

# Experimental Study on Uniaxial Compression of Bamboo Poles with Different Reinforcements

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**Abstract.** The natural round bamboo is a kind of ecological building material with many excellent physical and mechanical characteristics, such as fast growth, high strength and good environmental performance. However, the natural round bamboos were barely used for its worse durability and easiness to crack compared other bamboo productions after secondary operation. In order to improve the safety and durability of the round bamboo structure, the axial compression test of the GFRP (glass fiber-reinforced polymer) and/or mortar reinforcing cracked bamboo was conducted. The 20 cm tall round bamboo column specimens were divided into five categories: the first without cracks and reinforcement, the second with cracks but without reinforcement, the third with cracks and full GFRP reinforcement, the fourth with cracks and fulfil of cement mortar, and the last with cracks and reinforced using both GFRP and cement mortar. The bearing capacity and the failure modes were observed and studied. It was found that the composite reinforcement of GFRP and mortar could significantly increase the bearing capacity of the cracked round bamboos, and avoid brittle failure through improving the ductility of the specimens.

## 1 Introduction

Bamboo is a kind of ecological building material for its physical and mechanical characteristics, such as fast growth, light weight, high strength, and good environmental performance [1-4]. However, it was barely used for its worse durability and easiness to crack compared other bamboo productions after secondary operation [5]. Then it is very important to reduce the negative effects of cracks to improve the safety and durability of the round bamboo structure.

Fiber-reinforced polymer (FRP) has been widely applied to improve the bearing capacity and ductility of concrete and metallic structures due to their high strengths, low weights, anti-corrosion capability and easy forming characteristics. This method is typically used to reinforce columns via wrapping to provide confinement. Additionally, cement mortar has also been widely used to prevent the local bulking of thin-wall hollow structures. Awaludin et al. [6] used different fibers to reinforce the bolted joints, The results showed that a significant increase of joint slip modulus and load carrying capacity was found in the joints reinforced with FRP. The wrapping effect caused by FRP sheets successfully postpones the bamboo splitting failure. However, in the case of joints reinforced with natural fiber ijuk, this increase is negligible. Huang [7] studied the mechanical properties of bamboo reinforced with CFRP or wire in different ways, using experimental research analysis method, to find out the better

strengthening methods, which can provide reference for engineering applications.

In this study, natural round bamboo were reinforced using different methods, including fulfilling cement mortar, and/or wrapped with GFRP sheets. The specimens were tested to analyze the influence of the reinforcements on the failure mode, load capacity and ductility of the round bamboo elements.

## 2 Experimental Program

### 2.1 Specimens

The bamboo was cut from Xianning, Hubei Province. The bamboo was about 15 meters in length. The moisture content of the bamboo pole is about 15%. 15 bamboo nodes were cut from two natural bamboos. The specimen was named as  $x-y-z$ , where  $x$ ,  $y$  and  $z$  represented the group of the bamboo, the position of the bamboo node, and the reinforcement method. The group of bamboo was called A, B, C. The position was designated from the bottom (B) to the middle (M) and to the top (T). The reinforcement method was five groups: divided into unreinforced (U), unreinforced but cracked (UC), reinforced with GFRP (G), reinforced with cement mortar (M) and reinforced with both GFRP and mortar (GM). The details of the specimens was shown in Table 1.

The glass fiber sheets used in the tests were HITEX-G430S, which were produced by Nanjing Hitech

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Composites Co., Ltd, Jiangsu, China. The resin used in the study was Lica100 structural adhesive and was produced by the same company. In this study, a single layer of GFRP sheet was used, and the fiber mass fraction was approximately 35%. The compressive strength of the cement mortar was  $f_u=21.1$  MPa.

**Table 1.** The details of specimens

Specimens	Area (mm <sup>2</sup> )	Cracks	Reinforcement
A1-B-U	1967	None	None
A2-M-U	1855	None	None
A3-T-U	1790	None	None
B1-B-UC	2987	Severe	None
B2-M-UC	2452	Slight	None
B3-T-UC	1498	Slight	None
C1-B-G	2730	Severe	GFRP
C2-M-G	2298	Slight	GFRP
C3-T-G	1397	Slight	GFRP
D1-B-M	2356.34	None	Mortar
D2-M-M	1573.27	None	Mortar
D3-T-M	1275.99	None	Mortar
E1-B-GM	2149.72	Severe	GFRP+Mortar
E2-M-GM	1579.81	Severe	GFRP+Mortar
E3-T-GM	1007.82	Severe	GFRP+Mortar

## 2.2 Experimental setup and instrumentations

The typical test setups for the bamboo columns and beams are shown in Figure 1. Before loading to failure, each column was pre-loaded to a relatively small stress, and its position was correspondingly adjusted after each preloading based on the differences between the readings from the displacement transducers located on opposite sides of the specimens to minimize the loading eccentricity on each specimen. The loading was controlled by the displacement magnitude, and the loading rate was approximately 1 mm/min.

