Study on wave propagation law of blasting stress and crack evolution characteristics of granite with weak interlayer

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Abstract. To investigate the influence of weak interlayers in rock mass on the propagation law of blasting stress waves and the propagation characteristics of rock mass blasting cracks, numerical simulation methods were used to study the propagation law of blasting stress waves and the propagation characteristics of rock mass damage cracks in granite tunnels without and containing weak interlayers, based on a certain excavation project of a granite tunnel containing weak interlayers. The research results indicate that when there are weak interlayers distributed around the blast hole, on the one hand, the weak interlayers will have a blocking and reflecting effect on the blasting stress wave, and on the other hand, the existence of weak interlayers will change the evolution direction of rock blasting cracks, which is manifested as over-excavation in the weak interlayered area in engineering. The research results can provide guidance for the design of tunnel blasting parameters with similar adverse geological conditions.

Keywords: blasting; weak intercalation; blasting stress wave; crack growth; numerical simulation

1 Introduction

The drilling and blasting method is still an important method for excavation and excavation of mountain tunnels due to its universality, low cost, flexibility, and convenience[1]. However, in the process of tunnel excavation, the existence of adverse geological phenomena such as excessive damage to the surrounding rock caused by tunnel blasting and severe over-excavation and under-excavation is not uncommon. Engineering rock mass contains a large number of structural planes with weak mechanical properties such as joints, cracks, weak interlayers, and fractured zones. The existence of structural planes can affect the integrity of the rock mass and the propagation of blasting stress waves in the rock mass, thereby affecting the effectiveness of tunnel blasting forming. Therefore, studying the propagation law of explosive stress waves in rock masses containing structural planes has significant guiding significance for optimizing tunnel blasting parameters and improving blasting quality.

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The influence mechanism of the structural plane on the propagation of blasting stress waves in rock mass has always been the focus of geotechnical engineering research. Scholars at home and abroad have achieved rich results in the study of the propagation law of blasting stress waves in jointed rock mass[2-4].Li Kun et al.[5] studied the waveform of joints under different impact loads and the transmittance of stress waves under different joint morphology through impact load tests, and found out the law between JRC value and stress wave transmittance. Chen, X et al.[6] studied the relationship between the wave propagation coefficient and the contact condition of the joint surface through experiments. Liu Di et al.[7] studied the process and cause of blasting crack propagation in rock blocks with different weak interlayers by combining experimental and numerical simulation methods. Sun et al.[8] discussed the influence of the thickness, position, and angle of the weak interlayer on the propagation of explosion stress waves. Liu et al.[9] used the method of discrete element numerical simulation to study the propagation law of explosion stress waves in parallel filled joints with different spacing. From the above research, it can be seen that there are many studies on the propagation law and influence mechanism of stress wave in rock mass with joints and weak interlayers, and there are few studies on the influence of weak interlayers on blasting damage and crack propagation of rock mass.

This article relies on a granite tunnel excavation project and establishes a double-hole blasting model of granite with weak interlayers using finite element software ANSYS/LS-DYNA. The stress wave propagation law and rock damage crack propagation characteristics of granite blasting under different positions of weak interlayers are studied, providing guidance for the design of tunnel blasting parameters with similar adverse geological conditions.

2 Project overview

The surrounding rock category of a certain tunnel excavation project is mainly Grade III granite, with a relatively complete lithology. The main unfavorable geological phenomenon is that the face contains obvious weak interlayers, as shown in Figure 1. After on-site testing, its main component is a clay mixture with lower strength. From the perspective of the construction process and smooth blasting effect, under the conditions of construction according to the original blasting parameters, the phenomenon of over-excavation and under-excavation around the weak interlayer is relatively serious.

