Study on the mechanical properties and application prospects of the traditional and modern connection of wood structure

Lidan LI 1*, Jianying ZHOU2
1 School of Architecture and Engineering, Kaili University, Kaili, Guizhou, 556011, China
2 School of Architecture and Engineering, Kaili University, Kaili, Guizhou, 556011, China
*Corresponding author’s e-mail: Jiangong@klxy. com

Abstract. Based on the connection status of traditional wood structure nodes in southeast Guizhou, this paper analyzes the structural performance of traditional and modern connection methods of wood structure buildings, and analyzes the mechanical performance and deformation mechanism of the structure through basic traditional wood structure mechanical tests; Analyze the advantages and disadvantages of different connection methods, summarize the improvement ideas of node connection of residential wood structure buildings; compare traditional and modern wood structure systems, analyze the seismic performance of the structure; provide a reasonable reference for wood structure design. Further realize the industrialization and standardization of regional wood structures.

1. Research Background
Wood structure building has a long history in China, and its development process can also be described as long and tortuous. In recent years, wood structure has been fully recovered in our country due to its economical materials, superior seismic resistance, convenient construction, and green environmental protection. The residential buildings in southeast Guizhou have attracted wide attention because of their unique traditional national architectural elements[1]. The traditional tenon-and-mortise connection in China is a unique connection method created by ancient craftsmen. Undoubtedly, its connection performance has been recognized and affirmed by history[2]; with the emergence of many new wood products, most of the modern connection methods originated abroad. Southeast Guizhou is the core place for the preservation of the original ecological cultural heritage of the Miao and Dong nationalities in the world, and the exterior design of traditional houses is very ethnic. The research on regional traditional villages and national architecture began in the 1980s, and mainly focused on the exploration of traditional houses and textual research on the origins of Ganlan and Drum Tower. Since then, scholars have conducted research on traditional villages and ethnic architecture in Southeastern Guizhou in terms of architectural structure, aesthetics, cultural functions, construction techniques, and settlement patterns. With the successful application of modern wood structures in some engineering projects in our country, more industrialized wood structures are also emerging across the country[3]. Many domestic and foreign experts are committed to the research of traditional wood structures and modern wood structure connection methods and structural systems. But these studies are mostly based on the qualitative analysis of the structure, and there are few further quantitative studies. Although wood
structures have a long history in our country, the current wood structure buildings in my country are subject to varying degrees of limitations in height, space, and application fields. This is because the current design theories for various wood structures need to be more improved, which requires us to do more research and exploration on the connection and structure function of traditional and modern wood structures\(^4\).

2. Mechanical properties of traditional connection method of wooden structure

In this experiment, two groups of beam-column component models were made, and node connection was selected as the research object. Among the components, the diameter of the wooden cylinder was 300mm, and the wooden beam was 120*200mm. The connection position of the nodes was staggered in the vertical and horizontal directions. The model diagram is shown in Figure 1 and Figure 2. Carrying out stepwise loading at the loading point, and after integrating the test data, two typical load-deformation curves are obtained. Analyzing the curve data, the following rules can be obtained:

![Figure 1. Model size indication](image1)

![Figure 2. Strain gauge position](image2)

1. Curve 1 has a similar change trend with curve 2, and has experienced the elastic phase, the yield phase and the failure phase successively.
2. In the initial stage of loading, the load and deformation increase roughly in a linear elastic relationship. In the elastic stage, as the load increases, the rate of increase of the beam end deformation is slow.
3. After the elastic phase is over, the force on the beam end reaches its peak value, and then rapidly decreases to a certain value in a roughly linear change and then rises slightly. It shows that the member has entered the yielding stage, at this stage the plastic internal force redistribution occurs at the beam end.
4. After the yield stage, even if the force does not increase or gradually decreases, the beam end deformation still increases at a high rate, indicating that the component has been damaged at this stage.
5. The peak force is 1.04KN in curve 1, but 1.44KN in curve 2. This is due to the difference between the specimen material and the artificial model.
6. In the elastic stage, the slope of curve 1 is greater than that of curve 2, which indicates that the individual mechanical properties of Chinese fir used in curve 1 are higher than curve 2.
7. During the failure stage, the force of model 1 remained stable, and model 2 showed a decreasing trend, and the ratio of deformation of model 1 to deformation at yield (ductility coefficient) was higher than that of model 2, indicating that the ductility of model 1 was higher than that of model 2, the seismic performance is better than model 2.
8. The two models have high structural ductility and strong deformation capacity, which confirms the superior seismic performance of the wooden structure.
3. Comparison and improvement of traditional connection and modern connection

