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Structural Performance of Bamboo Sandwich Panel (BSP) With Openings as Load Bearing Wall

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ABSTRACT

Studies on utilizing bamboo as structural and strengthening components still need to be completed. This paper presents a case study on effective and practical approaches for bamboo sandwich panels (BSP) designed as load-bearing walls with and without openings that can withstand heavy weights. Three specimens for each type of wall, all with a height of 1200mm and a width of 600mm, were tested. The BSP walls without openings were tested and considered as control specimens. The BSP walls were constructed with a square opening of 150 x 150 mm at the centre of the panel. The compression and moisture content properties of small clear bamboo materials made of Bambusa Vulgaris species were also measured. The test results show the effectiveness of BSP as a strengthening material to reinforce load-bearing walls with significant stiffness and ultimate bearing load. The BSP with an opening has reduced 31.76% of the wall load-carrying capacity compared to the wall without an opening. The study's findings on BSP offer promising applications in various construction and architectural contexts. The significant stiffness and ultimate bearing load demonstrated by BSPs suggest their potential as sustainable alternatives to conventional load-bearing materials.

Keywords: Bamboo, Bambusa Vulgaris, stiffness, load-bearing wall, construction material

INTRODUCTION

Compared to other neighbouring countries that have explored and identified the potentials of bamboo in various construction works, the usage of bamboo in Malaysia is currently depleting and needs to be fully utilized. Locally, using bamboo as a material in the construction field has yet to be introduced. Lacking available information and not having specific proper management of bamboo throughout the countries has contributed to the lower percentage of bamboo applications, especially in the construction industry. The advantage of bamboo being matured in shorter life growth than timber should make bamboo one of the potential materials as a structural component.

Due to its high strength, workability, and availability, bamboo is used as trusses, foundations, flooring, walling, roofing, beams, columns, and slabs for buildings. Bamboo installation is fairly simple. Bamboo is easy to cut and has no bark to peel during processing, and its lightness makes it easy to handle, transport, and store. Due to its lightness, the bamboo wall system does not require sophisticated technical skills; only jointing at the site is needed (Vishal 2017).

Common load-bearing walls are made of unit's example, clay bricks or concrete blocks and mortar. This study introduces a mix of bamboo sandwiched with concrete as the load-bearing wall material. Bamboo functions to reinforce and act as the core strengthening material for the load-bearing wall. Common walls must frequently be opened to accommodate the function and vertical layouts of building structures. In order to apply bamboo as one of the strengthening materials for load-bearing walls, the reduction area due to the openings in the load-carrying capacity of walls must be studied. The design must withstand downward-acting in-plane vertical loads from the top of the wall.

Several studies carried out on raw bamboo as a reinforcing material to replace steel. Pankaj, Mali & Datta (2018) conducted experimental testing of concrete slab panels to determine this unique bamboo profile's feasibility and effectiveness as reinforcement. Terai & Minamim(2011) studied using raw bamboo as reinforcement in concrete beams and columns. Many researchers investigated the capability of load-bearing walls (Ibrahim & Salman 2015; Li et al. 2003; Lei et al. 2014; Wei & Zhou 2006; Mohamed et al. 2005; Bibiana & Viviana 2011; Hernan & Pablo 2011; Lei et al. 2013; Ola et al. 2007; Bashar et al. 2009a 2009b; Yu 2007; Maruthupandian et al. 2005; Abhijet & Chetia 2016; Khan 2014; Ab. Rahman et al. 2020; Himasree et al. 2023). For example, Ibrahim & Salman (2015) studied the effectiveness and efficiency of bolstering load-bearing walls with and without opening to resist extreme loads strengthened using a carbon fibre-reinforced polymer (CFRP) strip. In their study, an opening was made by occupying 16.6% of 1200 x 800 x 240 mm brick wall and 1200 x 800 x 200mm concrete block. Ibrahim & Salman (2015) reported that the ultimate load capacity for brick load-bearing and concrete block walls with and without opening was 469- 683kN and 440 - 640kN, respectively.

