Experimental Evaluation of Flexural Performance Lightweight Precast Slab with Combined Steel and Bamboo Reinforcement

Achmad Abdul Aziz Bakhtiar [1]**, Sri Murni Dewi** [1]**, Achfas Zacoeb** [1]**, Wisnumurti** [1]

[1] *Brawijaya University*
169 Jl. MT. Haryono, Ketawanggede, Lowokwaru Sub-District, Malang, East Java, 65145, Indonesia

Corresponding Author:
Achmad Abdul Aziz Bakhtiar
azizbakhtiara@gmail.com

Abstract. This research investigates the performance of lightweight precast slabs reinforced with steel and bamboo (PSSBR) under vertical loading, validated through numerical simulations. The maximum deflection capacity, crack patterns, and failure modes are compared with precast concrete panels reinforced with steel and bamboo as control specimens. Two panels were fabricated with 1600 × 1600 × 110 mm dimensions each and subjected to vertical loading. Based on experimental analysis and numerical simulations, comparing the test results with numerical simulations indicates a close agreement. The specific advantages of PSSBR include environmental friendliness and sustainability.

Keywords: Precast Panels; Bamboo; Bamboo reinforced concrete; Lightweight precast slab.

INTRODUCTION

The recent publication by the United Nations discusses the repercussions of global warming over the past decade and suggests measures to alleviate climate-related disasters [1]. Using fossil fuels significantly contributes to climate change, prompting numerous countries to explore green technology solutions. Research and innovation in renewable energy are crucial for achieving the Net Zero Emission target and addressing global warming. Bamboo emerges as a promising renewable energy source due to its environmental friendliness, affordability, accessibility, rapid growth rate, and ability to absorb CO_2 and release 35% more O_2 than other plants [2].

In a study [3], bamboo bio-concrete (BBC) buildings were tested, revealing that increasing the use of BBC in construction can enhance carbon stocks and reduce operational carbon. BBC technology offers a potential alternative for mitigating and adapting to climate change. Authors [4] suggested that bamboo, used as the primary material for glulam products in construction applications, tends to have a carbon-negative impact with higher carbon dioxide content than wood.

From an economic standpoint, bamboo is more cost-effective than steel, and bamboo-reinforced concrete is 50–65% more economical than steel-reinforced concrete. However, specific treatment processes are required for bamboo to be utilized as concrete reinforcement, including soaking [5], drying [5], and the application of either an epoxy layer [6] or a waterproof coating [7, 8].

In terms of resilience, bamboo exhibits a high tensile strength of up to 370 MPa [8], elasticity, and excellent energy absorption during earthquakes [5].

Authors [9] mentioned that bamboo-reinforced concrete panels incorporating styrofoam filler exhibit notable performance, as the nominal flexural capacity often falls below the design moment with minimal reinforcement. Despite a 15% decrease in capacity compared to standard concrete panels, their performance remains significant. Authors [10] asserted that bamboo reinforcement presents a viable alternative material for slabs, with its cost and suitability for low-cost housing extensively discussed in various studies.

Authors [11] investigated the energy absorption characteristics of panels under monotonous static loads, finding that variations in bamboo species do not significantly affect energy absorption capacity, making it suitable for broader applications. Authors [12] simulated the reinforcement ratio's influence on panel capacity using the ABAQUS program.

Previous studies indicate that bamboo-reinforced concrete performs less effectively than steel-reinforced concrete and exhibits similar failure patterns [13–16]. The differentiation in this study lies in the dimensions of reinforcement and geometry. Therefore, this research aims to investigate the behaviour of PSSBR.

METHODS

The panels were reinforced with petung bamboo aged 3 to 5 years, sourced in 6-meter lengths. Before utilization, the bamboo underwent an extensive treatment regimen. This process involved air-drying, shaping it to the required dimensions, and applying a waterproof coating with a sand sprinkle. Table 1 shows the results and mechanical properties of steel, concrete, AAC (Autoclave Aerated Concrete), bamboo, and wire mesh.

