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Study on the Dynamic Response Characteristics of Surrounding Rock Mass of Underground Caverns under Blast load

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Abstract: *To investigate the dynamic response and failure law of underground caverns during operation under explosive loads, the anti explosion performance of underground caverns was studied based on a three-dimensional finite difference numerical simulation platform. The stress, acceleration, displacement, and strain distribution patterns of the surrounding rock structure of the cavern under explosive loads were obtained, and the stress distribution and plastic zone state of the surrounding rock structure were compared and analyzed. The research results indicate that the peak stress generated by different models of explosions varies under different explosive dosages. At the same time node, the higher the peak stress, the greater the stress in the damage area generated by the explosives; When the explosion stress wave propagates to the tunnel, the surrounding rock structure enters a tensile plastic state, and the medium units near the borehole mainly undergo tensile shear failure, while the medium units far away from the borehole mainly undergo tensile failure.*

Keywords: *Deep cavern; Blast load; Dynamic response; Numerical simulation*

1. Introduction

At present, the impact of blasting load on the stability of underground caverns is an extremely complex rock engineering geomechanical problems, part of the explosive load penetration depth of up to several hundred metres, a major threat to the underground protection works, with the sustained and stable rapid development of China's national economy, resource development, transport infrastructure, water conservancy and hydropower and national strategic protection of a large number of underground rock projects in the field of the construction has been imperative. In order to meet the needs of the moment, underground protection engineering of blast resistance has also become the hot direction of the current research.

In order to systematically study the mechanical response and damage pattern of underground cavern under the action of explosion load, many scholars at home and abroad have carried out a large number of experimental studies.,Singh [1]found that the amplitude of vibration of the surrounding rock is the primary factor leading to the destruction of the surrounding rock of the underground cavern by studying the explosion response and damage pattern of the cavern.Rajmeny [2]et al. established a criterion for judging the damage to the surrounding rock of a cave chamber in a high stress zone by analysing the damage pattern of a model chamber under blast loading.Guangyong Wang [3]et al.used a combination of physical model tests and numerical simulations to investigate the blast resistance of underground caverns under blast loading.Weize Yuan [4]explored the dynamic response laws and damage patterns of the surrounding rock and lining materials by carrying out physical modelling tests.Chun Feng [5]et al.studied the physical process of rock damage rupture under the action of explosive load, and obtained the rule of change of the blast rupture zone with the intensity of rock strain.Jincai Gu [6]et al.have analysed the blast resistance of the cavern in the way of the surrounding rock by carrying out a physical model test comparison, and the results of the study are of great significance to the study of the blast resistance of underground engineering structures.Gang Lei [7]et al.obtained the dynamic response law of the surrounding rock by numerical simulation and analysis.Ziyou Yang [8]et al.used a combination of model tests and theoretical derivation to investigate the reinforcement effect and deformation damage characteristics of underground caverns under various anchor reinforcement methods.

The above studies mainly focus on anchored and unanchored small-span caverns, however, there are fewer studies on the blast resistance of large-span underground caverns.Therefore, based on the three-dimensional finite-difference numerical simulation platform, this paper investigates the dynamic response characteristics of underground cavern under blasting load, analyses the blast resistance of underground cavern surrounding rock structure, and elucidates the characteristics of the multivariate information evolution, such as displacement, stress, and plastic zone, in the process of blasting and excavation of deep cavern.The results of the study can provide a certain significance for the underground protection engineering anti-detonation work.

2. Numerical Modelling and Parameterisation

2.1 Numerical Model

Based on the St Vernand principle, Dimensions of the numerical model created: 2.5m in the x-direction (horizontal direction), 1.2 m in the y-direction(thickness direction), 1.2 m in the z-direction(vertical direction), The modelled gun holes were all simulated using a ball cavity with a diameter of 20 mm,encryption and meshing with small size cells in the vicinity of gun holes and chambers, and monitoring of points in the vicinity of chambers when blast loads are applied, as shown in Figure 1.

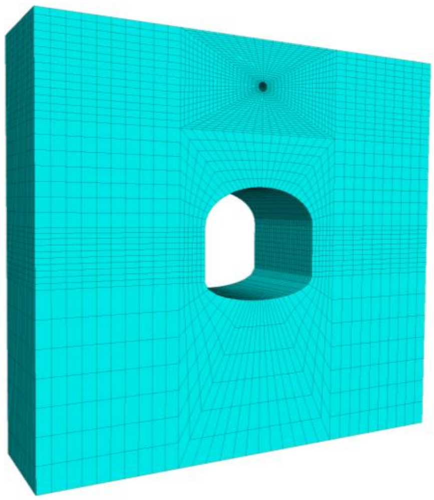

Figure 1: Numerical Simulation Computing Model

2.2 Intrinsic Modelling and Mechanical Parameters of Materials

Numerical simulation uses solid units to model the surrounding structural material,the Mohr-Coulomb criterion was chosen for this model.Parameters for dynamic calculation of surrounding rock materialsm, as shown in table 1.