Due to a reduction in the area and discontinuity surrounding the aperture, the strength and stiffness of the wall will be reduced. This reduction can be significant to the load-carrying capacity of the wall, especially to the design of slender walls. However, at the time of writing, no one has reported on the compression of load-bearing walls with openings strengthened using bamboo. Therefore, the primary goal of this study is to evaluate the structural performance of bamboo sandwich panel (BSP) load-bearing walls, comparing configurations with and without openings.

Bamboo belongs to the family Gramineae grasses (Anon 2019). It grows in the temperate zone in the semi-tropical area, which possesses an open and well-drained environment. Bamboo is categorized as Monopodial growth (single stem) and Sympodial (clump). Its features are versatile, powerful, renewable, and environmentally friendly materials. It is extremely strong due to its weight and can be used structurally as a finishing material. It can also withstand the forces created by wind and earthquakes at high speeds. For centuries, bamboo has been used in low-cost rural housing construction. New industrial materials invented from bamboo are expected to be needed by people in daily life (Yu 2007).

As Ghavami (2005) reported, the primary failure of bamboo is water absorption. The water absorption by the bamboo could cause cracks in cured concrete. The bamboo will swell and push the concrete away. Then, at the end of the curing period, the bamboo loses moisture and shrinks to its original dimensions, leaving voids around it. Bamboo must be treated before it can be used in work construction (Ghavami 2005). The moisture content of bamboo depends on bamboo species. The age of bamboo also influences the moisture content. It is necessary to check the moisture content prior to using bamboo. Bamboo has nutrients that attract insects and microorganisms (Yu 2007). The fungi also can attack bamboo in particular temperatures and humidity. The bond between bamboo and cement mortar must exist to use bamboo as a wall panel. The bond between concrete and treated bamboo is higher than that between concrete and steel or untreated bamboo (Ghavami 2005). The bond between untreated bamboo and cement mortar usually decreases because of the expanding behaviour of bamboo. The bamboo may absorb the water in the fresh cement mortar during the casting and curing of the wall panel, which could change the bamboo's physical properties.

Bamboo could replace steel as reinforcement as the tensile strength of bamboo is relatively high (Maruthupandian et al. 2016). Average tensile strength of 50% to 75% of steel or even more can be found in bamboo (Khan 2014). Several studies were conducted on raw bamboo as a reinforcing material to replace steel. Terai & Minami (2011) studied using natural bamboo as reinforcement in concrete beams and columns. They found a similar fracture behaviour to steel-reinforced concrete beams and columns. Terai & Minami (2011) present the feasibility of using bamboo and non-steel as the reinforcing material in concrete members. They studied the tensile strength filled with cement paste and reported that it cured w/c at 80% and 100% significantly increased with ageing time. The behaviour of the pull-out test with bamboo is almost the same as that of the plain steel bar; however, the bond strength with bamboo was higher than that with a plain steel bar. The bond strength covering with complete treatment shows the high-value 1.2-1.35MPa.

Many studies have been done to measure the flexural strength of bamboo-reinforced concrete and whether it can be the same as steel-reinforced concrete. A study by Khan

(2014) involved several types of cross-sectional areas of bamboo reinforcement in concrete beams and found that the flexural strength with square cross-sectional is higher than the triangular and circular cross-sectional areas. Unfortunately, the flexural strength of bamboo reinforced concrete was 50% less than steel-reinforced concrete in the beam. Few studies have reported on a bamboo replacement for steel in concrete slabs. Usually, conventional steel reinforcement provides concrete members with additional tensile strength and energy absorption capacity. However, traditional bars of mild steel (M.S) are heavy, expensive, non-renewable and not environmentally friendly material. To mitigate this concern, sustainable, renewable and eco-friendly materials like bamboo are used to substitute for steel in the present work (Pankaj et al. 2018). Pankaj et al. (2018) observed bamboo behaviour through several pull-out tests to identify it. From the pull-out test results, they concluded that the treated bamboo has better strength than untreated bamboo. Regarding load-deformation characteristics, energy absorption capacity, crack patterns and failure modes, the effect of replacement steel reinforcement with bamboo on the flexural behaviour of slabs has been studied.

