



# Axial load behavior of structural bamboo filled with concrete and cement mortar



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## HIGHLIGHTS

- The axial load behavior of material-filled structural bamboo was investigated.
- The effects of infilled materials, horizontal stiffener and node were investigated.
- The confining effects of bamboo were considered carefully in the study.

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## ABSTRACT

Bamboo has been widely used as a rapidly renewable structural material to build permanent and temporary structures in past decades. However, the compressive bearing capacity of bamboo is relatively low, which limits its applications only in the structures under light loads. This paper proposed an innovative scheme to improve the load bearing capacity of bamboo by filling concrete or cement mortar in bamboo cavity. An experimental study on the axial load behavior of material-filled structural bamboo was carried out, aiming at investigating the effects of the infilled materials, the horizontal stiffener and the bamboo node. A total of 19 specimens were tested under axial compression. It was found that the axial load bearing capacities and the initial stiffness of both concrete-filled bamboo columns and cement mortar filled bamboo columns are much higher than the conventional bamboo, which verified the feasibility of the proposed stiffening scheme. Concrete-filled bamboo columns show better ductility than cement mortar filled bamboo columns. Furthermore, the ductility of concrete-filled bamboo columns can be improved by increasing the steel reinforcement ratio. In addition, the beneficial effect of the node on the ultimate bearing capacity can be found in material-filled bamboo specimens, indicating that the integrity of the bamboo node is essential for the bearing capacities of material-filled bamboo columns. Similarly, the horizontal stiffener passing through bamboo internode has a beneficial effect on both the ultimate bearing capacities and the corresponding axial strains of material-filled bamboo columns and conventional bamboo. However, the stiffener passing through the node may result in a decrease in the bearing capacity. Finally, a simple and efficient method was proposed for predicting the ultimate bearing capacity of material-filled bamboo columns. The confining effects of bamboo on the infilled materials are considered carefully in this method. The calculated results by the proposed method were compared with experimental results, exhibiting a good agreement.

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## 1. Introduction

Bamboo as structural material has been extensively used to build permanent and temporary structures in past decades. Bamboo is recognized as a sustainable material that can serve as a com-

petitive and environmentally friendly alternative to non-renewable and polluting materials such as steel and concrete due to that it is a rapidly renewable structural material and has mechanical properties similar to timber [1–6]. In recent years, a large number of experimental and analytical studies on the mechanical properties of structural bamboo have been conducted [6–20]. Also, several researchers have investigated the behavior of bamboo as reinforcement in structural concrete [21–25]. According to the studies above, bamboo can be considered as an

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## Nomenclature

$D$	diameter of bamboo	$f_{hs}$	yield strength of the horizontal stiffener
$t$	wall thickness of bamboo	$\varepsilon_{cc}$	the peak axial strain
$A_b$	cross-sectional area of bamboo	$\varepsilon_{oh}$	the peak hoop strain
$A_s$	cross-sectional area of longitudinal steel bar	$N_{ue}$	the experimental ultimate bearing capacity of specimens
$A_{hs}$	cross-sectional area of the horizontal stiffener	$N_{uc}$	the calculated ultimate bearing capacity of specimens
$A_{cc}$	cross-sectional area of infilled material	$\mu$	the ductility ratio of specimens
$f_c$	cylinder strength of concrete	$\alpha_n$	the effect coefficient of bamboo node
$f_m$	cylinder strength of cement mortar	$\alpha_1$	the effect coefficient of horizontal stiffener
$f_{bc}$	longitudinal compressive strength of bamboo	$\alpha_2$	the size effect coefficient of specimens
$f_{bh}$	circumferential tensile strength of bamboo	$\alpha_3$	the strength reduction coefficient for the longitudinal steel bar
$f_l$	the lateral (radial) confining stress on the infilled material		
$f_{cc}$	longitudinal compressive strength of infilled material		
$f_y$	yield strength of steel bar		

attractive alternative to steel in tensile loading due to its relatively high tensile strength, falling within the range of 100 MPa–400 MPa. For some species of bamboo, the ultimate tensile strength is same as the yield strength of mild steel. However, the compressive strength of bamboo in cylindrical section is much lower than its tensile strength, falling within the range of 12 MPa–65 MPa [16,17,24]. The relatively low comprehensive strength of bamboo limits its applications only in the structures under light loads, such as short-span footbridges, low-rise houses, light roof structures and scaffolds. The typical bamboo structures constructed in China are illustrated in Fig. 1.

All the previous studies have been focused on the mechanical properties of structural bamboo or the behavior of bamboo as reinforcement in concrete. However, to the best knowledge of the authors, no existing studies have been concerned with the stiffening schemes aiming at improving the load carrying capacity of conventional structural bamboo. To improve the compressive bearing capacity of structural bamboo, a simple and effective stiffening scheme was originally proposed in the paper. The compressive bearing capacity of structural bamboo was intended to be improved by filling concrete or cement mortar in bamboo cavity. To verify the feasibility of the proposed scheme, this paper presents the first ever exploratory study on the experimental behavior of structural bamboo filled with concrete and cement mortar under axial compression. A total of 19 specimens were tested under axial compression, aiming at investigating the effects of the infilled materials, the horizontal stiffener and the node on the axial behavior of the specimens.

## 2. Experimental program

### 2.1. Test specimens

A total of 19 specimens, including 11 concrete-filled bamboo stub columns, 3 cement mortar filled bamboo stub columns and 5 conventional bamboo stub columns, were tested under axial compression. The details of the specimens are indicated in Fig. 2 and the properties of the specimens are listed in Table 1. Since Moso bamboo (*Phyllostachys pubescens*) is the most important structural bamboo species [16], Moso bamboo was selected as structural bamboo in this study. In addition, concrete (including plain concrete and reinforced concrete) and cement mortar were respectively selected as the infilled materials in this study due to that they serve as conventional construction materials under compression and they are both compatible with bamboo. As well as the infilled materials, the bamboo node as a key component of bamboo



(a) Bamboo footbridge



(b) Bamboo roof



(c) Bamboo building

Fig. 1. Typical bamboo structures in China (Photographed by the authors).

may influence the axial load behavior of structural bamboo filled with concrete and cement mortar. Thus, the effect of the bamboo node was investigated in this study. Furthermore, the horizontal

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