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Experimental Study on Mechanical Properties of Laminated Bamboo Board Rubber Isolation Bearing for Rural Buildings

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Abstract. A new type of isolation bearing with advantages of low carbon, low cost and light weight is designed for rural buildings by using reinforced and recombined bamboo board instead of steel plates. First, the compression shear static load test of the reinforced composite bamboo board is carried out. The results show that: When the pure pressure is 20 MPa, the through cracks begin to appear along the grain direction of the bamboo board; When the pressure bearing capacity is 5 MPa and the shear bearing capacity is 3 MPa, there are a few cracks in the transverse direction, but they still have integrity. Then, taking a double story rural building in Wenchuan County, Sichuan Province as an example, a new type of bearing is used to design the base isolation scheme, and the quasi-static test was carried out. The results show that: (1)During the small earthquake, the bamboo board is not cracked, and the support remains intact. The shear stiffness in the longitudinal direction is about 30% higher than that in the transverse direction, and the equivalent damping ratio in the longitudinal and transverse directions is about 5%;(2) During the medium earthquake, a few cracks appear in the bamboo board, but the support is still intact. The stiffness along the grain direction is reduced by about 20%, but the damping ratio remains unchanged, and the mechanical properties along the grain direction are not affected;(3)During a large earthquake, there are many cracks in the bamboo board, but the bearing can still effectively bear the load. The stiffness in the longitudinal direction is further reduced by about 13%, and the transverse direction is basically unchanged. The damping ratio in the longitudinal and transverse directions is increased to 8-10% respectively. Therefore, the new isolation bearing is feasible.

Keywords. Rural building, bamboo board, isolation bearing, pseudo-static testing, Equivalent stiffness

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1. Introduction

China's rural areas are vast and the economic development is uneven. For the sake of economic cost, farmers often neglect their seismic fortification requirements In the Wenchuan earthquake in 2008, the Ya'an earthquake in 2013 and 2022, the weak seismic performance of rural buildings caused a large number of casualties and property losses, causing the seismic problems of rural buildings to attract extensive attention from all walks of life. Since 2016, China's Seismological Bureau and construction authorities have raised the seismic fortification requirements of various buildings. However, the traditional lead rubber isolation bearing has high cost, large resource consumption, and high construction and installation difficulty, which is not suitable for promotion and application in rural areas with large quantities and wide areas.

Kelly [1] used fiber reinforced composite plate (FRP) instead of steel plate to make laminated rubber bearing, which greatly reduced its weight, but its stability problem under large shear deformation is prominent. Zhou et al. [2] made simple isolation bricks to reduce the size to improve its stability. The connection measures between isolation bricks are the weak link. Tan et al. [3] further reduced the cost of laminated rubber bearing of engineering plastic plate and carried out limit performance test. However, warping deformation and plate breaking occurred during compression shear test. Turer and Xiong [4,5] cut the waste tires into gaskets, bonded and stacked the gaskets to make a simple isolation bearing, which has the advantages of simple construction and low cost. However, the uncertainty of tire surface texture makes it difficult to accurately design its isolation performance, which may cause local internal force concentration of the isolation layer. Chen and Cai [6-7] found that the tire gasket has good seismic isolation performance, but the vertical ultimate compressive stress has large dispersion. In addition, Daniele et al. [8,9] and other researchers have studied the regenerative rubber fiber reinforced seismic isolation bearing through numerical simulation, and analyzed its feasibility in combination with rural buildings in the Himalayas. Aak et al. [10] proposed to use rubber balls to make low-cost isolators, but the phenomenon of excessive rolling friction due to excessive deformation still needs to be improved. In addition, the above research results have not carried out in-depth discussion on the connection requirements and construction convenience of the bearing.

At present, under the strategic background of "carbon peaking and carbon neutralization", people attach great importance to the strong carbon storage capacity, high tension, pressure and light weight of bamboo, which was once considered as one of the best materials to replace steel. In this paper, a laminated bamboo board rubber isolation bearing with low carbon, low cost, light weight, no complex connection requirements and low processing and construction difficulty is developed for rural buildings by replacing steel plate with recombined bamboo board and combining with high-strength cold adhesive glue. The mechanical properties and feasibility of the new bearing are tested through static and quasi-static tests.