Unfortunately, many researchers found that steel has more capability to withstand higher loading and deflection than bamboo (Ab Rahman et al. 2020). Regarding flexural tests, the different bamboo surfaces may influence the thickness of the bamboo reinforcement itself and make them synchronized. Bending tests with a short span do not reflect the true potential of bamboo because, in short-span testing, the specimens invariably fail due to crushing or shear, even at lower loads. Therefore, the importance of full-scale or full-size bamboo testing has been emphasized, quoting Meyer & Eukelund. They commented as early as 1924 that "bamboo must be accepted as it is naturally, should be tested in full size and in the same way as it is used in structures" (Gnanaharan et al. 1995). A research report on experimental observation of the structural performance of bamboo-reinforced concrete beams (RCB) has been reviewed by Azuwa (2024). He came to the conclusion that bamboo may be utilized in place of the standard steel reinforcing bars in RCBs as an alternative internal reinforcement. Bamboo can improve the structural behaviour and performance of reinforced concrete beams (RCBs) in civil and structural engineering, particularly in construction projects.

METHODOLOGY

MATERIALS

The species of bamboo used in this research is Bambusa Vulgaris, also known as Buluh Gading. Before the tests, bamboo specimens were treated using boric acid and borax in a 1:1 (8kg) ratio. Table 1 represents the material preparations for the experiments.

TABLE 1. Experimental preparation material

	Description		Standard	Size (mm)	Nos.
Bambusa Vulgaris (small clear)	Compression		ISO22157-1:2004	150 x dia.	10
	Moisture content			30 x dia.	10
BSP (actual size)	Compression	BSP with opening	BS EN 1990	1200 x 600	3
		BSP without opening		1200 x 600	3

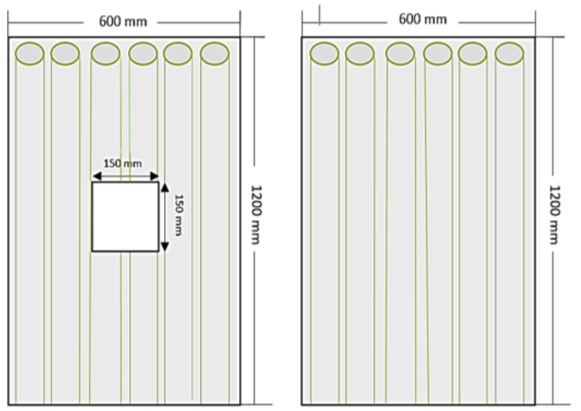
The properties of Bambusa Vulgaris were recorded in the form of small clear specimens tested for compression and moisture content tests. A compression test is one of testing to determine the mechanical properties of bamboo.

COMPRESSION TEST

The setup for small clear specimens was tested based on the ISO 22157-1:2004 standard. The actual size of BSP was set up according to BS EN 1990 and loaded under compression.

COMPRESSION SET UP

The Structural Laboratory of the College of Engineering at Universiti Teknologi MARA served as the site for constructing and testing all specimens, with square apertures taking up 3.13% of the wall surface. A 1000 kN load cell and a 2000 kN hydraulic jack were used to test and quantify the load-bearing walls. The load-bearing wall's top received an evenly distributed load from the hydraulic jack. Up to failure, the load was steadily increased in 10 kN increments. Two (2) types of bamboo sandwich panels (BSP) were arranged: BSP with and without opening. A total of six panels were prepared, three each for the with and without opening. Both BSP panels were cast at 1200mm x 600mm with 150mm thickness. For a panel with an opening, the opening size is 150 x 150 mm square at the centre (Figure 1).



