failure loads for the Slab (S80-B20) %

Cracking Behavior

The first crack appeared due to the combined action of bending and shearing at 11.72 KN, which spread as shown in figure No (16). The second crack also appeared at a load of 15.92 KN, and it was distributed as in the picture. The third crack appeared with a load of 18.88 KN and. The fourth crack appeared at a load of 24.39 KN, the fifth crack appeared at a load of 32.26 KN. The sixth crack appeared at a load of 35.87 KN, and the seventh crack appeared at a load of 43.45 KN. The eighth crack appeared at a load of 45.11 KN. The failure of the concrete slab occurs when a load (45.110) KN. After that, the cracks widen and the load gradually decreases as a result of the collapse of the slab.

Figure 16. Final Crack patterns for 20% Bamboo Reinforced Slab (S80-B20) %.

Slab with 40 % Bamboo Reinforcement

Flexural Behavior

Figure 17. Failure mode for the slab 40% Bamboo (S60-B40) %.

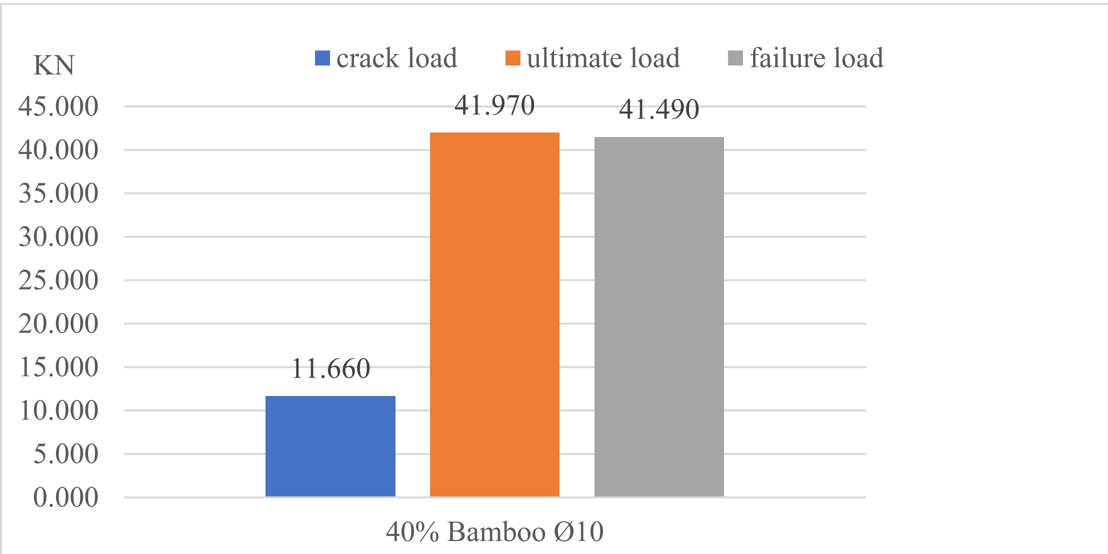


Figure 18. Comparison of the cracking, ultimate and failure loads for the slab (S60-B40) %.

Cracking Behavior

The first crack appeared due to the combined action of bending and shearing at 11.66 KN, which spread as shown in figure No (19). The second crack also appeared at a load of 15.09 KN, and it was distributed as in the picture. The third crack appeared with a load of 18.58 KN and. The fourth crack appeared at a load of 23.97KN, and the fifth crack appeared at a load of 37.88 KN. The failure of the concrete slab occurs when a load 41.97 KN. A widening of the cracks as the applied load increased, eventually leading to a major flexural crack. After that, the cracks widen and the load gradually decreases as a result of the collapse of the slab at the required load as shown in figure No (19).

Figure 19. Final Crack patterns for 40% Bamboo Reinforced Slab (S60-B40) %.

Slab with 60 % Bamboo Reinforcement

Flexural Behavior

Figure 20. Failure mode for the slab 60% Bamboo (S40-B60) %.

