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Precast segmental bamboo reinforced concrete beams with bolted connections subjected to flexural loads: an experimental investigation

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Abstract. Indonesia is one of the wealthiest botanically countries in the world. There are more than 1,18 species of Bamboo can be found in this country. Bamboo is a natural raw material which is one of the fastest growing plants that has many advantages as a construction material. We conducted an experimental investigation to study the performance of the precast segmental bamboo reinforced concrete beams with bolted connections subjected to flexural loads. Tests were carried out on three specimens with dimensions of 120 mm x 150 mm x 1000 mm, consisting of one control beams (BK), one precast segmental bamboo reinforced concrete beam with four bolted connections (BS4), and one precast segmental bamboo reinforced concrete beam with six bolted connections (BS6). We found that the load carrying capacity of precast segmental bamboo reinforced concrete beams with four bolted connections (BS4) and six bolted connections (BS6) had a decrease of 57.99% and 55.62% respectively compared to control beam (BK). Similarly, the deflection ductility index of the precast segmental bamboo reinforced concrete beams with four bolted connections (BS4) and six bolted connections (BS6) had a decrease of 49.78% and 46.59% respectively compared to control beam (BK). Also, we observed that the crack pattern developed in the control beam indicates a flexural failure mechanism while the crack pattern developed in the precast segmental bamboo reinforced concrete beams indicates a shear failure mechanism. As a conclusion, this study will significantly contribute to the growing development of research on the bolted connection system in bamboo reinforced concrete members, especially in Indonesia.

1. Introduction

Concrete is extensively utilized in construction. Its compression seems to be very strong, but the tension is weak. Because of this, concrete is reinforced with steel bars which improve the resulting tensile strength. But the use of steel as a material for reinforcement has some drawbacks such as higher costs and non-renewability. Beyond these, steel production seems to be accountable for greenhouse gas emissions. Hence, serious efforts have been made by a few academics to use renewable locally made material. Many scientists examined the possible outcomes in using natural fibers as a strengthening agent in concrete. Some of the natural fibers being explored in the past researches involve: jute [1, 2],



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coconut coir [3, 4], sisal [5], babadua [6], date palm [7], raffia palms [8], bamboo [9-11], and bamboo fibers [12]. Among these materials, bamboo has a distinct advantage compared to other natural reinforcing materials.

As a building material, bamboo has several economic benefits such as renewable, and as anisotropic material, having mechanical properties that vary in the longitudinal, radial and transverse directions [13]. Bamboo products are progressively being created internationally as a sustainable, low cost and environmentally friendly material [14]. Bamboo woodlands have higher carbon density due to the better growth rate [15]. Bamboo has been widely discovered in rapidly-growing areas such as Indonesia. There are more than 130 species of bamboo found in this country. While the potential of bamboo is promising, more widespread development and use of bamboo are hampered by the lack of engineering data for mechanical properties and appropriate building codes [16, 17].

Yamaguchi et al. [18] studied the performance of BRC beams using bamboo as the main rebar and stirrups in carrying flexural loads. Terai and Minami [19] assessed the viability by using bamboo in concrete as the reinforcing material. The cracking patterns found in bamboo RC beams are comparable to the RC beams and has a strong impact compared to the data. Thus, the fracture can be analyzed using the established RC beam formula. Karthik et al. [20] used bamboo strips in a concrete element made of additional cemented materials and manufactured sand (m-sand). Cement has been replaced by fly ash and ground granulated blast furnace slag (GGBS). The study revealed that the performance of bamboo reinforced concrete (BRC) produced from materials such as fly ash was very low as compared to traditional materials with BRC. Furthermore, BRC made from the traditional materials tend to have higher strength up to 6.5% than the SRC.

