An analysis of the geological conditions and the structural characteristics of the Changyu Caverns

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Abstract

The Changyu abandoned mining zone is a system of underground quarries that have been excavated for more than 1500 years. There are hundreds of caverns of different sizes and the distribution form is complex. The caverns were mined for a long time without a systemic and scientific plan. Under the complex geological environment geological disasters have resulted. Hydro-geological conditions, engineering geological conditions, structural characteristics of the caverns and the rock mass characteristics at the Changyu abandoned mining zone have been analyzed based on field geological investigation, theoretical analysis and the finite difference method. The advantageous and disadvantageous factors were analyzed and summarized for the structural stability of caves. The structural stability, mechanical characteristics and stress fields within the surrounding rock are calculated with the FLAC in this paper. The geological conditions and the structural characteristics of the Changyu abandoned mining zone are summarized in this paper, as a basis for the study of the caverns' stability.

Key words：The Changyu caverns；Rock mass characteristics；Numerical analysis

1. Introduction

Changyu Caverns, which was more than 1.55km^2 of quarry area, were excavated for more than 1500 years until 1998 when the government determined to stop mining there because of long-term exploitation. In recent years, due to the weathering of rock mass and other factors, the geological disasters of the Changyu caverns are increasing year by year. In 1997 August, rock falls occurred in the Biyutan areas, which were the most important events in recent years, of continuous rock fall and other geological disasters.

There is a lot of research on the mechanical problems of underground cavern groups at home and abroad(Pan Bietong, 1992; Wang Zhongfen,2002; Kawasaki S et al., 2001; He Yan et al., 2000; Wang Dongyun, 1994). But most of these underground cavern groups are of small and medium size, while research about large cavern groups is rare. Recent research about large underground caverns mainly concentrated on the famous Israeli Bet-Guvrin ancient quarries(Hatzor Y H et al., 2002) and the world's natural and cultural heritage of the ancient salt Wieliczka caverns in Poland(Zuber A et al., 2000). In China studies focus on the Longyou ancient underground caverns and the Longmen Grottos(LI Li-hui et al., 2005; LI Li-hui et al.,2004; ZHANG Chengyu, 2003; DING Wu-xiu et al., 2003).

The Changyu caverns are artificial and large underground cavern groups formed by mining. There is an intimate relationship between the distribution and structural characteristics of the caverns and geological environmental factors. But, it cannot be sufficient to reveal the mechanical characteristics in Changyu caverns from the existing research results. For further protection and development of Changyu caverns, according to the site survey, the influencing factors of cavern structure stability are analyzed and summarized, on the basis of the geological environment surrounding the caverns and the distribution and structure characteristics of the caverns.

2. Geological background

The caverns researched is located in the southwest and center of the Changyu, Zhejiang province, china . the caverns is Huaxuandong cavern, Huaju cavern and the Biyutan cavern, as Fig. 2.

2.1 The lithologic characteristics of the area

around the Changyu caverns

Changyu cavern is located in the bell-shaped Mesozoic volcanic activities area of East Zhejiang, and is in the middle of the Wenhuang plain. The strata are mainly composed of Jurassic and Quaternary gravel layers, and there are andesites distributed in the local mountain.

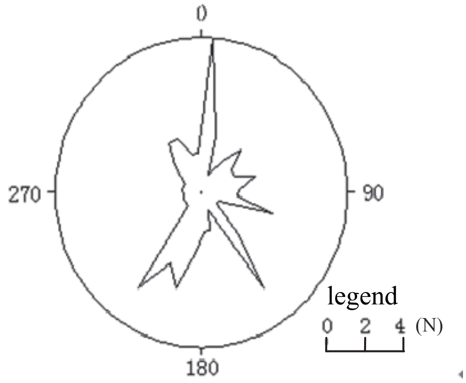

Fig. 1 The rose diagram of the joint rend of the exploration area

2.2 Geological structure

The geological structure of the caverns is simple. It has few faults and the structural features are mostly joints. The joints are compression-shear, and parts of the joint combinations are conjugate. According to the statistical results of measurements of the joints on the outcrops, such as the bedrock of the slope and cavern, the extended length of each single group generally ranges from 5~50m, which is micro tension, is 2~10 mm wide, and the density of joint rock mass is different. According to the rose diagram of joint dip orientation (Fig. 1), most of the joint dip orientation is nearly north (N) and SSW, and SE takes third place.