Table 1: Parameters for dynamic calculation of surrounding rock materials

ρ/kg·m^{-3}	E/GPa	ν	c /MPa	φ/°	σ_t/MPa
1852	2.1	0.46	0.57	48	0.1

In order to simulate the propagation characteristics of stress waves in a semi-infinite body, the upper boundary of the model is kept free; horizontal direction constraints are set on the left, right, front and rear boundaries;The lower boundary is set with vertical direction constraints, while the effect of material self-weight on the propagation of stress waves is neglected. In the dynamic analysis, in order to prevent the reflection of the stress wave transmitted to the model constraint boundary, the Rayleigh-damped viscous boundary is applied in the normal and tangential directions of the model constraint boundary [9-10]. In addition there will be wave reflection, refraction and absorption at the model boundary, so in this paper, static boundary conditions are used to absorb the incident wave on the boundary.

2.3 Application of Blast Loads

According to the characteristics of the dynamic calculation of the 3D finite difference software, the explosion load is loaded on the mesh nodes of the inner wall of the spherical cavity of the gun bore in the form of equivalent force,the blast load is modelled as follows:

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$$P_{\mathrm{b}} = \frac{1}{8}\rho_0 {D_0}^2 \left(\frac{R_{\mathrm{c}}}{R_{\mathrm{b}}}\right)^6 \eta \tag{1}$$

Where: ρ0 is the charge density; D_0 is the explosive bursting rate; R_c, R_b are the radius of the roll and the hole; η is the coefficient of pressure increase in the collision of the products of the explosion with the wall of the hole.

There is a limitation when applying dynamic loads, the quiet boundary conditions cannot directly impose velocity or acceleration time courses. The velocity timescale is converted into a stress timescale according to the following equation:

$$\sigma_n = 2(\rho C_p)\upsilon_n \tag{2}$$

$$\sigma_s = 2(\rho C_s)\upsilon_s \tag{3}$$

Where: σ_n , σ_s are the normal and tangential stresses applied on the boundary; ρ is the density;C_p, C_s are the propagation velocities of compression and shear waves in a medium; V_n , V_s are the input normal and tangential velocity timescales.The propagation speed of compression and shear waves is calculated according to the following equation:

$$w = \frac{\sqrt{2C_{\mathrm{P}}}}{3R_{\mathrm{b}}} \tag{4}$$

$$t_{\mathrm{R}} = \frac{\sqrt{2}\ln(n/m)}{2(n-m)w} \tag{5}$$

Where: w is a function related to the medium longitudinal wave velocity C_p and the gunnel radius R_b,t_R is the time to the peak of the blast pulse.

3. Analysis of Numerical Simulation Results

3.1 Characteristics of Stress Evolution in Cave Chambers under Explosive Loading

Burst pressure is one of the important factors affecting the stability of the modelled cavern, and the reliability of the numerical calculation results can be analysed by studying the stress change characteristics of the surrounding rock units under burst pressure.By the explosive load formula can be obtained from the different amounts of explosives corresponding to the peak burst pressure.The peak blast load curve is obtained as shown in figure 2.Figure 3 shows the velocity time profile after model simulation.

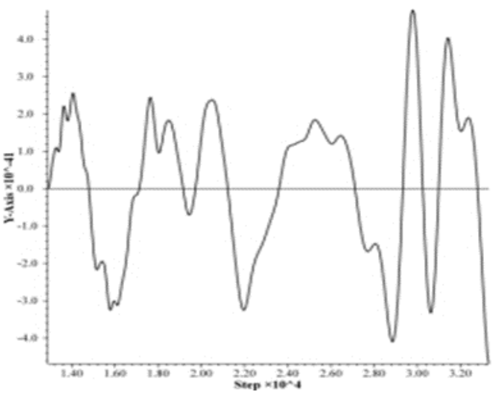

Figure 2: Peak Blast Load Time Course Curve

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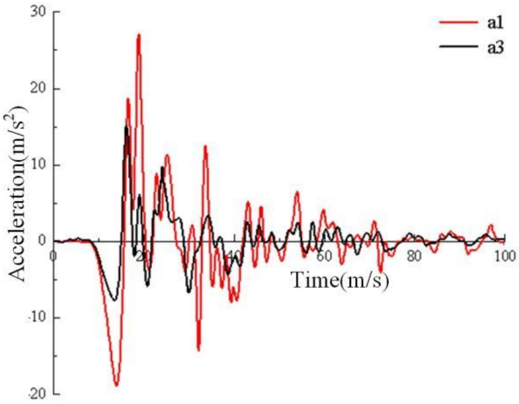
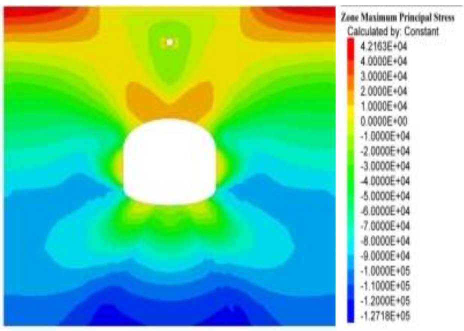