(a) BSP with opening (b) BSP without opening

FIGURE 1. Schematic diagram of a bamboo sandwich panel (BSP)

For the preparation of BSP, each 1200mm specimen was arranged together in vertical alignment. A gap of ±75mm was fixed between each bamboo aligned and connected with a C-channel at the top and bottom of the bamboo specimens (Figure 2). Figure 3 depicts the testing setup for all load-bearing wall specimens.

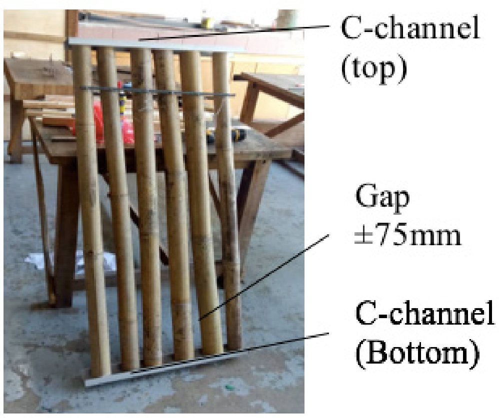


FIGURE 2. Vertically aligned bamboo specimens connected using C-Channel at the top and bottom

FIGURE 3. Casting of wall panel

All specimens were axially loaded until failure, and load and displacement were recorded using a data logger attached to a computer. The specimens were tightly griped on a strong floor using a steel jig holding both sides of the panel specimen. Figure 4 shows the arrangement of the compression test.

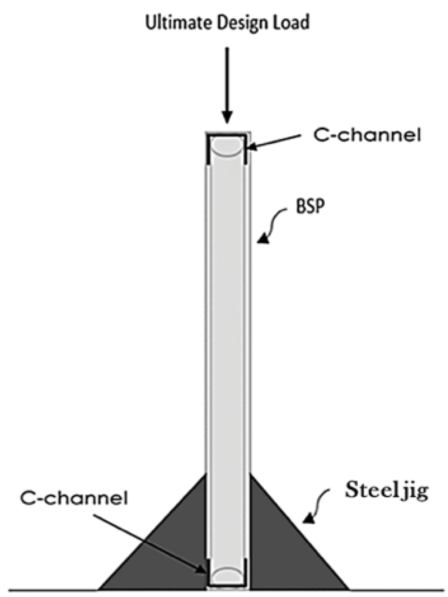


FIGURE 4. Schematic drawing of BSP wall compression test

RESULTS AND DISCUSSION

COMPRESSION AND MOISTURE CONTENT TEST

From the ten repetitions of the small clear compression test, the average maximum compressive strength, standard deviation and coefficient of variance is 12.13 kN/m2, 0.99 and 8.16%, respectively (Table 2). This value ranges from 11.01 kN/m2 to 21.06 kN/m2, as Mansor et al. (2019) reported for the compressive strength of dry and treated Bambusa Vulgaris. Figure 5 shows the typical load versus displacement for small clear bamboo specimens under compression load.

TABLE 2. Result of compression test for small clear specimens

Specimen	1	2	3	4	5	6	7	8	9	10	Avg.	Std.	Cov. (%)
Max Compressive Strength (kN/m^2)	13.39	11.18	13.46	11.69	12.51	12.38	11.07	10.83	13.18	11.64	12.13	0.99	8.16

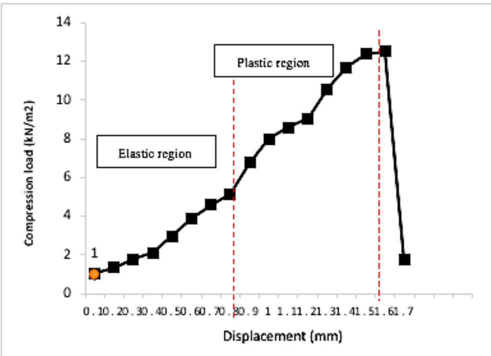


FIGURE 5. Typical load vs displacement for small clear bamboo specimen under compression load

