

Research Article

Application of BIM Technology in the Seismic Performance of “Wood Weaving” Structure of Wooden Arcade Bridges

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Received 1 June 2022; Revised 26 August 2022; Accepted 23 September 2022; Published 11 October 2022

Academic Editor: Denise-Penelope Kontoni

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The wood arch bridge has good seismic performance, and the “wood weaving” of its arch system is closely related. Wood weaving has the isolation function similar to that of rubber bearing isolation layer under earthquake, which is the key to ensuring good isolation performance of wood arch bridges. However, it is difficult to measure the seismic performance of the “wood woven” structure of the wooden arch bridge, which leads to its limited application. In order to solve this problem, building information model (BIM) technology is introduced into this field, and the application of BIM technology in the seismic performance of “wood woven” structures of wooden arch bridges needs research. First, the design principle of “wood weaving” is described, and then the seismic principle of “wood weaving” is analyzed. Finally, from the perspective of the structural strength index, the seismic performance of the wooden arch bridge “wooden woven” structure is analyzed in depth with BIM technology in order to provide some help for understanding the seismic performance of the wooden arch bridge “wooden woven” structure and promoting the effective application of wooden arch bridge.

1. Introduction

Earthquake ground vibration puts the building on the ground by dynamic action and produces passive vibration, resulting in deformation and displacement of the building structure [1]. The traditional seismic design method mainly uses the plastic deformation of the lateral resistance component to dissipate the seismic energy. Therefore, in the traditional structural seismic design, a multilayer seismic fortification line should be set up in the structural design. In the design, members with good stiffness, high quality, and high energy consumption and structures with large stiffness will be selected as far as possible to improve the seismic performance of the structure [2–5].

The ancient Chinese wooden arcade bridge has a good performance of shock isolation, mainly because the main force system of the wooden arcade bridge, the design of the “wood weaving” structure, is very scientific. The “wood braided” structure combines a variety of structures. The measuring mechanism close to the arch is that the vertical load is decomposed into the lateral thrust of the foundation

on both sides so as to reduce the impact on the main structure. Therefore, it has the isolation function similar to the rubber bearing isolation layer under the action of the earthquake, which is also the key to the good isolation performance of ancient wood structure arch bridges [6–8]. In addition, in view of the lack of research on the structural performance of this wooden arch bridge, Meng and others take a Hongqiao wooden arch bridge as an example to analyze the structural and mechanical properties of Hongqiao wooden arch bridge [9]. In order to analyze the stability of a glued wood arch bridge and evaluate whether its bearing capacity meets the design requirements, Wang et al. evaluated the structural performance of a modern glued wood arch bridge [10]. However, the building information model (BIM) is more and more widely used. Through point cloud verification, it is found that BIM will be affected by laser scanning technology in the process of case analysis and semantic segmentation [11]. Shape memory alloy can strengthen the concrete structure, reduce the residual displacement of the structure roof, and improve the seismic performance of the concrete structure [12]. Through BIM-

based measurement code mapping, the quantities are calculated, which improves the efficiency and accuracy of calculation [13].

In order to further reveal the seismic performance of the “wood woven” structure of the wooden arch bridge, based on the above analysis, in this paper, BIM technology is introduced to explore the seismic performance of the “wood woven” structure of the wooden arch bridge, in order to provide the theoretical basis for modern applications such as protection and reinforcement of ancient Chinese wooden arch bridge and also provide a reference for the research of seismic design of modern wooden structure [14, 15].

2. Design Principle of “Wood Weaving”

- (1) While satisfying the necessary vertical bearing capacity, the isolation device should reduce the horizontal stiffness as much as possible.

The purpose of reducing the horizontal stiffness is to reduce the natural frequency of the isolation structure and make it lower than the dominant frequency range of the seismic wave frequency so as to ensure that the seismic response of the structure has a great attenuation. “Wood weaving” bears load ability mainly through “three miao” and “five miao” fluctuation cross weaving force to implement together. The vertical load depends largely on the “three miao” and “five miao” inclined blade crossbite. It is as small as possible in the horizontal stiffness of circumstances and can achieve the purpose of supporting the maximum load [16–18].

