Performance of Precast Segmental Bamboo-Reinforced Concrete Columns with Bolted Connections: An Experimental Exploration

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Abstract Prefabrication systems such as precast segmental concrete columns have become popular in recent years to accelerate construction speed. We performed an experimental study to investigate the load capacity and crack growth characteristics of precast segmental bamboo reinforced concrete (BRC) columns with bolted connections. Examinations were conducted on 18 specimens measuring 150 × 150 × 600 mm, composed of 6 reference columns (KK), 6 precast segmental columns with 4 bolted connections (KS4), and 6 precast segmental columns with 8 bolted connections (KS8). It was discovered that bamboo strips are promising to be used as reinforcement in precast segmental column with bolted connections since their load capacity ratio is close to one compared to the monolithic column. The first cracks in the axial tested specimens began from the top fiber and propagated to the middle of the columns, leading in a concrete compression failure in the columns. Additionally, monolithic columns have their cracks starting from the center of the span at the tension face and stretch up to the neutral axis in the flexural tested specimens, leading a flexural failure in the columns. Furthermore, a shear failure is indicated by precast segmental columns.

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1 Introduction

Usually, the conventional building of reinforced concrete (RC) structures and bridges involves procedures such as erection, structuring, reinforcement of steel casting. All these processes are time-consuming, depend on weather conditions and types of equipment used. Prefabrication systems such as precast segmental concrete columns have become popular in recent years to accelerate construction speed [1]. They have a number of advantages compared to traditional cast-in-situ columns such as reducing in disruption, time saving and quality improvement [2]. Additionally, the implementation of bamboo reinforcement with bolted connections could be considered for precast segmental columns, as a significant portion of these columns are manufactured off-site in factories.

Bamboo is widely used in construction, as research encompasses the utilization of entire culm bamboo in construction and scaffolding [3, 4], as well as the use of bamboo composites in engineering [5–14]. Engineered bamboo composites are of particular interest due to their standardized shape and relatively low variability in material characteristics [15]. According to the authors' understanding, there are few studies available that examine the impact of bolted connections on precast segmental bamboo-RC (BRC) columns. Therefore, this study performed a laboratory experiment to investigate the behavior of precast segmental BRC columns with bolted connections under axial and flexural loads. Three series of columns measuring 600 mm in height and having a square cross-section of 150 $\times$ 150 mm were cast. Two series were made, each consisting of 2 segments and featuring 4 and 8 bolted connections, respectively. For evaluating the performance of the specimens, a set of monolithic BRC columns with identical height and cross-sectional area were also tested as a reference. The load capacity and crack propagation characteristics were measured and examined to assess the performance of the column.

2 Materials and Methods

The current study utilized various materials including cement, fine aggregates (with a specific gravity of 2.70 and a fineness modulus of 3.73), coarse aggregates (with a specific gravity of 2.68 and a fineness modulus of 6.08), potable water, bamboo, and bolts as connecting devices. The bamboo used was Gigantochloa apus, a type of bamboo commonly found in Central Java, Indonesia. The bamboo strips exhibited an average tensile strength of 112 MPa and an average compressive strength of 73 MPa. Furthermore, the bolt demonstrated an average tensile strength of 530.303 MPa and an average pullout strength of 387.707 MPa. The average compressive strength of

Table 1 Properties of column specimens

Series	Longitudinal reinforcement		Transverse reinforcement		Load type	Number of specimens
	Type	Number-diameter	Type	Diameter-spacing		
KK	Bamboo	12-Ø8	Bamboo	Ø6-94	Axial	3
					Flexure	3
KS4	Bamboo	12-Ø4	Bamboo	Ø6-109	Axial	3
					Flexure	3
KS8	Bamboo	12-Ø8	Bamboo	Ø6-109	Axial	3
					Flexure	3

the concrete, determined from tests conducted on two 150 × 150 × 150 mm concrete cubes, was 265.82 kg/cm^2 after 28 days.

A total of 18 prismatic specimens were prepared, as shown in Table 1. The specimens possessed a square cross section measuring 150 × 150 mm and a height of 600 mm. As depicted in Fig. 1, the first column series (KK) was a conventional monolithic column utilized as a point of comparison. The second column series (KS4) comprised a precast segment column with 4 bolted connections, while the third column series (KS8) featured a precast segmental column with 8 bolted connections. The structure utilized longitudinal reinforcement made of bamboo with a diameter of 8 mm, transverse reinforcement made of bamboo with a diameter of 6 mm, and a connection made with a 15 mm diameter bolt equipped with a ring. As depicted in Fig. 2, the specimens underwent a monotonic axial and flexural test.

