Experimental research on shear performance of single bolt joints of bamboo curtain plywood

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Abstract. This paper focuses on the shear resistance of the bolted connection between steel plate and bamboo curtain plywood. From the fifteen groups of specimens, the performance grade, bolt diameter and end distance of bolts have an influence on the ultimate bearing capacity of joints and the yield load of joints and the yield load is 65%~75% of the ultimate load. The initial stiffness of the node increases with the bolt diameter increasing. Provide certain materials and theoretical references for bamboo in the future design and research.

1. Introduction
Modern bamboo structure is an emerging architectural concept [1], and the research on bolt connection performance is also in the exploratory stage [2]. In the design of bamboo and wood structure, the rationality of the design of the beam-column connection nodes is the key link to ensure the overall stability of the structure. Bamboo and wood materials have similar characteristics and are both anisotropic materials [3]. When they simultaneously bear shear load and parallel (or perpendicular) material fibers direction tensile or compressive load, brittle tear failure will occur [4]. This article mainly conducts an experimental study on the shear performance of a single-bolt joint of bamboo curtain plywood, studies the influence of bolt strength and bolt diameter and end distance on the bearing capacity of the joint. Therefore, the characteristics of the single bolt connection node of the bamboo curtain plywood are obtained. The bamboo curtain plywood used in the experiment is produced in Yiyang, Hunan, the "hometown of phyllostachys pubescens".

2. Test materials and test pieces grouping
The size of the main component of the bolted connection node selected in this paper is 250mm (height) × 120mm (width) × 12mm (thickness); the side member is Q345 steel splint, the size is 250mm (height) × 120mm (width) × 8mm (thickness). The dimensions of bamboo and steel plates are shown in Figure 1.
Three different performance grades (4.8, 8.8 and 10.9) and five different diameters (M8, M10, M12, M14 and M16) were selected for the bolts. The load-bearing performance of a single-bolt connection node is affected by many factors. This paper mainly selects three influencing factors: bolt performance grade, bolt diameter and bamboo plate end distance. The longitudinal shear strength of bamboo curtain plywood is 19.17MPa. The yield strength of bolts of grades 4.8, 8.8 and 10.9 is 320MPa, 640MPa, and 900MPa. The yield strength of the steel plate is 345MPa.

3. Test method
This chapter refers to the test methods of China’s "Standard for design of timber structures" (GB50005-2017) [5], "Standard for test methods of timber structures" (50329-2012) [6] and the United States ASTM D5652-1995 (2013) [7]. The steel splints and bolts are assembled into symmetrical double-shear connection nodes. The test uses YES-1000 pressure testing machine to load, and uses YHD-50 displacement sensor and DH3818-2 static strain collector to collect displacement. Since the damage position of the main connector is concentrated in the middle of the test piece, two loading blocks are installed at both ends of the upper part of the bamboo board. The schematic diagram and physical diagram of the test device are shown in Figure 2 and Figure 3, and the size of the loading block is shown in Figure 4.
The test process is as follows:

(1) Assemble the connectors. The planes of the bamboo board and the two steel splints are kept vertical, the upper bearing surface of the bamboo board is horizontal, and the loading surface of the bottom of the two steel splints is horizontal and coplanar.

(2) Install test pieces and measuring instruments. Install the test piece to the press and install the displacement sensor. The displacement sensor wire is connected to the static strain collector.

(3) Zero the pressure value of the press and balance the strain collector.

(4) Load. In the test, load was carried out at a uniform speed by controlling the loading displacement of the press, and the loading speed was controlled at about 1mm/min, until the specimen was broken, and the loading was stopped. According to the displayed value of the strain collector, the test records the corresponding load every certain displacement.

\[ M_t = kP_0d \]  

(1)

Among them, \( M_t \) is the pre-tightening torque, \( k \) is the tightening force coefficient, which is related to the condition of the friction surface. This test takes 0.15 [8], and \( d \) is the bolt diameter \( P_0 \) as the pre-tightening force, which is calculated by the following formula:

\[ P_0 = \sigma_0 A_s \]  

(2)

In the formula, \( \sigma_0 = (0.5 \sim 0.7)\sigma_s \), \( \sigma_s \) is the limit of the bolt material, and \( A_s \) is the calculated area of the section of the critical section of the thread, which can be obtained by looking up the table or calculated by measuring the diameter of the section of the dangerous part of the thread, so \( A_s = \pi d_s^2 / 4 \).