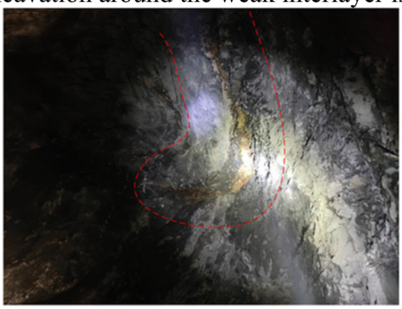


Fig. 1. Schematic diagram of weak interlayers on the site face

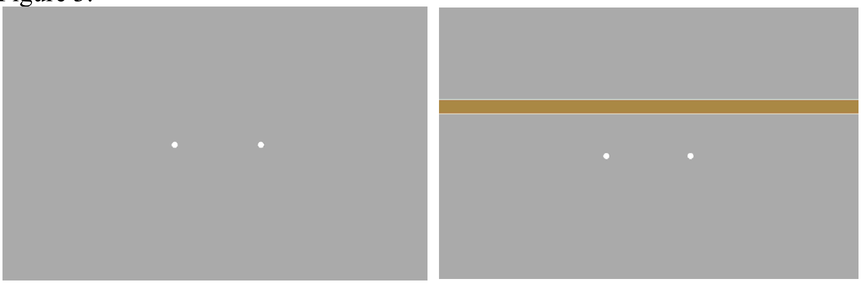
In summary, it can be seen that the original peripheral hole blasting parameters are no longer applicable to tunnel excavation sections containing weak interlayers. Therefore, it is necessary to optimize and improve the original plan. Therefore, further research is needed on the mechanism of the influence of weak interlayers on the blasting effect of peripheral holes.

3 Numerical simulation

3.1 Numerical model construction

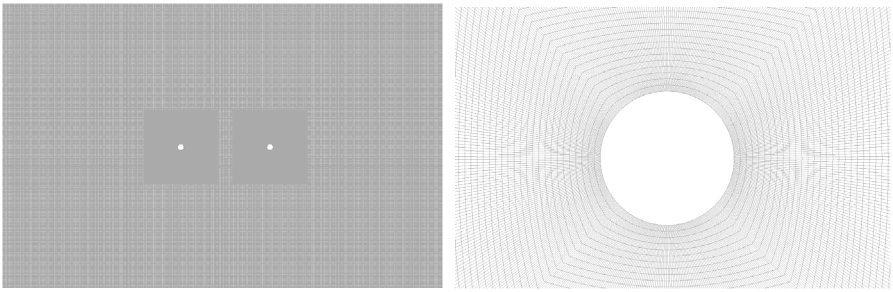
Geometric modeling and mesh generation.

To study the propagation law of stress waves and crack propagation characteristics of granite blasting with weak interlayers, two blasting models were established: without weak interlayers and with weak interlayers on one side of adjacent blast holes. To achieve a better crack propagation effect, this article chooses to establish a quasi-two-dimensional model, which means there is only one element in the thickness direction. The model size is 200 cm × 250 cm, with a blast hole diameter of 4.0 cm, an explosive diameter of 3.2 cm, and a weak interlayer thickness of 10 cm. The calculation models for each working condition are shown in Figure 2. The overall model grid quantity is 356825, and the schematic diagram of the overall and local grid of the model is shown in Figure 3.



(a) No weak interlayer (b) Weak interlayer on one side

Fig. 2. Schematic diagram of model operating conditions



(a) Overall grid (b) Local grid

Fig. 3. Schematic diagram of model operating conditions

Material model.

1) Rock material model.

Rock mass and weak interlayer are defined by HJC constitutive model, and the keyword is *MAT_JOHNSON_HOLMQUIST_CONCRETE[10]. The values of rock material parameters and weak interlayers are selected based on the surrounding rock conditions of the tunnel in the experimental section of this project and are determined by basic mechanical experiments and geological exploration data, with reference to the suggestions proposed by Fang Qin et al.[11]. The specific parameter values are shown in Tables 1 and 2.

Table 1. Material parameters of granite HJC model

Basic mechanical parameters		Limit surface parameters		Damage parameters		Pressure parameters		Strain rate parameter	
ρ	2660kg/m^3	A	0.30	D_1	0.04	p_c	50MPa	C	0.0097
f_c	154MPa	B	2.5	D_2	1	U_C	0.00162		
G	28.7GPa	N	0.79	$EFMIN$	0.01	K_1	12GPa		
T	12.2MPa	$S_{\max}$	15			K_2	25GPa		
						K_3	42GPa		
						p_l	1.2GPa		
						U_l	0.012		

Table 2. Material parameters of weak interlayer HJC model

Basic mechanical parameters		Limit surface parameters		Damage parameters		Pressure parameters		Strain rate parameter	
ρ	2340kg/m^3	A	0.79	D_1	0.04	p_c	17MPa	C	0.0097
f_c	25MPa	B	1.4	D_2	1	U_C	0.00125		
G	573MPa	N	0.51	$EFMIN$	0.01	K_1	85GPa		
T	1.3MPa	$S_{\max}$	7			K_2	-171GPa		
						K_3	208GPa		
						p_l	1.2GPa		
						U_l	0.38		

2) Air Material Model.