2. Design of the New Bearing

The three-dimensional sectional view and physical drawing of the new bearing are shown in figure 1. It only comprises two components, namely, a recombined bamboo board and a rubber sheet. In order to reduce its isolation frequency, the rubber sheet is made of 35 degree natural rubber. In order to make the mechanical properties of the bamboo board parallel to the transverse grain similar, a 0.5 mm thick steel ring is applied along the periphery of the bamboo board to strengthen the bamboo board, so that the tensile force of the bamboo board in the transverse grain direction is converted into the tensile force of the thin steel sheet.

(a) Sectional drawing (b) Physical drawing

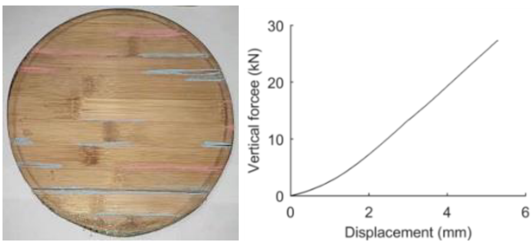
Figure 1. Drawing of new bearing.

3. Tests on the Mechanical Properties of Bamboo Board

3.1. Pure Pressure Test

During the test, the reinforced and recombined bamboo board with a diameter of 220 mm and a thickness of 10 mm as shown in figure 2 (a) shall be used and loaded to 30 MPa at a rate of 0.5 kn/s. Take down the bamboo board at an interval of 5 MPa to observe the crack change. The test photos under various pressures are shown in figures 2(b) ~ (c). The force displacement curve of the last load is shown in figure 2 (d).

(a) Before test (b) 15 MPa



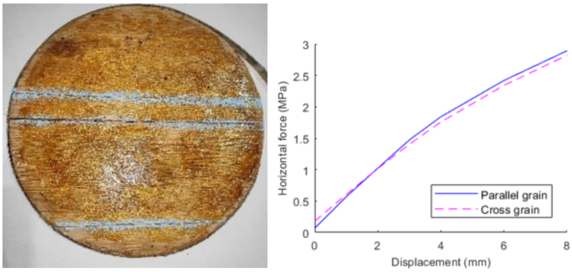
(c) 20 MPa (d) Force displacement curve

Figure 2. Compression test diagram of recombined bamboo.

The test results show that: (1) The cracks of bamboo board under pure pressure develop along the transverse direction, and there are no cracks along the grain direction; (2) The bamboo board has a high compressive bearing capacity. When it is loaded to 15 MPa, there are fine cracks, and when it is loaded to 20 MPa, there are through cracks; (3) The thin steel ring can significantly suppress the crack width of the bamboo board and keep its integrity, so it can significantly improve the compressive strength of the bamboo board.

3.2. Compression Shear Test

According to test methods for seismic isolation rubber bearings GB / T 20688.1-2007 [11], During the test, a constant vertical pressure of 5 MPa is applied, and then rubber sheets are pasted on the upper and lower surfaces of the bamboo board, and shear force is applied to the bamboo board by pushing the rubber sheets. Observe the cracking of bamboo board and record the force displacement curve. The photos of bamboo board in the final state and its force displacement curve are shown in figures 3(a) ~ (b).



(a) Bamboo board after test (b) Force displacement curve

Figure 3. Compression shear test of recombined bamboo.

During the test, the bamboo board did not crack when loaded along the grain. Under transverse load, when the shear force reaches 2 MPa, the bamboo board makes obvious sound, and its shear stiffness also decreases. When the load is continuously applied to 3 MPa along the transverse direction, as shown in figure 3(c), two through cracks appear, but the bamboo board is not seriously damaged, and can still effectively resist the pressure shear composite external force.

Assuming that it is placed at the bottom of a 17 ton column and the isolation period is 1.5 s, it can be seen from the response spectrum method that the seismic intensity is 9 degrees and the maximum base shear stress is about 3 MPa during a large earthquake, which can meet the needs of rural buildings in the design standard for seismic isolation of buildings GB / T 51408-2021 [12].

4. Base Isolation Design of a Rural Building

4.1. Overview of Rural Buildings

Taking a two-story rural residential building in Wenchuan County, Sichuan Province as an example, the base isolation scheme is designed. The seismic fortification intensity is 8 degrees, the basic acceleration is 0.2 g, the site category is I1 (mountain area), and the design earthquake group is group I (near earthquake). The building area is about 200m^2. It is planned to adopt 8 new seismic isolation bearings. The total weight of the superstructure is about 136 tons, and the compressive stress of each bearing is about 5 MPa.

