Study on the seismic performance of fuxi miao's congenital temple

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Abstract. In order to study the seismic performance of fuxi miao's congenital temple in Tianshui, we establish 3-D finite element model of the congenital temple in this paper. In the term of frequent earthquake and rare earthquake, Lanzhou wave and El-Centro wave and Taft wave are adopted to analyze the seismic response. It is shown the displacement reaction of the roof is largest, followed by Taft wave, and Lanzhou wave is smallest under El-Centro wave; The acceleration reaction of the roof is largest, followed by El-Centro wave, and Lanzhou wave is smallest under Taft wave. The displacement and acceleration maximum of the roof are slightly greater than that of the second floor, but are much greater than that of the first floor, thus the seismic response of the roof is the strongest. The acceleration peak of the nodes from the top of the first floor column to the roof increases very little, therefore it indicates the column base's isolation and the friction energy dissipation of the mortise and tenon joint of beam and column make the congenital temple have good performance and shock absorption.

1. Introduction

China is one of the ancient civilizations, which boasts a large number of ancient architectures that are an important historical and cultural heritage as well as national treasure. Tianshui is located at the intersection of the north and middle sections of the north-south seismic belt in China. It is the area with the strongest seismic activity and the most frequent occurrence of large earthquakes. Earthquake brings a fatal threat to thousands of years of the ancient building security. As a result of long-term damage accumulation, the ancient building suffers fatigue damage, and life greatly reduces. Especially after May 12 earthquake, the wooden structure of fuxi miao's temple has seriously damaged. To study the seismic behavior of the congenital temple, we establish the 3d finite element model with ANSYS finite element, and analyze the dynamic characteristics and seismic response. It provides theoretical basis and technical reference to strengthening and maintenance of the congenital temple.

At present, fuxi temple is one of the most magnificent and well-preserved buildings of the Ming dynasty. It is located at xi guan’s fuxi road in Tianshui. The Gansu province government announced it as a key cultural relic protection unit of Gansu province in 1963, and now it is a national key cultural relic protection unit. Fuxi temple sits in the north to the south, and is built along the street. It appears magnificent and deep.

The congenital temple is called the main temple, which is the most important building in the fuxi temple complex. It is a brick-wood structure of large double eaves, with a length of 26.420 meters and
a width of 17.260 meters and a height of 15.086 meters. Its plan and section are shown in Figure 1 and 2\cite{1}. Many experts and scholars at home and abroad believe that the complex has great value for the study of ancient Chinese history and Ming dynasty architectural art as well as the folk customs of Tianshui.

2. Finite element model of the congenital temple

(1) Beam188 element is selected for the simulation of beam and column, and Mass21 element is used for the simulation of large roof, and Combin14 element is used to simulate semi-rigid mortise and tenon joint of beam and column. Stiffness coefficient of spring is used as $k_x=1.26\times10^9\text{kN/m}$, $k_y=k_y=k_z=1.41\times10^9\text{kN/m}$, $k_{\theta_x}=k_{\theta_y}=k_{\theta_z}=1.5\times10^{10}\text{kN\cdot m/\text{rad}}$\cite{2,3}.

(2) The density is 410 kg/m$^3$, the flexural elasticity modulus is $8.3073\times10^9\text{ Pa}$, and the poisson's ratio is 0.25\cite{4,5}.

(3) According to the principle of area equivalence, the roof load is concentrated on the corresponding column end, and is adopted as $G=1.925\text{kN/m}^2$\cite{6}.

(4) The column is placed on the plinth with grooves and connects the column and the plinth with a fixed hinge pedestal for easier simulation\cite{7,8}. Based on the above basic assumptions and relevant data, the finite element model of the congenital temple's wood structure is established. See Figure 3 below.

3. Dynamic characteristics of the congenital temple

Block Lanczos method is used to extract the modal order 6 and extend the modal order 6. The modal analysis results are shown in table 1.

| order | 1    | 2    | 3    | 4    | 5    | 6    |
|-------|------|------|------|------|------|------|
| frequency | 1.3769 | 2.5409 | 3.1332 | 4.2195 | 7.6295 | 7.7315 |

The sixth vibration mode of the congenital temple is shown in Figure 4. From the vibration mode diagram, the first and second vibration modes are shown as the plane sliding vibration of the wood structure along X direction, and from the third to sixth vibration modes are shown as the bending and
torsional vibration of the wood structure along z direction, mainly in the bending and torsion of beam and column and roof. Its low vibration mode is mainly the vibration of the wood structure. The vibration mode after the third order is the bending and torsional vibration of beam and column and roof, especially the roof torsion is more obvious.