- (2) Under the action of overload, the isolation structure cannot have too large displacement.

“Wood weaving” is composed of the first stress system and the second stress system. It is the main stress system of the wooden arcade bridge and also serves as a complete isolation support. During an earthquake, the “wood weaving” consumes energy through a small range of displacement of the seedling base.

- (3) When the displacement of the component occurs, the displacement of the structure should be automatically restored after the vibration disappears.

When the vibration disappears, the “wood weaving” cushion seat and other components connected by mortise and tenon will recover automatically under the interaction of static friction force, the restraining force between mortise and tenon, and the gravity of the corridor bridge. Among them, the mortise and tenon joint has the function of half “hinge,” which plays an important role in automatic recovery [19–22].

- (4) When deformation is affected by irresistible factors, there is enough free expansion space.

The wood chips are flexible and connected by tenon and mortise. This can make the “wood weaving” have enough free expansion space under the influence of

large temperature differences, thermal expansion, cold contraction, or moisture expansion. In addition, the unique texture and osteoporosis of wood chips and the redundancy of tenon and mortise joints are also the reasons for providing enough free expansion space. The schematic diagram of the design principle of “wood weaving” is shown in Figure 1.

3. Seismic Principle of “Wood Weaving”

The “wood weaving” is made of the first stress system (“three-section seedling”) and the second stress system (“five-section seedling”) crossed up and down, as shown in Figure 2.

For this kind of structure, many aspects of it conform to the general principles of modern isolation structure design. For example, the relationship between the vertical bearing capacity and the horizontal stiffness, the displacement range of the structure under overload, the ability to automatically recover the structural displacement after the member displacement and vibration disappear, and the free expansion space during the deformation process. Many aspects, such as free expansion space during deformation, are consistent with the general principles of modern isolation structure design. “Wood weaving” has an excellent function of isolation or dissipation of seismic energy. In case of an earthquake, “wood weaving” can make the superstructure work elastically on the basis of protection. Moreover, the combination of “three segment seedlings” and “five segment seedlings” is equivalent to a current device that absorbs and consumes seismic input energy. It can also use slippage to dissipate seismic energy, providing isolation similar to the rubber bearings or “isolation layers” made of similar materials used in isolation technology. The sliding and elastic work of “wood weaving” can effectively absorb and dissipate the seismic energy transmission to the upper structure of the corridor bridge, thus effectively enhancing the seismic performance of the wooden arch bridge.

The wooden arch bridge is a rectangular vertical plane projection of “wood weaving.” The overall appearance of the wooden structure is a typical solid structure, which is one of the most common structures in ancient dwellings. The rules of this structure enhance the overall stability of “wood weaving.” The practice has proved that the design of this structure is conducive to resisting the torque of earthquakes [23, 24].

The connection between “wood weaving” and needle leaf shape is completed through the cushion (stone) seedlings at the bottom of the seedlings. Among them, the seedling block made of wood is called a cushion seedling, and the cushion stone made of stone is used to support “wood weaving.” Once again, the wooden arch is supported by “wooden fabric,” finally, the wooden arch supports the entire wooden arch bridge, and the bridge must bear the maximum load. The connection between the cushion seedling seat and the platform is only through the cushion seedling (stone) floating on the foundation surface of the platform, which is a simple mobile connection between the planes and some even just the connection between the plane and a few points

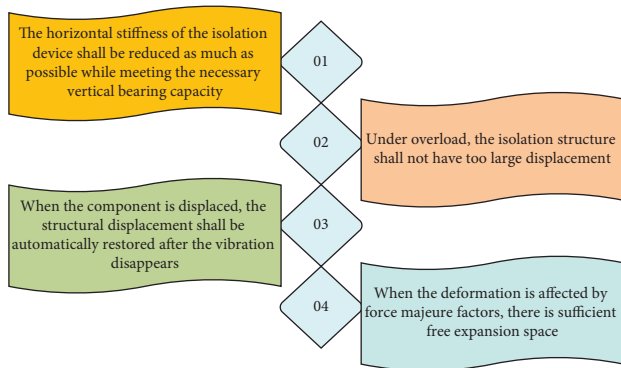


FIGURE 1: Structural diagram of “wood weaving.”