4.2. Base Isolation Design

The shear stiffness calculation formula of traditional laminated steel plate rubber isolation bearing is shown in formula (1). Where, G is the shear elastic modulus of the rubber material, a is the area of the rubber plate, and H is the total thickness of the rubber layer. According to the shear modulus of 35 degree natural rubber, the shear stiffness of the new bearing is estimated to be about 0.3 kn / mm [13].

$$K_H = \frac{GA}{h} \tag{1}$$

At this time, the stiffness of the isolation layer is about 2.4 kn / mm, and the isolation period is 1.5 s. According to the response spectrum method, the horizontal seismic action of the isolation layer in small, medium and large earthquakes is about 5.33 kn, 14.83 kn and 29.65 kn. The corresponding shear strain is 49%, 137% and 275% respectively, meeting the relevant requirements that the shear strain of the bearing is less than 300%.

5. Isolation Performance Test of Bearing

5.1. Test Scheme

Combined with MTS actuator and vertical self reaction frame, carry out quasi-static test. According to test method for seismic isolation rubber bearings GB / T 20688.1-2007 [11], the vertical compressive stress is 5 MPa, and the horizontal load is controlled according to the displacement, and the speed is 1 mm / s. In addition, 50%, 150% and 300% shear strains were respectively loaded along the longitudinal and transverse directions. After that, it was loaded 20 times along the transverse grain with 300% shear strain. The device is shown in figure 4.

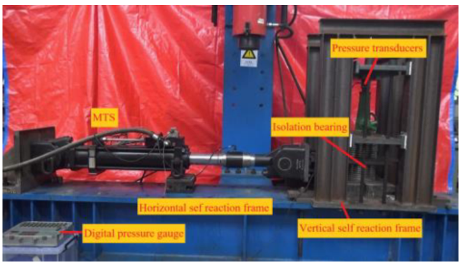


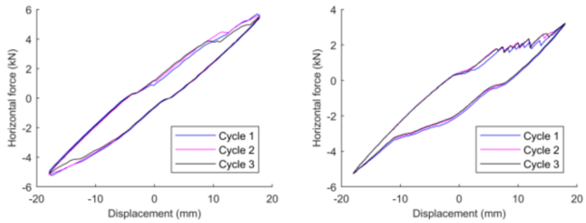
Figure 4. Test device diagram.

5.2. Test Results and Analysis of 50% Shear Strain

The hysteresis curve along the grain is shown in figure 5(a), and the transverse grain is shown in figure 5(b). According to test methods for seismic isolation rubber bearings GB / T 20688.1-2007 [11], the shear stiffness and effective damping obtained by calculation are shown in table 1. The calculation formula is shown in formula (2).

$$K_h = \frac{Q_1 - Q_2}{X_1 - X_2}$$

$$h_{eq} = \frac{2\Delta W}{\pi K_h (X_1 - X_2)^2} \tag{2}$$



(a) Parallel grain (b) Cross grain

Figure 5. Hysteretic curves under small earthquake.

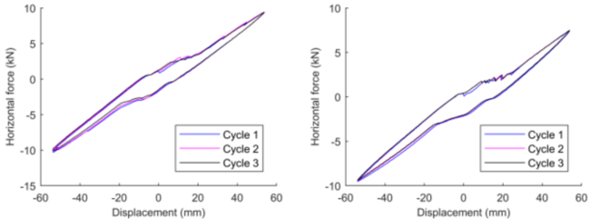
Table 1. Equivalent stiffness and effective damping of bearings under small earthquakes.

Small earthquakes	Equivalent stiffness (kN/mm)	Effective damping ratio
Parallel grain	0.3	4%
Cross grain	0.2	5%

The results show that: (1) the bamboo board is not cracked and the hysteresis curve is stable; (2) The shear stiffness along the grain is about 30% higher than the transverse grain; (3) The effective damping ratio of the bearing along and across the grain is similar.

5.3. Test Results and Analysis of Shear Strain 150%

The hysteresis curve along the grain direction is shown in figure 6(a), and the transverse grain direction is shown in figure 6(b). The calculated shear stiffness and equivalent damping are shown in table 2.



