



Connectivity and Fire-resistant and Durable Renovation of Traditional Wooden Structures in Southeastern Guizhou under the Background of Rural Revitalization

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Abstract: Under the background of the country's comprehensive promotion of rural revitalization strategy and cultural heritage protection, this paper focuses on the residential buildings in southeastern Guizhou, and studies the joint performance of tenon and mortise joints and the optimization of fire resistance and durability. Through on-the-spot investigation and data analysis, it is found that traditional joints are insufficient in strength and seismic performance. As an important carrier of minority culture, traditional villages in southeastern Guizhou face multiple challenges, such as weak fire resistance, insufficient durability of materials and low energy consumption efficiency. Combined with the research status at home and abroad, optimization strategies such as joint reinforcement and material improvement are put forward, and at the same time, the transformation design strategy of "layered intervention and performance coordination" is put forward for fire resistance and durability.

Keyword: Rural revitalization; National architecture; Connection performance; Fireproof and durable; Energy-saving transformation

1. Introduction

The Central Committee of the Communist Party of China and the State Council recently issued the "Plan for Accelerating the Construction of a Powerful Agricultural Country (2024-2035)", which made a phased goal plan for rural revitalization. In the past three years, the goal was to achieve substantial progress in the overall rural revitalization, and in the past decade, decisive progress should be made, rural revitalization and agricultural and rural modernization should be fully realized [1].

2. The relationship between rural revitalization and national architecture

National architecture is an important carrier of national culture, bearing rich history, folk customs and regional culture. The rural revitalization strategy emphasizes the protection and inheritance of national culture, and the protection and restoration of national buildings is the key link. Ethnic architecture can become the new engine of rural development. By developing rural tourism, ethnic architecture can be transformed into economic resources, attracting tourists to visit and experience, thus driving local economic development. Some Dong villages in southeastern Guizhou have taken the lead in launching the first shot of combining architecture with rural tourism, which not only increases villagers' income, but also responds to the call of national rural comprehensive revitalization. The relationship between rural revitalization and national architecture complements each other. National architecture is not only the carrier of rural culture, but also the resource of rural economic development, and it is also a model of rural ecological construction. Through scientific planning, rational utilization and policy support, national architecture can play a greater role in rural revitalization and achieve a win-win situation in cultural inheritance, economic development, ecological construction and national unity.

3. Analysis of joint connection performance and fire resistance and durability of ethnic buildings in Qiandongnan

In southeastern Guizhou, bucket-type wood structure is the main feature, and tenon-mortise joint connection is its core feature, that is, wood members can be closely connected without nails by embedding their concave and convex parts. This connection not only makes the structure stable, but also can effectively resist some natural disasters, which reflects the wisdom of ancient craftsmen.

The joints in wood structure are related to the strength, stiffness, ductility and effective load transfer of the structure,

and also affect the energy consumption, standardization of installation, economy of the structure and aesthetics of the results. The bearing capacity of tenon-mortise joints mainly depends on the strength of wood and the processing accuracy of tenon-mortise. However, the humid climate in southeastern Guizhou and the use of unprocessed logs will also affect the strength and durability of materials, and wood will be easily affected by moths and decay. Liu Chengyang and others [2] used AB-AQUS finite element analysis software to conduct numerical simulation and analysis of the seismic performance of various mortise-tenon joint types. The results show that the straight-tenon-through-tenon joints have strong bending bearing capacity and good energy dissipation capacity, but the stiffness degradation is serious. Semi-tenon joints have poor flexural bearing capacity, but the stiffness degradation is weak (Figure 1); The stepped half-tenon joint has the strongest energy dissipation capacity (Figure 2), while the straight half-tenon joint is weak (Figure 3). The amazing seismic performance of the traditional connection method has been proved by history [3]. Under the influence of extreme weather, the Dong Drum Tower collapsed in southeastern Guizhou, causing casualties and other cases. In fact, in recent years, due to the influence of extreme weather or rare wind load, a number of wooden structures, including wind and rain bridges, have been damaged to varying degrees or even collapsed in southeastern Guizhou, which has a great impact on people's life and health and property safety. Therefore, it is particularly important to study the joint connection and stability of wooden structures in southeastern Guizhou.

