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Detection and Evaluation of a Migrated Timber Structure House

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Abstract

This article takes the inspection and appraisal of a certain migratory wooden structure as the backdrop, presents the inspection process of the wooden structure. Upon on-site examination, it was discovered that the connection (or node) construction mode of the building was correct. Only local surface flaws were present, and the operation was normal. The stress wave velocity of the randomly inspected wooden columns with surface cracking was close to the critical velocity, suggesting that no obvious cavities or decay defects existed within the measured wooden components. Based on the inspection outcomes, finite element computations were carried out for the wooden structure, arriving at the conclusion that the maximum stress value of the wooden members was smaller than the designed value of wood strength, and the vertical bearing capacity conformed to the requirements of the specifications. And rationally offered relevant treatment suggestions, providing a reference for the inspection and identification of such projects.

Keywords

Wooden Structure, Stress Wave Inspection, Structural Appraisal

1. Introduction

The wood structure was the principal structural form employed in ancient Chinese architecture, bearing witness to the historical information of ancient Chinese buildings. In recent years, as people's awareness of protecting historical buildings has been continuously increasing, the number of wood structure relocation projects has also been growing. How to conduct the identification and maintenance of the relocated wood structures has become a significant subject. This paper, taking the detection and identification of a certain migrated wood structure as the background, elaborates in detail on the detection process and the calculation of the bearing capacity of the migrated wood structure [1]-[3].

2. Project Overview and Research Purposes

2.1. Project Overview

A certain migrated wooden structure has one floor above ground, with a floor area of 111.56 square meters. It was constructed in the distant past. This project involves the relocation of an ancestral hall with a wooden structure. The original building was a wooden ancestral hall with three bays and a covered walkway. The existing wooden structural components are largely intact. Due to usage requirements and architectural effects, a covered walkway was added to the north façade after the relocation, and new wooden partition doors were fabricated along the style of the south façade on the cornice columns.

When the building's purpose or usage environment changes, structural inspection should be carried out. Moreover, considering that the building has been in use for a considerable period after the assembly of its main structure was completed, in order to understand the current actual bearing capacity of this structure, guarantee the safety of personnel and property, and meet the safety requirements for building usage, a detection and identification assessment is conducted [4] [5].

2.2. Research Purposes

Through on-site inspection, testing and load-bearing capacity verification of the wood structural members in this project, the defect conditions and safety status of the wood members were obtained, providing a reference basis for the overall thinking and methods of other similar wood structure appraisal projects [6].

3. Field Survey

3.1. Investigation of Building Structures

This building is of long standing, and no archival materials have been collected. During the relocation phase, the responsible management unit commissioned the design unit to undertake the relocation design, and the architectural drawings of this phase were retained intact. On-site investigations and consultations were carried out with the responsible management unit, the surrounding people and relevant individuals. The usage environment of this building is free from environmental factors such as vibration, corrosion and high temperature, and the building has not encountered accidental loads such as fire and explosion since its relocation.

3.2. Verification of Structural Layout

The house is a one-story wooden structure with a rectangular plan, double-sloped roof, and a total length of about 12.1 meters in the north-south direction and a total width of about 9.0 meters in the east-west direction. The eaves height is about 5.4 meters. The house is a traditional raised-beam wooden structure with a total of 3 facades, each measuring 3.7 meters in width. The depth is 4.5 meters, and the height is 1.65 meters. Round wooden pillars with a diameter of 230 mm are used, and round wooden beams with a diameter of 370 mm are used. The hip rafter pillars are rectangular wooden pillars with a cross-sectional size of 150 mm × 100 mm. The floor plan of the building is shown in **Figure 1**, and the elevation plan of the wooden structure is shown in **Figure 2**.