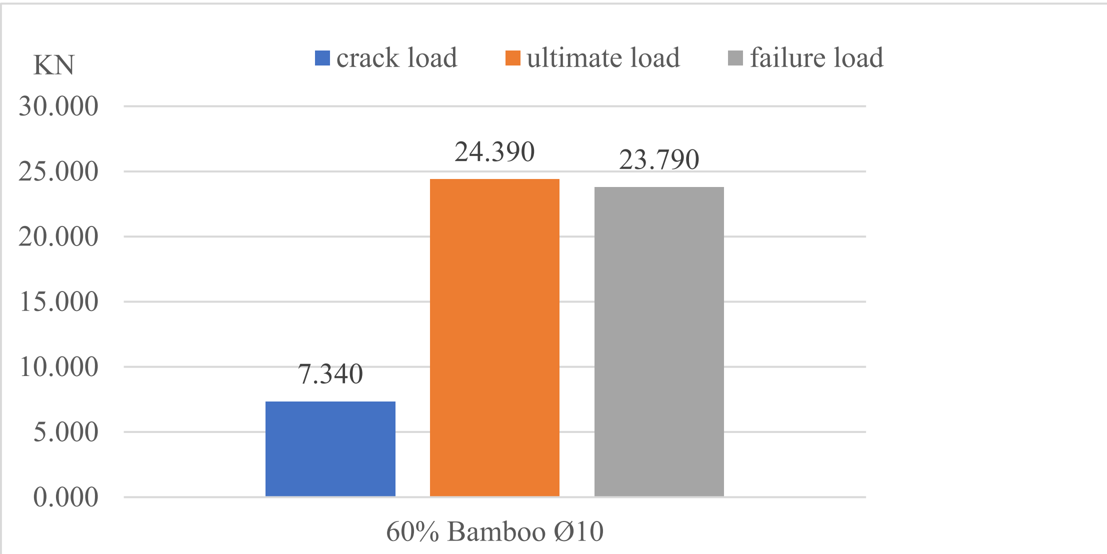


Figure 21. Comparison of the cracking, ultimate and failure loads for the slab (S40-B60) %.

Cracking Behavior

The first crack appeared due to the combined action of bending and shearing at 7.34 KN, which spread as shown in figure No (22). The second crack also appeared at a load of 11.6 KN, it was distributed as in the picture. The third crack appeared with a load of 13.37 KN, the fourth crack appeared at a load of 17.46 KN, and the fifth crack appeared at a load of 19.53 KN. The failure of the concrete slab occurs when a load 24.39 KN. A widening of the cracks as the applied load increased, eventually leading to a major flexural crack. After that, the cracks widen and the load gradually decreases as a result of the collapse of the slab at the required load as shown in figure No (22).

Figure 22. Final Crack patterns for 60% Bamboo Reinforced Slab (S40-B60) %.

Slab with 60 % Bamboo Reinforcement with Different diameter (12mm)

Flexural Behavior

Figure 23. Failure mode for slab Reinforced (S40-B60 12mm) %.

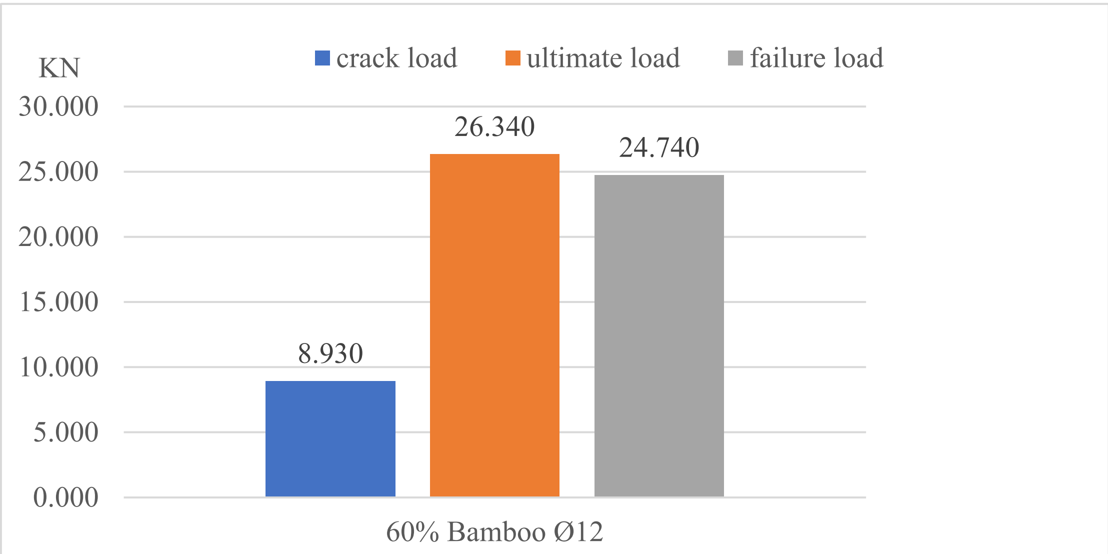


Figure 24. Comparison of the cracking, ultimate and failure loads Slab Reinforced (S40-B60 12mm) %.