4. Test results

The test result analysis is divided into the ultimate bearing capacity analysis of the joint and the initial stiffness and yield load analysis of the joint. The schematic diagram of the load-displacement curve of the specimen is shown in Figure 5, which can be divided into four stages: elastic stage, yield stage, strengthening stage and descending stage. The curve in the elastic phase is linearly fitted, and the slope of the fitted straight line is the initial stiffness of the specimen; the yield load of the specimen is obtained by the 5%d (bolt diameter) offset method; the load corresponding to the highest point in the strengthening phase is the ultimate load of the specimen.

4.1. Analysis of ultimate bearing capacity of joints

Table 1 shows the statistical data of the bearing capacity (ultimate load) of each batch of specimens and the corresponding coefficient of variation. The measured bearing capacity of the first to third groups of specimens is the ultimate load. According to the deformation and test results of the first to third groups of specimens. The bolts premature buckling will reduce the load-bearing performance of the joints. When the bolt performance level is increased from 4.8 to 8.8, the bearing capacity of the joints has improved 17.48%, and when the level is further increased to 10.9, the bearing capacity changes less obviously.
According to the test results of the second, fourth to seventh groups, it can be seen that with the increase of bolt grade, the bearing capacity of the test piece increases first and then stabilizes with the increase of bolt diameter. This is mainly due to the increase of the bolt diameter, which increases the contact area between the bolt hole and the bolt, and the pressure bearing capacity of the bolt hole wall is improved. Among them, the test results of the bearing capacity of the 7th group of specimens fluctuate greatly, with a coefficient of variation of 15.79%, which is related to the dispersion of the material properties of the bamboo plywood and the errors caused by the production of the specimens.

According to the test results of groups 2, 8-14, it can be seen that the coefficient of variation of the test pieces in each group is between 5% and 11%, and the bearing capacity test results are relatively stable and reliable. According to the table, it can be seen that when the end distance is not more than 40mm (4d), the bearing capacity of the test piece increases monotonically with the increase of the end distance; when the end distance is 40mm–60mm (4d–6d), the bearing capacity of the test piece is relatively stable; When the end distance is increased to 80mm and 100mm, the load-bearing capacity of the specimen is further increased, but the increase is significantly reduced compared to the specimen with the end distance of 40mm. Therefore, when the end distance exceeds 4d, continue to increase the end distance, and the increase in the bearing capacity is limited, which is not economical.

Therefore, for the bamboo curtain plywood and 8.8 grade M10 bolts used in this article, when the end distance reaches 40mm (4d), the bearing capacity of the bolted joints tends to be stable, and the improvement of the bearing capacity by continuing to increase the end distance is not obvious. With the increase of the end distance, the damage mode of the node changes from overall damage to local damage. At this time, the increase of the end distance has little effect on the local bearing capacity of the node.

### Table 1. Test results of bearing capacity of single-bolt joint specimens.

| Group No | Bolt model | Edge distance /mm | Specimen bearing capacity /kN | average value /kN | Standard deviation /kN | Coefficient of Variation |
|----------|------------|------------------|-----------------------------|-----------------|------------------------|-------------------------|
| 1        | 4.8, M10   | 100              | 18.31 14.03 15.56 17.47 14.75 | 16.02           | 1.81                   | 11.31%                  |
| 2        | 8.8, M10   | 100              | 18.6 17.94 19.34 16.48 18.52 | 18.18           | 1.07                   | 5.89%                   |
| 3        | 10.9, M10  | 100              | 19.64 17.8 20.62 18.8 17.22 | 18.82           | 1.37                   | 7.28%                   |
| 4        | 8.8, M8    | 100              | 14.16 13.73 13.16 14.78 11.82 | 13.53           | 1.12                   | 8.31%                   |
| 5        | 8.8, M12   | 100              | 19.16 16.06 18.56 18.92 17.98 | 18.14           | 1.24                   | 6.85%                   |
| 6        | 8.8, M14   | 100              | 21.92 17.42 22.34 16.50 18.26 | 19.29           | 2.67                   | 13.85%                  |
| 7        | 8.8, M16   | 100              | 19.20 15.60 16.42 19.06 23.13 | 18.68           | 2.95                   | 15.79%                  |
| 8        | 8.8, M10   | 30               | 13.02 15.80 14.18 12.09 15.17 | 14.05           | 1.52                   | 10.82%                  |
| 9        | 8.8, M10   | 35               | 15.96 13.97 16.57 13.27 15.40 | 15.03           | 1.38                   | 9.17%                   |
| 10       | 8.8, M10   | 40               | 13.84 14.70 17.29 15.67 16.62 | 15.62           | 1.40                   | 8.93%                   |
| 11       | 8.8, M10   | 45               | 16.97 15.87 16.44 14.95 14.47 | 15.74           | 1.03                   | 6.56%                   |
| 12       | 8.8, M10   | 50               | 16.45 14.30 15.57 17.23 15.31 | 15.77           | 1.12                   | 7.09%                   |
| 13       | 8.8, M10   | 55               | 16.54 14.52 15.21 16.72 17.58 | 16.11           | 1.23                   | 7.64%                   |
| 14       | 8.8, M10   | 60               | 16.72 16.94 15.66 18.13 17.01 | 16.89           | 0.88                   | 5.21%                   |
| 15       | 8.8, M10   | 80               | 16.03 19.20 17.30 17.84 18.15 | 17.70           | 1.16                   | 6.58%                   |