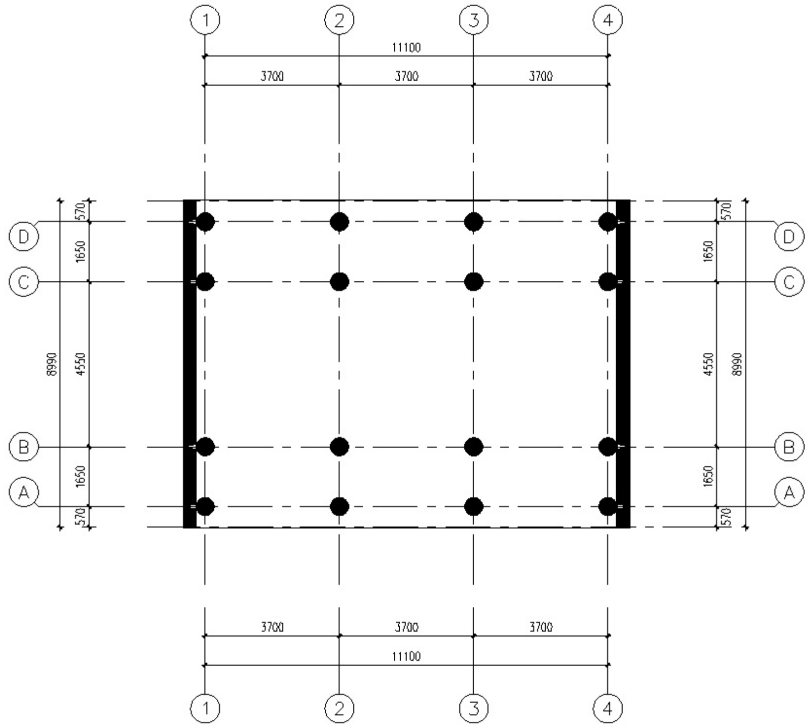

Figure 1. Architectural floor plan of the project (Dimensions are all in millimeters).

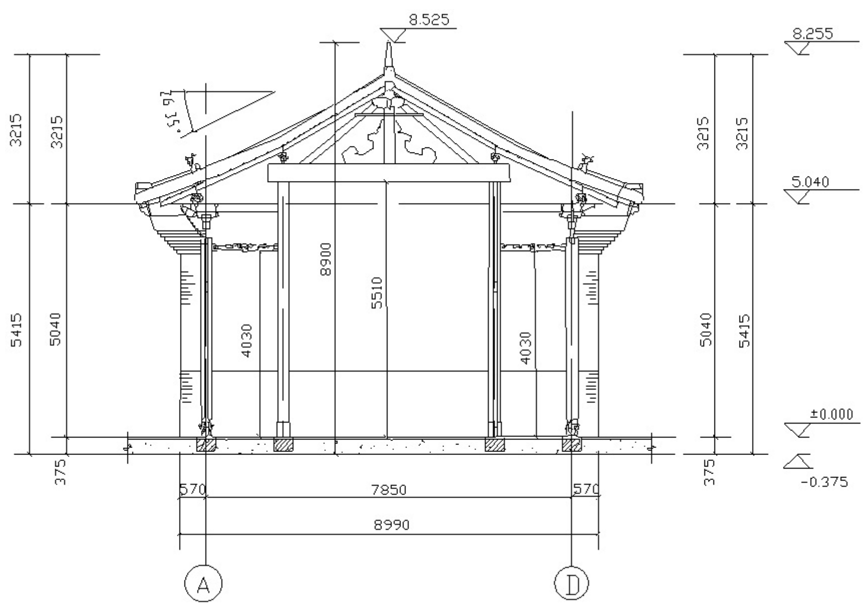

Figure 2. Elevation of the wooden structure of the building (Dimensions are all in millimeters).

4. Visual Quality Inspection

4.1. Foundation and Substructure Inspection

During the on-site detection, no obvious cracking or slipping of the superstructure caused by foundation deformation was observed. The building foundation and substructure have no static load defects and are basically in good condition.