The air material is defined using the keyword *MAT_NULL[12], and the detailed parameters are shown in Table 3.

Table 3. Air material parameters

ρ /(kg/m^3)	C_0	C_1	C_2	C_3	C_4	C_5	C_6	E_0 /MPa
1.20	0	0	0	0	0.4	0.4	0	0.25

3) Explosive material model.

The explosive material is defined by the keyword *MAT_HIGH_EXPLOSIVE_BURN, and the detailed parameters are shown in table 4.

Table 4. Explosive material parameters

ρ /(kg/m^3)	D /(m/s)	A /GPa	B /GPa	R_1	R_2	ω	E_0 /GPa
1250	5600	276.4	8.4	5.2	2.1	0.57	3.87

Model boundary conditions.

To prevent the reflected traction wave from affecting the calculation results and achieve the purpose of simulating infinite rock mass in a finite model, the keyword *BOUNDARY_ NON_ REFLECTING defines interfaces other than free surfaces.

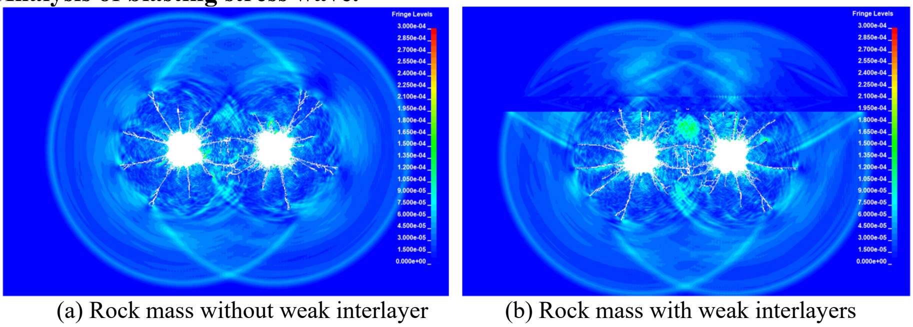
When using ANSYS / LS-DYNA for blasting analysis, the contact needs to be added between different Lagrange elements to achieve force transmission. In this paper, granite and weak interlayer are defined as different Lagrange elements, so a contact setting is needed. The contact types in ANSYS are mainly divided into three categories: single-sided contact, node-surface contact, and surface-surface contact. In this paper, surface-surface contact is used to realize the contact between granite and weak interlayer by keyword *CONTROL_CONTACT.

Implementation of Crack Propagation in Rock Mass Blasting.

In LS-DYNA, to more intuitively characterize the evolution process of blasting damage and achieve the propagation of blasting cracks, the keyword *MAT_ADD_EROSION is usually used as the failure criterion, and the propagation of cracks is achieved by deleting grid elements. This article selects the composite criterion of "maximum tensile stress" and "maximum shear strain" to achieve circumferential failure and radial crack propagation of rocks.

3.2 Analysis of Simulated Result

Analysis of blasting stress wave.



(a) Rock mass without weak interlayer (b) Rock mass with weak interlayers

Fig. 4. Comparison of two operating conditions at the same time

Figure 4 shows the equivalent stress cloud diagram of the model without a weak interlayer and the model with a weak interlayer at t = 250μs. From the diagram, it can be seen that the stress wave propagates outward uniformly in the homogeneous rock mass, and the strength of the stress wave gradually decays with the increase of the propagation distance. The existence of the weak interlayer has a barrier effect on the propagation of the stress wave. The stress wave reaching the weak interlayer loses some energy under the action of transmission and reflection so that the strength of the stress wave finally passing through the weak interlayer is severely attenuated. In addition, the stress concentration phenomenon occurs at the position near the blasting side of the weak interlayer in the middle of the two-hole connection, which is formed by the superposition of the stress wave generated by the explosive explosion in the two holes and the reflected tensile wave reflected by the weak interlayer.

To more intuitively explain the barrier effect of the weak interlayer on the stress wave, the monitoring point a below the weak interlayer and the monitoring point b above the weak interlayer is set up. At the same time, monitoring point A and monitoring point B are set up at the same position in the rock mass model without the weak interlayer. The layout of the four monitoring points is shown in Figure 5. The unit stress values of each monitoring point at different times are extracted, and the stress time history curves of each measuring point are obtained as shown in Figure 6.