Figure 4. Six vibration modes of the congenital temple

4. Seismic response analysis of the congenital temple
Using the viscous proportional damping defined by Rayleigh, we adopt $\zeta_1=\zeta_2=0.03$ in the aseismic analysis,[9] and analyze the seismic response of the congenital temple with time-history analysis method. We consider the seismic fortification intensity is 8 degrees in Tianshui of Gansu province, and the design basic earthquake acceleration value is 0.30g. Lanzhou wave and El-centro wave and Taft wave are selected, and the amplitude of the frequent earthquakes is adjusted to 110 gal, and the amplitude of rare earthquakes is adjusted to 510 gal, then the calculation results of the congenital temple are analyzed. Taking the top of the first floor column and the second floor column and the roof, we analyze the model with time-history. The time-history curves of the displacement and acceleration are obtained under frequent and rare earthquakes as shown in Figure 5 and Figure 6:

(a)The displacement time-history curve under 110gal Lanzhou wave (b) The displacement time-history curve under 110gal El-centro wave (c) The displacement time-history curve under 110gal Taft wave
Figure 5. The time-displacement and time-acceleration curves under frequent earthquake

Figure 6. The time-displacement and time-acceleration curves under rare earthquake

The displacement and acceleration maximum of each layer node are shown in table 2 and table 3.

| Seismic wave   | Earthquake excitation ( m/s²) | the first floor pillar (mm) | the second floor pillar (mm) | The roof (mm) |
|----------------|-------------------------------|-----------------------------|------------------------------|---------------|
| Lanzhou wave   | 1.1                           | 3.840                       | 8.470                        | 8.890         |
|                | 5.1                           | 17.820                      | 39.260                       | 41.230        |
| El-centro wave | 1.1                           | 8.690                       | 19.330                       | 20.300        |
|                | 5.1                           | 40.269                      | 89.602                       | 94.127        |
| Taft wave      | 1.1                           | 8.198                       | 17.913                       | 18.793        |
|                | 5.1                           | 38.007                      | 83.050                       | 87.133        |

| Seismic wave   | Earthquake excitation ( m/s²) | the first floor pillar (m/s²) | the second floor pillar (m/s²) | The roof (m/s²) |
|----------------|-------------------------------|-------------------------------|-------------------------------|-----------------|
| Lanzhou wave   | 1.1                           | 1.334                         | 1.385                         | 1.373           |
It can be seen from Figure 5 and Figure 6 and table 2 and table 3 that under frequent and rare earthquakes, the displacement response of the roof is the largest under El-centro wave, followed by Taft wave and Lanzhou wave is the smallest. Under frequent earthquakes, the displacement maximum of the roof is 20.300 mm, and is 1.05 times that of the second floor, and is 2.34 times that of the first floor. Under rare earthquakes, the displacement maximum of the roof is 94.127 mm, and is 1.05 times that of the second floor, and is 2.34 times that of the first floor. Under frequent and rare earthquakes, the acceleration response of the roof is the largest under Taft wave, followed by El-centro wave and Lanzhou wave is the smallest. Under frequent and rare earthquakes, the acceleration maximum of the roof is 2.143m/s^2, and is 1.05 times that of the second floor, and is 2.32 times that of the first floor.

Under frequent and rare earthquakes, the displacement and acceleration maximum of the roof are slightly bigger than that of the second floor, but are far bigger than that of the first floor, thus the seismic response of the roof is the strongest. It indicates that the vibration isolation of the base and friction dissipation of the mortise and tenon joints of beam and column make the congenital temple have good shock absorption and isolation performance.

5. Conclusions
In order to study the seismic performance of fuxi miao's congenital temple in Tianshui, we establish the three-dimensional finite element model in the paper. According to frequent and rare earthquakes, Lanzhou wave and El-centro wave and Taft wave are selected for seismic response analysis, the conclusions are drawn:

(1) The modal of the congenital temple is analyzed, and the sixth natural vibration frequency and mode are obtained.

(2) Under frequent and rare earthquakes, the displacement response of the roof is the largest under El-centro wave, followed by Taft wave and Lanzhou wave is the smallest.

Under Taft wave, the acceleration response of the roof is the largest, followed by El-centro wave and Lanzhou wave is the smallest.

(3) Under frequent and rare earthquakes, the displacement and acceleration maximum of the roof are slightly bigger than that of the second floor, but are far bigger than that of the first floor, thus the seismic response of the roof is the strongest.

(4) It indicates that the vibration isolation of the base and friction dissipation of the mortise and tenon joints of beam and column make the congenital temple have good shock absorption and isolation performance.

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