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Mechanical properties of laminated bamboo lumber column under radial eccentric compression

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HIGHLIGHTS

- Three typical failure modes were identified for LBL columns under radial eccentric compression.
- Lateral displacement curves for the LBL columns closely followed sine curves irrespective of the eccentricity.
- Load vs displacement curves showed high stiffness initially but gradually reduced with increasing load.
- Both the lateral and axial displacements were significantly influenced by the eccentricity ratio.
- An equation for calculating the radial eccentricity influencing coefficient ϕ_e for LBL columns has been proposed.

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ABSTRACT

A comprehensive experimental investigation on the mechanical properties of 35 laminated bamboo lumber (LBL) column specimens with a design dimension of 73mm × 73mm × 1000mm under radial eccentric compression in presented in this paper. A wide range of eccentricities was considered to carefully examine the failure modes in LBL columns due to interaction between compression and bending. Presence of natural defects such as bamboo joints and use of mechanical connectors to manufacture long columns, produced different failure modes. Key parameters such as lateral displacement and axial deformation at ultimate load, distribution of strains over cross-sections, ultimate load and the corresponding moment were recorded to understand the overall response of eccentrically loaded LBL columns. Typically, all displacements showed an increasing trend with an increase in eccentricity ratio e_0/h, where e_0 is the eccentricity and h is the depth of the considered cross-section. Regression analyses were carried out to identify influence of e_0/h on the key mechanical parameters such as displacements and resistances of the LBL columns. Finally, a simplified technique has been proposed to predict the ultimate capacity of LBL columns under radial eccentric compression.

1. Introduction

Diameter of the bamboo culm and the natural low rigidity limit its wider applications in structures. In order to solve these problems, the bamboo culm can be disassembled into thin flat laminates, which are glued together to form certifiable structural members. This led to the concept of laminated bamboo lumber (LBL) [1–4]. With a complete control over cross section and length, LBL has the potential to compete with commonly used building materials, whilst offering additional renewable and environmentally friendly characteristics.

Most of the available studies on the performance of laminated bamboo have been concerned with small specimens rather than practical sized structural members. Effects of layered structure, bamboo species, oil treatment, loading direction, processing methods, glue type, finger joint, etc., were considered in previous research to determine mechanical properties such as tensile, compressive and bending behaviour [5–13]. From structural point of view, Sharma et al. [14], Lee et al. [15], Wei et al. [16], Lima Douglas Mateus de et al. [17], Sinha et al. [18], Li et al. [19] examined the bending properties of LBL beams, and reported considerable bending resistance that would benefit structural applications.

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However, limited research is available for LBL columns. Li et al. [20–21] tested LBL columns with a cross section of 100mm × 100mm in compression and observed significant plastic deformation before crushing. Observed stress-strain relationship in compression could be represented using a tri-linear model with an elastic behaviour followed by an elasto-plastic and a purely plastic response. Su et al. [22] investigated the mechanical performance of laminated bamboo lumber column pier under axial compression. Luna P. et al. [23] and Li et al. [24] investigated the mechanical performance of laminated bamboo columns under axial compression for a wide range of slenderness ratio. Xiao-hong Lv [25] examined the mechanical performance of five groups of GluBam column with a cross section of 56mm × 56mm; influence of slenderness ratio on ultimate load was thoroughly investigated. Su et al. [26] investigated the mechanical performance of parallel bamboo strand lumber column under axial compression considering the influencing of slenderness ratio. Li et al. [27] studied the eccentric compression performance of parallel bamboo strand lumber column, and also reported some preliminary discussion on the experimental study and analysis on LBL [28] under tangential eccentric compression; however the considered specimen was short and the number of test specimens was limited with only a few mechanical properties being investigated.

Behaviour of LBL columns under eccentric compression has not been reported in the literature showing a clear gap in knowledge on this important topic; although, almost all columns used in the building industry experience eccentric compression to some extent. Only a few studies were performed under eccentric compression for bamboo lumber pieces. As the shear strength of the material is low and the test setup is complicated, it is relatively difficult to perform eccentric compression tests. The behaviour of structural members under eccentric compression could be significantly different from its behaviour under axial compression. This study aims to examine the radial eccentric compression behaviour of LBL structural members, and to investigate how the eccentricity ratio influences the behaviour of LBL columns based on a significant number of test evidences. As part of the current study, a wide range of eccentric compression tests were conducted on full size structural members with a design dimension of 73mm × 73mm × 1000mm produced from LBL. Obtained test results were used to propose formulations to determine a number of coefficients to predict effects of radial eccentricity on the ultimate load carrying capacity of LBL columns.

