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Steel and glubam hybrid space truss

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ABSTRACT

This paper introduces a new type of hybrid truss system composed of glue laminated bamboo (glubam) for web and upper chord members and steel pipes for lower chords. Several experiments of physical and mechanical properties were carried out on the glubam material for structural design and construction according to timber specifications and codes. A full-scale space truss model with different configurations was constructed and tested under gravity loads. Different failure modes, such as buckling of web chords, shear fracture of bolted connecting joints and yield of bottom steel pipes, were discussed. Analyses of the structural behavior under static load are compared with the experimental results, showing a good agreement. The experimental results validate that the space truss system is of excellent load carrying capacity. If yielding of the lower chord steel pipes can be realized, the system can also have a large plastic deformation under the ultimate loading condition. A prototype structure was successfully designed and constructed as a rain-shed canopy of an office building.

1. Introduction

Bamboo has been used by mankind all over the world in different ways for thousands of years, such as eating bamboo shoots, making bamboo boats and clothes and building bamboo structures. In recent years, bamboo has been more and more widely applied in the field of civil engineering as a modern green building material especially in Asia and South America, which has also been an alternative of wood or wood-based materials. Bamboo is widely cultivated in many areas, especially in some developing countries. The characteristic of fast growing makes it a renewable material, in comparison with other materials, which can even reach the full height of 15–30 m within a period of 2–4 months [1]. Bamboo is of same or even better physical and mechanical properties compared with normal wood-based materials.

With the development of modern construction technologies, timber structures have made great progress in building large span buildings. The structures which were built with steel and reinforced concrete in the past can also be built with timber now. One of the most famous timber roofs is the Tacoma Dome, built in 1983, of which the diameter is 162 m [2]. The Ohdate Jukai Dome in Japan is a multifunctional stadium finished in 1997, with the span in the direction of long axis being 178 m, while 157 m in the other direction, and 52 m vertical height in the center. The roof of Ohdate Jukai Dome is a space truss system composed of bidirectional glulam chords and bracing members [3]. Another famous stadium in Oguni, Japan was built in 1980s with timber square pyramid space truss system, of which the span reached up to 56 m [4]. Nowadays, large span timber roofs have been more and more widely applied for the ecological and aesthetic characteristics with the optimization of connecting joints and structure forms, especially in industrialized countries.

Compared with large span timber roofs, bamboo truss roofs are still in the research stage. In the 1950s, Chen [5] carried out a research on bamboo roof trusses, and suggested some common forms of full culm bamboo roof trusses and their connecting joints. Recently, a special PVC joint designed for lightweight bamboo double layer grid system [6] was studied by Albermani et al. The results show that the bamboo species used were of good structural characteristics and excellent attributes of environmental protection. The new PVC joint system can also be used in constructing lightweight medium-span bamboo double layer grid structures. Xiao et al. [7] carried out experimental and analytical studies on trusses made of glue-laminated bamboo with two different configurations and dimensions. The results show that the structures were of enough stiffness and capacity. Another study of two full-scale 20 m long glue-laminated trusses was carried out by Xie and Xiao [8]. Compared with conventional Howe truss, the glubam beam and high-strength steel string truss system uses less materials and may be more suitable for constructing building roofs.

Some studies have been conducted on the full culm bamboo structures in the last century. The reasons why they haven't become the mainstream of the research include: single round hollow cross section; complicated connecting joints which are not suitable for modern constructions; relatively low strength in transverse direction, etc. In the

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purpose of overcoming the shortcomings of full culm bamboo, the second author's research team developed and studied a new type of glue-laminated bamboo or glubam [9] for more than ten years. Glubam is similar to the wood-based product of glulam, and Xiao et al. studied its production process, environmental impact and mechanical properties for structural applications [10]. It is an environment-friendly material which sequesters more carbon dioxide than timber. Several demonstration structures were also designed and built by the research team using glubam material, such as bridges [11], roof trusses [7,8], girders and lightweight dwelling buildings [12].

The steel space truss structures are widely used as roofs of large span buildings, especially gas stations, stadiums and train stations. This type of structure is of good out-plane stiffness and large carrying capacity with relatively light weight. It is an ideal structure for large span buildings which are subjected to concentrated load, local overloading and differential settlement of foundation. The pyramid space truss is composed of a plurality of pyramids, and the direction of chords between the upper and bottom layers can be parallel and mutually oblique. Under the effects of load applied on the joints of upper and bottom panels, the chord members are mainly in axial compression or tension, and the internal force of mid-span members tends to be larger than the members on the edge.

Compared with traditional steel space trusses, the steel and glubam hybrid space truss system is developed with the concept of achieving possible maximum carrying capacity and lighter self-weight together. This paper introduces the design, study and construction of this type of steel and glubam hybrid space truss system.