Table 1 – The properties of steel, concrete, AAC (Autoclave Aerated Concrete), and bamboo

Material name	Size (mm)	Modulus of elasticity, E (MPa)	Poisson's ratio, ν	Yield strength, f_y/f_b (MPa)	Compressive strength, f'c (MPa)
Steel	Φ8	200,000	0.30	240	-
Concrete	-	21,538	0.20	-	21
Bamboo	5 x 5	10,122	0.229	387.7	-
AAC	-	1,119	0.15	-	2.23
Wire mesh	-	200,000	0.3	240	-

Two precast slab test specimens, using bamboo reinforcement for PSSBR, made with a dimension of 5 × 5 mm, and steel reinforcement was built from plain steel bars with a diameter of 8 mm for the length of the bar according to the panel size minus 30 mm for the concrete cover. The details of slab reinforcement and installation are shown in Figure 1.
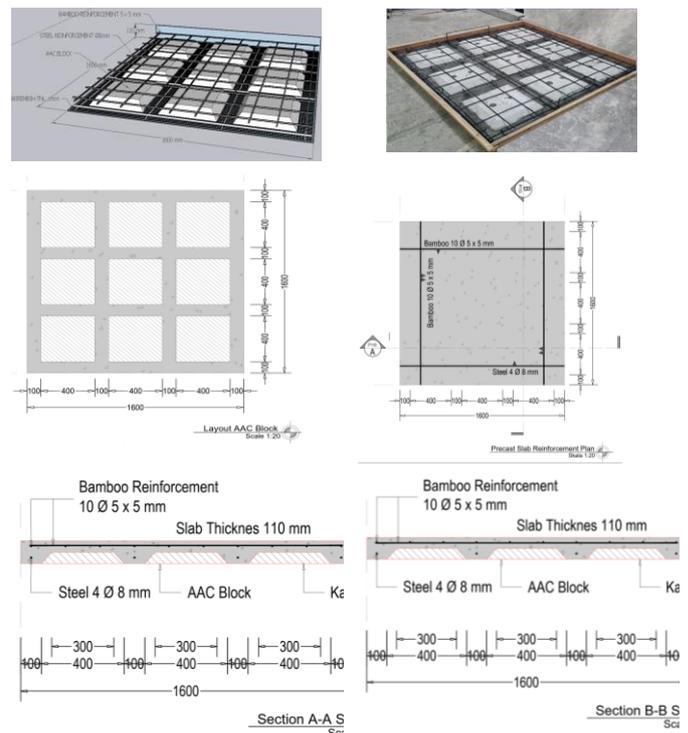

Figure 1 – Details of panel reinforcement and installation of bamboo reinforcement, steel reinforcement, and wire mesh

The loading frame with a capacity of 100 kN was used for the primary test. It is even loaded using a hydraulic jack and load cell connected directly to a data logger. To detect panel deformation or displacement due to vertical loads, 3 LVDTs were installed in the middle of the span and the right and left edges of the concrete slab. Loading was carried out monotonously and gradually to obtain load and displacement. The load was applied progressively and monotonously to read the displacement according to the planned loading stage. The loading was carried out until the panel attained the ultimate load or collapsed, using two methods, namely the load and the displacement control. The load control method was applied from the initiation of loading until the panel attained the request, where the readings control the hydraulic pump. A displacement reader continuously controlled the hydraulic pump. Crack and failure patterns were observed and identified, from initiating the first crack until the panel collapsed. Load and displacement data were collected and recorded on the logger tool. In the final step, the load, displacement, and failure pattern data obtained from the experimental results were validated using the FEM numerical method. At the same time, the test setup of the panel is shown in Figure 2.
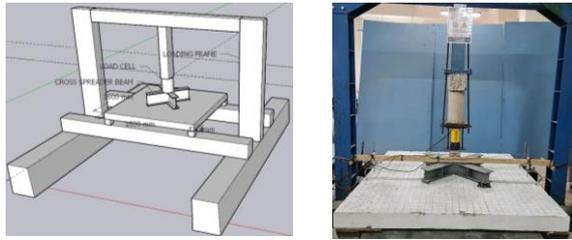
Figure 2 – The test setup of the precast slab

RESULTS AND DISCUSSION

The flexural capacity of the PSSBR slab is shown in Table 2.

