Research on Mortise Nodes of Flat Steel, Carbon Fiber Reinforced Repair Method of Huizhou Ancient Residential Renovation

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Abstract. Huizhou ancient residential flat carbon fiber cloth mortice and tenon joints, repair and reinforcement design method is one of the hot spots in the present study of ancient architecture. According to the data collection and field research and then combined with the research on reinforcement repair method of ancient houses of Huizhou state mortice and tenon joints procedures, analysis of Huizhou ancient dwellings mortice and tenon joints forms of damage, summarizes the Huizhou ancient dwellings mortise and tenon joints the ability to check formula, and the Huizhou ancient residential flat mortice and tenon joints using the finite element method, the carbon fiber cloth reinforcement method is analyzed by numerical simulation. The study shows that by node force performance before and after the reinforcement of mortise and tenon mortise and tenon contrast, mechanical properties of the reinforced joints is improved obviously; damaged ancient dwellings mortise and tenon nodes through flat steel, carbon fiber cloth etc. a method for stabilizing after the renovation is meet the requirements of the standard. Based on the comparison of theoretical calculation and numerical analysis of the mortise and tenon joints of Huizhou ancient residential buildings, the calculation results are consistent, which verifies the feasibility of the flat steel and carbon fiber cloth reinforcement and repair design method, To provide reference for the restoration and protection of Liang Fang in Huizhou traditional architecture.

1. Introduction
Huizhou ancient houses have rich historical significance and value in Huizhou architecture, but with the passage of time, due to the influence of natural and human factors, a large number of ancient buildings in Huizhou have suffered serious damage to the internal and external structures. Huizhou ancient buildings take certain measures to reinforce and repair, especially the connection and reinforcement of the ancient houses with tenon joints play an important role in the repair of the overall structure of ancient buildings, and the overall stability of the ancient tenement joints of the ancient houses in Huizhou determines the safety of ancient buildings in Huizhou The key. In the actual project, many traditional Huizhou buildings have been damaged seriously, which proves that it is necessary to study the method of strengthening and repairing Huizhou traditional buildings. At present, some experts and scholars at home and abroad have carried out the tenon joints of ancient Huizhou residential houses. Research; Zhao Hongtie [1] conducted a series of experimental studies based on the scale of the second-class material hall-style frame. Among them, during the analysis of the tenon joints of the wooden frame, the energy dissipation capacity and dovetail joints were mainly analyzed. The principle and comparative analysis before and after the reinforcement of flat steel and carbon fiber. Zhao Junhai, Xu Qiwen and other scholars [2] ~ [6] also made relevant research on the reinforcement and repair of the mortise and tenon joints of Huizhou ancient houses, and Lan. Smith [7] on the
wooden frame. The tenon and mortise joints are discussed, and their mechanical properties are analyzed to obtain the overall stability and stiffness matrix of this wooden structure. Antonio Borri [8] conducted an experimental study on the flexural performance of wooden beams strengthened with CFRP cloth, combined with national regulations [9] and Code [10] further study the wooden construction industry. From the domestic and foreign research literatures, it can be seen that there are few studies on the research and application of Huizhou traditional building wooden structure reinforcement and repair design methods [11] In this paper, through the research on the repair method of the flat steel and carbon fiber cloth of the tenon joints of the ancient residential houses in Huizhou, the calculation formula of the bearing capacity of the tenon joints of the ancient residential houses of Huizhou is summarized, and the flat steel and the carbon fiber cloth of the joints of the ancient residential houses of Huizhou are reinforced by numerical analysis. The study of the method is of great significance to the repair and reinforcement of the tenon joints of Huizhou ancient houses and the inheritance of traditional buildings in Huizhou.

2. Repair and reinforcement method of mortise and tenon joints of ancient residential houses in Huizhou

There are two main reasons for the damage of traditional buildings in Huizhou: First, the destruction of straight tenon joints. The ancient buildings located in the southern Anhui area are affected by their regional climate, and their straight tenon joints are very susceptible to moisture and corrosion, and they are cracked and tenoned. The main form of damage is very common. Second, the destruction of the dovetail joint. Under normal circumstances, the dovetail can only allow the vertical movement of the tenon in the vertical direction, which can restrict the freedom of the tenon width and the depth of the tenon. When the bending moment acts, because the cross-sectional area of other parts is larger than the tenon neck, the edge fibers at the base of the tenon neck are more likely to be damaged. In view of the above reasons that caused the damage of the mortise and tenon joints of Huizhou ancient residences, this article summarizes The tenon joint reinforcement methods are: the flat steel and carbon fiber cloth reinforcement methods of the mortise and tenon joints in Huizhou ancient residences.

2.1. Principles of repair and reinforcement of mortise and tenon joints of ancient residential houses in Huizhou

Ancient residential architecture is a gem that interprets history, reflects building culture of a specific period, and civilization of dynasties. Its rich structural content can convey important information and materials to us. Cultural heritage always follows the principle of not changing the original state of cultural relics. The Technical Specification for Maintenance and Reinforcement came into being, and the theme of the original state of the building cannot be changed during the maintenance and renovation of ancient residential buildings. The reinforcement and protection work cannot change the nature and principles of the existing building body of the wooden pillar, which will cause damage to the building. The mortise and tenon joints of Huizhou ancient houses are reinforced and repaired by flat steel and carbon fiber cloth, etc., so that the mortise and tenon joints of Huizhou ancient houses are restored to the state when they were healthy, and the safety of Huizhou traditional buildings is normally used.