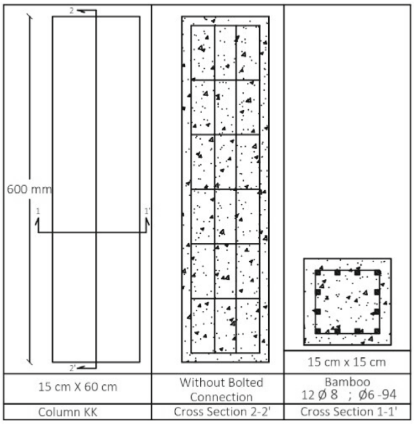
3 Results and Discussion

Tables 2 and 3 display the average value of axial and flexural load capacity obtained from three samples of each column specimen in the tested series.

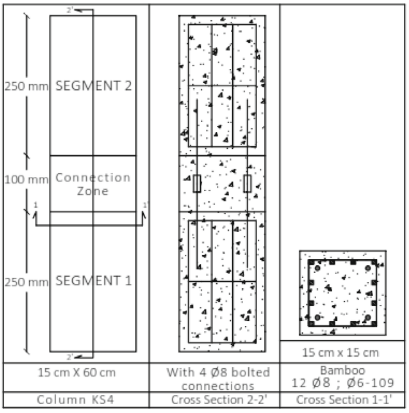
The load capacity of a column is influenced by the type of specimen, whether it is a monolithic column or a precast segmental column. Furthermore, the rise in the quantity of bolted connections resulted in a corresponding enhancement in load capacity. The average axial load capacity of precast segmental columns has a ratio of 0.98 and 0.99 to the control column, for KS4 and KS8, respectively. While the average flexural load capacity of precast segmental columns has a ratio of 0.81 and 0.94 to the control column, for KS4 and KS8, respectively.

Due to the punching effect, the first cracks in the axial tested specimens originated from the top of the column, making it a critical position. This is consistent with the results reported by Muhtar et al. [16], indicating the existence of a stress concentration at the location of the initial crack. Figure 3 indicates that the cracks propagated to the center of the columns, leading to a concrete compression failure in the columns.

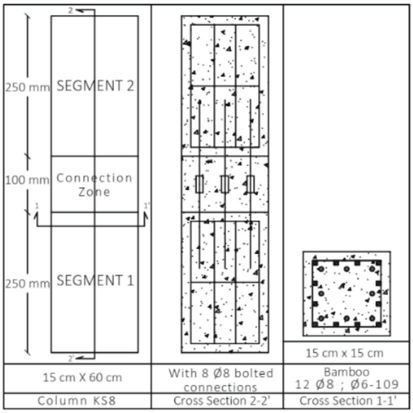
Figure 4 indicates that the cracks in monolithic columns originate from the center of the span at the tension region and extend up to the neutral axis in the flexural tested



(a) Specimen KK



(b) Specimen KS4



(c) Specimen KS8

Fig. 1 Detail of specimens

specimens. This leads to a flexural failure in the columns, which aligns with a prior investigation conducted by Agarwal et al. [17].

The widths of crack are most prominent on the tension region and decrease with distance from that location. In addition, a shear failure is indicated by precast segmental columns. The cracks emerge in proximity to the connection region, and as the load intensifies beyond the initial crack load, multiple cracks manifest, causing the inclined cracks to expand even further.

(a) Axial load test (b) Flexural load test

Fig. 2 Experimental setup

Table 2 Axial load capacity

Specimens	Code	Axial load capacity (kN)	Average axial load capacity (kN)	Ratio
Monolithic column	KK-1	285.0	265.23	–
	KK-2	195.7		
	KK-3	315.0		
Precast segmental column with 4 bolted connections	KS4-1	220.8	260.73	0.98
	KS4-2	266.8		
	KS4-3	294.6		
Precast segmental column with 8 bolted connections	KS8-1	258.4	262.73	0.99
	KS8-2	249.2		
	KS8-3	280.6		

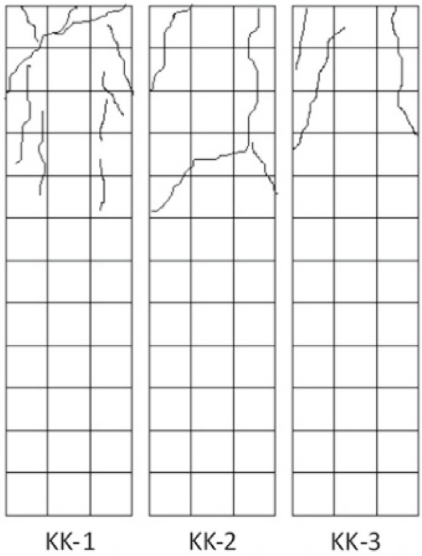
4 Conclusions

A study was conducted to evaluate the effectiveness of precast segmental bamboo reinforced concrete columns with bolted connections. Ultimately, bamboo strips show great potential for use as reinforcement in precast segmental columns with