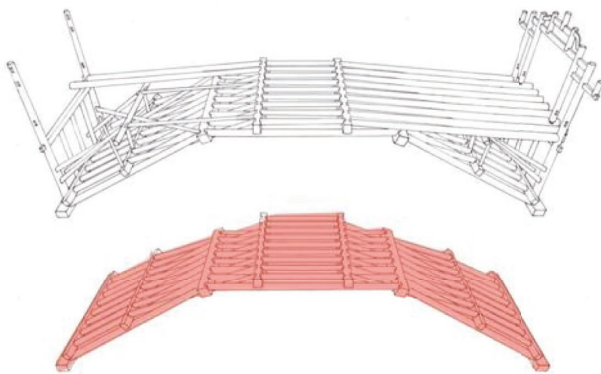


FIGURE 2: “Wood weaving” structure diagram.

[25, 26]. This connection is only made by relying on the weight of the wooden arcade bridge itself and the friction force between the cushion seat and the base. The greater the relative weight of the corridor bridge, the greater the static friction force generated and the stronger the connection is [27, 28]. Therefore, when the relative weight of the long-span covered bridge fails to reach the design requirements, bricks and cobblestones are often laid on the bridge deck, which can not only prevent fire and wear but also increase the weight of the bridge so that the connection between the whole bridge and the foundation is more stable [29].

It can be seen that the connection between the “wooden fabric” and the base is a “floating raft” mode, which makes the whole “wooden fabric” like a bamboo raft floating on the water, and can make the connection between the main body of the bridge and the foundation both firm and natural. This makes the connection between the subject and the foundation both solid and natural. During the earthquake, the total horizontal shear force of the structure under the action of general horizontal load will not exceed the sum of the friction force at the bottom of the seat cushion. Moreover, its base is generally wider than the seat cushion, so there is enough sliding isolation space to ensure the overall stability of the “wood fabric.” Such a connection is like the connection between the column and the column in ancient dwellings. The area of the column is generally larger than the column which was widely used in ancient dwellings in China thousands of years ago [30–32].

The principle of slip isolation is that the structure slides horizontally under the influence of seismic waves to reduce the seismic action and consume seismic energy by friction damping. Base isolation is a new type of seismic structure. The sliding layer is used to separate the foundation from the upper structure of the isolated structure. During the earthquake, the sliding layer is relatively sliding, which extends the natural vibration period of the structure and reduces the seismic effect. It has obvious development prospects by changing the traditional structure and relying on increasing the strength and stiffness of the structure to resist the earthquake action, which is attracting great attention in the field of engineering earthquake resistance [33].

The “wood braid” between the superstructure and the foundation can be provided with sliding isolation support in a small range. The self-weight, wind load, and braking force of the bridge must bear the load or small impact. The static friction makes the whole structure firmly stand on the foundation. The “floating raft” structure and “wood braid” reflect the function of sliding isolation bearing to some extent: that is, the “wood braid” base slides back and forth in a small range due to the impact wave. On the one hand, sliding directly consumes seismic energy; on the other hand, it prolongs the natural vibration period of “wood weaving” and reduces the seismic effect, thus effectively avoiding the shear failure of “wood weaving.” This back-and-forth sliding is mainly determined by the shock characteristics of seismic waves and is restored under the joint action of the static friction force of the upper and lower “wood weaving,” the controlling force between tenon and mortise, and the gravity of the corridor bridge. This process consumes a lot of energy and improves the seismic performance of the corridor bridge [34].