4.2. Inspection of the Upper Load-Bearing Structures

This structure is of wood construction, and the materials of the wooden components are mostly Larix principis-rupprechtii or Pinus tabuliformis. Traditional mortise and tenon joints are widely adopted among the wooden components.

The conditions of appearance defects of the components were examined through means such as visual inspection, tapping, and dimensional measurement. The exterior wall tiles of the building are relatively intact, and no phenomena of wall weathering or plaster layer cracking were discovered. The roof rafters are relatively well preserved, with local dry shrinkage cracks. The roof trusses show no sagging, inclination, tenon dislocation, sliding, or out-of-plane bending. The nodes of the wooden components have no obvious loosening or tenon pulling, the wooden frame has no obvious inclination or deflection, and the wooden columns show no obvious deterioration or insect damage. During the on-site inspection, cracking was found on the surface of the round wooden columns, and the severely cracked areas have been reinforced with flat steel hoops [7].

4.3. Investigation on Structural Integrity, Nodes and Connections

Through on-site actual investigation and inspection, it was found that the connection (or node) construction of this building is correct, with only local surface defects and no abnormal operation.

5. Detection of Internal Defects in Wooden Components by Stress Wave

5.1. The Mechanism of Stress Wave Detection for Internal Defects in Wooden Components

The detection of internal defects in wooden components necessitates the utilization of a stress wave detector. Based on the detection outcomes, it is determined whether there exist defects like decay, cavities, and cracks within the cross-section of the tested wooden component.

The FAKOPP stress wave measuring instrument (Microsecond Timer) manufactured by a company in Hungary is adopted. During the measurement, the two probes of the stress wave measuring instrument are inserted into the surface of the wooden component under test: In the case of defect detection, the two probes are inserted relatively on the cross-section of the wooden component. The reading of the propagation time for the first strike is invalid. Starting from the second strike, the average of the propagation time readings obtained from three consecutive strikes is taken as the measurement result of this detection. The propagation speed of the stress wave for this detection is calculated based on the distance between the two probes and the propagation time of the stress wave.

The stress wave tester generates acoustic stress through impact, inducing vibration in the tested object and determining the propagation time of the stress wave. The propagation speed of the stress wave is calculated based on the measured distance and propagation time. Decay or damage within the wood can be identified through comparative experiments. When wood undergoes decay or is attacked by insects, the propagation speed perpendicular to the wood grain direction drops rapidly. Any speed lower than that of healthy wood can be judged as decay or insect damage. Detecting the transverse (radial or tangential) stress wave propagation speed of wood is the optimal approach for detecting wood decay.

When detecting pillars, the test section is determined through meticulous observation of the entire wooden component, and then three positions on the section are inspected at 120-degree intervals.

When detecting beams, stress wave detection is carried out at intervals of 50 cm in a continuous manner to determine whether there are internal defects. The judgment method is to see whether the stress wave speed is less than the stress wave speed of good wood (critical speed): if the stress wave speed at the detected position is less than the critical speed, it indicates that there is a defect inside the wooden component at that position; the greater the speed difference, the more severe the internal defect [8] [9].

5.2. Detection Outcomes

Internal defect sampling detection of the wooden columns with surface cracking in this project was carried out by the stress wave method. The mainly sampled round wooden columns were 2/C, 2/B, and 3/C. The detection work was performed in accordance with the provisions of "Regulations for Non-destructive Inspection of Internal Decay and Elastic Modulus of Ancient Building Wooden Components by Stress Wave Method" (GB/T 28990-2012). Through observation, it was determined that the stress wave detection was conducted at three heights of 0.3 m, 0.8 m, and 2.0 m from the bottom surface of the column. For each cross section, measurements were taken three times at three diameter positions spaced 120˚ apart. The detection results are shown in **Tables 1-3**.