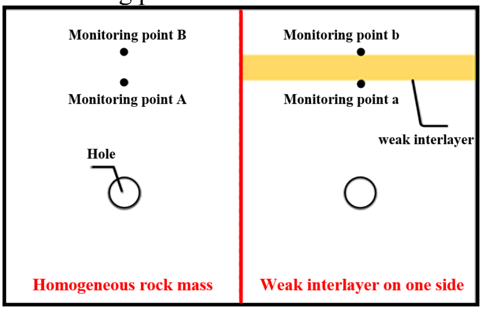


Fig. 5. Layout of monitoring points

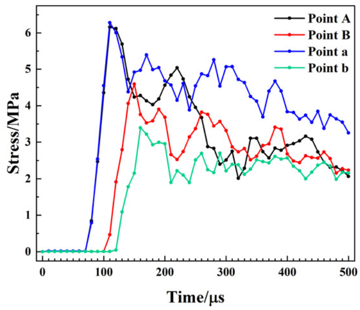
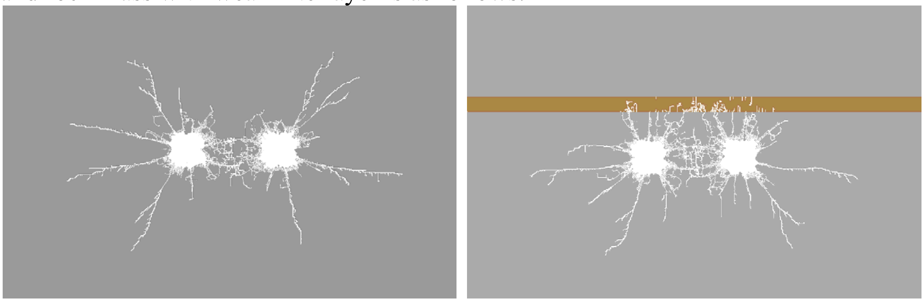


Fig. 6. Monitoring point unit stress time history curve

It can be seen from the analysis of Figure 6 that the peak stress of the two points of monitoring point A and monitoring point a is not much different. However, with the continuous propagation of stress waves, the rock mass unit at monitoring point a is affected by the reflected wave reflected from the weak interlayer, resulting in the stress at this point being greater than that at monitoring point A. By comparing the stress time history curves of the monitoring point B and the monitoring point b unit, it can be seen that the stress of the rock mass unit at the measuring point b is obviously smaller than the stress at the measuring point B at the same time, and the peak stress attenuation rate reaches 26.1 %. The weak interlayer has an obvious barrier effect on the stress wave.

Analysis of Explosion Crack Propagation.

When t = 500μs, the blasting crack propagation effect of homogeneous rock mass and rock mass with weak interlayer is as follows.



(a) No weak interlayer (b) Weak interlayer on one side

Fig. 7. Comparison of final crack propagation under two working conditions

Figure 7 shows the weak interlayer has a significant influence on the crack propagation direction and shape during the blasting process. When there is a weak interlayer, after the crack extends to the contact surface, it will hinder the crack from expanding in the original direction, but the cracks at the center of the two holes are more dense. When the crack extends to the blasting surface of the weak interlayer, it forms a penetrating crack with the cracked weak interlayer, which aggravates the damage of the retained rock mass.

During the blasting process of rock mass with weak interlayer, the damage range of weak interlayer and its surrounding area will be larger, and it is more likely to form overbreak in engineering. Therefore, when designing blasting parameters, especially surrounding hole parameters, the blast hole in the weak interlayer area should be appropriately reduced or the hole spacing should be increased.

4 Conclusions

1) The existence of a weak interlayer will produce a blocking effect, transmission, and reflection effect on the blasting stress wave, and will change the shape and development process of rock mass crack propagation, thus affecting the blasting effect.

2) When the weak interlayer is located on the side of the blast hole, the existence of the weak interlayer makes the rock mass damage between the blast hole and the weak

interlayer obviously intensified, and there are dense cracks, which leads to the expansion of the penetrating fracture area between the adjacent blast holes.

3) In the blasting process of rock mass with a weak interlayer, the damage range of the weak interlayer and its surrounding area will be larger, and it is easier to form overbreak. Therefore, in the design of blasting parameters, especially the surrounding hole parameters, the hole parameters in the weak interlayer area need to be designed separately.

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