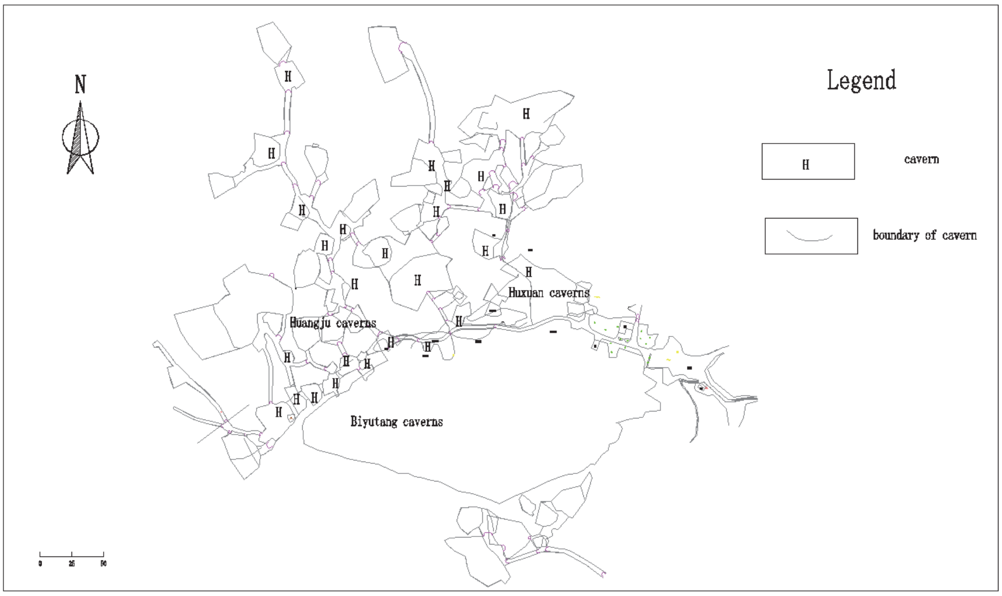

Fig. 2 distribution of the caverns

Table 1 the physical and mechanical properties of rock

Lithology	Dry density ρ_d g/cm^3	specific gravity G_s	Dry compressive strength R_d MPa	Compressive strength R_w MPa	Softening coefficient K_R	Dry strength of extension σ_{td} MPa	Strength of extension σ_{tw} MPa	Elasticity modulus E GPa	Poisson ratio μ
volcanic tuff	2.31	2.57	66.0	47.3	0.71	10.4	6.98	26.2	0.25
andesite	2.88	2.88	84.8	66.2	0.78	10.2	5.86	35.2	0.24

2.3 Hydro-geological conditions

According to the field survey, the groundwater of the caverns can be divided into loose rock pore water, bedrock fissure water and accumulation water in the caverns.

The pore water in loose rock mainly occurs in loose pores of the mountain surface and slope foot, and the aquifers are gravel soil with clay, and cohesive soil with gravel. It is 2 ~6m depths, and the local depth is 12m. Because of the geomorphologic characteristics of the terrain, it cannot form a unified water table, the pore water in loose rock is downward slope runoff, and part of it infiltrates the bedrock fissures.

Bedrock fissure water: Groundwater mainly occurs in the rock mass structural fissure and the rock mass is brecciated tuff with blocky structure. Joints and fissures are highly developed with poor connectivity, so the bedrock fissure water is extremely poor quality.

Accumulation water in caverns: most of the part of caverns under the surface have been not backfilled, and have accumulated groundwater, but the depth of the accumulated water is not consistent, varying in the range of 10m~20m. Groundwater dynamics are controlled by seasonal changes, and are mainly recharged by atmospheric rain.

2.4 The physical and mechanical properties of rock

Rock mass in the caverns is mainly tuff. Part of it is volcanic clastic sedimentary rock and ground. There is clay in the volcanic tuff, while the size of the rock fabric is varied, from large conglomerate and breccias to fine volcanic tuff and a few clay minerals. The combination of these different components and different particle sizes is arranged with no obvious stratification, mostly in a blocky structure. Due to the characteristics of the rocks, it is not easy to failure load along the layers or split joints under vibration. Through experiment, the rock mechanical parameters are shown in table 1.