4.2. Analysis of joint initial stiffness and yield load
According to the test results, this section compares and analyzes the initial stiffness and yield strength of each group of specimens connected by single bolts. Table 2 shows the statistics of the initial stiffness and yield load of the batches of specimens and the corresponding coefficient of variation.
Table 2. Initial stiffness and yield load of the first batch of specimens for single-bolt joints.

| Group No | Bolt model | Edge distance /mm | Failure part of the joint | Initial stiffness / (kN·mm\(^{-1}\)) | Coefficient of Variation | Yield load /kN | Coefficient of Variation |
|----------|------------|-------------------|---------------------------|---------------------------------------|-------------------------|----------------|-------------------------|
| 1        | 4.8, M10   | 100               | Hole wall                 | 7.36                                  | 10.25%                  | 10.12         | 12.32%                  |
| 2        | 8.8, M10   | 100               | Hole wall                 | 8.89                                  | 8.53%                   | 12.46         | 9.85%                   |
| 3        | 10.9, M10  | 100               | Hole wall                 | 8.62                                  | 6.22%                   | 11.85         | 6.17%                   |
| 4        | 8.8, M8    | 100               | Hole wall                 | 5.77                                  | 7.53%                   | 9.61          | 10.99%                  |
| 5        | 8.8, M12   | 100               | Hole wall                 | 12.6                                  | 5.86%                   | 12.71         | 5.04%                   |
| 6        | 8.8, M14   | 100               | Hole wall                 | 13.84                                 | 8.72%                   | 13.23         | 14.47%                  |
| 7        | 8.8, M16   | 100               | Hole wall                 | 15.23                                 | 16.56%                  | 12.8          | 14.36%                  |
| 8        | 8.8, M10   | 30                | Bamboo board              | 10.61                                 | 14.25%                  | 10.19         | 7.55%                   |
| 9        | 8.8, M10   | 35                | Bamboo board              | 8.37                                  | 14.28%                  | 10.88         | 7.27%                   |
| 10       | 8.8, M10   | 40                | Hole wall                 | 9.12                                  | 11.61%                  | 11.63         | 4.91%                   |
| 11       | 8.8, M10   | 45                | Hole wall                 | 8.58                                  | 9.24%                   | 11.75         | 7.02%                   |
| 12       | 8.8, M10   | 50                | Hole wall                 | 8.18                                  | 8.51%                   | 11.54         | 11.90%                  |
| 13       | 8.8, M10   | 55                | Hole wall                 | 9.85                                  | 14.35%                  | 11.76         | 12.27%                  |
| 14       | 8.8, M10   | 60                | Hole wall                 | 9.29                                  | 21.04%                  | 12.12         | 13.04%                  |
| 15       | 8.8, M10   | 80                | Hole wall                 | 8.33                                  | 8.57%                   | 12.63         | 8.51%                   |