4. BIM Technology Analysis and Application

4.1. BIM Technology Analysis. BIM is a new tool for architecture, engineering, and civil engineering. The building information modeling was coined by Autodesk. It is the term used to describe computer-aided design (CAD) based on three-dimensional graphics, object orientation, and architecture.

The core of BIM is to provide a complete and consistent building engineering information base for this model by establishing a virtual three-dimensional building model and by using digital technology. The information base not only contains the geometric information, professional attributes, and state information of building components but also the state information of noncomponent objects (such as space and motion behavior). With the help of this three-dimensional model containing information on construction engineering, the degree of information integration of construction engineering is greatly improved [35].

4.2. Application of BIM Technology. This study builds a seismic detection system based on BIM technology, adding sensors to the “wood weaving” structure of the wooden arch bridge and connecting them with the detection base station

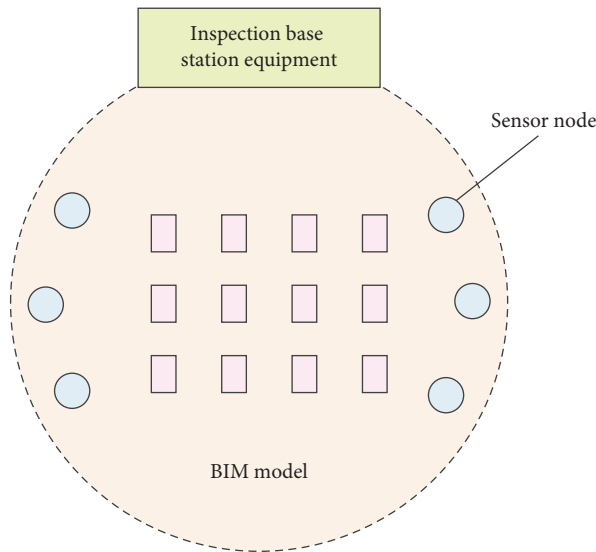


FIGURE 3: Structure block diagram of a seismic detection system based on BIM technology.

equipment, which can form the hardware structure of the detection system. The specific structural design is shown in Figure 3.

As can be seen from Figure 3, with the support of BIM technology, the microprocessor can be used to process the collected data and transmit the processed data to the base station equipment so as to detect the seismic performance of the “wood woven” structure of the wooden arch bridge.

4.2.1. Sensor Node Design. Wireless sensor nodes are designed, and the basic block diagram is shown in Figure 4.

In Figure 4, the wireless sensor node is designed to collect seismic signals, the signal is processed by RF communication mode, and all the processed data are transmitted to the detection base station equipment. The sensor node is composed of a processing node, data storage node, and sensing node. Flashat45DB041 chip is selected for memory, which has the advantages of low power consumption and simple circuit connection and is suitable for the use of sensor nodes.

4.2.2. Software Flow Design and Implementation. The software design of the seismic performance detection system of the “wood weaving” structure of the wooden arcade bridge based on BIM technology is mainly to design the sensor node program and the detection base station program in the hardware. BIM technology is based on the “wood weaving” structural data of the wooden arcade bridge, obtained through the digital information simulation of the real information and the use of a three-dimensional building model to achieve digital management. The BIM model is shown in Figure 5.

Based on the information from the two-dimensional drawing model, a three-dimensional BIM model of the stress structure is constructed. The model was built on the Revit software platform.