3. Analysis of the characteristics of the cavern group

3.1 Analysis of the characteristics of the cavern structure

During the long period of mining, the complex structure of the caverns in the mining area of Changyudongtian was formed, mainly including Huaxuan caverns, Huaju caverns and Biyutan caverns. The Huaxuan and Huaju caverns were well protected because the surrounding rock of these caverns is relatively stable. These caverns are very complex, and connected by channels. Due to excessive mining, the Biyutan caverns were damaged completely by rock falls. According to field investigation in the Huaxuan and Huaju caverns, compared with the channel, the caverns are larger, and most of these caverns are small clear spaces. So the size of cavern controls the stability of the caverns. To this end, the structure and surrounding rock of these caverns were analyzed.

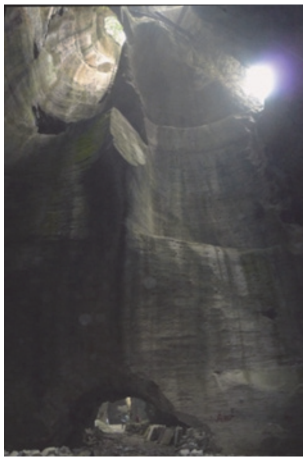

Photo. 1 A cavern excavated by quarrying

Photo. 2 A cavern formed by rock block stacking

Photo. 3 The cavern with water

(1) According to the formation mechanism of the caverns, this can be divided into two categories: One is formed by quarrying (see Photo. 1), and the other is formed by giant rock falls and accumulation (see Photo. 2).These caverns were mainly formed by quarrying and connected by channels, and these form a tunnel network. There are a few caverns formed by giant rock falls and accumulation, and only three caverns. The stability of these caverns controlled by giant rock falls has less affect on the stability of the caverns. So the stability of the caverns formed by quarrying is the subject of this analysis.

(2) The large cavern spans over 70 m, its height more than 53 m. The diameter of the small cavern is 5 ~ 8 m, and its height is more than 7 m, as shown in Photo. 4. According to field investigation, the rock mass in the caverns is mainly tuff, mostly in block structure. Joints and fissures are highly developed, so the large-span cavern can be formed and be stable. The cavern scale largely depends on the surrounding rock, and the better the integrity of the surrounding rock, the larger the cavern can be.

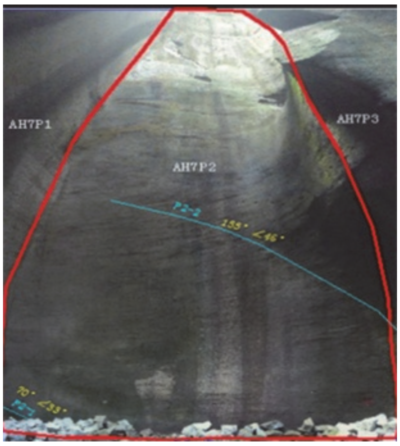

Photo. 4 The structure of bell-shaped

(3) Most of the caverns are bell shaped, and the cavern cross-sectional size reduces gradually from bottom to top. As a structure of rock and soil in a mine, the bell-type is more stable when affected by force. It can remain stable without any supporting measures.

(4) Cavern distribution in the mine is dense with only thin walls between some small caverns: the thicknesses of the walls are from 2m to dozens of meters. From the analysis of rock mass mechanics, due to the cavern distribution in the mine, the internal stress fields of the rock mass have changed greatly. In some areas there will be inevitable cross plastic zones, which is adverse to the stability of the overall group of caverns. According to the field investigation, the rock mass is mainly hard with the saturated average compressive strength of 47.3 MPa, so the overall caverns group should remain stable.

3.2 Analysis of the characteristics of the rock surrounding the caverns

As a stone mine, the rock mass structure and mechanical properties of Changyudongtian should be better. But in order to further evaluate the stability of the caverns, the characteristics of the rock surrounding the caverns are summarized and analyzed.