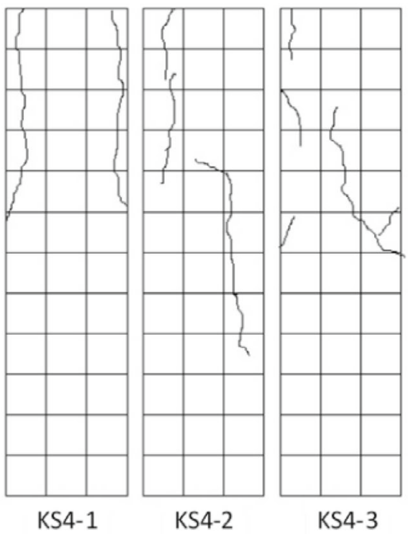
Table 3 Flexural load capacity

Specimens	Code	Flexural load capacity (kN)	Average flexural load capacity (kN)	Ratio
Monolithic column	KK-4	32.7	29.33	–
	KK-5	31.4		
	KK-6	23.9		
Precast segmental column with 4 bolted connections	KS4-4	22.9	23.80	0.81
	KS4-5	28.9		
	KS4-6	19.6		
Precast segmental column with 8 bolted connections	KS8-4	23.9	27.57	0.94
	KS8-5	32.1		
	KS8-6	26.7		

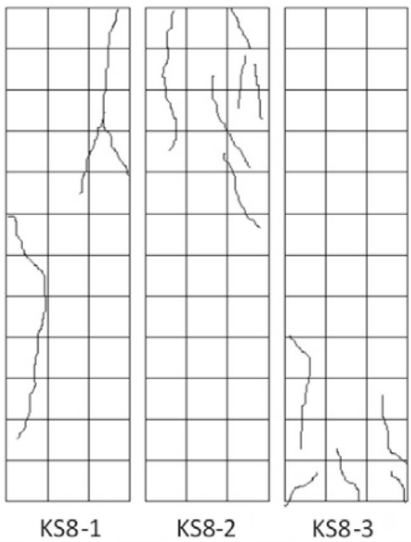
bolted connections due to their high load ratio, which is comparable to that of monolithic columns. Bamboo strips degrade over time and lack a solid grip. Applying an impermeable surface coating such as bitumen increases its resistance to decay. Additionally, the application of a sand coating further improves the bonding, resulting in excellent strength. Therefore, the proposal is to use precast segmental bamboo reinforced concrete columns for lightly loaded structures and low-rise buildings. Nevertheless, the significant deformation that occurs during its failure makes it unsuitable for structures that need to retain water.



(a) Specimen KK

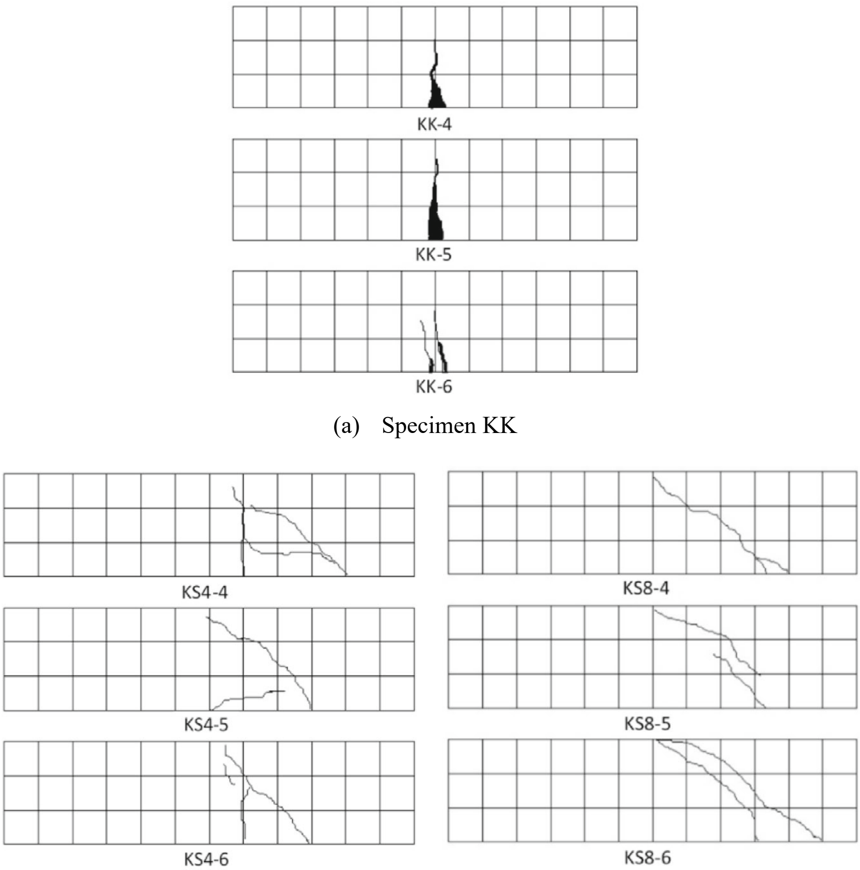


(b) Specimen KS4



(c) Specimen KS8

Fig. 3 Crack pattern in the axial tested specimens



(a) Specimen KK

(b) Specimen KS4 (c) Specimen KS4

Fig. 4 Crack pattern in the flexural tested specimens

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