Table 2 - The capacity data of Slab Flexural load from experimental and theoretical results

Specimen	Flexural Load Capacity, kg	Displacement, mm
A1-T4	4346	9.080
A2-T4	4300	4.550
ABAQUS CAE	4350	4.445

The maximum displacement of the PSSBR slab was obtained in 2 test specimens. In specimens A1-T4, the displacement value at mid-span was 9.08 mm with a load of 4346 kg; in specimens A2-T4, the maximum value was 4.55 mm. with a load of 4300 kg. The displacement value obtained from the ABAQUS CAE calculation is 4,445 mm with a load of 4350 kg.

Displacement observations and analysis were carried out at points 1/3 and ½ of the span of the test object. Figures 5a and b show the relationship between load vs displacement of PSSBR panels. In the early stages of loading, until the crack is visible, displacement occurs and does not show an entirely linear load and displacement relationship. This indicates that the elastic properties and density of bamboo sclerenchyma tissue fibres influence the stiffness of the panels. The density of sclerenchyma tissue fibres is an indicator of increasing the compressive strength capacity of bamboo [17]. The difference in initial cracking load between A1-T4 and A2-T4 was measured at 2350 kg and 2450 kg, respectively. Likewise, there is a difference in the ultimate load achieved, namely Slab A1-T4 reaches 4346 kg compared to 4300 kg for A2-T4. The load-displacement relationship pattern after the initial crack shows differences, and slab A2-T4

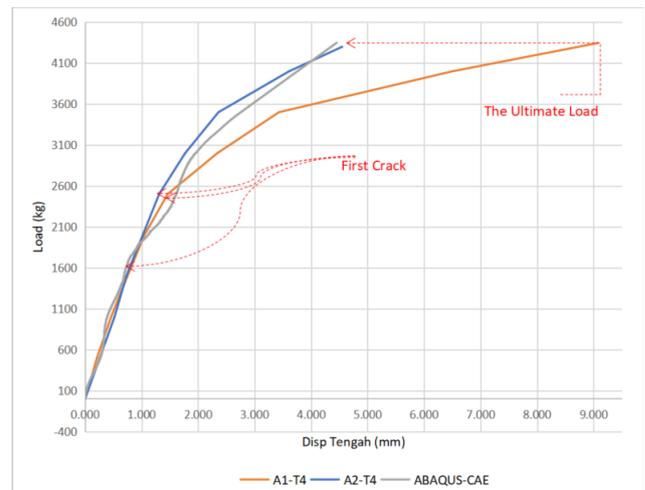shows higher stiffness in carrying the load than A2-T1, as shown in Figure 3.

Figure 3 – The relationship between load vs. displacement PSSBR

Validation of panel crack and failure patterns was carried out by finite element method (FEM) simulation using the ABAQUS program. Concrete was defined as a homogeneous 3D solid component that can be deformed, with a Poisson's ratio value of 0.2, and included in the element type C3D20R. Steel and bamboo reinforcement were defined as 3D bars that can be deformed, with a Poisson's ratio value of 0.3 and 0.229 for steel and bamboo reinforcement, respectively, included in element type T3D3. Steel and bamboo reinforcement were designed with embedded truss elements. AAC was defined as a homogeneous 3D solid component that can be deformed, with a Poisson's ratio value of 0.15, and included in the element type C3D20R. Wiremesh was defined as a homogeneous 3D solid component that can be deformed, with a Poisson's ratio value of 0.3, and included in the element type C3D20R. Concrete meshing was limited by the type of material available in ABAQUS called brick elements, enabling the most appropriate force distribution to be obtained in 3D analysis, as shown in Figure 4a.
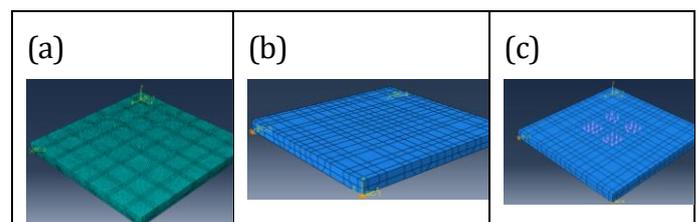