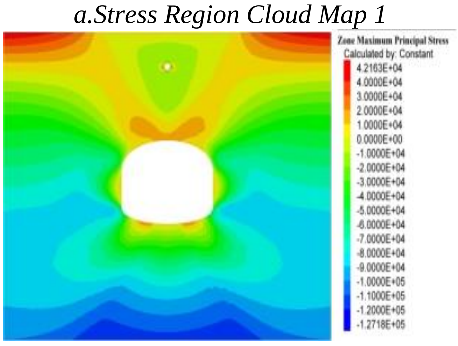
Figure 3: Acceleration Time-course Curves

From the analysis in Figure 3, it is clear that modelled accelerations are the first to peak. Then it quickly reaches another peak and finally the vibration stabilises near the zero point.Overall, the data are more credible.

Plots of the maximum principal stress distribution for each time course, As shown in Figure 4; Where positive values indicate tensile stress and negative values indicate compressive stress.As can be seen in Figure 4, After the blast load is applied, the value of compressive stress around the perimeter of the borehole begins to gradually increase and propagate outwards;During the rising stage of the stress wave, tensile stress zones appeared in both the top region of the modelled chamber and the lower region of the floor slab, and with the passage of time, the upper and lower tensile stress zones were gradually connected and extended to the left and right boundaries of the model.Tension zones have formed on the sides of the cave chamber and cracks may have formed there;A more pronounced compressive stress zone was observed at the arch foot of the modelled cavern, where the media unit has entered the destruction phase;In the descending phase of the stress wave, the development of the model tensile stress zone basically tends to stabilise with the increase of loading time, and the stress magnitude basically remains unchanged.Therefore, the damage damage produced to the rock body of the cave during the rising phase of the stress wave will play a decisive role in determining the size of the damage damage of the whole process.The time required for the stress wave to reach its peak is mainly related to factors such as the diameter of the borehole, the line of resistance, the strength of the rock mass and the geological environment.The time-course curve of compressive stress is a rapid rise to the peak value, then a rapid fall, and finally the vibration stabilises near the zero point.



a.Stress Region Cloud Map 1



b.Stress Region Cloud Map 2

Figure 4: Maximum Principal Stress Distribution of the Model

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3.2 Characteristics of Displacement Evolution of the Cavern under Explosive Loading

Figures 5 and 6 show the displacement time-course curves and vertical displacement distributions of the model, respectively, with positive values indicating upward displacement and negative values indicating downward displacement.

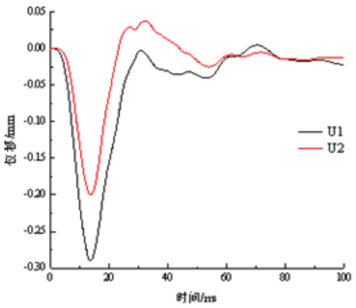
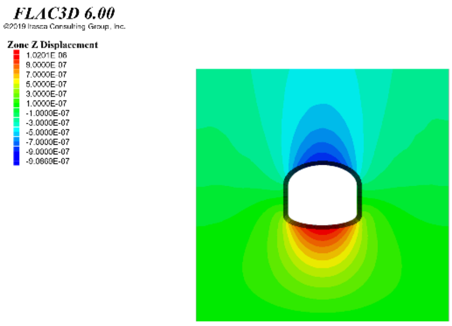
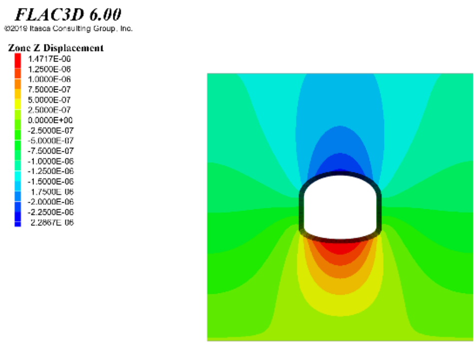


