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CASE REPORT

Structural design and construction of an office building with laminated bamboo lumber

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Abstract: With so many advantages such as environmental friendliness, fast-growing, high strength-to-weight ratio, sustainability, and the capability of being reused or recycled, bamboo structures has gained more and more attention for scientists. This paper shows the feasibility of the design of an office building using laminated bamboo lumbers in compliance with the Chinese standards as GB50009-2012, GB50011-2010, GB50016-2014, and GB 50005-2017. Detailed information about the materials and building were offered. A lot of related construction photos were offered to show the building process. This case is a very good application example for laminated bamboo lumber buildings and has attracted many engineers' attention in industrial field. Laminated bamboo lumber structures should have a bright future. It should become one main structure form in civil engineering area. However, due to none existing engineered bamboo structures design standard now, engineers have to take reference to standards for timber structures. Setting up the standard system is very important for engineered bamboo structures' application. Through more and more scientists' hard working, it might be not a long way to build the code system.

Keywords: Laminated bamboo lumber; office building; design; construction

1 Introduction

As known by everyone, mineral resources for constructions are limit in our globe. That is why more and more scientists are paying attention to the bio-resources [1-28]. Bamboo and wood are natural green building materials [1-5]. They have many advantages such as environmental friendliness, sustainability, and the capability of being reused or recycled [5-8]. While it takes shorter harvesting period for bamboo than that for wood. Just 3–5 years from the time of planting is needed for bamboo [9-15]. Besides the above advantages, bamboo also has high efficiency in comparison to other construction materials, and its strength-to-weight ratio is greater than that of common wood, aluminum alloy, cast iron, and steel [15-22].

Due to limit diameter and low rigidity, bamboo can't be used widely in modern buildings. Engineered bamboo materials could solve these problems [1-22]. There are many different kinds of

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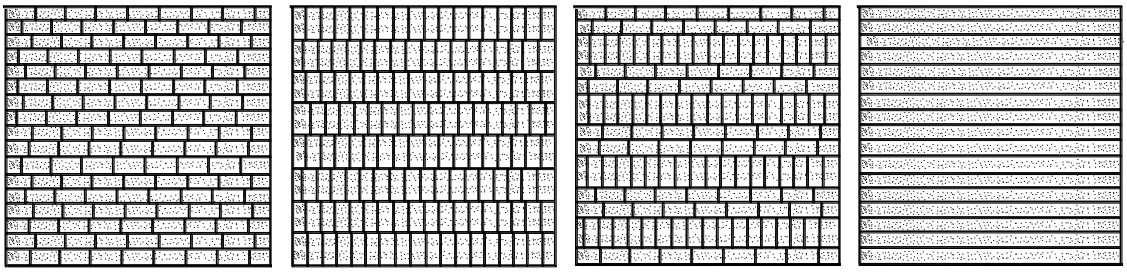
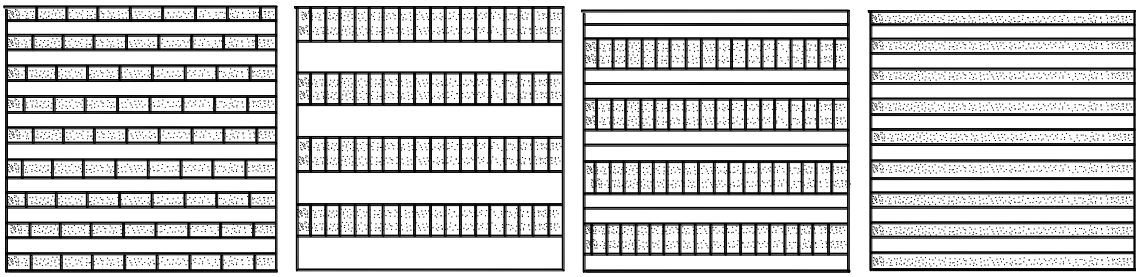
industrial bamboo products now such as laminated bamboo lumber (LBL), parallel bamboo strand lumber (scrimber bamboo) , bamboo winding composite materials, bamboo plastic composite materials, bamboo weave composite materials (glue bamboo), bamboo particle composite materials, bamboo wood composite materials and so on [1-9, 28]. Different products have different characteristics and manufacturing technologies. Laminated bamboo lumber (LBL) is one kinds of main products in the supermarket and has been widely used in construction area [9-28].

After disassembling the natural bamboo tubes into thin flat laminae and some treating procedures, laminated bamboo lumber LBL could be formed by laminating the thin strips together. LBL could solve the problems of size limitation and dimensional consistency, strength, and uniformity [22-28]. There are two main series of LBL products which are parallel laminated bamboo lumber (Fig. 1) [25-28] and cross laminated bamboo lumber (Fig. 2) [25-28].