The problem of fire prevention and durability of wooden structures in traditional villages in southeastern Guizhou presents a deep tension between traditional wisdom and modern demand. The survival of local "fire pond culture" makes the frequency of indoor open flames higher than that of modern houses [4]. The durability crisis is characterized by the coupling decline of biodegradation and mechanical properties. The fungal erosion rate at the base of the column without anticorrosion treatment reaches 2.3mm per year, and its failure mechanism changes from simple fiber degradation to stress cracking caused by moisture content fluctuation, and fire prevention and durability have formed an interactive influence. Treating wooden structures as "living heritage" rather than static cultural relics means that the dynamic balance between material life cycle and functional requirements must be recognized. In villages lacking modern fire-fighting facilities, it may be more culturally adaptable to re-evaluate the fire-fighting spacing standard of "Zhaihutang" layout than to force the installation of smoke detectors.

4. Current situation of node optimization research

4.1 Domestic development status quo

Based on the above, in recent years, domestic scholars have made extensive research on the mechanical properties and strengthening methods of wood structure joints, and made remarkable progress. The following is an analysis of the specific research status: Liang Xu et al. [5] carried out quasi-static tests on 9 unreinforced and 33 reinforced wooden joints in order to study their seismic performance. The results show that, except for the steel members with triangular stiffeners, the seismic performance of mortise-tenon joints in wood structures can be improved effectively by other steel members, and the seismic performance of pine straight mortise joints strengthened with the same steel members is better than that of pine semi-mortise joints and Chinese fir straight mortise joints. However, this method only considers the tenon-mortise joint reinforcement of the reinforced wood structure, and has not studied the overall performance and overall reinforcement benefit of the wood structure. Xie Qifang et al. [6] made three scale models of second-class wooden frames made according to the Building Method, and carried out experimental research under horizontal low cyclic loading. The results show that although the strength and stiffness of the wood frame strengthened with carbon fiber sheet and flat steel have increased, its energy consumption capacity has also decreased. Flat steel reinforcement is suitable for tenon-mortise joints with obvious insufficient strength or stiffness, while carbon fiber sheet reinforcement is more suitable for tenon-mortise joints with less damage. Moreover, the reinforcement of flat steel increases the stiffness of tenon-mortise joint, which makes it subjected to greater earthquake action, so the amount of flat steel remains to be studied. It is worth noting that the excellent deformation performance of the wooden frame connected by tenon-mortise joints has also been confirmed. Based on the mechanical model of straight tenon joints, Pan Yi et al. [7] took the Emperor's Hall in Qingchengshan, which was injured in Wenchuan earthquake, as an example, and strengthened its tenon-mortise joints with flat steel and dampers respectively. Through finite element simulation, the natural vibration period of the structure before and after strengthening, the acceleration amplification factor of the node and the internal force of the adjacent members of the strengthened node are compared and analyzed. The results show that both flat steel and dampers can improve the seismic performance of the structure. Strengthening with dampers can increase the damping and natural vibration period of the structure, reduce the seismic response of the structure without increasing the stiffness of the joints, and play a role in energy consumption and preventing tenon from being pulled out. However, flat steel increases the stiffness of joints and the internal force of some adjacent members, which is easy to cause tenon failure of adjacent joints.