Puri et al. [21] suggested the use of bamboo prefabricated reinforced walls that are favorable to low-cost housing, which showed that the walls are 56% lighter, 40% less expensive, and stronger than partition brick walls. It has been found that the advantages of these walls over conventional brick walls are substantial, leading to the conclusion that these wall panels have great promise for low-cost residences. Haryanto et al. [22] investigated the flexural strengthening of reinforced concrete beams with the NSM technique using bamboo reinforcements through both experimental tests and a finite element analysis (FEA). It has been concluded that the flexural strength of the beam with NSM bamboo reinforcements was increased by 41.7%. Moreover, the result of FEA behaved similarly to the results of the experimental test. To date, there is little data on bamboo precast reinforced concrete beam in the literature. In this study, therefore, bamboo has been used as reinforcing material for precast segmental beam specimens with bolted connections. The properties being investigated include load carrying capacity, deflection ductility index and the crack pattern.

2. Experimental work

2.1. Material properties

In the current study, materials such as cement, fine (specific gravity: 2.62 and fineness modulus: 3.73) and coarse (specific gravity: 2.68 and fineness modulus: 6.08) aggregates, potable water, bamboo, and bolt as a connecting device were used. Table 1 shows the physical properties of aggregates used. The bamboo was string bamboo (*Gigantochloa apus*), which can be found in Central Java, Indonesia. The average tensile strength and compressive strength of the bamboo strips used were 112 MPa and 73 MPa, respectively. In addition, the average tensile strength and the average pullout strength of bolt were 530.303 MPa and 397.707 MPa, respectively. The 28 days average compressive strength of the concrete was 153.24 kg/cm² based on tests of eight 150 x 150 x 150 mm concrete cubes.

Table 1. Physical properties of aggregates used

Aggregates	Specific gravity	Water absorption (%)	Fineness modulus
Fine aggregate	2.62	4.42	3.73
Coarse aggregate	2.68	2.04	6.08

2.2. Precast segmental beams design

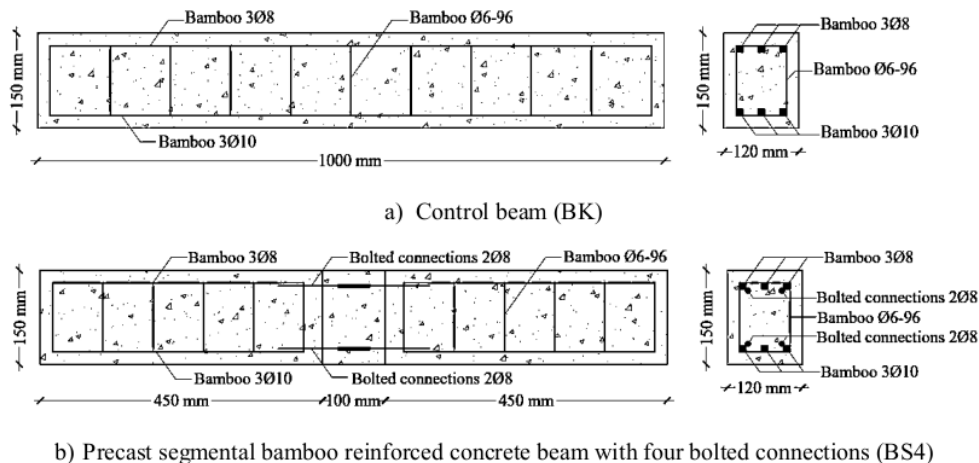
For the experimental program, a total of three series of specimens, consisting of 1000 mm long beams with a rectangular cross-section of 120 x 150 mm were conceived. The tension and compression reinforcements used were 8 mm bamboo strip which was fastened firmly together with stirrups of 6 mm bamboo strips spaced at 96 mm using the binding wire (figure 1). The first beam specimen was the control beam, a monolith beam reinforced with 8 mm bamboo strips (BK). The remaining beam specimens were precast segmental bamboo reinforced concrete beam with four bolted connections (BS4) and six bolted connections (BS6). Beams have been subjected to a monotonous four-point bending test as illustrated in figure 2 while the detail of specimens is shown in figure 3.

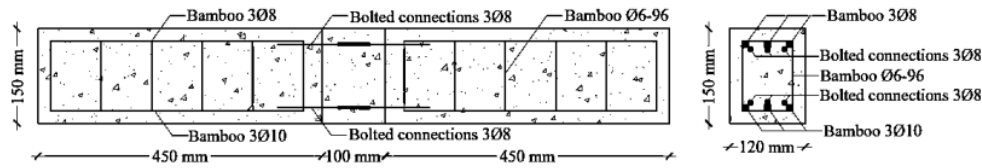


Figure 1. Bamboo reinforcements.