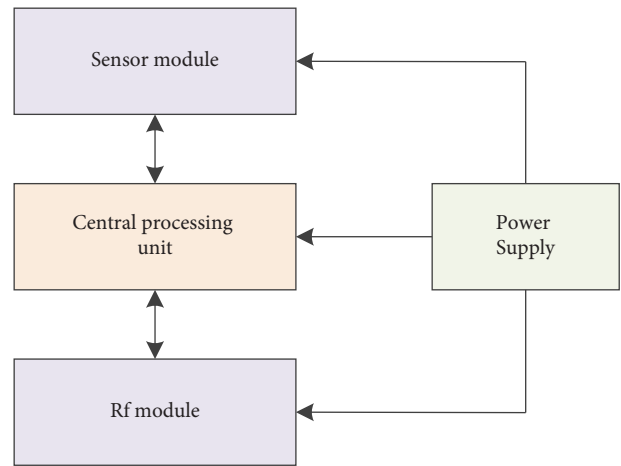


FIGURE 4: Wireless sensor node basic block diagram.

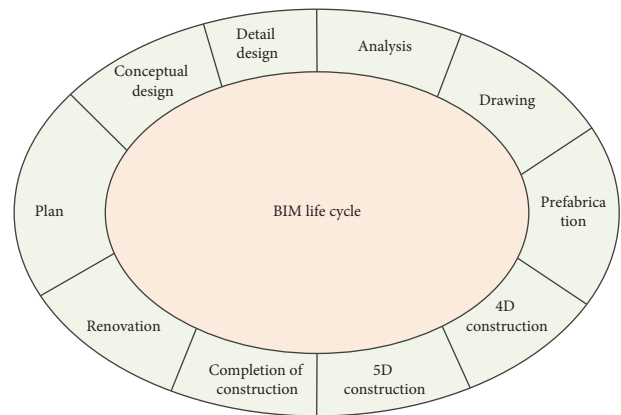


FIGURE 5: Seismic performance detection model based on BIM technology.

In addition, the software flow of the sensor node can mainly realize the process of seismic signal acquisition, processing, and base station communication. The sensor node is initialized and waits for the request of the connection command. If the connection is successful, the sensor will receive the sleep request; otherwise, it will return to the previous step. At the same time, the connection is successful, and all data is sent out. At this time, the sleep is lifted. When the sensor node receives the data transmission signal, it starts to send the request assignment command to the detection base station and waits for the receiving address assignment signal to be issued. If no assignment signal is received, the assignment request shall be issued again after a random delay, and this step shall be repeated continuously until the address assignment information is received. After receiving the address assignment information, it needs to record its own node address and send it to the detection base station until it returns an address confirmation signal to complete the node entry process.

When the detection base station receives the data transmitted by the sensor node, it needs to transmit it to the computer host for processing and continue to detect the network to ensure that the data sent by other nodes will not

be missing. Repeated iterations will be carried out until all the data is detected. According to the structure block diagram of the BIM seismic detection system, the central microprocessor is used to process the data obtained from the sensor nodes and the wireless communication method is used to transmit the data to the base station equipment. According to this principle, the basic structure of the wireless sensor node is analyzed and its circuit diagram is designed. The detection base station can scan the channel to assemble the communication network and wait for the sensor node to join so as to facilitate the system detection.

5. Using BIM Technology to Analyze the Seismic Performance of “Wood Weaving” Structure of Wooden Arcade Bridges

This section mainly expands the design in the “Analysis” section of Figure 4.

The seismic capacity index of the “wood weaving” structure of the wooden arcade bridge can be expressed as

$$I_s = CF. \quad (1)$$

In (1), I_s is the seismic capacity index, C represents the strength index of the “wood weaving” structure of the wooden arcade bridge, and F represents the ductility index of the “wood weaving” structure of the wooden arcade bridge. The strength index of the “wood weaving” structure of the wooden arch bridge can be calculated by grouping the members, and the ductility index of the structure can be used to analyze the influence of the ductility of the members on the seismic performance. Therefore, the strength index of the j group member in a certain direction of the “wood weaving” structure is calculated by the following formula:

$$C_j = \frac{Q_j}{\sum W'}. \quad (2)$$

In (2), C_j represents the strength index of the “wood weaving” member in group j , Q_j represents the bearing capacity of the “wood weaving” member, and $Q_j = \tau_j A_j$, where τ_j and A_j , here, respectively, represent the standard strength value and the area of the effective section of the “wood weaving” member; $\sum W'$ represents the “wood weaving” of the wooden arcade bridge to calculate the total gravity above the floor.