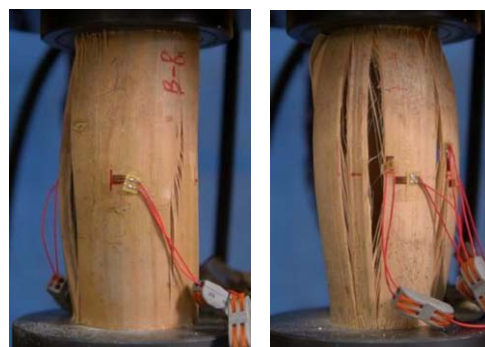


**Fig. 1.** Experimental setup and instruments

## 3 Experimental Program

For the specimens in Group A and B, at the beginning of the loading, the bamboo columns were slowly

compressed, and a slight sound might occur. At the same time, the curve rose linearly. Then the curve began to soften slowly. When the load increased to the peak load, the cracks developed rapidly, the lower part of the bamboo node gradually expanded, and the bearing capacity decreased rapidly, accompanied by a relatively loud sound. Then the crack developed and the bearing capacity of the bamboo columns continued to weaken. The cracks of the specimens in Group B mainly occurred at the original cracks as Figure 2 shown.



(a) Group A (b) Group B

**Fig. 2.** Compressive failure of specimens Group A and B.

For the specimens in Group C, with the confinement of GFRP, the development of cracking was restrained. However, the inward buckling deformation was clearly observed. The capacity was held on a high level until the buckling fully developed.

For the specimens in Group D, the infilled cement mortar was already compressed to failure even the cracks not showing on the surface, so the mortar was a bad effect to the outer bamboo wall to accelerate its buckling outward.



(a) Group C (b) Group D (c) Group E

**Fig. 3.** Compressive failure of specimens Group C, D and E.

For the specimens in Group E, The observations of reinforced column specimens during their early loading processes were similar to Group C. The mechanical behaviors of these specimens, including compression and lateral deformation, were not significant at the beginning of the loading process. When the stress increased, the color of the FRP material at the end of the columns first changed to white, and then, transverse cracks formed. However, the white zones did not evenly spread to the middle of the specimen thereafter. As the yielding load was approached, the fibers at the end of the specimens started to rupture, and the columns gradually

started to densify. When the specimens reached their maximum load, failure occurred in one or two primary fracture zones, where compression rapidly progressed, fractures rapidly developed, and the load capacity of the specimen sharply decreased.

## 4 Results and discussion

### 4.1 Capacity and deformation

The results of the axial compressive strength of the bamboo columns are shown in the Table 2 below.

**Table 2.** The experimental results of specimens

Specimens	Area (mm <sup>2</sup> )	Peak load (kN)	Maximum stress (MPa)
A1-B-U	1967	109.89	55.9
A2-M-U	1855	107.24	57.8
A3-T-U	1790	103.68	57.9
B1-B-UC	2987	122.97	41.1
B2-M-UC	2452	123.74	50.5
B3-T-UC	1498	90.73	60.6
C1-B-G	2730	152.67	55.9
C2-M-G	2298	137.24	59.7
C3-T-G	1397	106.54	76.3
D1-B-M	2356.34	124.48	52.8
D2-M-M	1573.27	99.28	55.0
D3-T-M	1275.99	64.72	63.1
E1-B-GM	2149.72	260.31	121.1
E2-M-GM	1579.81	212.15	134.3
E3-T-GM	1007.82	114.68	113.8

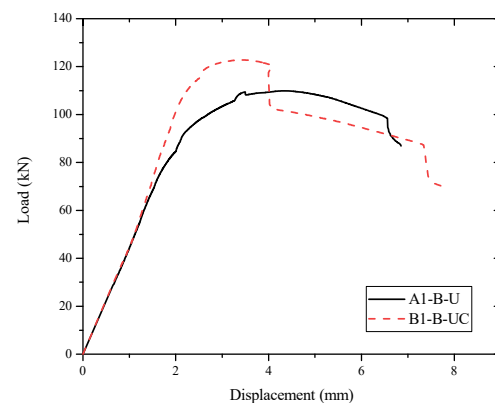
### 4.2 The influence of original cracks

It was clearly seen that the Group B had lower stress than that of Group A, which showed the original cracks decreased the capacity of the specimens. Additionally, it was also observed that the development of the cracks for Group B was along the original cracks, and the cracks were less uniform on the surface when reaching the maximum load.