(1) The surrounding rock of the caverns is primarily volcanic tuff, with massive structure, and tuff structure.

(2) There are penetrating joints in the inner walls, and most of these are closed joints, without groundwater seepage. But when there are too many joints, due to the joints cutting each other, the integrity of the rock mass has deteriorated. There is a lot of water in most of the caverns (Photo. 3).According to the field investigation and analysis the water should be mainly supplied by surface rainfall, so this can prove that the joints of the rock mass should be closed joints and have poor connectivity.

(3) The walls of the caverns are approximately vertical, due to limitations of the mining process. The structure of the rock walls is irregular, and form steps. Depressions usually appear (as shown in Photo. 1), and sometimes there are unstable rocks.

4. Analysis of mechanics characteristics of rock surrounding cavern

Based on the analysis of the Changyudongtian caverns, the geological environment conditions and the structural features of the caverns, it has been shown that the geological conditions are good and the structural characteristics of the caverns are stable. But due to other factors which impact the caverns, such as excavation, weathering of rock mass and geological disasters, the regional stress fields have changed, and the structural stability of the caverns group have certainly been impacted. Because of the collapsing of the Biyutan, the rock mass close to the collapse area is widely distributed, and a free face is formed. The regional stress in the rock mass has changed, and stresses in the face have disappeared, so the stability has decreased.

So, the cavern with a wall which is a free face, is the most important cavern affecting the stability of the caverns. The cavern near the collapse area with a free face as a wall is being analyzing and calculation done with FLAC(Fig. 3), a continuum model framework. The cavern is 24m wide. The model is 168m wide and 175m high, and the grid space is 1m. Because the cavern near the surface, we only considered the gravity stress. The surround wall of the cavern is volcanic tuff, and the parameters of the model are determined according to the table 1.

4.1 Stress field of surrounding rock

By calculation, the natural state of the surrounding rocks under the self-weight stress field is shown in Fig. 4,Fig. 5 and Fig. 6. The maximum and minimum principal stress distributions increase gradually from the surface to the deeper levels of the caverns. The characteristic of the major principal stress on the boundary is approximately parallel to the boundary (as show in Fig. 6), and the minor principal stress is close to zero. The stress concentration at the foot and the top of the cavern is clear. In the range of 0.5 times of diameter of the caverns, the major principal stress direction is close to the vertical direction, and the minor principal stress is in a horizontal direction. It was showed that in the natural state, due to the good mechanical properties of surrounding rock, the rock stress distribution surrounding the cavern under the influence of cavern formation is not significant.

