Study on seismic and shock absorption performance of Yi Ci Hui stone pillar

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Abstract: The rigid block structure composed of multiple blocks of stones will sway during an earthquake. The rocking and rocking impact dissipates the seismic force and has good shock absorption performance. The seismic and seismic performance of Yi Ci Hui stone pillar with multi-layer block stones was studied. The results showed that: only the acceleration increases to a certain value, the rocking amplitude of the multi-layer stacked stone pillar occurs; with the continuous increase of the earthquake acceleration, the rocking amplitude of the stone pillar will rapidly decay or even be stationary. Stacking stone pillar can effectively take advantage of high compressive strength of block stone, and only produce compressive stress in the pillar root section to avoid stress failure of stone pillar. The energy reaction of the multi-layer stone pillar is mainly kinetic energy, which reaches the maximum when the stone pillar begins to shake, and then decreases rapidly. The total strain energy reaches the peak value when the stone pillar shakes, and then remains unchanged. The rocking and shaking of stacked stone pillars causes the impact of rock interface edge to dissipate seismic energy, which makes the rocking amplitude and kinetic energy of stone pillar gradually decrease, and the total strain energy is basically unchanged, which effectively plays the role of seismic shock absorption.

1. Introduction
When an object is subjected to a dynamic action, the relative position of its internal points does not change, which is called the rigid body. The rigid block structure composed of several rigid bodies will swing and sway during an earthquake. Through this shaking impact, the seismic force can be dissipated and good shock absorption performance can be achieved. Therefore, such stacked ancient buildings and structures can be seen all over the world (as shown in Figure 1). Although they have suffered many strong earthquakes, they still remain good after thousands of years and become precious cultural heritage [1].

Similar to the spine type stacked ancient buildings, by releasing the constraints between the structure and the foundation or structural pillar components, there is only pressure and friction force on the contact surface between the interface without any tension to form a rocking structure. When the size of each cross-section member is appropriate, the overall swing response is generated, and the seismic energy is dissipated by the impact of the interface edge It does not collapse in the process, and can quickly recover to the original position under the action of gravity, so it also has the ability of self reset [2-5].

Yi Ci Hui stone pillar, a national key cultural relic, is a multi-layer stone pillar structure, which has not been damaged or collapsed after several major earthquakes. In this study, Yi Ci Huistone pillar is taken as an example, and the elastoplastic dynamic time history analysis is carried out to explore the
motion characteristics of stacked ancient buildings under earthquake, and their seismic and seismic performance is also investigated.

![Figure 1. Multispondyle pillars at the temple of Zeus at Nemea (330 B.C.)](image)

2. **Structure size and numerical model**

2.1. **Overview of Yi Ci Huistone pillar**

Yi Ci Huistone pillar is located in Dingxing County, Hebei Province. It was built in the second year of Daning in the Northern Qi Dynasty (AD 562). It has been more than 1400 years ago. It has not collapsed after many earthquakes. It was only repaired in 1990 because of the inclination of the pillar caused by the differential settlement of the foundation. The total height of the stone pillar is 6.17 m, which is divided into foundation stone, rosette, pillar body (two sections), cover plate, stone layer and roof from bottom to top[6], as shown in Figure 2.

![Figure 2. Yi Ci Hui stone pillar](image)

2.2. **Material parameters**

According to the structure size in reference [6], the weathered limestone is collected for strength test. The compressive strength, tensile strength and elastic modulus of weathered limestone cube are 58.2 Mpa, 4.6 MPa and $4.1 \times 10^4$ MPa respectively. use MSC.Marc software. In the software, the block stone is regarded as a semi brittle friction material, and the elastic-plastic and fracture model is used to simulate [7-10], and the elastic-plastic numerical calculation model is established, as shown in Figure 3.
2.3. Seismic response analysis

According to the references[11,12], the fortification intensity of Dingxing county is 7 degrees, and the peak ground acceleration is 0.15 g. Ninghe seismic wave is selected to analyze the seismic response of stone pillars under rare earthquake action (peak acceleration is 0.31 g, as shown in Figure 4), so as to study the seismic performance of stone pillars under large earthquakes.

2.3.1. Displacement response analysis of stone pillar

The dynamic response of rocking angle at the bottom of the stone pillar under the action of Ninghe earthquake wave is shown in Figure 5. When the local seismic wave acceleration is small, the stone pillar basically remains stationary (when the local seismic wave acceleration is less than 7.16 s in Figure 5); when the seismic wave acceleration reaches a certain value (when it is greater than 7.16 s in Figure 5), the rocking amplitude of the stone pillar will decay quickly and even be static, so as to achieve the function of self recovery. The results show that the stone pillar structure composed of multiple blocks of stones will swing and sway under earthquake action, and the seismic force can be dissipated by the rocking and rocking impact, which has good shock absorption performance.

2.3.2. Stress response analysis of stone pillar root section

The vertical stress response of the root section of stone pillar under the action of Ninghe earthquake wave is shown in Figure 6. and Figure 7. There is only compressive stress in the section at the root of the pillar, which increases and rapidly decreases at the beginning of rolling. The maximum compressive stress is only 6.67 MPa, which is far less than the compressive strength of 58.2 MPa, which indicates that the strength of stone pillar is safe under the action of large earthquake.
2.3.3. Energy response analysis of stone pillar

The energy response of the stone pillar under the action of Ninghe earthquake wave is shown in Figure 8. The energy response of the stone pillar is mainly kinetic energy. When the stone pillar begins to shake, it gradually reaches the maximum and then rapidly decays. The total strain energy reaches the peak value when the stone pillar shakes, and then remains unchanged. It shows that when the kinetic energy of the stacked stone pillar is large, the violent shaking will cause the impact of the rock interface edge to dissipate the seismic energy, so that the kinetic energy gradually decreases, the total strain energy is basically unchanged, and the structure will not be damaged.

3. Conclusions

In this paper, Yi Ci Hui stone pillar, a national key cultural relic was taken as an example to analyze the elastoplastic dynamic time history and study its seismic performance. From that research, the following conclusions are drawn.

(1) Under the action of Ninghe earthquake wave, when the acceleration increases to a certain value, the multi-layer stacked stone pillar will swing; with the continuous increase of earthquake acceleration, the rocking amplitude of the stone pillar rapidly attenuates or even stops, achieving the effect of functional recovery. This is also the reason why the ancient stone pillar which has experienced many earthquakes for thousands of years has not collapsed.

(2) Under the action of Ninghe earthquake wave, the stacking stone pillar effectively takes advantage of the high compressive strength of the block stone, and only produces compressive stress.
at the pillar root section, and the peak compressive stress of 6.67 MPa is far less than the material compressive strength of 57.2 MPa, which ensures the safety of the stacked stone pillar structure strength.

(3) The energy response of multi-layer stone pillar is mainly kinetic energy response under earthquake action. When the stone pillar begins to slosh, it gradually reaches the maximum and then decreases rapidly. The total strain energy reaches the peak value when the stone pillar shakes, and then remains unchanged. The results show that when the kinetic energy of the stacked stone pillar is large, the violent shaking will cause the impact of the rock interface edge to dissipate the seismic energy, so that the kinetic energy gradually decreases, the total strain energy is basically unchanged, and will not be damaged.

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