Cracking Behavior

The first crack was observed in the mid-span at 8.93 KN. Upon increasing the load, more flexure cracks appeared in the bottom of the tension zone and expanded vertically upward. The cracks propagated at the maximum tension zone during the sequent loading stages up to failure shown in figure 25.

Figure 25. Final Crack patterns for 60% Bamboo Reinforced Slab (S40-B60 12mm) %.

Slab with 80 % Bamboo Reinforcement

Flexural Behavior

Figure 26. Failure mode for the slab 80% Bamboo (S20-B80) %.

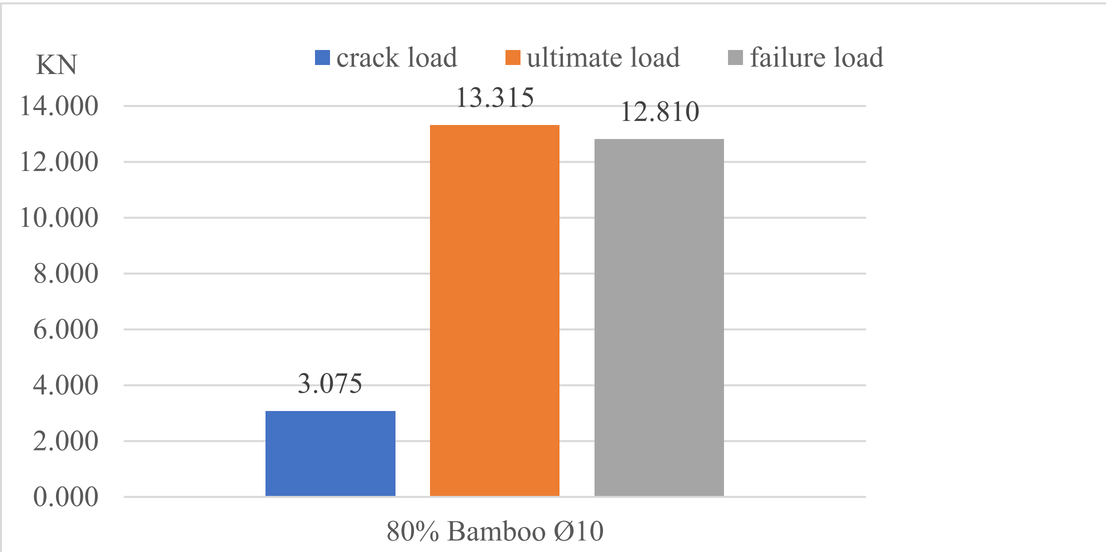


Figure 27. Comparison of the cracking, ultimate and failure loads for the slab (S20-B80) %.

Cracking Behavior

The first crack appeared due to the combined action of bending and shearing at 3.075 KN, which spread as shown in figure No (28). The second crack also appeared at a load of 4.080 KN, it was distributed as in the picture. The third crack appeared with a load of 5.205 K, the fourth crack appeared at a load of 3.300 KN, and the fifth crack appeared at a load of 8.345 KN. The failure of the concrete slab occurs when a load 13.315 KN. A widening of the cracks as the applied load increased, eventually leading to a major flexural crack. After that, the cracks widen and the load gradually decreases as a result of the collapse of the slab at the required load as shown in figure No (28).

Figure 28 Final Crack patterns for 80% Bamboo Reinforced Slab (S20-B80) %.

Slab with 100 % Bamboo Reinforcement

Flexural Behavior

Figure 29. Failure mode for the slab 100% Bamboo (S0-B100) %.