Figure 4 – a) Meshing, b) Constraints, c) Boundary conditions and load direction

Steel and bamboo reinforcement meshing was defined as a 3D truss element about the nature of the force distribution. This followed the nature of the truss element in ABAQUS, distributing the force along the component and enabling proper behaviour for steel and bamboo reinforcement. Figure 4a shows the constraints panel, and Figure 4b indicates the boundary conditions in the slab performance simulation. The boundary conditions in the slab performance simulation were determined in two stages. The first was defining support and final conditions, assuming that the fitting surface of the panel was a joint or pin support. In contrast, the suitable surface was restrained vertically to apply the displacement to the panel. Figure 4c shows the boundary conditions and loading directions.

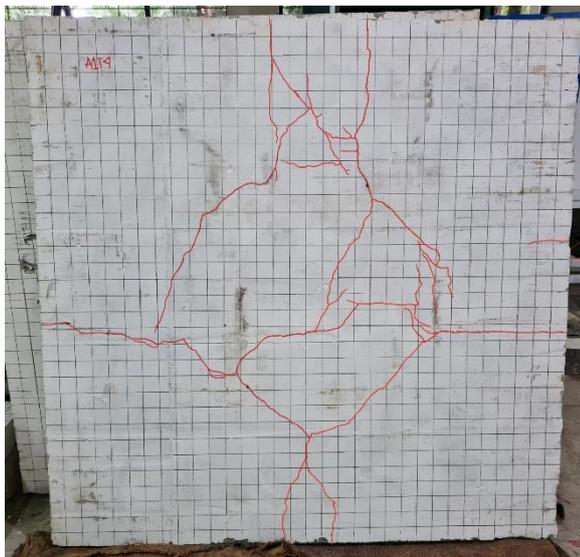Figure 5 shows the crack and failure patterns of the BRCPP panels.

Figure 5 – Crack and failure patterns of PSSBR slab

The pattern commenced with an initial crack of one to three at the bottom-middle of the slab. As the load increases, new cracks continue to appear and become prevalent. Most cracks occurred in areas along 1/2 of the slab, only the bottom sides. However, the most significant number of cracks occurred in the bottom-middle area of the slab. Figure 5 shows the failure pattern of the PSSBR, with the worst damage occurring in the 1/2 area at the bottom-middle of the slab. The failure of the PSSBR Slab showed that the concrete failed in Flexural, as shown in Figure 5. The pattern of cracking and failure of the slab, in correlation with the maximum stress zone from the FEM results.

CONCLUSIONS

Based on experimental analysis and numerical simulations on the performance of the PSSBR slab, the following conclusions were obtained:

1. The load capacity of the PSSBR plate on test objects A1-T4 is 4346 kg, and A2-T4 obtained a value of 4300 kg, while the value received in the ABAQUS CAE analysis was 4350 kg

2. The PSSBR panel failure pattern is a flexural failure in the maximum stress and displacement zone.

3. The pattern of cracks and fractures in PSSBR panels mainly occurs in the 1/2 area in the plate's middle-bottom position, the maximum stress and displacement zone.

4. The crack and failure patterns of the PSSBR panel experimental results show a correlation with the results of FEM simulations and previous research.

Based on the results of theoretical and numerical simulations, the performance of PSSBR panels shows suitability, so they are an option worth considering, especially for precast panels. The unique advantages of PSSBR panels include environmental friendliness and sustainability.