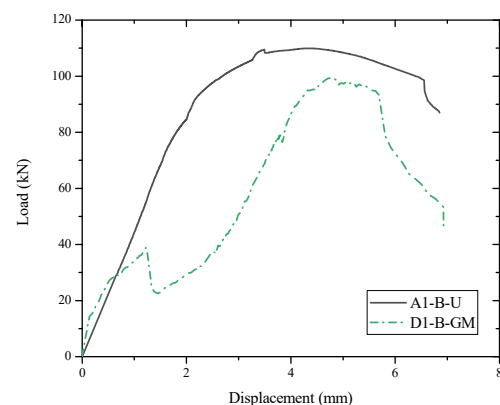
The typical load-displacement curve was shown in Figure 4, which indicated that the original cracks decreased the deformation performance, and increased the brittle characteristic of the final failure.

### 4.3 The comparison of reinforcements

The cement mortar could prevent the inward local buckling and provide a bearing part for the column theoretically. However, the mortar fulfilling the bamboo polo didn't improve the mechanical behaviour at all as Figure 5 showed. The reason was that the mortar had already failed and dilated before the bamboo cracking, which would accelerate the development of cracks and make the distribution of cracks uneven.

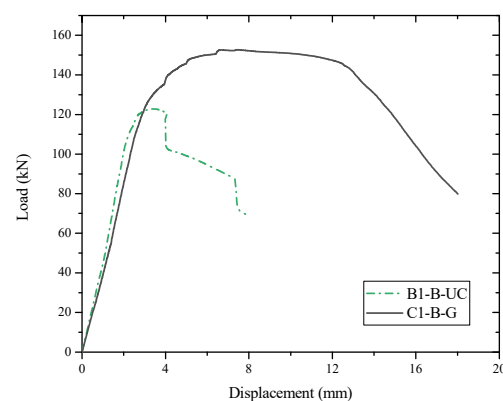


**Fig.4.** Load-displacement curves of Group A and B



**Fig.5.** Load-displacement curves of Group A and D

The GFRP reinforcement could provide the confinement to the column. It was shown in Figure 6 that the wrapping method changed the failure modes from outward split to inward deformation, and improved the peak loads and markedly improved compression deformation. However, the inward local buckling could not be avoided.



**Fig.6.** Load-displacement curves of Group B and C

In this case, the composite of GFRP and mortar was reasonable to improve the mechanical behaviour. The GFRP provided the confinement and the mortar prevent the inward buckling. It was demonstrated in Figure 7 that the composite had the best effect.

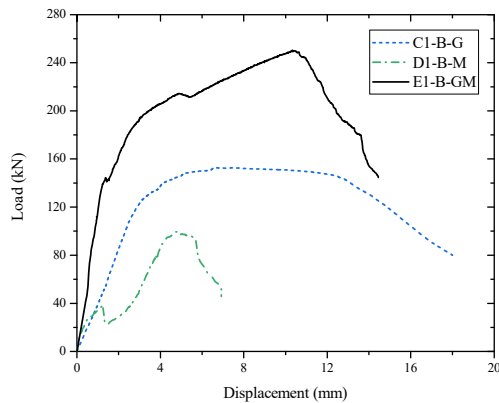


Fig.7. Load-displacement curves of Group C, D and E

## 5 Conclusion

In this paper, the axial compression test of the GFRP and/or reinforcing cracked bamboo was conducted. The bearing capacity and the failure modes were observed and studied. The main research conclusions and achievements includes:

(1) The wrapping method changed the failure modes from outward split to inward deformation, and improved the peak loads and markedly improved compression deformation.

(2) The composite reinforced method showed better mechanical behavior. The confinement effect of FRP sheets wasn't fully used if without fulfilling cement mortar.

(3) The reinforced cracked round pole bamboos might promote the development and application bamboos in constructions and buildings.

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