The connection of nodes in wooden structures is very important, not only related to structural strength, stiffness, ductility and effective load transfer, but also affecting the energy consumption of the structure, the standardization of installation, the economy of the structure and the aesthetics of the results.

3.1. Traditional connection and modern connection status

The skeletons of the residential buildings in Southeast Guizhou are mostly connected by buckets, supplemented by wooden dowels. Certain characteristic buildings such as Fengyu Bridge and Drum Tower also use bucket arches and tenon-and-mortise connections. The superior seismic performance of traditional connections has been proven by history. But with the development of industrialization and standardization, this connection method undoubtedly reduces work efficiency. Many beam-column junctions are branched out (Figure 5), and relatively complex joints are difficult to achieve with traditional tenon and tenon joints. Modern connection forms such as bolt connection and nail connection have many advantages such as good toughness, tight connection, safety and reliability\(^5\). The theoretical formula for calculating the bearing capacity is shown in Equation 1. In addition, the wood components can be connected as a whole through steel plates. It can effectively transmit shear force and resist pulling force. Another example is the tooth plate used in light wood structure, which is mainly connected with light wood truss made of specification material, and it can also be used for extension of tension members. In this way, the bearing capacity of the joints can be quantitatively analyzed according to the current design standards, which is a leapfrog relative to traditional connections.

\[
N \leq N_v = n_p n_s V \tag{1}
\]

\(N\)--Design value of axial force of component transmitted by bolt or nail
\(n_p\)--The number of bolts or nails in the connection
\(n_s\)--Number of shear faces of bolts or nails
\(V\)--Design value of bearing capacity on each shear surface of each bolt or nail
In addition, at the connection between the bottom of the column and the foundation, most traditional houses put the upper structure directly on the foundation stone with a flat surface (Figure 6), and there are no other anchoring measures; modern wooden structures use metal connectors to connect the bottom of the column to the foundation stone. This method will greatly improve the house's anti-side displacement stiffness, effective load transfer and integrity. At the connection between the floor and the beams and columns, the traditional houses use rectangular planks of similar size, and use ordinary iron nails to nail the floor and the wooden beams together. This has no effect on the load transmission, but the length of the plank limits the spacing of the wooden beams. The thickness of the board limits the flatness of the floor and the aesthetics of the house; modern wood structure floor slabs are all standard production specifications, and the installation process is standardized, so the above problems do not exist.

3.2. Improvement ideas
According to the above-mentioned connection status of wood structure, the author summarizes the following improvement ideas:

①Optimize the traditional tenon-and-mortise connection form, and realize standardization and standardization of typical beam-column lap joints and other component connection methods from material selection to construction technology.

②According to traditional construction experience, sum up the basis for the cross-sectional dimensions of the main stressed members.

③When necessary, it incorporates the modern wooden structure connection method, but the architecture must conform to the characteristics of the local famous residential buildings, and integrate the traditional and classic ethnic elements into the improved connection method.

④Improve the anti-corrosion and fire-proof properties of the components, and increase the function of the house.
5. Improve the connection between the bottom of the column and the foundation of the traditional structure. Metal connection or other embedded methods can be used to improve the overall working performance of the house's anti-side displacement rigidity.