(a) Flat pressure type (b) Side pressure type (c) Combined pressure type (d) Flattening bamboo type

Fig. 1. Parallel laminated bamboo lumber [2]



(a) Flat pressure type (b) Side pressure type (c) Combined pressure type (d) Flattening bamboo type

Fig. 2. Cross laminated bamboo lumber [28]

As one main promising wood substitute, LBL has attracted more and more researchers' attention. A large quantities of studies [9-28] have been carried out about its basic mechanical properties and structural performance. More and more structural applications appeared in construction filed. This paper will introduce one main application example which was started in 2019 and finished in 2020 as an office building.

2 Materials chosen for the case

The main manufacturing process for laminated bamboo lumber used in this project were shown in Fig. 3. Harvested at the age of 3–6 years (Fig. 1a), Moso bamboo (*Phyllostachys pubescens*, from Fujian province) was chosen for LBL. Firstly, original bamboo poles were cut into a length of 2005 mm and then split into bamboo strips with the width of 22-24 mm (Fig. 1c). Secondly, both the inner cavity layer (pith peripheral) and the outer skin (epidermal) of the strips were removed (Fig. 1d) by a planer. Then all strips were put in one specific tank for charring to remove the nutrition, sugar and so on (Fig. 1e). After drying and fine planning, the final bamboo strips with the thickness of 7 mm and width of 21 mm were obtained for the glue rolling process (Fig. 1f). Phenol glue was chosen here. Side pressure type was chosen for LBL making. The single layers (Fig. 1g) were manufactured firstly and then were put into a tank for durability treatment (Fig. 1h). Finally, all single layers were pressed together to form the big blocks (Fig. 1i).

The basic mechanical properties of LBL have been tested and the main test results could be seen from Table 1. The test mean value for the density of the materials is 0.622 g/cm^3 with the standard

deviation of 0.019 g/cm^3. It could be seen from the test that LBL has good mechanical characteristics which was also proved by other scientific research.

Table 1. Mechanical properties of LBL [28]

	Tensile parallel to grain	Tensile perpendicular to grain	Compression parallel to grain	Compression perpendicular to grain	Shear parallel to grain	Bending
Strength /MPa	84.5	4.15	71.6	16.5	13.9	92.6
Elastic modulus /MPa	7013	-	9680	1867	8658	7999