2.2. The tenon joints of ancient residential houses in Huizhou are reinforced with flat steel and carbon fiber cloth

The main failure modes of the wooden frame mortise and tenon joints common to traditional buildings in Huizhou include falling off of the tenon, breakage and groove decay. Most of these damages are caused by the humidity of the environment and the load of the components. For the tenon joints, there are mainly several typical damage forms, which are not only common in the wooden beams of ancient buildings in the Huizhou area, but also exist in other areas.

The reinforcement method of mortise and tenon joint carbon fiber cloth in huizhou ancient folk houses
3. Checking calculation of bearing capacity of mortise and tenon joints of ancient residential houses in Huizhou

3.1. Force analysis:
In actual engineering, the tenon often breaks, grooves, and pulls out. When the tenon fails, the tenon is compressed at the joint of the tenon, and then generates a rotational displacement. The schematic diagram of the force of the tenon joint performs analysis. As shown in Figure 3.

It can be seen from the schematic diagram of the force on the tenon joints that the compressive stress $f_n$ and the frictional force $f$ will occur where the tenon joint and the column overlap. The compressive stress and friction force are $F_{N1}$, $F_{N2}$ with $F_1$, $F_2$. The squeezing force and friction force are also generated at the tenon. The side of the tenon and the column squeezing each other will also generate pressure and friction. When the critical bending moment is reached, the node starts to rotate.

3.2. The calculation formula of the mortise joint of Huizhou ancient residence:
According to the elastoplastic mechanics and structural mechanics, the equivalent calculation formula is deduced:

$$M = 13.812\theta + 0.348 \quad \theta \in \left[0, 0.0829\right]$$  \hspace{1cm} (1)

The calculation of equation (1) called the equivalent balance equation is much simpler, but the formula does not take into account the dimensional damage caused by factors such as wood aging and damage to the tenon and other factors. There are influential factors. So we need to multiply it by a correction factor to be more objective and true to the actual calculation formula:

$$M = \alpha \times \beta \times \gamma \times 13.812\theta + \alpha \times \beta \times \gamma \times 0.348 \quad \theta \in \left[0, 0.0829\right]$$ \hspace{1cm} (2)

In the formula: $\alpha$ A correction factor of the pressure strength of the wood horizontal grain (considered by the full surface pressure); $\beta$ A tenon and mortise size correction factor,
A tenon-and-mortise joint corner (rad);
\( \gamma \) A wooden frame tenon joint reduction factor ([0,1]);
\( \gamma' \) A wooden frame mortise and tenon joint performance reduction index ([0,1]);

When the tenon joint rotates to the maximum \( \theta = \theta_u \), the simplified calculation formula of the bearing capacity of the tenon joint of the ancient wooden house with wooden frame:

\[
M_u^0 = 1.145\alpha \cdot \beta \cdot \gamma + \alpha \cdot \beta \cdot \lambda \cdot 0.348
\]  
(3)

In the formula \( \alpha, \beta, \gamma, \gamma' \) Meaning and value and (2) the same.

From the force analysis and bearing capacity calculation of the tenon joints, it can be seen that the bearing capacity of the tenon and tenon joints is greatly improved by the reinforcement of carbon fiber and flat steel, and the bearing capacity improvement after flat steel reinforcement is more obvious than that after carbon fiber cloth reinforcement. In order to further verify the rationality of the bearing capacity calculation model we gave above, next, the article will also carry out the simulation experiments of the joints of the tenon and mortise structure of the ancient residential buildings, and compare the experimental data with the theoretical results to observe whether the two are consistent.

4. Numerical analysis of mortise and tenon joints in Huizhou ancient houses

4.1. Calculation parameters

This article uses a Huizhou traditional dwelling as an example, and the finite element software analysis takes the straight tenon of the single-span wooden frame as the calculation model. The dimensions of the components are shown in Table 1, and the schematic diagram of the wooden frame is shown in Figure 3.

| Artifacts | Section size mm×mm | The length of the |
|-----------|--------------------|-----------------|
| Beam      | 270×450            | 4500            |
| A joint   | 90×450             | 270             |
| Column    | Φ300               | 3600            |

Figure 3. Sketch of bottom frame structure

The calculation model is divided from the shape of the column, which is divided into a cylinder and a square column. The dimensions of the cylinder and the square column have been given in the calculation model. Regarding the selection of material elements, the selection of the beam in ANSYS is the mapping mesh division, the hexahedral mesh, the element type is solid185, the column is a free mesh, the tetrahedral mesh, the element type is solid187.
4.2. Structural calculation conditions
1) Working condition one: According to the above parameters, the first model is established, that is, the single-span wooden frame model of the Huizhou ancient dwellings in the unreinforced state, as shown in Figure 4.

