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EVALUATION OF BAMBOO REINFORCEMENT FOR STRUCTURAL SUSTAINABILITY

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Abstract - **Bamboo, a fast-growing and renewable resource, provides an appealing alternative to traditional construction materials, which frequently have a negative environmental impact. This study investigates the use of modelling approaches to assess bamboo reinforcement's potential to improve structural sustainability. Bamboo reinforcement has the potential to reduce environmental impact, increase sustainability due to its renewable nature, and make structures lighter in weight, which is especially useful in earthquake-prone locations. Researchers used software not limited to such as ETABS, Staad Pro, and ANSYS to simulate and study the structural behaviour of bamboo-reinforced parts, including load estimates, stress distribution, and connection behaviour. This study intends to improve modelling tools for accurately representing bamboo-reinforced structures, analyse their performance under different loads, and compare them to traditional solutions. Finally, this work can help improve the understanding of designing and assessing bamboo-reinforced structures, optimise their performance, and promote sustainable construction techniques.**

Keywords - **Bamboo reinforcement, ETABS, Modelling approach, Structural sustainability, and Sustainable Construction**

I. INTRODUCTION

The world of plants unfolds like a magnificent tapestry, with threads of vivid hues, intriguing textures, and an incredible variety of life forms. Each species in this beautiful world of art plays an important function in maintaining the delicate balance of our planet's environment. However, Yadav and Mathur (2021) stated that within this engaging assortment, bamboo stands out as a genuinely extraordinary wonder, exhibiting features that distinguish it from its plant kingdom counterparts. Boity et al. (2022) studied that bamboo unlike traditional construction materials such as timber, has a quick development cycle, maturity in 3-7 years. This quick regeneration enables ethical harvesting procedures, reducing environmental impact compared to slower-growing trees.

Traditional concrete constructions are substantially reinforced with steel. However, various issues linked with steel raise the need for a more sustainable option. Steel production emits a considerable amount of carbon dioxide, which contributes to climate change. The energy-intensive processes involved in mining, processing, and transporting steel leave a significant carbon footprint. Moreover, steel prices can change dramatically, making construction projects more costly and uncertain. Additionally, reliance on global steel markets can have an influence on local economies. Fahim et al. (2022) have highlighted that bamboo may be used to build entire homes, schools, and bridges. Treated bamboo can be as robust as steel under tension and performs well in earthquake zones.

Simultaneously, Ingole et al. (2020) stated that bamboo is a lightweight and strong alternative to typical construction materials, making it a sustainable option. Engineered bamboo panels are suitable for floors, walls, and roofs, providing a durable and attractive surface. Split bamboo can be woven into walls and ceilings, creating a natural and eco-friendly look. It could be bent and sculpted into various furniture components. Bamboo pieces can be used in walls, ceilings, and decorative features to provide a natural touch to interior spaces. Scientifically, bamboo's strength in tension for beams, trusses, and columns minimises stresses drawn along their length. Ingole et al. (2020) identified that the building sector is continuously looking for sustainable alternatives to standard materials, and bamboo, such material, is deemed fit for the purpose.

Currently, there is a dearth of accurate and comprehensive models for predicting the structural performance of bamboo-reinforced components. Bamboo's widespread use in a sustainable building is hampered by uncertainty about its long-term behaviour and load-carrying capabilities. Hence, creating accurate models for bamboo reinforcing is critical for enhancing structural safety, discovering the best design combinations and promoting structural construction.

II. RESEARCH BACKGROUND

The present study investigation began with a thorough examination of bamboo construction procedures around the world. This preliminary inquiry sought to comprehend bamboo's rich historical and cultural relevance in architectural design. Researchers looked at how different locations used bamboo for structural parts ranging from walls and roofs to entire houses and bridges. This literature study aimed to gather existing knowledge concerning bamboo's mechanical qualities, such as tensile strength, compression strength, and flexibility. Furthermore, the review gave useful data on the performance of bamboo reinforcements in concrete structures, such as their ability to increase crack resistance and energy absorption capacity.

Hashna and Elizabeth (2017) have stated that the construction industry is facing a critical juncture, as growing awareness of the environmental impact of traditional building materials like concrete and steel necessitates a shift towards more sustainable practices. Conventional materials are energy-intensive to produce and contribute to greenhouse gas emissions throughout their life cycle, from resource extraction and processing to transportation and construction. Additionally, their reliance on finite resources raises concerns about long-term sustainability.