2. Materials and test methods

The source for the considered LBL columns was chosen as Moso bamboo (*Phyllostachys pubescens*, from Jing-an county in the Jiangxi province), which were harvested at the age of 3–4 years. Bamboo strips from the lower growth heights of 2100mm tall culm were

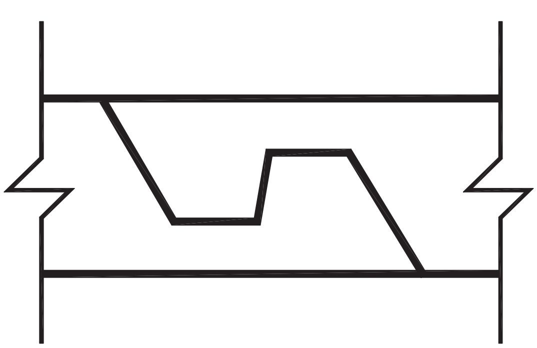

Fig. 1. Connection way.

selected to maintain consistency in material properties. Fig. 1 shows the mechanical connection between two strips along the longitudinal direction of the LBL specimens. The cross sections of bamboo strip elements used for LBL columns were rectangular, as shown in Fig. 2a, with the dimension of 8mm × 21mm. Phenol glue was used to manufacture the laminated specimens. Single layers were produced first, and those layers were pressed together to form bamboo blocks. A pressing temperature of 140 ± 5 °C was used. A transverse compression of 1.82MPa was applied for both the sheets and the blocks, and a confining pressure of 4.74MPa was used when manufacturing the sheets. With the final moisture content to be 7.6% and a density of 635 kg/m^3, experimental investigations showed that the compressive strength for the laminated bamboo was 58.68MPa with a modulus of elasticity of 9643MPa, and the ultimate strain in compression was 0.02.

Different eccentricities of 0mm, 10mm, 20mm, 30mm, 50mm, 80mm, 90mm, 120mm were considered for the considered cross-section of 73mm × 73mm with a column length of 1000mm. Five identical specimens were tested for the considered 8 eccentricities giving a total of 40 specimens. Specimen groups were designated by 'JZC + eccentricity', and four side surfaces of each specimen were marked in alphabetical order from A to D, as shown in Fig. 2. B and D faces were parallel to the shorter 8 mm dimension of the bamboo strip elements, whilst the other two side faces were parallel to the 21 mm side. In the current study, eccentric loads were applied in such a way that the resulting moment was applied about the longitudinal direction of the bamboo strips. This direction is clearly shown in Fig 2a, and is usually called as the radial direction. It is worth noting that eccentricity could also arise in the other orthogonal direction causing moments about the shorter side of the bamboo strips. However, the current paper only investigates the behaviour of LBL columns against radial eccentricities, which will pave the way for further investigations.

Axial displacements as well as transverse displacements at the quarter points and at the mid-height were measured by three Laser Displacement Sensors (LDS type: Keyence IL-300) for all specimens. Two strain gauges were placed at the mid-height of A, B and C side surfaces, whilst 6 strain gauges were used on Face D; the numbering for the strain gauges are shown in Fig. 2b. Bamboo surface should be treated first before attaching the strain gauges. A rough textured cloth was used for polishing the surface, which was later cleaned by alchohol. The strain gauges were pasted when the surface was dry. Axial loads parallel to the bamboo strips were applied using a microcomputer-controlled electro-hydraulic servo universal testing machine with a capacity of 1000 kN with a TDS Data Acquisition System. A typical test arrangement is shown in Fig. 3.

The load was applied initially through load control in the elastic stage, and then was changed to displacement control before the proportional limit was reached. The total loading time was controlled between 8 and 12 minutes. The test was continued at a certain displacement rate until the load reduced by 15% of the ultimate load or the mid-height deflection reached 40mm after the peak load point or the specimen showed significant damage.

3. Test results and analysis

3.1. Failure modes and analysis of observed mechanisms

Key parameters obtained for the eccentrically loaded specimens are reported in Table A1. Stable failure occurred for the concentrically loaded JZC0 (laminated bamboo lumber column under axial compression) specimen group with an average ultimate failure load of 220.6kN with an acceptable coefficient of variation of 7.2%. Based on the obtained mean and standard deviation, the