2) Working condition 2: The second model is established based on the same parameters as the first, that is, the single-span wooden frame type of Huizhou ancient houses under the reinforcement of flat steel, as shown in Figure 5.

3) Working condition 3: The second model is established based on the same parameters as the first, that is, the single-span timber frame type of Huizhou ancient houses under the state of carbon fiber reinforcement, as shown in Figure 6.

![Figure 4. Beam stress nephogram](image1)
![Figure 5. Nephogram of stress cloud of flat steel](image2)
![Figure 6. CFPR stress nephogram](image3)

4.3. Comparison of numerical analysis and formula check calculation before and after the tenon joints of ancient residential houses in Huizhou

Through numerical analysis of the mortise and tenon joints of the ancient residential houses in Huizhou before and after reinforcement, it can be concluded that the stress analysis results of Liang Fang under different working conditions are shown in Table 2 below.

![Table 2. under different working conditions of liang fang force analysis contrast table](image4)

| Displacement/stress Working condition | Working condition of a | Condition 2 | Working condition of the three |
|--------------------------------------|------------------------|-------------|-------------------------------|
| Beam beam mid-span deflection (mm)   | 147                    | 128         | 129                           |
| Longitudinal displacement of beam beam (mm) | 23 | 20 | 20 |
| at the lower surface tenon          | -16                    | -14         | -14                           |
| Beam beam XY shear stress (Mpa)     | -3                     | -2          | -2                            |
| at the lower surface tenon          | 2                      | 2           | 2                             |
| Beam beam YZ shear stress (Mpa)     | -11                    | -8          | -9                            |
| Right surface tenon                 | 2                      | 8           | 9                             |
| Beam beam XZ shear stress (Mpa)     | -3                     | -2          | -3                            |
| Right surface tenon                 | 2                      | 2           | 2                             |
| Maximum stress at the joint (Mpa)   | 33                     | 26          | 29                            |

The numerical analysis and comparison of the mortise and tenon joints of ancient residential houses in Huizhou are summarized as follows:
(1) Through numerical comparison and analysis of unreinforced tenon joints, flat steel and carbon fiber cloth reinforced tenon joints, it can be concluded that after the wooden frame tenon joints are reinforced by flat steel and carbon fiber cloth, the mid-span deflection of Liangfang is reduced. The longitudinal displacement of the tenon neck position before and after reinforcement has a tendency to pull out the tenon. However, after being reinforced with flat steel and carbon fiber cloth, the longitudinal displacement of the tenon has been greatly reduced, indicating the prevention effect of the tenon extraction after reinforcement. Obviously. Through the analysis of stress diagrams in all directions, it can be seen that the tenon neck is the weakest part, which is prone to broken tenon. Through the comparative analysis of the mechanics after reinforcement with flat steel and carbon fiber and when it is not reinforced, the stress at the tenon joint is reduced. It shows that the flat steel reinforcement effectively improves the structural load-bearing capacity.

(2) By comparing the numerical simulation force analysis of the tenon joint reinforced by the carbon fiber cloth and the flat steel reinforced tenon joint, the force analysis and theoretical calculation of the tenon and tenon joints before and after reinforcement can be obtained, and it can be seen that the flat steel and the carbon fiber cloth The wooden frame reinforcement of ancient houses is effective. At the same time, the reinforcement of the wooden joints and tenon joints of ancient residential buildings with flat steel is more obvious than that of the carbon fiber reinforced ancient joints. It works.

5. Conclusion
This article has conducted in-depth research and analysis on the method of picking and enlarging and reinforcing wood pillars in Huizhou traditional architecture, and further demonstrated the reinforcement methods such as picking and enlarging and reinforcing wood pillars in Huizhou traditional architecture, and summarized the following conclusions and suggestions:

(1) On the basis of consulting a large number of documents and materials, the structure and structural characteristics of Huizhou traditional dwellings are explained: Huizhou traditional dwellings have obvious regional characteristics, which are divided into beam-lifting structure, bucket-type structure, and hybrid structure. Bucket structure.

(2) Through on-site investigation and data review, the basic forms and damage reasons of the wooden frame tenon joints of Huizhou ancient houses were clarified, and the design methods for the reinforcement and repair of the tenon joints of Huizhou ancient houses were summarized.

(3) Summarized the calculation formula of the bearing capacity of the tenon joints. By calculating the bearing capacity of the tenon joints before and after reinforcement, and comparing and analyzing the bearing capacity before and after reinforcement, it was found that the bearing capacity was significantly improved after reinforcement, and the ratio of the bearing capacity after flat steel reinforcement was improved. After being reinforced by carbon fiber cloth, the lifting effect is large, so the reinforcement effect of flat steel is better than that of carbon fiber cloth.

(4) The finite element software was used to numerically analyze the wooden frame of the ancient residence, and the rationality of the reinforcement method was verified according to whether the bearing capacity was improved before and after the reinforcement, and whether the reinforcement effect reached the requirements was determined. Through analysis and comparison, the two conclusions are the same, which verifies the feasibility of the design method of the reinforced and repaired wooden frame mortise and tenon joints of Huizhou traditional buildings, and provides a reference for the future reinforcement of Huizhou ancient houses.

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