When the “wood weaving” structure of the analyzed wooden arch bridge has many types of members, it is necessary to calculate them in layers, determine them according to the deformation capacity, and balance the bearing capacity of the “wood weaving” members according to the lateral deformation of the structure. The calculation of the first floor is as follows: the “wood weaving” structure is regarded as an integral whole without considering the ductility of the structure. If the ductility index of the “wood weaving” structure is selected as $F = 0.1$, the seismic capacity of the “wood weaving” structure is

$$I_s = CF = \frac{\tau_c A_c}{\omega \sum A_f} + \frac{\tau_w A_w}{\omega \sum A_f} = \frac{\tau_w (nA_c + A_w)}{\omega \sum A_f}. \quad (3)$$

In (3), τ_c and τ_w , respectively, represent the standard strength value of a constructional column and the standard strength value of support structure in the “wood weaving” structure. ω is the gravity load per unit area of the “wood weaving” structure; A_c and A_w , respectively, represent the area and total structural area of the constructional column in the “wood weaving” structure; $\sum A_f$ represents the sum of the area of the plane of the “wood weaving” structure; and n is the modulus ratio of “wood weaving.”

The seismic performance of the “wood weaving” structure of the wooden arcade bridge means that the “wood weaving” structure will not be destroyed when a large earthquake occurs. The damage can be classified as severe, moderate, minor, and collapse. The analysis index varies with the damage degree. In the above process, this study uses BIM-related software to analyze the seismic performance of the “wood woven” structure of the wooden arch bridge. The hierarchical model of “wood woven structure” is also established, and the final analysis results are obtained [36].

6. Experiment and Analysis

In order to verify whether the seismic performance analysis process of the “wood weaving” structure of the wooden arcade bridge based on BIM technology is reasonable, the following experiments are carried out. Experimental parameter settings are shown in Table 1.

According to statistics, in 2020, there will be 28 earthquakes with a magnitude of more than 5 in China, including 20 on the mainland. In addition to these large earthquakes, there will still be smaller earthquakes every day. Because the scale is too small or too far from the ground, the human body cannot feel them, so seismographs must be used to record them (the above data is from the review of earthquake events of the China Seismological Bureau). In view of the setting of the experimental environment, this study selected the seismic data of a day in May 2020 and the approximate orientation could be determined as 12 km from the ground. According to the seismic environment in the figure, the experimental verification and analysis were carried out.

According to the above experimental environment, a comparative analysis is conducted between the traditional seismic performance analysis process and the BIM-based seismic performance analysis process designed in this study. The seismic waveform obtained by using these two processes is shown in Figure 6.

Base station equipment is detected through a wireless communication connection, and data is transmitted to the PC host using RS 232 interface. According to the comparison results in Figure 6, the seismic waveform obtained by the traditional seismic performance analysis process is not obvious and the fluctuation amplitude is small; especially after 0.10 s, the fluctuation amplitude fluctuates around 0 V. However, the seismic waveform obtained by the seismic performance analysis process based on BIM technology designed in this study is relatively obvious, and the wave amplitude is large; especially when the time is about 0.46 s, the fluctuation amplitude is the largest; the time is around 0.70 s, and the fluctuation range is small. The above results

TABLE 1: Setting of experimental parameters.