The graph shows a maximum compression load for the specimen as 12.51 kN/m2 with 1.6 mm displacement. The compression behaviour went through various stages before fracture. The proportional limit and yield points were 4.57 kN/m2 and 5.14 kN/m2, respectively. The specimen was in the elastic region from 0.1 mm to 0.8 mm on average until it reached the yield point. The limit value of stress is that a small clear specimen is fully elastic in the elastic region. Specimen will be returning to its original position. After the specimen reached the yield point, it extended to the plastic region. The ultimate stress point is the maximum strength specimens must bear before the total fracture.

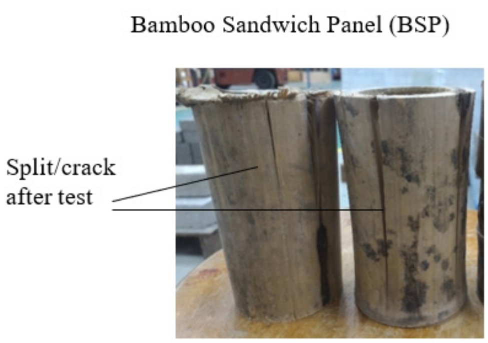


FIGURE 6. Failure pattern of the specimens after the test

Ten (10) small clear bamboo specimens were prepared and tested for moisture content measurement. The length for each small clear specimen is 30mm in a whole cut of bamboo diameter (± 55 mm). From the experimental test, the average moisture content is 16.9%. The result shows that the bamboo was in over-dry conditions, as the typical moisture content was previously found in a range of 20.4% to 30.78% (Mansur et al. 2019) when Bambusa Vulgaris was left dried at ambient temperature. Table 3 shows the compression test results for BSP with and without openings. BSP without an opening is more capable of withstanding higher loading and higher compressive strength than BSP with an opening. The pattern of failure for load versus displacement of the BSP with opening and without opening and the comparison between the two performances are presented in Figures 7, 8, and 9, respectively.

TABLE 3. Comparison between BSP with and without opening

Types of panels	Ultimate load capacity, P_u (kN)		% Decreasing in P_u
	BSP with opening	BSP without opening	
Specimen 1	498.41	818.28	39.09
Specimen 2	570.91	751.41	24.02
Specimen 3	525.72	767.58	31.51
Average	531.68	779.09	31.76
Std. Deviation	36.62	34.89	-
CoV	6.89 %	4.48 %	-