(1) Initial stiffness
The performance level of the bolt does not affect the initial stiffness of the node. As shown in Figure 6 (a), when the bolt level is 4.8, 8.8 and 10.9, the initial stiffness of the node fluctuates between 7kN/mm~9kN/mm, and there is no obvious difference or monotonicity. Because at the beginning of loading, the bearing capacity of the node is greatly affected by the bamboo around the node, while the bamboo material at the far end is relatively less affected, so the increase in the end station has almost no effect on the initial stiffness. For the bolt diameter, the initial stiffness of the node increases with the increase of the bolt diameter, as shown in Figure 6 (b), as the diameter increases from 8mm to 16mm, the initial stiffness of the node gradually increases from 5.77 kN/mm As large as 15.23 kN/mm. As the diameter of the bolt increases, the pressure area of the bolt hole on the bamboo plywood increases and the ability of bolts and hole walls to resist deformation increases. For the end distance, the initial stiffness of the node is hardly affected by the end distance. As shown in Figure 6 (c), when the end distance is increased from 40mm to 100mm, the initial stiffness of the node fluctuates between 7kN/mm~9kN/mm, There is no significant difference and monotonicity. Because at the beginning of loading, the bearing capacity of the node is greatly affected by the bamboo around the node, while the bamboo material at the far end is relatively less affected, so the increase in the end station has almost no effect on the initial stiffness.

(2) Yield load
The variation law of the yield load of the joint is similar to the ultimate load of the joint. As for the performance level of bolts, in general, the improvement of the performance level of bolts can help increase the yield load of the joint. As shown in Figure 7 (a), the yield load of the joints with bolt grades of 8.8 and 10.9 is higher than that of 4.8. However, because the bolts of the two groups of 8.8 and 10.9 are in an unyielding state, there is little difference in the yield load of the joints. For the bolt diameter, the yield load of the node increases as the diameter increases, as shown in Figure 7 (b). As for the end
distance, the yield load of the node increases with the increase of the end distance, and then fluctuates gently and then gradually increases, as shown in Figure 7 (c). With the increase of the end distance, the damage mode of the node changes from overall damage to local damage. At this time, the increase of the end distance has little effect on the local bearing capacity of the node.

Figure 6. Multiple comparison chart of initial stiffness of single bolt joint.

Figure 7. Multiple comparison chart of initial stiffness of single bolt joint.

5. Summary
This paper selected three influencing factors, that are bolt performance grade, bolt diameter and end distance, designed 15 sets of tests to study the load-bearing performance of single bolt connection nodes. The specific conclusions are as follows:

(1) For the ultimate bearing capacity of joints, the performance grade, bolt diameter and end distance of bolts have an influence on it. When the bolt is increased from 4.8 to 8.8, the bearing capacity of the joint has increased 17.48%. When the grade is increased to 10.9, the change in the bearing capacity is not obvious; as the diameter of the bolt increases, the bearing capacity of the tested piece increases first. When the end distance is not more than 4d, the bearing capacity of the test piece increases monotonically with the increase of the end distance. When the end distance is 4d~6d, the bearing capacity of the test piece is relatively stable. When the end distance is changed from 6d to 10d, the bearing capacity of the specimen has been increased by 7.64%. Generally, when the end distance exceeds 4d, the end distance is continued to increase, and the extent of the increase in the bearing capacity is limited;

(2) For the initial stiffness of the node, the performance grade and end distance of the bolt have little effect on it, and the influence of the bolt diameter is more obvious. The initial stiffness of the node increases with increasing the bolt diameter.

(3) For the yield load of joints, the influence of the three factors is similar to that of the joint ultimate bearing capacity, and the yield load is 65%~75% of the ultimate load.
References

[1] Xiao Y, Chen G, Shan B, Yang R Z, She L Y 2010 Research and application of bamboo structure light frame house *J. Build. Struct.* 31(6) 195-203.

[2] Yang R Z 2007 Research and application of the mechanical properties of glued bamboo and the properties of bolted joints (Hunan: Hunan University).

[3] Ma H X 2009 *Interface gluability and its affecting factors of bamboo/poplar composite* (Beijing: Chinese Academy of Forestry)

[4] Bouchaïr A, Racher P, Bocquet J F 2007 Analysis of dowelled timber to timber moment-resisting joints *Mater. Struct.* 40(10) 1127-1141.

[5] General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China 2012 *Standard for design of timber structures GB50005-2017*

[6] General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China 2012 *Standard for test methods of timber structures GB/T50329-2012*.

[7] ASTM International 2013 *Standard test methods for bolted connections in wood and wood-based products, ASTM D5652-1995(2013).*

[8] Xu B and Jiang S X 2000 Study on the static friction coefficient of bamboo-wood composite laminated timber *China Forestry Sci. Technol.* 6 22-3.