Table 1. Stress wave detection results of column. (2/C)

Detection point number	Position	t (μs)	Space between (cm)	Speed (m/s)
1	From the bottom 0.3 m	163	23.15	1420
2		159	23.15	1456
3		162	23.15	1429
4	From the bottom 0.8 m	164	23.15	1412
5		161	23.15	1438
6		157	23.15	1475

Continued

7	From the bottom 2.0 m	160	23.15	1447
8		159	23.15	1456
9		162	23.15	1429

Table 2. Stress wave detection results of column (3/C).

Detection point number	Position	t (μs)	Space between (cm)	Speed (m/s)
1	From the	163	23.20	1423
2	bottom	160	23.20	1450
3	0.3 m	167	23.20	1389
4	From the	164	23.20	1415
5	bottom	164	23.20	1415
6	0.8 m	165	23.20	1406
7	From the	162	23.20	1432
8	bottom	161	23.20	1441
9	2.0 m	162	23.20	1432

Table 3. Stress wave detection results of column (2/B).

Detection point number	Position	t (μs)	Space between (cm)	Speed (m/s)
1	From the	151	23.05	1526
2	bottom	155	23.05	1487
3	0.3 m	155	23.05	1487
4	From the	155	23.05	1487
5	bottom	152	23.05	1516
6	0.8 m	154	23.05	1497
7	From the	160	23.05	1441
8	bottom	158	23.05	1459
9	2.0 m	157	23.05	1468

5.3. Analysis of Detection Results

From the aforementioned on-site detection results, it is known that the stress wave velocity of the wooden columns with surface cracking sampled and inspected in this project is close to the critical velocity, suggesting that there are no obvious cavities or decay defects within the measured wooden components.

6. Detection of Component Deformation

The lateral displacement of the apex of the building structure was detected on-site using a total station. The detection work was carried out in accordance with the relevant regulations of JGJ 8 Code for Building Deformation Measurement. A total of 8 detection points were laid out for the lateral displacement of the building apex, and the detection results are as follows: The height of the set detection points was approximately 3.421m to 4.758m, the minimum apex displacement was 4mm, and the maximum apex displacement was 8 mm.

According to DB11/T 637 Standard for Comprehensive Safety Appraisal of

Building Structures, the lateral displacement of columns ≤lc/250. The lateral displacements of the measured points of this building all meet the requirements of the code [10].

7. Checking and Calculation of the Structural Vertical Bearing Capacity

7.1. Explanation of Structural Calculation

The bearing capacity of the wood structure was checked and calculated by employing the finite element calculation software SAP2000. The main procedures of the calculation are as follows: Establish the calculation model; Input the structural calculation information, load action information, and other structural design parameters, etc.; Adjust the structural calculation control parameters (such as geometric dimensions, strength, etc.) in accordance with the measured values to ensure that the results of the structural calculation and analysis can truly reflect the current status of the structure; Conduct the overall structural calculation and summarize the calculation results. The calculation model is shown in **Figure 3**.

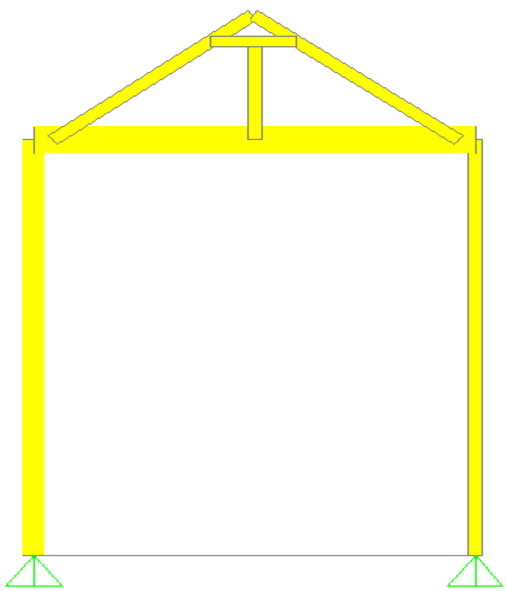

Figure 3. The simplified computational model.