4.2 Present situation of foreign development

There are also many wooden structures abroad, but they are different from the traditional bucket-piercing and beam-lifting structures in China, mostly in light wood frame construction. Nickolay et al. made a composite material for wood structure reinforcement [8]. The experimental results show that the strength of the composite reaches 95% of the calculated value 60 days after the surface of the structure begins to cure. This method has a good reinforcement effect on the surface of wood members, but it does not consider the reinforcement of tenon-mortise joints and other parts. Yeboah, Gkantou and others set up 20 models of rectangular cross-section wood beams with the size of 70×215mm, and used glass and basalt FRP bars to reinforce the wood beams [9], and carried out quasi-static monotonic loading tests through displacement control. The results show that the ultimate load and bending stiffness of wood beams have been significantly improved. Triantafillou and others studied the shear performance of wood beams strengthened with FRP, and put forward the formula of shear bearing capacity of wood beams strengthened with FRP [10]. The experimental results of shear strengthening with U-shaped FRP show that FRP can obviously improve the shear performance of wood beams, and the experimental results are basically consistent with the calculated results. Francisco J et al. strengthened the wood beam of *Pinus sylvestris* var. *mongolica* with natural defects (such as nodules, cracks and wear) with carbon fiber composite material (CFRP), and bonded the CFRP to the tensile side of the wood beam with epoxy resin, and set up an unreinforced specimen for a comparative test [11]. The results show that the reinforced specimen has better mechanical properties, and the flexural bearing capacity of the reinforced specimen is improved by 88%. The methods proposed in the above three studies have good reinforcement effect on wood beams, but the reinforcement of tenon-mortise joints and other parts is not considered.

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To sum up, no matter domestic or foreign research, the research results of wood structure repair and reinforcement are very rich, and the proposed reinforcement methods are numerous and the system is complicated. Some of these methods have mature skills and simple materials, and have many years of practical engineering experience. However, there are many studies on the optimization of wood structure connection joints in China, but there are basically no studies abroad. However, in general, these technologies or construction have some shortcomings, such as great disturbance to the structure, time-consuming construction or high construction cost. In addition, most of these reinforcement methods are aimed at different parts of the wood structure, and there are few studies on the overall reinforcement of the wood structure, especially on the overall reinforcement of the bucket wood structure.

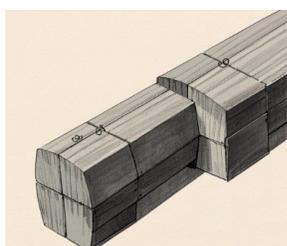


Figure 1. Semi-tenon joint



Figure 2. Step-type semi-tenon joint

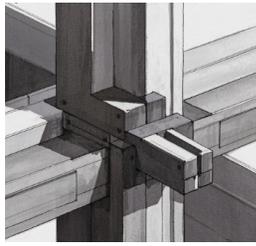


Figure 3. Straight half tenon joint



Figure 4. U-shaped steel plate reinforced joints

5. Structural optimization scheme and fire-proof, durable and energy-saving lifting technology

According to the research results of researchers at home and abroad, combined with the current situation of wooden buildings in southeast Guizhou, the author summarizes some optimization schemes. Qiandongnan ethnic architecture is famous for its unique tenon-mortise structure, but it is faced with the optimization demand of joint connection performance in modern use. The following is the optimization scheme from the connection node:

5.1 Optimization of traditional tenon-mortise joints

First of all, the size and fit can be optimized. The mechanical properties of tenon-mortise joints are closely related to the dimensions and fitting accuracy of tenon and mortise. The research shows that the length of tenon should be 1~2 times of the width to improve the bearing capacity and uplift resistance of joints. In the process of design and repair, the machining accuracy of tenon-mortise should be strictly controlled to ensure the close fitting of tenon and mortise. Secondly, scientific selection and treatment of wood. Wood density has a significant effect on the mechanical properties of tenon-mortise joints. High-density wood has better bearing capacity and deformation resistance. When selecting wood, high-density wood, such as Chinese fir or pine, should be given priority and properly dried to reduce joint looseness caused by wood shrinkage and wet expansion. Then improve the mechanical properties of the interface. The interface mechanical properties of tenon-mortise joints are the key factors affecting their overall performance. By improving the interface contact force of tenon-mortise joints, the bearing capacity and durability of joints can be effectively improved. For example, modified wood or new adhesives are used to enhance the friction coefficient and bonding strength of the interface.