Javadian et al. (2020) and Gobi et al. (2021) research works investigated bamboo fibre-reinforced polymer (BFRP) composites as a game-changing sustainable alternative to traditional steel and synthetic fibre reinforcement in concrete beams. Kumar and Ashish (2015) emphasised that bamboo offers a unique combination of sustainability and cost-effectiveness, making it a promising alternative compared to wood and steel, by which bamboo boasts rapid renewability, reaching maturity in just a few years.

An experimental study by Huang et al. (2015) discussed that the structural strength of bamboo is longitudinally six times stronger than transversal arrangement. This makes bamboo ideal for beams and columns in buildings with minimal bending but less appropriate for applications requiring steady pressure from the sides, such as poles buried underground. An analytical work of Quintero et al. (2022) highlighted about the structural analysis of a real-world example: a pedestrian footbridge in Colombia constructed entirely from Guadua bamboo, a specific species (Guadua angustifolia Kunth) known for its potential in construction. The research utilised advanced software to create a digital model of the bridge, meticulously examining its behaviour under stress, loads transfer throughout the structure, inherent properties of the bamboo, and the methods used to connect the bamboo elements. This bridge analysis adhered to Colombia's national building regulations (NSR-10). His study proposed revisions to existing building codes to integrate better and accommodate the use of bamboo in construction.

Long, hollow bamboo tubes, for example, may support a great amount of weight when placed on top of them, spreading force down the length. Based on the conducted study, the observed limitations are; a) existing bamboo reinforcement models fail to account for the variety of bamboo qualities, such as strength and stiffness, which vary greatly depending on species, age, processing methods, and environmental conditions, b) lack of explicit laws or design standards governing the use of bamboo as reinforcing and c) lack of skilled labour and knowledge to develop bamboo handling in building projects.

III. METHOD AND METHODOLOGY

The purpose of this study is to conduct an in-depth investigation of bamboo reinforcement methodologies in construction by the integration of bamboo reinforcement into conventional building practices and conduct a comprehensive comparison between Reinforced Concrete (RCC) structures and those with bamboo-reinforced concrete (BRC).

The present study developed on incorporating bamboo reinforcement into traditional building procedures. It involved embedding bamboo elements into structural components such as columns, beams, and slabs. A full comparison was made between typical RCC and those reinforced with BRC. This comparison will consider factors including structural performance, cost-effectiveness, and sustainability. Eventually, the applicability of BRC would be determined by considering variables such as load-bearing capability, resistance to environmental elements, construction processes, and regulatory compliance.

In this connection, a G+3 building was designed utilising the ETABS, stands for "Extended 3D Analysis of Building Systems." It is a tool developed by Computers and Structures, Inc. (CSI) - a well-known industry standard for building analysis and design software. Initially, the G+3 building was simulated and analysed for conventional materials, which were Fe500 rebars and concrete of grade M30. The load-bearing components were beams, columns and slabs. The loads applied on the structure were dead load, live load, floor finish load, wall load and earthquake load respectively. Later, the columns of the same building were replaced with the properties of bamboo and analysed for comparison and conclusions.

IV. EXPERIMENT AND RESULTS

The dead load calculations of beams, columns, and clubs have been shown in Table 1. The live load for slabs has been shown in Table 2, and the same for the terrace floor has been considered as 2KN/m, based on IS 875 part 2. The floor finish load calculations have been discussed in Table 3. Terrace wall and Parapet wall load calculations are discussed in Table 4.

Table 1. Dead Load Calculations

Load Carrying Elements	Size (m)	Calculation (KN/m)	Value (KN/m)
Beams	0.3×0.3	0.3×0.3×20	1.8
Columns	0.3×0.3	0.3×0.3×20	18
Slabs	0.125	0.125×20	2.5

Table 2. Live Load Calculations

Load Carrying Elements	Size (m)	Calculation (KN/m)	Value(KN/m)
Slabs	0.125	3	3
(For general residential buildings based on IS 875 part 2)			

Table 3. Floor Finish Load Calculations

Load Carrying Elements	Size (m)	Calculation	Value(KN/m)
Slabs	0.125	$0.125 \times 20 \times 1$	2.5

Table 4. Wall Load Calculations

Load Carrying Elements	Size (m)	Calculation (KN/m)	Value (KN/m)
Terrace Wall	0.15×2.7	2.7×0.15×20	8.1
Parapet Wall	1.2×0.15	1.2×0.15×20	3.6