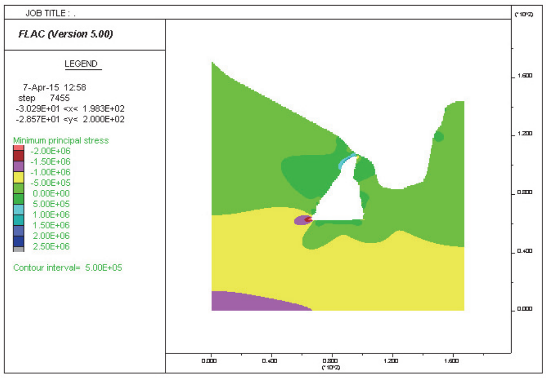

Fig. 5 the minimum principal stress

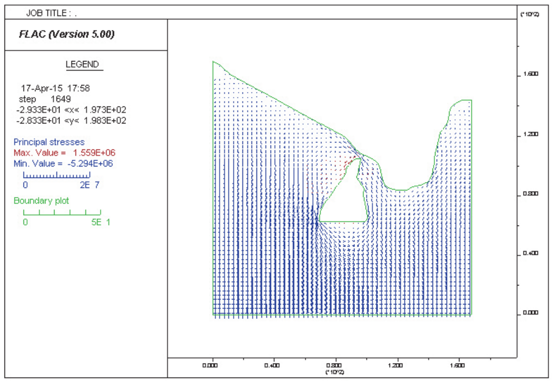

Fig. 6 principal total stress tensors

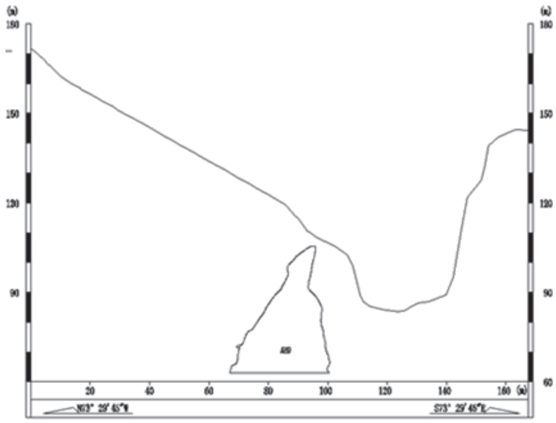

Fig. 3 Profile of the cavern

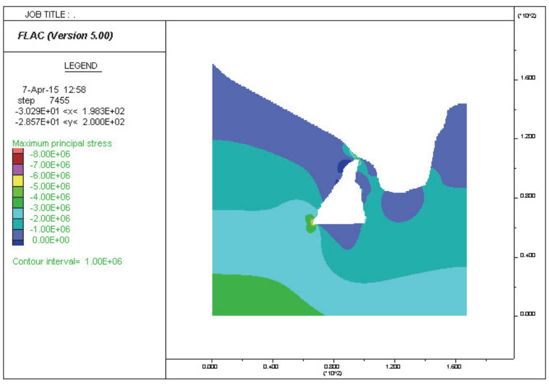

Fig. 4 the maximum principal stress

4.2 Potentially unstable areas

The calculation results show that the actual maximum shear strain distribution of the surrounding rock under natural conditions, as shown in Fig. 7, and the maximum shear strain in the bottom of feet and top in the local is relatively large, and is an easily deformed area. A cavern potential fracture plane, which are marked by the red line in Fig. 8, is located in the left foot at about 60 degrees obliquely upward and in the ceiling position. It takes the general characteristics of a shallow buried cavern.

5. Conclusions

(1) Changyudongtian caverns, abandoned after being mined for many years, are surrounded primarily by hard rock. Few joints developed, and these are mostly closed joints with poor connectivity.

(2) The regional tectonic conditions are relatively simple. Faults are not developing, and the

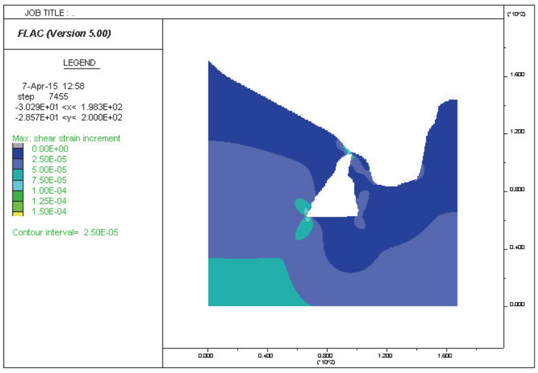

Fig. 7 the maximum shear strain

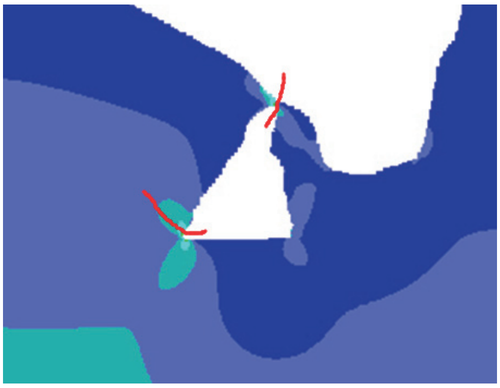

Fig. 8 the maximum shear strain

structural feature is mainly the joint. Due to rock mass joint development, and poor connectivity, bedrock fissure water doesn't develop.

(3) Although the chamber is large, and close to each other. The cavern structure favors cavern stability, and the integrity of the surrounding rock is good, therefore the groundwater seepage effect is smaller.

(4) Because the cavern surrounding rock mechanics performance is good, the influenced range of the rock stress field is not more than 0.5 times the cavern span, and even in bad conditions the cavern can keep stability.

According to the analysis, Changyudongtian large caverns group under the present condition is stable. Due to one thousand years of mining and rock weathering, there are unstable rocks mass in the local. So, it is necessary to rectification.

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