Figure 2. Four-point bending test.





c) Precast segmental bamboo reinforced concrete beam with six bolted connections (BS6)

Figure 3. The detail of specimens.

3. Results and discussion

Figure 4 shows the load versus midspan deflection for all beam specimens. As can be seen from the figure, the BK beam showed a tri-linear response defined by elastic, concrete cracking to bamboo failure and bamboo failure to collapse stages. BK beam's failure was the result of diagonal tension cracks as shown on the tension face of the beam in figure 5. The displacement ductility index of 2.29 was found to be maximum in this category among all of the beams considered as can be seen in table 2. Table 2 also shows that BK beam has the highest load carrying capacity of 16.90 kN at the displacement of 20.57 mm.

Table 2. Experimental result.

Beam series	Load carrying capacity (kN)	Displacement (mm)	Displacement ductility index
BK	16.90	20.57	2.29
BS4	7.10	1.84	1.15
BS6	7.50	1.22	1.22

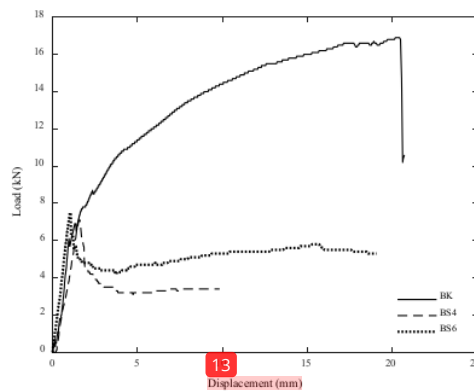


Figure 4. Load-displacement response of all specimens.

Figure 4 shows the BS4 beam's linear elastic behavior until the final load is reached, then the curvature starts dropping. The results of the BS4 beam in table 2 have shown a decrease in load carrying capacity and displacement ductility index by 57.99% and 49.78% compared to BK beam, respectively. Figure 6 reported that BS4 beam has a diagonal tension crack in the shear span outside the connections zone. The BS6 beam demonstrates a linear elasticity until the ultimate load was achieved and afterward the curve begins to fall from the failure point quickly as seen in figure 4. Similarly, BS6 beam exhibited a decrease in load carrying capacity and displacement ductility index by 55.62% and 46.59% compared to BK beam, respectively as presented in table 2. Figure 7 shows that the crack on the bottom face has started in the shear span outside of the connections and propagated towards the loading point.

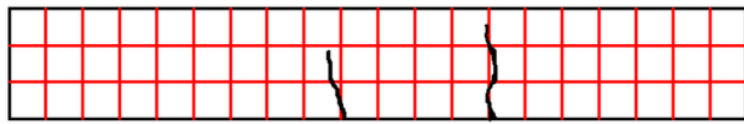


Figure 5. Crack pattern in BK beam.



Figure 6. Crack pattern in BS4 beam.



Figure 7. Crack pattern in BS6 beam

4. Conclusions

The current study examined the performance of the precast segmental bamboo reinforced concrete beams subjected to flexural loads. The contribution of bolted connections was observed during the tests. The research found that the load carrying capacity of precast segmental bamboo reinforced concrete beams with four bolted connections (BS4) and six bolted connections (BS6) have a decrease of 57.99% and 55.62% respectively compared to control beam (BK). Similarly, the deflection ductility index of the precast segmental bamboo reinforced concrete beams with four bolted connections (BS4) and six bolted connections (BS6) have a decrease of 49.78% and 46.59% respectively compared to control beam (BK). It was also observed that the crack pattern developed in the control beam indicate a flexural failure mechanism while the crack pattern developed in the precast segmental bamboo reinforced concrete beams indicate a shear failure mechanism. As a conclusion, the precast segmental bamboo reinforced concrete beams with six bolted connections (BS6) has a slightly better performance than the precast segmental bamboo reinforced concrete beams with four bolted connections (BS8). Furthermore, this study will contribute to the growing development of research significantly on the bolted connection system in bamboo reinforced concrete members, especially in Indonesia.

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