Earthquake loads are considered as 50% of the live load applied on the slab, which is 1.5KN/m, same for both EQ-X (Earthquake loads along X direction) and EQ-Y (Earthquake loads along Y direction). The next phase comprised BRC analysis. Hence the changes were made with respect to bamboo properties. As per Ramesh et al. (2021), Kavitha and Sandeep (2019), the modulus of elasticity and weight per unit volume for bamboo have been mentioned in Table 5

Table 5. Material Property Data of Bamboo

S.No	Material Property Data	Value
1.	Specific Weight Density (kN/m^3)	8
2.	Modulus of Elasticity (E) (MPa)	14350

The frame sections were selected from the defined section; over there, the column named C(300X300)M30bamboo was selected, and the material property of bamboo was given to its rebars. The diameter of the bamboo was taken as 20mm. After the addition of the corresponding property, 8 columns at the centre were assigned as the columns with bamboo rebars. This was done for each floor in the entre building. Later, the changes were made for minimum yield strength(f_y), minimum tensile strength(fu), expected yield strength(f_{ye}), and expected tensile strength(f_{ue}). As per Abdullah (2020), the changes have been mentioned in Table 6.

Table 6. Rebar Properties

S.No	Design Properties for rebar materials	Value (MPa)
1.	Minimum yield strength, f_y	157
2.	Minimum tensile strength, f_u	187
3.	Expected yield strength, f_{ye}	140
4.	Expected tensile strength, f_{ue}	92.84

The structure was checked for the presence of errors. The error-free structure was identified, and storey response plots were generated for both cases of RCC and BRC. The following nomenclature represents different load conditions used in the simulation of the developed model. UDCon1-Dead, wall, and floor finish load, UDCon2-Dead, live, wall, and floor finish load, UDCon3-Dead, live, wall, floor finish, EQX load, UDCon4-Dead, live, wall, floor finish, EQX load, UDCon5-Dead, live, wall, floor finish, EQY load, UDCon6-Dead, live, wall, floor finish, EQY load, UDCon7-Dead, wall, floor finish, EQX load, UDCon8-Dead, wall, floor finish, EQX load, UDCon9-Dead, wall, floor finish, EQY load,

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UDCon10-Dead, wall, floor finish, EQY load, UDCon11-Dead, wall, floor finish, EQX load, UDCon12-Dead, wall, floor finish, EQX load, UDCon13-Dead, wall, floor finish, EQY load, UDCon14-Dead, wall, floor finish, EQY load.

