DAMAGE ANALYSIS OF THE TYPICAL ADOBE CAVE IN SHANXI NORTHERN RURAL AREAS UNDER SEISMIC ACTION

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ARTICLE DETAILS

Article History:

Received 02 october 2017

Accepted 06 october 2017

Available online 11 october 2017

Keywords:

Adobe Cave, Seismic Action,
Damage Analysis.

ABSTRACT

A large number of adobe caves in the northern part of Shanxi Province were still used for dwelling until now, and the safety performance of these caves under seismic action related to the life and property safety of the masses. Based on explicit dynamic finite element analysis software, the seismic response of the typical cave was analysed to simulate the whole process of cave damage for discovering weak parts, the simulate result of adobe cave's weak position is close to the real earthquake damage. The conclusion can provide a reference for earthquake disaster prevention and post - earthquake assessment.

1. INTRODUCTION

The casualties and economic losses caused by the earthquake were mainly due to the damage of buildings, which was found in a large number of earthquake damage cases. The structure of the cave dwelling houses with strong regional characteristics has suffered serious damage and heavy casualties. The northern part of Shanxi Province, which is located in the earthquake fault zone and the seismic activity frequently in history, is key monitoring area. A large number of adobe cave is still in use in these rural areas, and cave is a major residential structure in some poor areas. Most previous research studies on the cultural attributes or insulation, thermal insulation, and lighting of the adobe cave, and there is rare research on its seismic performance. Based on the ANSYS / LS-DYNA finite element software, the dynamic response of the cave structure under seismic action was calculated. Combined with the history seismic damage data, the damage condition of the cave structure under the seismic action was analysed, which could provide the scientific basis for the earthquake damage defences and post-earthquake assessment.

2. The Introduction of typical independent adobe cave in Shanxi northern rural areas

The arch adobe cave is widely distributed in Shanxi northern rural areas. Most of caves were constructed in the 40-60's, their structural system is similar and the bearing structure is arches. The foundation of the cave is strip foundation masonry structure, and the arch legs is built by original clay mixed with straw, some of the cave is also used stone. The arch of cave is built with adobe or brick. The cave's interior is width between 2.6-3m and height 2.6-2.9m. And it's general fill 20-60cm clay at the top of the cave arch for heat insulation and structure protection, which makes roof so heavy that seismic performance is poor. The typical cave structure is shown in Fig.1~Fig.3.

Fig.1 Front view of typical cave structure

Fig.2 Aerial view of typical cave structure

Fig.3 Internal diagram of typical cave structure

3. Numerical simulation of typical adobe cave

Numerical methods include continuous medium numerical method and discontinuous medium numerical method in years of research and development. At present, the more commonly used are: finite element method (explicit and implicit), discrete element method, massless method and other methods. In this paper, the finite element method is used to build the finite element model according to the characteristics of the cave structure. Then it needs to select the appropriate mesh size as required and the appropriate failure criterion based on the nature of the failure mechanism and material. After the constraints are imposed and the boundary conditions are determined, one or several sets of natural seismic wave time or simulated artificial wave timings are input according to the site type, and the dynamic analysis of the structure is carried out by the stepwise integration method. ANSYS / LS-DYNA finite element analysis

software is used, which combined with strong organic pre-processor (PREP7), post-processor (POST1, POST26, LS-PREOST) and powerful nonlinear dynamic analysis function. The suitability of an explicit analysis to solve for the seismic response of the scaled model was studied using the FE model defined in LS-DYNA. This is a general purpose finite element program for the analysis of large deformation static and dynamic response of structures.

3.1 The analysis model of cave

The typical cave is arch structure build with adobe blocks. The adobe masonry structure is made of masonry and mud, both of them are made of clay, but they are difference in mechanical properties by produced in different ways. Therefore, there is two ways to establish finite element modelling of masonry structure, the one is the separation of modelling (separate blocks and mud) and the other is the overall modelling (considered the block and the mud as same material). The geometry of the cave is shown in Fig.4

Fig.4 Geometrical dimensions of typical adobe cave

This paper adopts overall modelling for the convenience of modelling, meshing and calculation. SOLID 164 is chosen to simulate adobe masonry. The SOLID164 element is a three-dimensional solid element, which is specially developed for inhomogeneous materials with high compressive strength, such as concrete and rock. The unit uses a single point of integration can be controlled of viscous hourglass for calculating faster and large deformation, which could simulation such as high-speed collision, earthquake and other nonlinear dynamic problems.