REFERENCES

1. DW. (2023). *PBB Rilis Laporan Situasi Perubahan Krisis Iklim Terbaru* [UN releases latest climate crisis situation report]. Retrireved from https://www.dw.com/id/pbb-rilis-laporan-solusi-atasi-krisis-iklim-terbaru/a-65045065

2. Lewis Bamboo. (2023). *About Bamboo*. Retrieved from https://lewisbamboo.com/

3. Rosse Caldas, L., Bernstad Saraiva, A., Andreola, V. M., & Dias Toledo Filho, R. (2020). Bamboo bio-concrete as an alternative for buildings' climate change mitigation and adaptation. *Construction and Building Materials, 263*, 120652. doi: 10.1016/j.conbuildmat.2020.120652

4. Xiao, Y., Yang, R. Z., & Shan, B. (2013). Production, environmental impact and mechanical properties of glubam. *Construction and Building Materials, 44*, 765–773. doi: 10.1016/j.conbuildmat.2013.03.087

5. Muhtar. (2019). Experimental data from strengthening bamboo reinforcement using adhesives and hose-clamps. *Data in Brief, 27*, 104827. doi: 10.1016/j.dib.2019.104827

6. Thangaraj, S., & Madasamy, M. (2023). Performance Of An Epoxy-Filler-Modified Bamboo-Reinforced Concrete Slab. *Materiali in Tehnologije, 57*(1). doi: 10.17222/mit.2022.637

7. Agarwal, A., Nanda, B., & Maity, D. (2014). Experimental investigation on chemically treated bamboo reinforced concrete beams and columns. *Construction and Building Materials, 71*, 610–617. doi: 10.1016/j.conbuildmat.2014.09.011

8. Ghavami, K. (2005). Bamboo as reinforcement in structural concrete elements. *Cement and Concrete Composites, 27*(6), 637–649. doi: 10.1016/j.cemconcomp.2004.06.002

9. Wibowo, A., Wijatmiko, I., & Remayanti Nainggolan, C. (2017). Bamboo reinforced concrete slab with styrofoam lamina filler as solution of lightweight concrete application. *MATEC Web of Conferences, 101*, 05012. doi: 10.1051/matecconf/201710105012

10. Kantharuban, K., Mani, A., & Krishnaiah, R. V. (2021). *A Comparative Performance Study on Bamboo Reinforced Concrete Slab*. Retrieved from https://www.nveo.org/index.php/journal/article/view/1390/1205

11. Dash, A. K., & Gupta, S. (2022). Energy absorption behavior of bamboo concrete composite wall panel. *Journal of Building Engineering, 57*, 104857. doi: 10.1016/j.jobe.2022.104857

12. Abdel-Jaber, M., & El-Nimri, R. (2022). Comparative investigation, numerical modeling, and buckling analysis of one-way reinforced concrete wall panels. *Results in Engineering, 14*, 100459. doi: 10.1016/j.rineng.2022.100459

13. Dewi, S. M., Hasyim, H., Susanti, L., Sulkan, R. P., & Setyowulan, D. (2022). The experimental study of lightweight precast concrete slab with bamboo reinforcement. *The 4th International Conference On Materials Engineering And Nanotechnology (ICMEN 2021)*. doi: 10.1063/5.0075663

14. Govindan, B., Ramasamy, V., Panneerselvam, B., & Rajan, D. (2021). Performance assessment on bamboo reinforced concrete beams. *Innovative Infrastructure Solutions, 7*(1). doi: 10.1007/s41062-021-00616-8

15. Kathiravan, N. S., Manojkumar, R., Jayakumar, P., Kumaraguru, J., & Jayanthi, V. (2021). State of art of review on bamboo reinforced concrete. *Materials Today: Proceedings, 45*, 1063–1066. doi: 10.1016/j.matpr.2020.03.159

16. Kumar, D., & Mandal, S. (2014). Uncertainty in improving durability aspects and mechanical properties of bamboo reinforced concrete. *International Journal of Advance Research, Ideas and Innovations in Technology, 1*(1), 1–5.

17. Lo, T. Y., Cui, H. Z., & Leung, H. C. (2004). The effect of fiber density on strength capacity of bamboo. *Materials Letters, 58*(21), 2595–2598. doi: 10.1016/j.matlet.2004.03.029