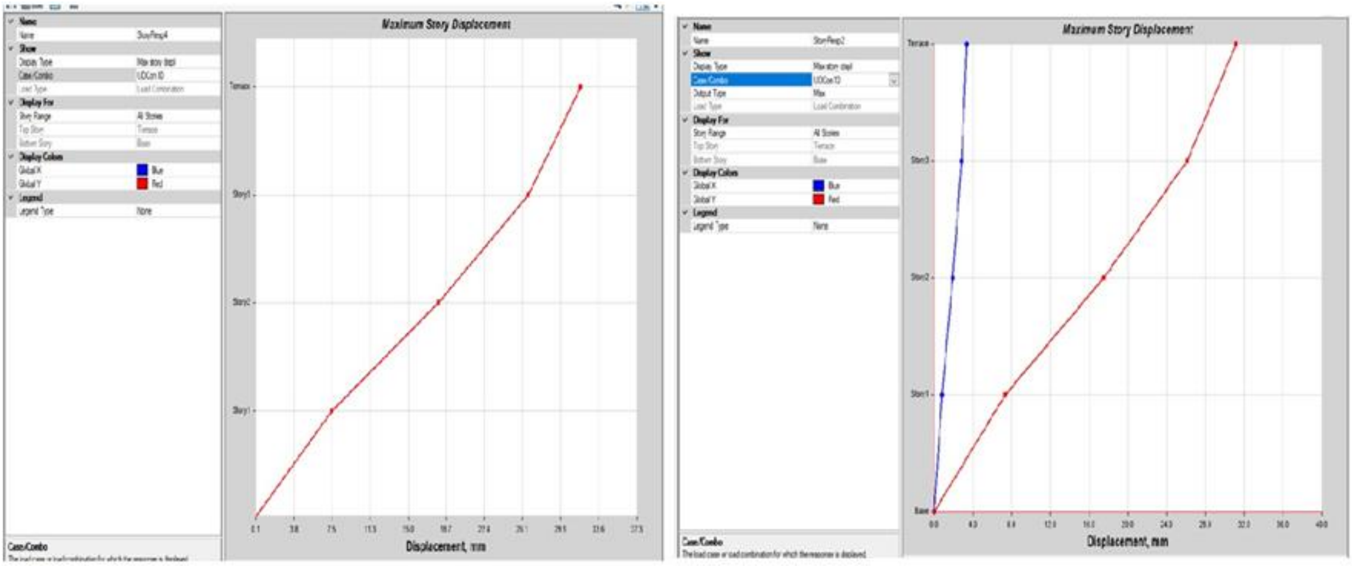

Fig. 1. Comparison of deflection graphs for both BRC and RCC for UDcon10

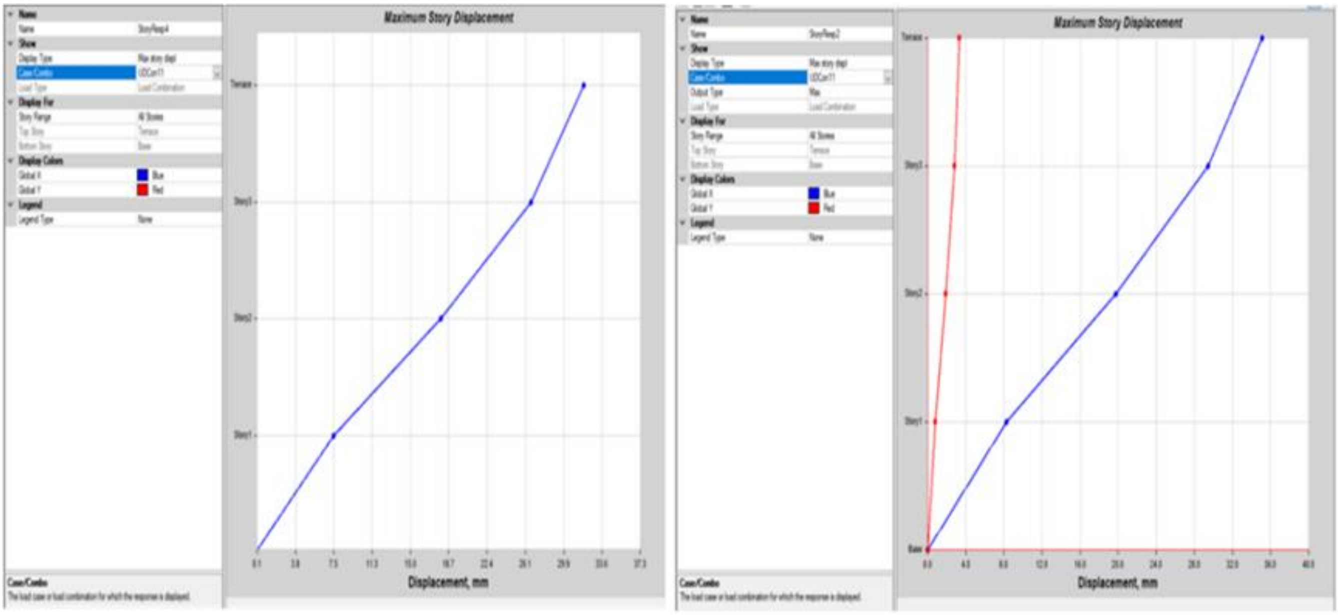

Fig. 2. Comparison of deflection graphs for both BRC and RCC for UDcon11

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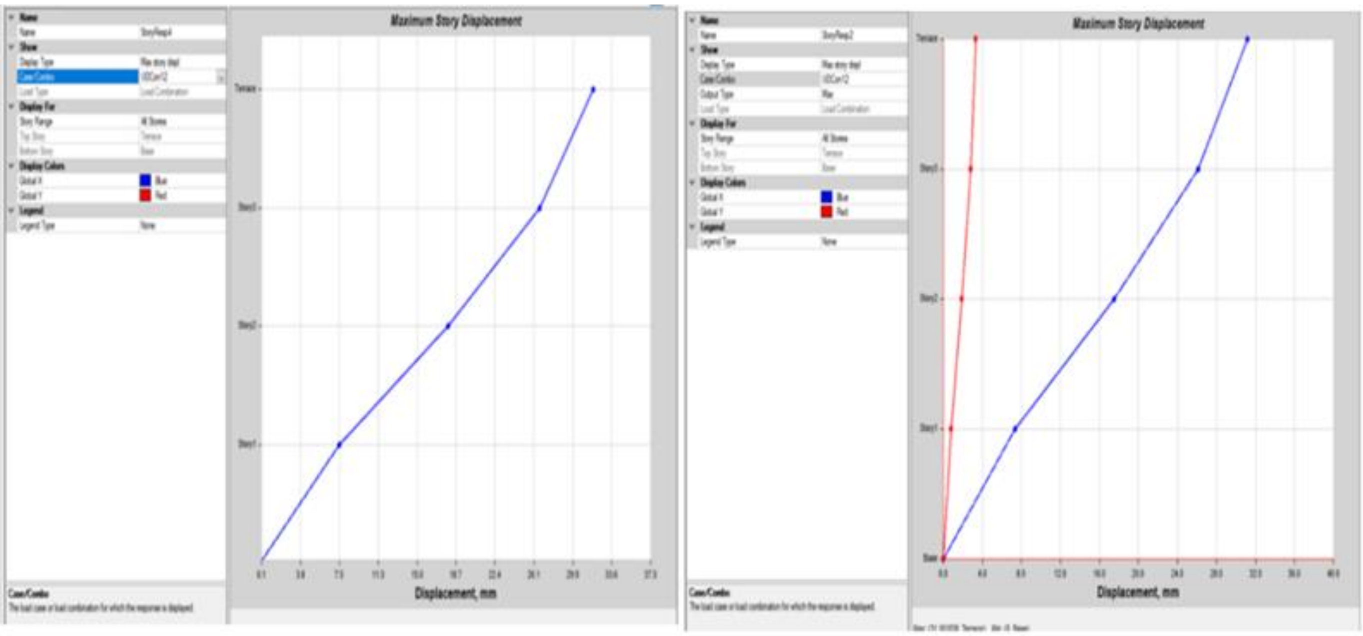

Fig. 3. Comparison of deflection graphs for both RCC and BRC for UDcon12

Table 7. Deflection Table for load combinations

	RCC (mm)		BRC (mm)		Variation (mm)	
	X	Y	X	Y	X	Y
UDCon1	0	0	0	0	0	0
UDCon2	0	0	0	0	0	0
UDCon3	28	2.5	25	0	3	2.5
UDCon4	25	2.6	25	0	0	2.6
UDCon5	2.8	28	0	25	2.8	3
UDCon6	2.6	25	0	25	2.6	0
UDCon7	34	3.8	32	0	2	3.8
UDCon8	30	3.8	32	0	-2	3.8
UDCon9	3.8	34	0	32	3.8	2
UDCon10	3	30	0	32	3	27
UDCon11	34	3	32	0	3	3
UDCon12	30	3	32	0	-2	3
UDCon13	3	34	0	32	3	2
UDCon14	3	30	0	32	3	-2

The graphs mentioned above signify the amount of deflection for multiple load case scenarios. After the simulation of the model, the produced results were in favour of BRC. This comes with the conclusion that bamboo reinforcements can be used with a combination of steel reinforcements for a G+3 building.

V. CONCLUSION

The incorporation of bamboo reinforcements into the corners of the G+3 structure has proven to be a realistic and promising solution. The analysis performed in ETABS yielded excellent results, demonstrating that the structure remains solid and well-supported with the addition of bamboo. Furthermore, the similarity in deflection graphs between RCC and BRC structures indicates that bamboo effectively fulfils its role as a reinforcing material, performing similarly to traditional materials such as steel. This study demonstrates bamboo's potential as a sustainable construction material. Bamboo's renewable characteristics, high tensile strength, and lightweight nature make it a promising solution for developing resilient and eco-friendly buildings. Furthermore, the use of bamboo can help the socio-economic growth of the communities that cultivate it.

Moving forward, more studies on the use of bamboo reinforcements in construction could result in substantial advances in sustainable building techniques that benefit both the environment and society as a whole. Continued research and development into simulating bamboo's structural behaviour will result in more accurate design tools and optimum BRC structures. This will maximise bamboo's strength and flexibility for creative and high-performance constructions. Investigating the usage of bamboo in conjunction with other sustainable materials like hemp or recycled plastic can result in the creation of unique and even more environmentally friendly construction materials with improved qualities. Other potential areas with standardised rules and practices could be created and implemented and design guidelines tailoring to bamboo reinforcement will lay the groundwork for widespread industry acceptance. Integration of BRC with varied bamboo thickness might be simulated to understand the behaviour of bamboo and specifically sustainable structures that are environmentally friendly.

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