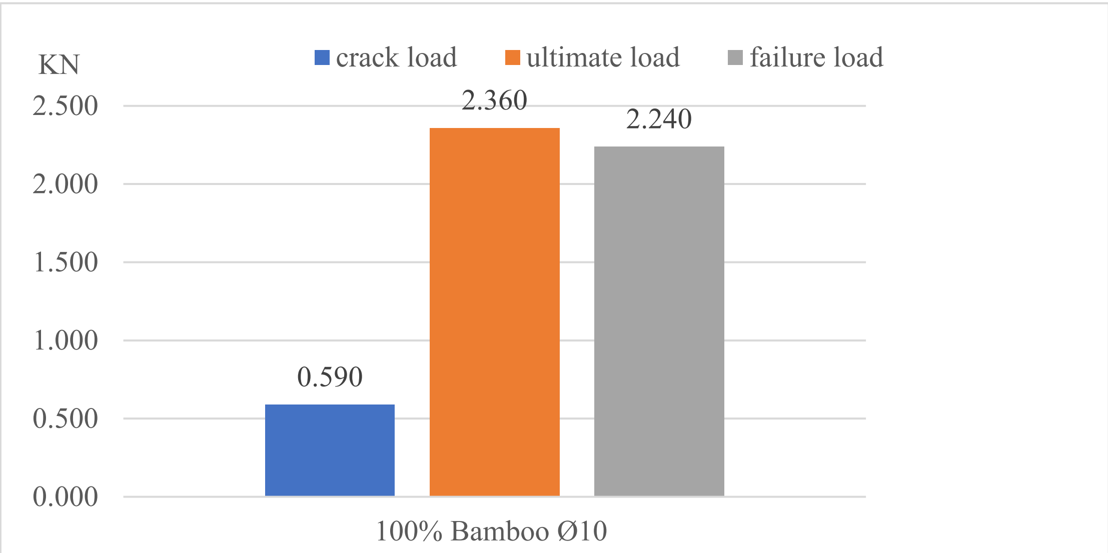


Figure 30. Comparison of the cracking, ultimate and failure loads for the slab (S0-B100) %.

Cracking Behavior

The crack appeared due to the combined action of bending and shearing at 0.590 KN, the failure of the concrete slab occurs when a load 2.360 KN. After that, the crack widens and the load gradually decreases as a result of the collapse of the slab at the required load as shown in figure No (31).

Figure 31. Final Crack patterns for 100% Bamboo Reinforced Slab (S0-B100) %.

Summary of Load Results for All Slabs

The table below summarizes the cracking, ultimate, and failure loads for all tested slabs. All values are presented in kilonewtons (kN).

Table 7. Results of the Cracking, Ultimate, and Failure loads for all tested slabs.

Specimen Code	Cracking Load (kN)	Ultimate Load (kN)	Failure Load (kN)
S100-B0	18.94	47.00	47.00
S80-B20	11.72	45.11	45.11
S60-B40	11.66	41.97	41.97
S40-B60	7.34	24.39	24.39
S40-B60 (12mm)	8.93	27.00	27.00
S20-B80	3.08	13.31	13.31
S0-B100	0.59	2.36	2.36

4. Conclusions

This study examined the flexural performance of one-way concrete slabs reinforced with varying ratios of bamboo and steel. Based on the experimental findings, the following conclusions can be drawn:

1. Bamboo reinforcement demonstrated limited structural capacity when used alone. Cracking occurred early, and failure was brittle with dense fine cracks throughout the slabs.
2. Increasing the bamboo reinforcement ratio led to marginal improvements, but the overall load-carrying capacity remained significantly lower than that of steel-reinforced slabs.
3. The hybrid use of bamboo with steel (especially in the 20–40% bamboo range) provided a balance between strength and sustainability, showing potential for use in non-critical or temporary structures.
4. Specimens with steel reinforcement exhibited superior performance in terms of strength, ductility, and crack control, highlighting the continued importance of steel in primary load-bearing elements.
5. The behavior of slabs reinforced with larger-diameter bamboo (12 mm) showed slight improvements, suggesting that bamboo geometry influences structural performance.
6. Bamboo remains a promising renewable material, and its effective use in concrete depends heavily on treatment methods, placement strategy, and intended structural application.
7. Future research should focus on bond improvement, durability assessment under environmental exposure, and the long-term behavior of bamboo-reinforced members.

These findings support the potential of bamboo as a sustainable alternative reinforcement in specific applications, contributing to greener construction practices in developing regions.

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