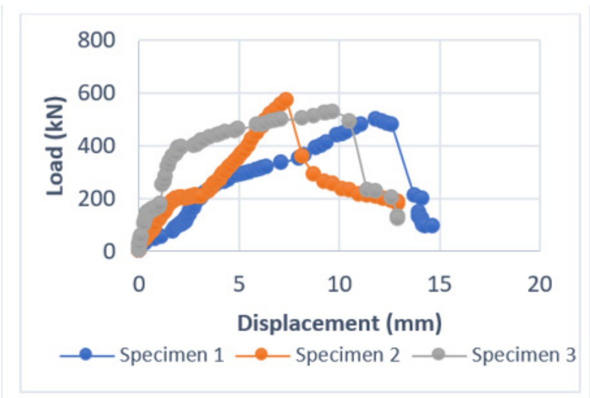


FIGURE 7. Compression load versus displacement BSP with opening

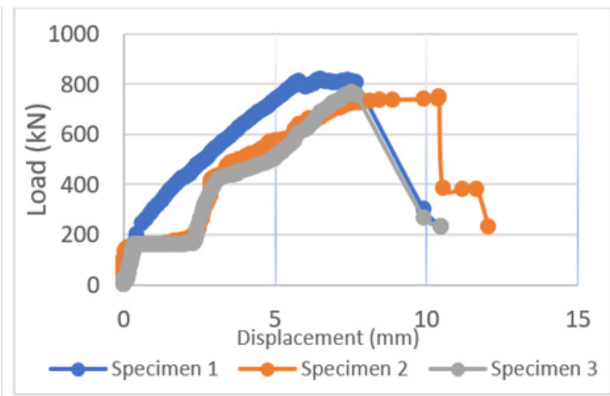


FIGURE 8. Compression load versus displacement BSP without opening

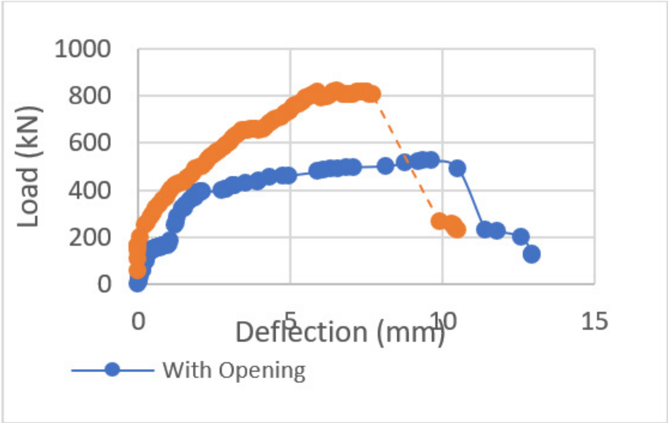


FIGURE 9. Comparison of load versus displacement for BSP with and without opening

Figure 9 shows the comparison result of compression BSP with and without opening. The pattern of behaviour was almost similar; however, specimens with openings reached the earlier stage of the plastic limit and showed a lower value of the ultimate load. This pattern indicates that BSP without an opening can withstand higher loading and compressive strength than BSP with an opening. By percentage difference, the ultimate compression load for BSP with the opening is a 31.76% decrease compared to BSP without the opening (Figure 10).

This result confirmed the research on the behaviour and strength of CFRP's bearing wall strengthening, which Ibrahim and Salman (2011) reported. The outcome indicates that opening in load-bearing walls will result in a reduction in the ultimate load capacity, with the load failure in load-bearing walls with openings decreasing by approximately 31.14% (for brick) and 31.25% (for concrete blocks) in comparison to load-bearing walls without openings. The BSP without opening was slightly similar to the brick load-bearing wall and concrete block load-bearing wall without opening (Table 3). However, further study is needed to confirm the structural performance of BSP compared to brick and concrete block load-bearing walls since the reduced opening area within these studies is different.