4. Comparison of traditional and modern wood structure systems

Modern wood structure is a structural form that integrates traditional building materials and modern advanced processing and construction technology. The material is not only natural wood, but also many new wood products such as structural plywood, laminate plywood, and "I" "beams and wooden trusses, etc[7]. Modern wood structures mainly have two structural forms: "beam-column wood structure system" and "light-weight wood structure system". The former is a traditional structural form, which consists of beams and columns with larger spans forming the main force transmission system; The latter is made up of uniformly densely connected specification materials with smaller component sections, and its main structural members and secondary members jointly bear the load[8].

![Figure 9. Modern wood structure connection fasteners](image1)

![Figure 10. Sketch of light timber structure with partial building](image2)

The wooden structure in Southeast Guizhou belongs to a bucket-piercing wooden structure system, that is, the wooden arches are connected between the columns by dense thin columns, the columns are connected by tenon and tenon, and fixed with wooden tips to form a whole, and each column is embedded a purlin[9]. This system is similar to the beam-column structure system, but most residential construction lacks theoretical basis. Instead, it is organized and built by experienced local masters. Practice has proved that the network structure of this system is firm, and the carrying capacity of ordinary two-story residential buildings is basically reliable. However, due to its lack of structural calculation theory, the limitation of building height, the randomness of the construction process, and the aesthetics of the building results have also become obvious problems.

The investigation found that the semi-barreled buildings of the Miao nationality conformed to the basic characteristics of the modern beam-column wooden structure system, while the dry-barreled buildings of the Dong nationality conformed to the basic characteristics of the modern light wood structure system. Therefore, it is possible to incorporate local architectural elements into the structural design according to the "Wood Structure Design Standard" GB50005-2017. On the other hand, with the basis, the production, selection processing and post-processing of structural materials become more standardized.

5. Summary

①The test of the traditional wooden structure node shows that the beam end has experienced the elastic phase, the yield phase and the failure phase.

②The structural ductility coefficients of each group of models are slightly different, but they are all high. When the structure fails, there is a large deformation but none of them collapses. This shows that the structure has large ductility and strong deformation ability, which confirms the superior seismic performance of the wooden structure.
Traditionally connected wooden structures have strong deform ability, but they have disadvantages such as messy nodes, lack of theoretical basis, irregular construction, and poor material corrosion resistance. Therefore, modern connection methods can be appropriately combined with local architectural elements, and new processed building materials can be used to make structural construction more standardized.

Traditional and modern wood structure systems have their own characteristics. The Miao architecture conforms to the basic characteristics of the modern beam-pillar wood structure system, and the Dong architecture conforms to the basic characteristics of the modern light wood structure system. Therefore, the traditional structure system can be further optimized according to modern theory.

From the perspective of ecological benefits, the environmental protection and sustainable development of the construction industry does not allow random selection of materials, and the wood has poor corrosion resistance and fire resistance performance. Special technical treatment is required. Modern wood structure buildings have the advantages of green ecology, good seismic performance, high degree of industrialization, and health and livability. The development of modern wood structures is in line with the national strategy of sustainable development[10].

From the perspective of industrial development, China's modern wood structure research has been relatively complete, with significant progress in materials, components, connections, systems, and durability. Standards and specifications and the entire industry chain are becoming more and more perfect, and engineering applications are increasing year by year. Combining the characteristics of residential buildings and the development trend of prefabricated wood structures, the modern wood structure system may form another green building industry chain, which improves the residential environment pattern and highlights the national elements while bringing considerable economic benefits.

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Corresponding author
Lidian LI, master student, worked in Kaili University as a lecturer and engineer, mainly engaged in geotechnical engineering and structural engineering work.
contact number: 15985503710
E-mail: Jiangong@klxy. Com

The second author introduction
Jianying ZHOU, master student, worked in Kaili University as a lecturer and engineer, mainly engaged in structural engineering work.

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