7.2. Calculating Loads

(1) Categories of Loads

1) Dead load: Comprising the self-weight of structural components, ground treatments, etc.

2) Live Loads: Comprising wind loads and live loads on building floor roofs.

(2) Value Assignment of Loads

1) Wind load: Basic wind pressure 0.45 kN/m^2;

2) Snow load: Basic snow pressure 0.40 kN/m^2;

3) Roof live load: 0.5 kN/m^2;

4) Roof dead load: 4.0 kN/m^2.

7.3. Checking Results of Bearing Capacity for Wood Structures

In accordance with the relevant regulations of GB50009 Building Structure Load Code, the axial force combination calculation results of the wood structural members of this project are presented as shown in Figure 4. In line with the stipulations of GB50005 Wood Structure Design Code regarding the design value of the strength of wood materials, the verification results demonstrate that the maximum stress value of the wood members in this project is smaller than the design value of the wood strength. The vertical bearing capacity complies with the requirements of the code, namely $R/(\gamma_0 S) > 1.0$ [11].

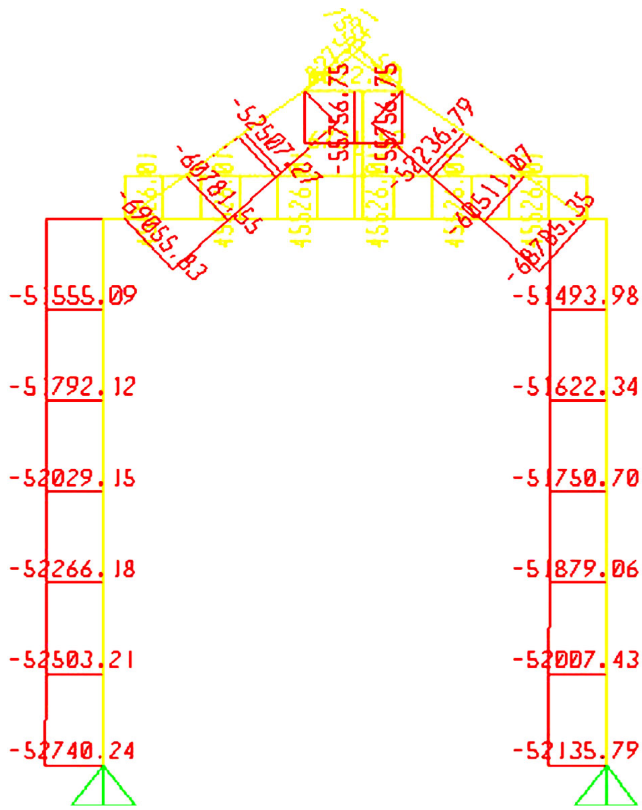

Figure 4. Calculation results of combined axial forces of wooden components.

8. Conclusions

Through the on-site inspection and testing of the wood structural components of this project, and by employing the finite element structural calculation software, under the existing structural system and the given loading conditions, the bearing capacity verification of the wooden framework is conducted, and the conclusion of the detection and identification is obtained.

1) Through on-site inspection, the connection (or node) construction method of this building is correct. Only local surface defects exist and the operation is normal.

2) The stress wave velocity of the wood columns with surface cracking randomly inspected in this project is close to the critical velocity, suggesting that there are no obvious cavities or decay defects inside the measured wood components.

3) The lateral displacement of the wood components of this building satisfies the requirements of the code.

4) The verification results indicate that the maximum stress value of the wood components in this project is smaller than the design value of the wood strength, and the vertical bearing capacity meets the requirements of the code.

5) It is suggested that the wood components of this project that have not received anti-corrosion paint treatment undergo anti-corrosion processing; during the subsequent use of this project, effective maintenance should be carried out.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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