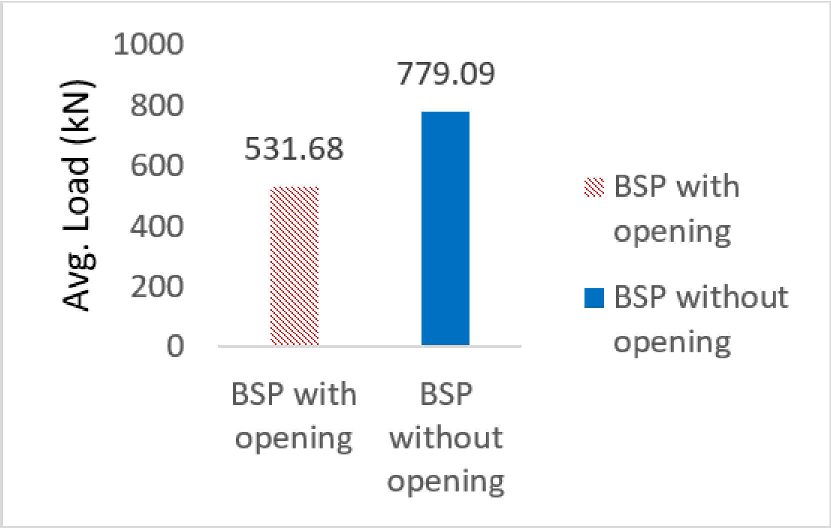


FIGURE 10. Average ultimate compression load for BSP with and without opening

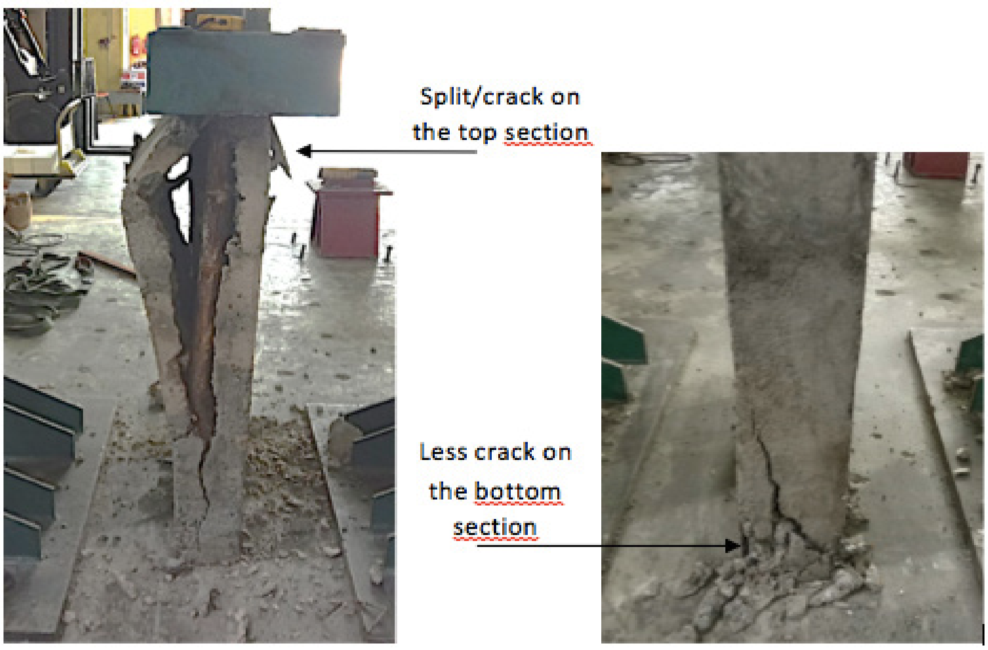
TABLE 3: Comparison of BSP to Ibrahim and Salman (2015)

	This study	Ibrahim and Salman (2015)	
Material	BSP	Brick	Concrete block
Ultimate load (without opening) kN	779	683	640
Wall size (mm)	1200 x 600 x 150	1200 x 800 x 240	1200 x 800 x 200
Wall area (mm2)	720,000	960,000	960,000
Reduced Opening area (%)	3.13	16.17	16.17
Ultimate load, P_u with vs without opening decreases (%)	31.76	31.14	31.25

FAILURE MODE BEHAVIOUR

One of the usability criteria in structural elements is crack width calculation. Due to the low tensile strength of concrete, cracks on the structure are predicted to appear under service load. Crack control is critical for achieving a pleasing appearance and ensuring the long-term longevity of wall structures, particularly those exposed to harsh conditions. Excessive fracture width can shorten the life of a building by allowing corrosive elements to penetrate more quickly. Additionally, structural cracking affects the structure's stiffness, capacity, ductility, and energy absorption. Figure 11 depicts the load-width crack curve for each load-bearing wall. Low loads result in minor or non-existent fissures in the wall surface that are not visible.

The crack pattern for the tested wall was observed. Figures 11 and 12 show the failure mode observation for BSP with the opening. From the observation, BSP tends to crack under the load-localized zone at the top section of the panel. The crack started once the compression load exceeded 100kN. Specimen 1 is split at the top area, while specimens 2 and 3 display cracking failure at the top and bottom sections. The bamboo in the middle of the sandwich concrete was found to have minor splitting after the total concrete fracture.