5.2 Application of modern reinforcement technology

Traditional metal connectors can effectively improve the bearing capacity and stiffness of tenon-mortise joints, but may reduce the energy consumption capacity of joints. In modern reinforcement, new metal connectors can be used, such as U-shaped steel plate (Figure 4) and self-tapping screws (STS), which are convenient to install and can significantly improve the bearing capacity and stiffness of the joint. Fiber composite materials (such as carbon fiber cloth) have the advantages of high specific strength and corrosion resistance, and are suitable for strengthening tenon-mortise joints. The research shows that the tenon-mortise joint strengthened with carbon fiber sheet has a significant improvement in bearing capacity and energy consumption capacity. This reinforcement method is especially suitable for wood members with less damage. Embedding energy dissipators in mortise-tenon joints can effectively improve the seismic performance of joints. The research shows that mortise-tenon joint with embedded energy dissipator has bidirectional energy dissipation, multi-point yield and strong design, which can significantly improve the initial stiffness and energy dissipation capacity of the joint.

5.3 Fire-proof, durable and energy-saving lifting technology

In the exploration of the fire prevention path of a piece of wood structure, the research and development of fire prevention technology has turned to structural-material cooperative protection, such as embedding expandable fire prevention adhesive strips in the joints of beams and columns and tenons, and sealing the air passage by thermal expansion to improve its fire resistance limit. The improvement of durability needs to break through the dual constraints of material degradation and biological erosion, and this cognition has shifted from simple anti-corrosion treatment to coordinated regulation of material and environment, such as transforming the overhead floor of traditional dry-fence buildings into controllable airflow channels, and determining the optimal ventilation area ratio through computational fluid dynamics simulation; For example, optical fiber sensors are embedded in key load-bearing components, and deformation early warning is realized through strain-temperature coupling algorithm; Another example is grafting hydrophobic modifier from molecular level, optimizing the stress field of component scale, adjusting the microclimate of the whole building, and increasing the weather resistance

of wood structure. In energy-saving transformation, it is necessary to overcome the bottleneck of passive adaptation to active regulation, enhance the coordination between materials and fire prevention, and improve energy-saving efficiency by pouring paraffin-expanded graphite composite materials into structural materials and reducing solar radiation heat. The above can be summarized as the transformation design strategy of “layered intervention and performance coordination”.

5.4 Suggestions for the implementation of the optimization scheme

The optimization of mechanical properties of tenon-mortise joints should be fully considered when repairing and building new ethnic buildings. Through scientific planning and design, reasonable selection of wood, optimization of tenon and mortise size and matching accuracy, and combined with modern reinforcement technology, the bearing capacity and durability of joints are ensured. On the basis of retaining the traditional tenon-mortise structure, modern reinforcement technology and materials are introduced to realize the organic combination of traditional technology and modern technology. For example, modern energy dissipators are embedded in mortise and tenon joints or reinforced with fiber composite materials. The mortise and tenon joints of national buildings need regular maintenance and monitoring to ensure their long-term stability and safety. By regularly checking the looseness of nodes, the shrinkage and swelling of wood and the performance of reinforcements, timely repair and adjustment can be made. Of course, traditional national architecture carries not only the wisdom of the ancients, but also the beliefs of modern residents. The author believes that the original style of the building should be preserved as much as possible, and the modern joint connection performance, structural optimization and fire prevention and energy saving transformation should be carried out while preserving the original wisdom.

6. Conclusion

Overall, the optimization of the connection performance of the ethnic wooden structures in Qiandongnan requires a comprehensive consideration of planning and design, material selection, size optimization, and processing technology. In terms of fire resistance, in fact, fireproof coatings and new composite materials have emerged. Even local researchers have conducted intelligent analysis of video content and utilized image processing and deep learning methods. This enables real-time online recognition of fire smoke alarms and has a certain application foundation.

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