(a) Parallel grain (b) Cross grain

Figure 6. Hysteresis curve under moderate earthquake.

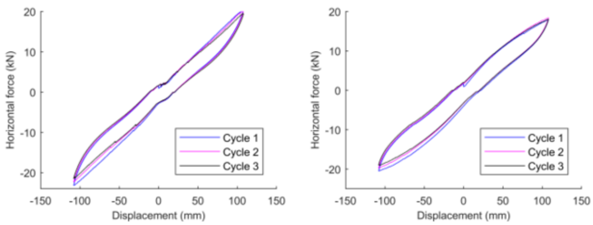
Table 2. Equivalent stiffness and effective damping of bearings under moderate earthquakes.

Moderate earthquakes	Equivalent stiffness (kN/mm)	Effective damping ratio
Parallel grain	0.24	5%
Cross grain	0.20	6%

The test results show that: (1) the shear stiffness of the bearing is reduced by about 20%; (2) the hysteresis curve in each cycle is stable, indicating that the bearing remains intact; (3) The effective damping ratio of the bearing along the longitudinal and transverse directions increases by 1%.

5.4. Test Results and Analysis of Shear Strain of 300%

The hysteresis curve along the grain direction is shown in figure 7(a), and the transverse grain direction is shown in figure 7(b). The calculated shear stiffness and equivalent damping are shown in table 3.



(a) Parallel grain (b) Cross grain

Figure 7. Hysteretic curve under large earthquake.

Table 3. Equivalent stiffness and effective damping of bearings under large earthquakes.

Large earthquakes	Equivalent stiffness (kN/mm)	Effective damping ratio
Parallel grain	0.17	8%
Cross grain	0.18	10%

The test results show that: (1) the shear stiffness of the bearing is only slightly reduced in large earthquakes, which proves that the steel sheet significantly improves the mechanical properties in the transverse direction; (2) The hysteretic curve in each cycle period is basically stable, indicating that the bearing can still carry effectively; (3)

The equivalent damping of the bearing along the longitudinal and transverse directions increases to 8 ~ 10%, which is similar to the high damping bearing.

5.5. Test Results and Analysis of Multiple Effects of Main and Aftershocks

The hysteresis curve obtained by reciprocating loading 20 times at 300% shear strain along the transverse direction is shown in figure 8. The gradual change process of shear stiffness and equivalent damping ratio calculated according to hysteresis loop is shown in figure 9.

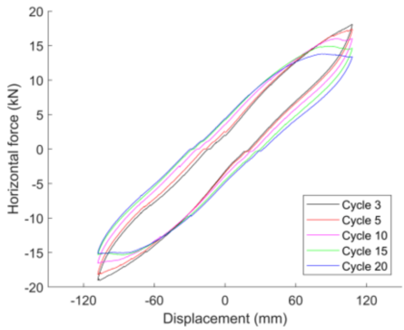


Figure 8. Hysteresis curve at each cycle number.

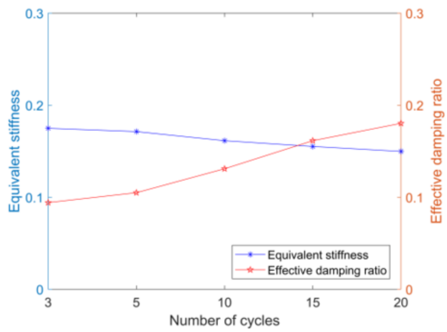


Figure 9. Shear stiffness and damping ratio.

6. Conclusion

(1) When the compressive stress is 5 MPa and the shear stress is 3 MPa, the bamboo board is still intact, and the compressive and shear mechanical properties along the grain and transverse grain are basically the same, meeting the mechanical isotropy;

(2) The equivalent stiffness along the grain is slightly higher than the transverse grain, and the effective damping ratio is close; In the middle earthquake, a few cracks appear in the bamboo slab, the equivalent stiffness decreases and the effective damping ratio increases; There are many cracks in the bamboo slab during the large earthquake. The equivalent stiffness continues to decrease and the effective damping ratio increases to 8% ~ 10%, which is close to the high damping bearing.

(3) With the increase of the number of cycles, the shear stiffness decreases linearly, the area of hysteresis loop increases, the effective damping ratio increases to 20%, the bamboo board cracked in a large area and some steel sheets fell off, but the integrity and mechanical stability were not affected;

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