(a) Top failure (b) Bottom Failure

FIGURE 11. Side view of BSP with opening failure

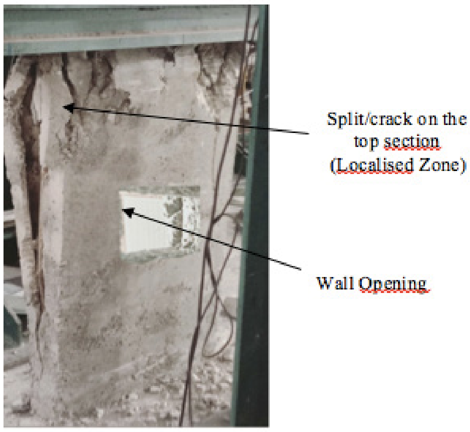


FIGURE 12. Front view of BSP with opening failure

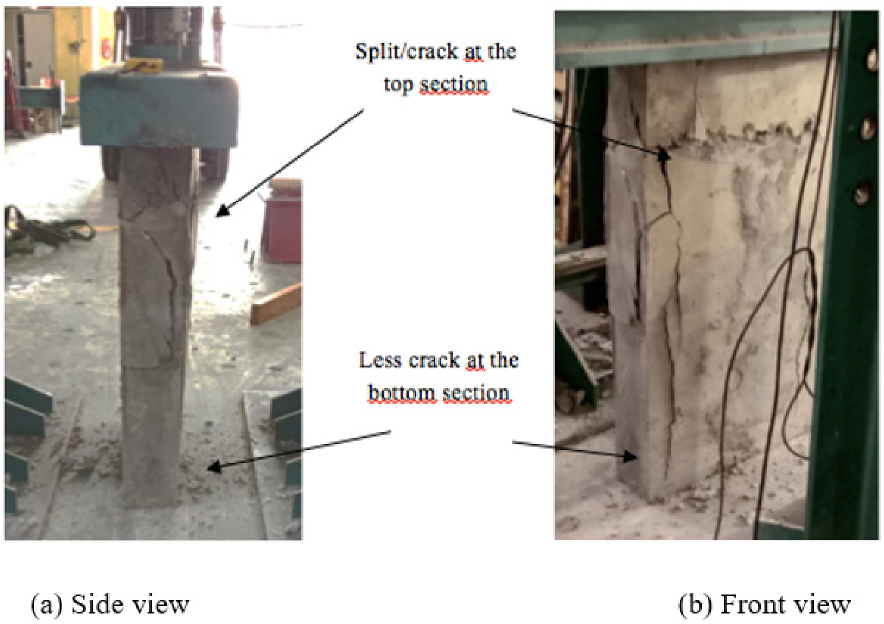


FIGURE 13. BSP without opening failure

Figure 13 shows the failure mode observation for BSP without opening. On average, all three BSPs without the opening panel performed in a similar failure mode sequence. This failure occurs when the BSP begins to crack at the top of the panel, which can be considered the direct compression zone. The onset of cracking occurs when the compressive load exceeds the average of 150 kN. Cracks or failures begin to move to the bottom of the panel before the final compressive load is reached. Lei et al. (2020) reported a similar pattern of failures.

CONCLUSION

Generally, the average compressive strength and moisture content for small clear bamboo specimens is 12.13 kN/m2 and 16.9%, respectively. BSP's average ultimate load-carrying capacity with and without openings is 531.68 kN and 779.09 kN, respectively. This data means that the BSP-reinforced technique is 46.53% more efficient in the case without openings. According to the results of the actual size tests, the opening and strengthening significantly impact the failure modes for load-bearing walls. The wall's stiffness and strength are reduced by intensive opening. Failure of walls without opening started by splitting and local crushing at the direct compression zone followed by sliding over the whole wall length, while the wall with opening started by splitting on the compression zone at the top of the opening section.

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DECLARATION OF COMPETING INTEREST

None.

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