The physical parameters of adobe masonry are as follows: density is 1980kg/m³, the Young's modulus is 48MPa, the Poisson's ratio is 0.3, the compressive strength is 0.55MPa, the tensile strength is 0.05MPa. The material model is *MAT_PLASTIC_KINEMATIC. The model includes strain softening in tension. Tensile cracking with up to three orthogonal crack planes per element is available. Once a crack is formed it can be closed and reopened. As the opening size increases, the length also increases and the work done in crack propagation is utilized to create a new crack surface. The completed finite element model is shown in Fig.5.

Fig.5 The finite element model of typical adobe cave

3.2 Mechanical analysis under seismic action

The most widely used El-Centro seismic waves is selected to numerical simulation analyse. The amplitude of the seismic wave is adjusted to make the peak acceleration of the seismic wave to be 0.15g, and then applied to the seismic waves along the bottom of the cave structure along the longitudinal (model coordinate axis x direction).The original recorded waveform shown in Fig.6.

Fig.6 The acceleration wave of El_Centro

In order to calculate the stress of the cave structure under earthquake action, the peak acceleration of the El-Centro seismic wave is adjusted to 0.05g, which could ensure the cave structure will not collapse. The stress and deformation of the cave at a moment during process of dynamic analysis is shown in Figure 6.

Fig.7 The deformation and stress of the cave during loading

It can be known from Fig.7, the stress at the bottom of the cave leg is greatest, and there is tensile stress and compressive stress regions alternate in the cave dome expand direction along the 45° to the top of the cave. The stress situation is very unfavorable for adobe-bearing cave, as the compressive strength of the adobe material is much greater than the tensile strength, and cracks are easily formed in the region where the tensile stress is exist. The stress intensity results of the middle cave legs Fig.8.

Fig.8 The Stress intensity of the arch legs middle position

As can be known from Fig.8, the stress intensity varies with the seismic wave, and the maximum intensity occurs around 3.8 s, which is lagging behind the peak acceleration of the seismic wave.

3.3 Damage analysis under seismic action

The damage of the cave under El-Centro seismic waves with 0.15 g peak acceleration is shown in Fig. 9-13.

Fig.9 Deformation of structure at 1s

Fig.10 Deformation of structure at 2.10s

Fig.11 Deformation of structure at 2.18s

Fig.12 Deformation of structure at 3.20s

Fig.13 Deformation of structure at 3.5s

The breaking first from the bottom of the cave leg, and the innermost cave's leg was the first to be destroyed. As time go on, the internal arch is gradually destroyed and the structure collapsed, and the cave leg and arch is most weak position from the failure mode. It can be found that the arch legs and arch often use two different materials. Some cave legs are built with stone masonry, and some are clay compact with straw, and the arch is mostly built with adobe masonry. It is more prone to damage under the seismic action because of the junction between two materials is poor combined. The damage states of cave in Zhangbei earthquake is shown in Fig.14.

Fig.14 Damage states of cave in Zhangbei earthquake

It is found that the numerical simulation results are close to the actual seismic damage. The poor mechanical properties of the material and structural system are the main reason for the damage of the cave. The cave leg should be strengthened to improve the seismic capacity.

4. Conclusions

The numerical analysis results show that the weakest part of the cave structure is the middle, bottom position of the cave leg and the vault. This is related to the dimensions of the cave structure, where rigidity abrupt change due to the size change, which lead to stress concentration. The initially destruction is occurred in bottom of the inside cave leg, then the cave began to collapse, the structure of the overall instability and destruction finally.

Acknowledgements

The paper was supported by earthquake emergency youth emphasis project of China Earthquake Administration (Grant No. CEA_EDEM-201604). Thank you guidance of Professor Rushan Liu (Institute of Engineering Mechanics, China Earthquake Administration). Thank you Dr. Wan Jia (Taiyuan University of Technology) to provide analysis.

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