2. Characteristics of materials

2.1. Materials and configurations

The hybrid space truss system specially designed by the authors is composed of two main materials, glubam and steel. The glubam chords are mainly used for the upper compressive chords and web chords, while the steel pipes are mainly used for the bottom tensile chords. Glubam structural members are typically made with two-step processes of lamination. The first process is pressure lamination of layers of bamboo strips into boards under elevated temperature, while the second process is to laminate the elements cut from the boards into structural elements under either elevated temperature or mostly room temperature. The glubam boards are categorized into two typical types of veneers or plybamboo boards, including thin and thick layer laminations [13]. The thin layer glubam boards are mainly manufactured with modifications for concrete formwork in China because of the low cost. However, the thick layer glubam elements are adopted by the authors to manufacture the members of space truss system for its better outdoor weather-resistance performance, which is expected to suffer the combination of UV ray degradation, thermal cycling, dry-wet cycling and corrosion. Typically, the bamboo strips or fibers are arranged in bidirectional configurations, however, for the truss members, the bamboo strips are arranged only in the longitudinal direction since the glubam chords are considered to bear only axial compression or tension.

The glubam specially designed for the space truss system was processed and manufactured by Greezu in Jiangxi Province of China. As it is shown in Fig. 1(a), the cross section of the glubam is 56 mm × 56 mm, which can be considered to be glued together with 9 squares, and each square is glued together with three bamboo strips. The dimension of each bamboo strip cut from the full culm bamboo is about 19 mm × 6 mm and was treated with carbonation before lamination. The production process involves three stage pressing processes. First, three layers of bamboo strips were glued together to form a bar with square section. Then, the bar was polished to a specific section of 18.6 mm square. Three of the bamboo bars were glued together under pressure to form a flat glubam strip with 18–19 mm thickness and 56 mm width, and then three of such flat elements were glued together to form a member with a 56 mm square section, as shown in Fig. 1(a).

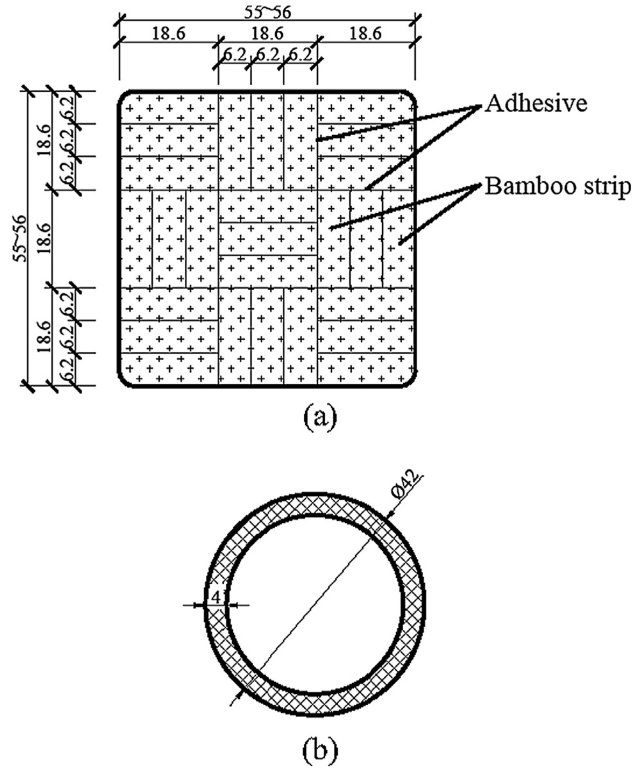

Fig. 1. Configurations of the space truss members: (a) glubam coupon; (b) steel coupon (unit: mm).

The cross section of full sectional steel pipe is given in Fig. 1(b). The outer diameter of steel pipe is measured as 42 mm and the wall thickness is 4 mm. Different tests were conducted on both materials to study the physical and mechanical properties.

2.2. Steel pipes

In order to determine the stress-strain relationship and tensile strength of the bottom steel pipes, two different configurations of specimens were manufactured according to the Chinese specifications [14,15], including longitudinal thin steel strip and reduced sectional steel pipe, and 3 specimens were manufactured for each configuration. The thin steel strip was partly cut from the steel pipe in the longitudinal direction and the length of specimen is 325 mm.

The specimens were tested with a universal testing machine, and the loading speed was controlled by displacement, which was 10 mm/min. All of the specimens were attached with strain gauges in the middle, and the extensometer was used in the group of longitudinal steel strip to measure the large deformation after the yield. Fig. 2 shows the average stress-strain relationship of 3 longitudinal thin steel strips, in which the enlarged curve exhibits the elastic range of the stress-strain curve before yield. After the yield occurs, the strain increases evidently with stress fluctuating, and the specimens broke suddenly after the stress reached the maximum tensile strength. The average tensile strength of steel pipe tested was 513 MPa, while the average yield strength was 420 MPa. The elastic modulus of steel was 212 GPa. After the specimen reached the maximum load, tensile fracture occurred following apparent necking. The test results of the steel pipes with reduced section were similar to the results of the strips.

2.3. Properties of glubam

Considering the fact that there are no practical testing standards for