Analysis of Blasting Failure Characteristics and Damage Mechanism of Different Rock Mass Elastic Modulus Under Deep Crustal Stress

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Abstract: In order to study the effect of elastic modulus of rock mass under deep crustal stress on blasting failure characteristics and damage mechanism, this paper simulates rock blasting with different elastic modulus through particle flow software. The blasting failure characteristics of rock mass are obtained by reading the peak stress changes from the measuring points. The damage mechanism of rock blasting is revealed from the aspects of crack distribution, crack development trend, fragment formation. The results show that: As the elastic modulus increases, the peak stress of each measuring point is gradually decreasing; with the increase of elastic modulus, the macro cracks of rock mass become shorter after blasting; when the elastic modulus is 48 GPA, the number of cracks is the largest and the development is relatively gentle.

1. Introduction
Blasting can cause great damage to surrounding materials (such as hard rock, coal seam.) at the moment of energy release. Rock blasting is widely used in underground chimney, oil field, coal seam, tunnel and mine mining[1-5]. With the continuous demand of human resources, the mining depth is also increasing. The complexity of the modulus of elasticity has a certain impact on the blasting effect. Chinese and foreign scholars[6-12] have extensively studied the influence of crustal stress on blasting.

Ma[13] and others analyzed the influence of in-situ stress, joint surface, blasting loading rate and other parameters on the distribution of rock blasting cracks through LS-DYNA software, and considered that the blasting loading rate has a significant impact on the blasting cracks of rocks. Hu[14] and others simplified the rock as elastic medium. From the theoretical point of view, it is considered that the bond coefficient and elastic modulus of rock have great influence on the attenuation of stress wave produced by rock blasting. The attenuation coefficient decreases with the increase of elastic modulus and increases with the increase of viscosity coefficient. Yuan[15] and others analyzed the influence of different decoupling coefficients on the permeability of sandstone after blasting and the influence on the meso parameters of rock mass. The above scholars have made outstanding contributions to the study of different parameters on the surrounding rock blasting effect. At present, most of the surrounding rock blasting is simulated by the finite element method. The analysis mainly focuses on the attenuation of the propagation process of the blasting stress, velocity, energy, etc., and few scholars use the discrete element method to analyze the research on meso failure mechanism of different elastic modulus of rock mass on surrounding rock blasting cracks.

This paper takes sandstone as the research object, compiles fish function to simulate the evolution law of rock mass blasting macro and micro damage under different elastic modulus, and deeply analyzes
the influence mechanism of elastic modulus on blasting. The results have certain theoretical significance for practical blasting engineering.

2. Establishment and theoretical analysis of numerical blasting model

2.1. The application of blasting load in numerical simulation
Particle flow simulation of rock blasting is mainly due to the rapid expansion of the blasting point particles in the model, resulting in the extrusion of the surrounding particles. Meanwhile, the explosion stress wave quickly scatters to the surrounding area in the form of cylindrical wave with the explosion point as the center. Generally, the explosion stress wave is equivalent to a pulse wave, which is simplified as a half sine wave with equal stress rise and fall time.

2.2. Model parameters and material parameters
In order to explore the impact of blasting on rock meso damage, this paper establishes a 800mm × 800mm single hole blasting model. The center of the model is a blasting point with a diameter of 40mm. The measuring circle in the direction of large principal stress and small principal stress is added to the blasting model as shown in Figure 1, which is used to measure the change of velocity and stress of local rock under blasting impact after blasting. The blasting point is located in the center of the model. Sandstone is used as the rock, and the main simulation parameters are from the article of yuan [15] and others.

![Figure 1 Schematic diagram of blasting model](image)

2.3. Model implementation and boundary conditions
The generation of particles in particle flow simulation includes void ratio generation and particle size distribution generates the particle sample. In this paper, the void ratio is used to generate the particle sample which advantage is that it can generate a large number of particles quickly. After the sample is generated, servo pressure is applied to the sample to make the sample reach the preset confining pressure to simulate crustal stress, and the particle displacement is cleared to eliminate the imbalance of internal force caused by servo.

In the particle flow code, firstly, the wall is servo controlled by fish function, and the wall moves slowly to the sample, causing extrusion to the sample generated in the wall until the preset confining pressure is reached, so as to realize the effect of crustal stress on the sample (P in Figure 1 represents the confining pressure). When the explosion stress propagates to the boundary, the existence of the wall will make the stress wave reflect. Therefore, before blasting, it is necessary to apply the same force to the boundary particles as the wall to the boundary particles and remove the wall to achieve the effect of applying crustal stress.
2.4. Test plan
The single hole blasting model with model size of 800mm × 800mm was used to simulate the blasting conditions with the crustal stress of 4 MPa and the elastic modulus of 28, 38, 48, 58, 68 GPA respectively.