Parameter	Model/value
Acceleration sensor	MMA1220D
Turntable	Horizontal 0° to 180° and pitch 0° to 45°
Channel	16
Data interface	RS 232
PC host	2 sets

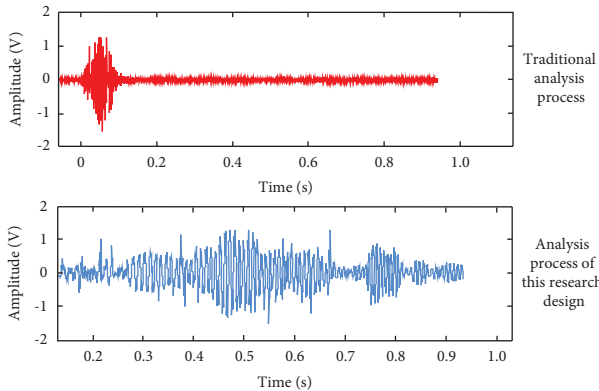


FIGURE 6: Seismic waveforms obtained by different analysis processes.

fully demonstrate the effectiveness of the design process of this study. The reason for this result is that BIM technology takes the relevant information data of the construction project as the basis of the model, establishes the building model, and simulates the real information of the building through digital information simulation, which has strong advantages. Therefore, after the analysis of the seismic performance of the “wood woven” structure of the wooden arch bridge using BIM technology, the seismic performance of the “wood woven” structure of the wooden arch bridge can be accurately understood.

7. Discussion on the Reasons for Good Aseismic Performance of Wood Structure “Wood Weaving”

On the basis of the above research, the reasons why the “wood weaving” structure of the wooden arcade bridge has good seismic performance are analyzed and discussed.

Some seismic studies show that the seismic response control parameters of structures can directly reflect the seismic performance of buildings, such as the fracture or sliding characteristics of the ground crust on which the buildings are located. The inherent natural vibration shape, natural frequency, and damping dynamic characteristics of the building, rigidity, strength, flexibility, and ductility of a building are the control parameters of the anti-deformation properties. These control parameters determine the severity of the response of the building to ground movement. The latest research found that the wooden structure has good control parameters, so the “miracle” that the entire wooden structure moves but does not collapse often occurs in earthquakes. It is proved that timber-framed buildings have excellent aseismic performance under various extreme load

conditions. The aseismic performance of a timber structure building is shown as follows:

- (1) *Rigid and Flexible Combination, Effective Earthquake Resistance.* Wood has a good bearing capacity, that is, rigidity. At the same time, wood has certain flexibility and elasticity, will deform under the action of certain external forces, and has the ability to recover to the condition before deformation within the effective range. When an earthquake occurs, “wood weaving” dissipates the seismic energy damage to the structure through its inherent rigidity and deformation ability so as to protect the overall structure of the wooden arch bridge within a certain limit. It is precisely because of the characteristics of “wood weaving” of a wooden arch bridge, which combines rigidity and flexibility, that it can effectively isolate earthquakes.
- (2) *Good Ductility, Effective Earthquake Resistance.* The property that the object shows the ability to extend without breaking under the action of external force is called ductility. Represented in buildings, it is the ability to yield, deform, or resist collapse. Building materials such as masonry and concrete need to undergo strict design and detail treatment to ensure better seismic performance. Wood is pulled and extruded within a certain range and has good automatic recovery ability, showing good ductility. The numerous mortise and tenon connections of the wood structure greatly increase the overall ductility of the wood structure. During the earthquake, the excellent ductility of the wood structure effectively dissipates the earthquake energy and improves the seismic function.
- (3) *Integral Connection, Effective Earthquake Resistance.* A 90 degree gap will be made at the lower end of the bridge body for a “Wood weaving” bridge, which is called “duck bill armour” by carpenters. That is, rectangular seedlings are connected without mortise and “bite” (several notches are made into small tenons, which are connected to the place where the seedlings are made into orthogonal frame grooves), and all the bases are connected with mortise, so that the whole bridge body becomes a solid whole. When contacting with large loads, the load can be quickly transferred to adjacent nodes or components, so as to effectively share the load and improve the use effect of the bridge body. For example, the Wan’an Bridge built in the Song Dynasty in Changqiao Village, Changqiao Town, Pingnan County, Fujian Province is shown in Figure 7.
- (4) *Tenon and Mortise Structure, Effective Seismic Performance.* Tenon and mortise are the most commonly used joint method of concave-convex treatment in the connection of two wooden parts in ancient China. The convex part is called tenon (or mortise), and the concave part is called socket (or socket). Chinese people invented mortise and tenon