(a) Original bamboo (b) Cut off (c) Original bamboo strips

(d) Plane (e) Charring (f) Roll gluing

(g) Single layer (h) Durability treatment (i) Structural section

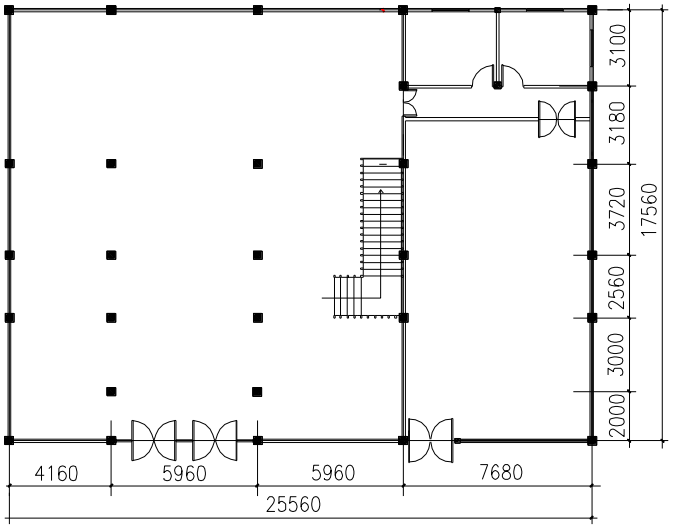
Fig. 3. Manufacturing process for LBL

3 Design of the building

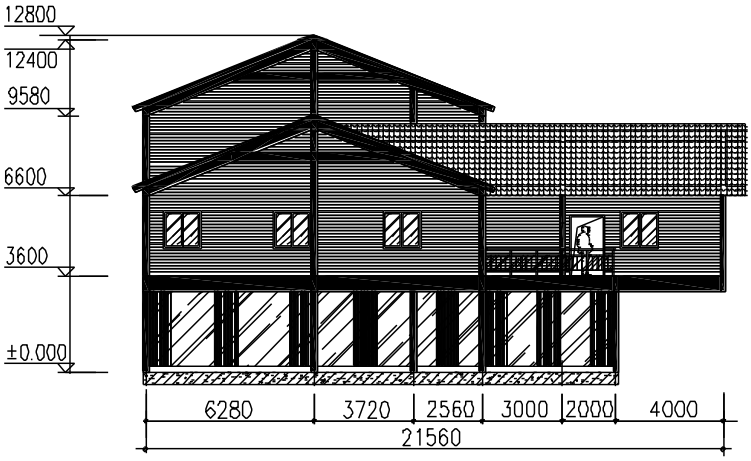
The case was inspired by a laminated bamboo lumber building designed by Haitao Li's team working with Ganzhou Sentai Bamboo Company LTD and it's mainly used as the company's office building, shown in Fig. 4. The design work for this building was finished in 2018. The structure of the building is a beam-column system. Steel plates and bolts were chosen for the structural connections. The materials used were illustrated in the above and manufactured by Ganzhou Sentai Bamboo Company LTD. With the height of 12800 mm for the tallest building point, the total building area for

the case is about 1100 square meters. Concrete foundation combined with bricks was chosen for the building. The space for the ground floor of the building is mainly used for products exhibition and staff canteen. While the second floor is mainly for the staff office and the third floor is a big meeting room. The height for the tallest building point is 12800 mm.

Both the calculations methods by hand and by the finite element software SAP2000 were chosen for structural design of the building. The actions on the building, such as snow, wind and earthquake, the requirements set out in Chinese standards as GB50009-2012 [30], GB50011-2010 [31], GB50016-2014 [32], and GB 50005-2017 [33] are adopted. As the stiffness for the bolt steel plate connections lies in between the rigid connections and hinge connections, two models of the same structure were considered and calculated. The first one is with rigid constraints in the beams-columns nodes to maximize the stresses in the columns, and the other is with hinges in the connections to maximize the stresses in the beams. The heaviest stresses deriving from these two models were considered for each structural member to be in the most unfavorable possible condition for each member.



(a) Structural plan of the first floor (unit: mm)



(b) South Elevation (unit: mm)

Fig. 4. Plan and section of the building

4 Construction of the building

The building was set up for two years off and on. The construction work began in 2019. Concrete foundation combined with bricks was finished during this period and most of columns were erected on the foundation by using bolt and steel plate connections meanwhile. Due to many other reasons, all other construction work was finished in Ganzhou in 2020. Carriage hoist played an important role in the construction process. Oriented Strand Boards (OSB) were chosen both for the walls and the roofs.

Nails were used to connect OSB boards with the structural elements such as the beams or columns. Fig. 5 shows some typical photos for the whole construction process.

(a) Foundation

(b) Bolts and steel plates

(c) Connection and the base

(d) Bolts connection side

(e) Steel plate connection side

(f) Connections between columns and beams

(g) Structural system for the first floor

(h) Structural system for the whole building

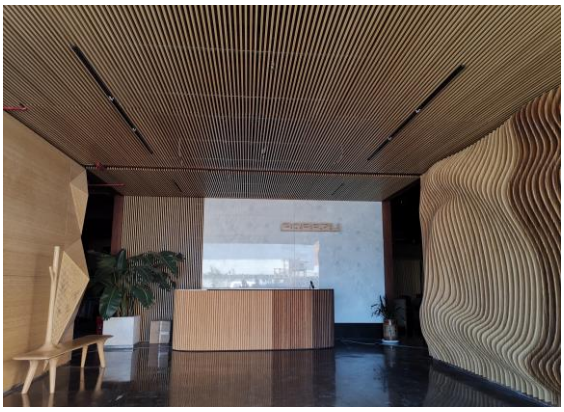
(i) Roof construction

(j) Inner side of the roof

(k) Stairs

(l) Structural system for the roof

(m) Structural system inside



(n) Entrance of the building

(o) Photo taken from the south

(p) Photo taken from the entrance side

Fig. 5. LBL building construction

5 Conclusions

The paper shows the feasibility of the design of an office building using laminated bamboo lumbers in compliance with the Chinese standards as GB50009-2012, GB50011-2010, GB50016-2014, and GB 50005-2017. Detailed information about the materials and building were offered. A lot of related construction photos were offered to show the building process. This case is a very good application example for laminated bamboo lumber buildings and has attracted many engineers' attention in industrial field. With so many advantages such as environmental friendliness, fast-growing, high strength-to-weight ratio, sustainability, and the capability of being reused or recycled, laminated bamboo lumber structures should have a bright future. It should be one main structure form for the future buildings. However, there are still none engineered bamboo structures design standard now. Engineers have to take reference to the standards for timber structures. Setting up the standard system is very important for engineered bamboo structures' application. Through more and more scientists'

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Conflicts of Interest

The authors declare that they have no conflicts of interest to report regarding the present study.

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