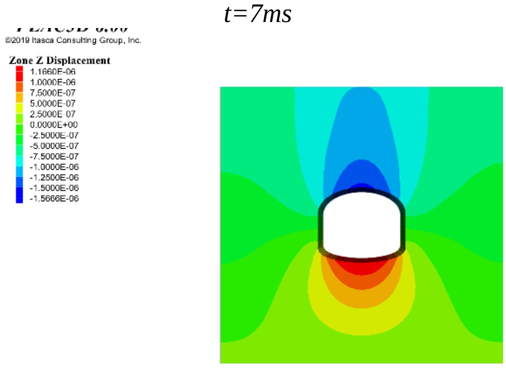
Figure 5: Displacement Time Curve



t=3ms



t=7ms



t=10ms

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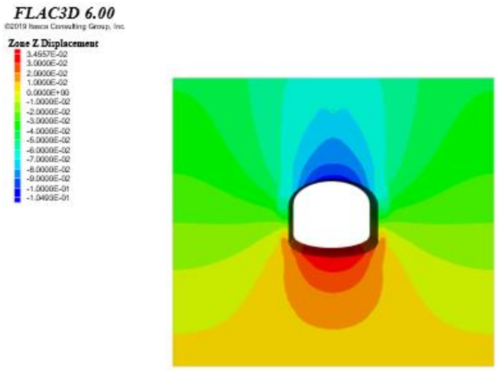
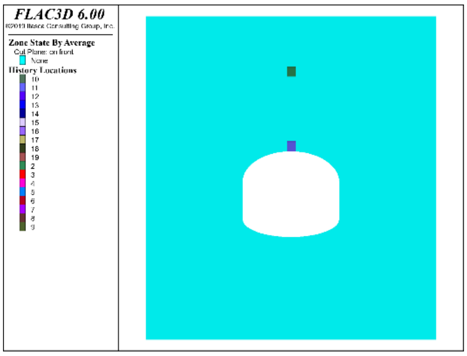


t=20ms

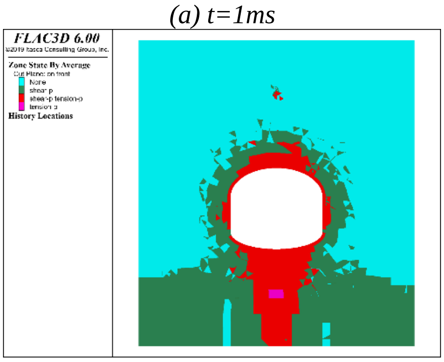
Figure 6: Vertical Displacement Distribution of the Model

As can be seen in Figure 6, after the application of the explosion load, the displacement of the chamber from the "U" shape gradually to the two sides of the expansion of the area first gradually increased, and finally tend to stabilise; In this case, the displacement of the media unit is relatively greater in the region near the gunhole, where significant fracture fragmentation may have occurred.

3.3 Characteristics of the Evolution of the Plastic Zone of the Cavern under Explosive Loading



(a) t=1ms



(b)t=10ms

Figure 7: Cloud Map of the Plastic Zone of the Modelled Dielectric Cell

As can be seen in Figure 7, modelled cavern under the action of the explosion stress wave will occur in shear and tensile two plastic states, when the explosion stress wave did not propagate to the cavern, the medium in contact with the first tensile yielding;The development of the tensile plastic zone is significantly weakened due to the propagation distance and the attenuation effect of the cavern; cracking of the cavern vault may occur due to the large peak of the modelled burst pressure;With the change of time, the development of the plastic zone of the model basically tends to be stable, and the media unit near the vicinity of the borehole mainly undergoes tensile-shear damage, and the media unit away from the periphery of the borehole mainly undergoes tensile damage.The concentration and extent of the plastic damage zone develop faster during the loading process. However, when the stress wave reaches the peak stress, the damage sizes corresponding to different loading rates are basically equal, and the loading rate does not have much influence on the final damage extent, but the development speed of the

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damage zone is more related to the loading rate.

4. Conclusion

In this paper, based on the three-dimensional finite-difference numerical simulation platform, the dynamic response characteristics of underground cavern under blasting load are investigated, and the following conclusions are drawn:

(1)The stress characteristics of the cave chamber under the action of stress waves are show that During the rising phase of the stress wave, the cavern has entered the destructive phase; In the descending phase of the stress wave, with the increase of loading time, the change of the tensile stress zone of the numerical model basically tends to stabilise, and the stress magnitude is basically unchanged.

(2)The displacement characteristics of the cavern under the action of stress waves are shown that The displacement area of the cave chamber gradually expands from the "U" shape to both sides, and the area first gradually increases and finally tends to be stable; obvious rupture and fragmentation may occur in the area of the modelled cave chamber.

(3)Characteristics of the plastic zone of the cave chamber under the action of stress waves are shown

That when the explosion stress wave propagates to the cavern, the lining structure enters the tensile plastic state, and the media unit near the gunhole mainly undergoes tensile shear damage, and the media unit away from the periphery of the gunhole mainly undergoes tensile damage.

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