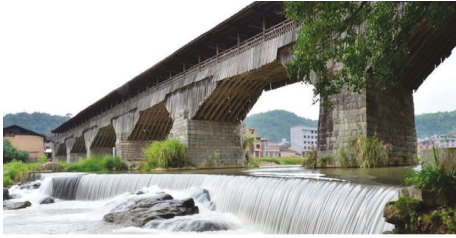


FIGURE 7: Wan'an Bridge, the longest ancient Chinese wooden arcade bridge in the world.

as early as 7000 years ago, and it has been used to this day. Tenon and mortise joints are typical flexible joints, which is the key to earthquake resistance of ancient wooden structures. Professor Huang Sheng from the Department of Architecture, Shandong University, believes that the antiseismic mechanism of the mortise-tenon joint is as follows: critical mutation after impact, elastoplastic deformation, energy dissipation of extrusion friction, and the resonant damping organic decay process of space-time shock absorption. According to the concept of “strong column and weak beam, plastic hinge point,” a kind of Chinese mortise-tenon profile reinforced concrete joint is conceived, and the energy dissipation is completed by the extension elastic junction breakthrough, plastic development, friction, and shear, bending moment constraint resistance under the ultimate stress state. The “wood weaving” of the wooden arcade bridge is not made of inch pieces of iron, but a few groups of logs are interwoven from top to bottom, put together, and will bite each other and are connected by mortise and tenon. During the earthquake, the bridge body compresses and deforms rapidly. At this time, a certain gap will be formed between the mortise and the looseness, so that the bridge base and tenon can rotate slightly. The overall recovery will be carried out by relying on the elasticity, friction force of the wood itself, and the force contained in the “wood woven fabric.” This can not only bear large loads, but also produce certain deformation, and absorb seismic energy through deformation and minimize the seismic impact on the bridge structure.

- (5) *Lightweight, Effective Earthquake Resistance.* The wooden structure is relatively light, and after “wood weaving” is completed, the main stress system of the wooden arcade bridge is basically completed, while the reinforced concrete construction is about 6 to 10 times the weight of the wooden structure. Because the horizontal seismic force and the weight of the structure are proportional, therefore, by the penetration of wood through the upper and lower cross braiding, the formation of the arch “wood weaving” constitutes the main force system and the use of reinforced concrete structure, steel structure, and so on in the weight has obvious antiseismic advantages.

8. Conclusions

In order to more clearly reveal the seismic performance of the “wood woven” structure of the wooden arch bridge, this study uses BIM technology with three-dimensional information integration ability to analyze the seismic performance of the “wood woven” structure of the wooden arch bridge. This paper first introduces the design principle of “wood weaving” and then analyzes the seismic principle of “wood weaving.” Finally, from the point of view of the structural strength index, the seismic performance of the “wood woven structure” of the wood arch bridge is deeply analyzed by using BIM technology. It can be seen from the results that the seismic waveform obtained in the traditional seismic performance analysis process is not obvious, and the fluctuation amplitude is small; especially after 0.10 s, the fluctuation amplitude is about 0 V. However, the seismic waveform obtained by the seismic performance analysis process based on BIM technology designed in this study is relatively obvious, and the wave amplitude is large; especially when the time is about 0.46 s, the fluctuation amplitude is the largest; the time is around 0.70 s, and the fluctuation range is small. Through the comparison of the results, it can be seen that the design of this study is effective and feasible. Through this research design, we hope to provide some theoretical basis for the reinforcement and repair of wooden arch bridges and also hope to provide a feasible research idea for the seismic design of modern wooden structure buildings.

Data Availability

The datasets used and/or analyzed during the current study are available from the author upon reasonable request.

Conflicts of Interest

The author declares that there are no conflicts of interest.

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