3. Influence of elastic modulus on deep rock mass

3.1. Analysis of peak stress at different measuring points

![Graphs showing variation of peak stress with blasting center distance under different elastic modulus](image)

Figure 2. Variation of peak stress with blasting center distance under different elastic modulus: (a) Measuring circles 1-4; (b) Measuring circles 5-8

It can be seen from Figure 2 that with the increase of blasting center distance, the blasting of rock mass with different elastic modulus tends to decay. Figure 2 (a) when the blasting center distance is less than 0.2 m, the influence of different elastic modulus on the peak stress of rock mass after blasting is small. When the blasting center distance is greater than 0.2 m, the peak stress of rock blasting appears two trends, and the peak stress of elastic modulus of 48-68 GPa is significantly lower than that of 28-48 GPa. Figure 2(b) shows the influence of different elastic modulus on the stress peak value of blasting center distance in the direction of small principal stress. The stress peak value with elastic modulus of 68GPa is significantly higher than that of other elastic modulus, and the stress curve with elastic modulus of 28GPa has the most obvious downward trend, which indicates that the stress dissipation is large in the process of blasting stress propagation.

3.2. Crack distribution of different elastic modulus

![Crack distribution images](image)
Figure 3 Schematic diagram of rock blasting crack under different elastic modulus: (a) 28GPa; (b) 38GPa; (c) 48GPa; (d) 58GPa; (e) 68GPa

It can be seen from Fig. 3 that the blasting crack diagram of rock mass with different crustal stress can be roughly divided into two areas. The first area is a crushing area near the blasting hole. At the moment of explosive explosion, a large amount of energy in the blast hole directly acts on the nearby rock mass, resulting in crushing failure of rock mass. The second area is the rock mass cracking area outside the first area. The first area absorbs the blasting energy, and the second area's energy rapidly decays, causing the rock mass to crack, which is shown as a through crack.

It can be seen from Figure 3 that with the increase of elastic modulus, the number of macrocracks in the cracking zone is significantly reduced, and the length of macrocracks is significantly shortened. When the maximum elastic modulus is 68 GPa, there are almost no macrocracks. The change of elastic modulus has little effect on the fracture zone. In Figure 3, the fracture zone is filled with a large number of tensile cracks and a small number of shear cracks (red is tensile crack, black is shear crack). The fracture area in Figure 3 (d) and (e) is obviously larger than other figures. The main reason is that with the increase of elastic modulus, a lot of blasting stress is absorbed in the fracture zone, resulting in insufficient stress in the cracking zone and a large number of macrocracks with long length. Therefore, with the increase of elastic modulus, the dissipation of blasting load transferred to the cracking zone is greater, which is not conducive to the application of practical engineering.

3.3. Development trend of cracks with different elastic modulus

Figure 4 Development trend of rock crack in blasting with different crustal stresses: (a) Shear cracks; (b) Tensile cracks

In the process of rock blasting, the blasting load is released rapidly, and the rock mass will occur plastic deformation rapidly, and the cracks will develop rapidly. By counting the change curve of the number of cracks, and analyzing the characteristics of crack development under the action of different elastic modulus, the blasting failure characteristics of rock mass are further analyzed from the micro perspective.

Figure 4 shows the development trend of shear cracks and tensile cracks in the process of rock blasting. It can be seen from the figure that the number of tensile cracks is far less than the number of shear cracks,
and the tensile cracks develop more rapidly, and they basically do not develop after 50 microseconds of rapid development. Shear cracks dominate the whole development process of cracks in the blasting process. In Figure 5(a), with the increase of elastic modulus, the tensile cracks produced by rock blasting show a decreasing trend, and the tensile cracks are the most when the elastic modulus is 28GPa. In Figure 5(b), when the elastic modulus is 48 GPa, the number of cracks is significantly more than that of another elastic modulus, indicating that when the elastic modulus is 48 GPa, the rock mass is most likely to crack due to blasting.

3.4. The number of fragments produced by rock blasting

Based on the statistics of the number of fragments in the process of rock blasting and the change rate of the maximum fragment volume, the mechanism of rock blasting is further analyzed from the micro perspective.

It can be seen from Figure 5 that the development curve of the number of fragments produced by rock blasting firstly shows an upward concave trend. The main reason is that the blasting point of the simulated explosive bag expands rapidly in the initial stage of blasting, while the blasting stress wave has not yet propagated, resulting in the generation of small-scale fragments, and then the blasting stress wave propagates rapidly. The number of fragments developed rapidly, and the number of elastic modulus cracks was the largest, and secondary fragments increased around 180 microseconds. The main reason was that the rapid increase of blasting load produced a large number of cracks, and the subsequent residual blasting load continued to act on these cracks to produce more fragments.

4. Conclusion

In this paper, the change of peak stress, crack distribution and crack trend, the change of fragment number and trend, the change of fractal dimension of crack and the change of internal energy of blasting rock mass under different elastic modulus are simulated by particle flow numerical simulation. The blasting mechanism of rock mass under different crustal stress is analyzed deeply from the micro perspective.

1) For different elastic modulus, the peak stress of each measuring point decreases with the increase of the blasting centers distance, and the decreasing trend becomes gentle when the blasting centers distance is greater than 0.2m.

2) With the increase of crustal stress, the fracture area of rock blasting cracks is increasing, and the macrocracks in the cracking area are gradually becoming shorter.

3) Analysis of crack generation trend which can well simulate the process of crack formation during blasting under different crustal stresses. With the increase of elastic modulus, the number of shear cracks increases, and when the elastic modulus is 48 GPa, the number of tensile cracks is the most. The development trend of rock fragments after blasting from cracks is similar.
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