Study on Dynamic Load of Surrounding Rock Failure Based on Finite Element COMSOL Numerical

Chengyu Xie 1, *, Hao Lu 1, Jie Cao 1, Lei Chao 1, Nan Jia 2

1 School of Environment and Resources, Xiang tan University, Xiang Tan, China.  
2 Institute of public safety, Tsinghua university, Beijing, China.

*Corresponding author e-mail: 187194616@qq.com

Abstract. In the stope or other blasting excavation process, it is difficult to directly analyze the stress change process of the shock wave generated by the blast in the rock, and the change of the shock wave is very important for the selection of the explosive parameters and the analysis of the excavation process. Taking a mining blasting as the actual background, according to the parameters of rock parameters, using COMSOL Metaphysics simulation software, the transient force variation model of blasting rock was constructed with and without reflection boundary conditions, and the transient change at 1600ms interval was used. The force law of blasting waves in rock is analyzed. In the simulation numerical analysis, the time when the pressure wave reaches the surface is the same as the time when the reflected pressure wave reaches the sampling point under the condition of using the reflection boundary. In the early stage of elastic wave propagation, the stress change of the block first rises first. After reaching the peak value, it falls below the original stress and then slowly rises again. Then the two responses caused by the reflected wave begin to deviate from each other. The simulation results can provide reference and technical support for controlling the damage of surrounding rock under blasting impact.

Keywords. Dynamic load; roadway surrounding rock; finite element analysis; numerical simulation.

1. Introduction

In the stope blasting or other excavation, blasting bankruptcy shockwave raw force changes in the rocks of the process is difficult to directly analyze, and change of explosive shock wave parameters and the excavation process analysis is very important of. Literature [1] uses FLAC3D numerical simulation software to simulate the distribution of plastic zone between two blast holes with different intervals from three-dimensional angle, and evaluate the development of cracks in blast holes. In [2], FLAC(~ 3D) and COMSOL software were used to study the arrangement of different spacing blast holes, and the optimal blasting hole spacing was determined. Based on the fluid-solid coupling theory, the literature [3] uses the multi-physical coupling analysis software COMSOL to find that the stress and strain of surrounding rock have changed greatly due to mining. Literature [4] the relationship between the structural characteristics of the rough single rock fracture and the seepage characteristics was studied using COMSOL multiphasic software. The literature [5] uses COMSOL to numerically simulate the
bolt grouting process. The diffusion of slurry under different grouting pressures and different bolt arrangements was studied. Literature [6] uses COMSOL the HTC coupling process in fractured carbonate rocks was simulated.

In summary, the use of COMSOL software to study the solid - gas coupling problem has a strong advantage [7–9]. Therefore, based on the relevant research and design data, the COMSOL Metaphysics simulation software simplifies the reasonable model, aiming to obtain the stress change map in the early block of elastic wave propagation and the displacement of the upper surface applying low reflection boundary conditions. FIG changes with time, the final result of the simulation by sub- resolution variation thereof. The simulation results can provide reference and technical support for controlling the damage of surrounding rock under blasting impact.

2. Project Overview

Taking a metal mine as an example, the model of the experimental stope is simplified. The blasting rock is a rock with a length and width of 9.6 m and a depth of 4.8 m. The explosion point is the center of the bottom surface, and the minimum resistance line is 4.8 m (shown in Figure 1).

![Figure 1. Dynamic simulation model](image)

3. Numerical simulation model

Select 1/4 modeling of the project, the blasting charge is 2g, the model width is 4.8m, the length is 4.8m, and the depth is 4.8m.

The study step is 4e-6 and the study duration is 1600ms. The study load function is:

\[ P_0 \times \exp(-\gamma t/t_0) \times \sin\left(\frac{4\pi t}{1+t_0/t}\right) \]  

(1)

Where \( P_0 \) is the load, and the load calculation formula is \( \gamma \) is the decay rate; \( t_0 \) is the current time.

\[ 140e6 \text{[N]} \times (Q/1[\text{kg}])^{2/3} \]  

(2)

Other parameters are as follows:

| Table 1. Main parameters of rock and ore body |
|---------------------------------------------|
| **Rock parameter** | **Ore body** |
| Density \((\text{kg} \cdot \text{m}^{-3})\) | 2700 |
| Modulus of elasticity / GPa | 50 |
| Poisson ratio \(\nu\) | 2/7 |
Figure 2. Model definition diagram
Figure 3. Load function diagram

the bottom boundary load is:

\[ 0.25 \times P_b (t)/L_1^2 \times (X \leq L_1) \times (Y \leq L_1) \]  

(3)

3.1. Numerical analysis results

Explosives release huge energy during the explosion, and the outward propagation of the explosion shock wave acts on the surrounding medium. Therefore, it can be considered that the action is the process of stress wave propagation in the medium. As shown in Figure 4, the stress wave propagates from the explosion source. The distance between the fulcrum in the medium and the center of the explosion is different, and the stress wave exhibits different characteristics. And when the time is \( t_0 = 9 \times 10^{-4} \), the stress wave reaches the top surface of the rock, as shown in Figure 4:

Figure 4. Stress wave propagation

This simulation mainly explores the time relationship and propagation characteristics of stress waves reaching the boundary of the model under different boundary reflection conditions. It can be seen from Figure 5 (a) and (b) that the conditions of low reflection boundary and non-low reflection boundary are the results are consistent. When the time is:

\[ t_0 = 1.016 \times 10^{-3} \]  

(4)
Figure 5. (a) Stress wave reaches the side boundary (low reflection boundary condition) (b). Stress wave reaches the side boundary

After the stress wave reaches the boundary, a boundary is generated in the primary reflection phenomenon makes some stress cloud explosion boundary hair coupled back stress wave emitted interaction, such that the stress in the cloud model showing the change, As shown in Figure 6, the reflection phenomenon is most pronounced at the near boundary.

Figure 6. Stress wave reflections

At: $t_0=1.6\times 10^{-3}$ the low-reflection boundary conditions and the non-low-reflective boundary conditions show different stress clouds. As shown in Fig. 7, it can be found that the boundary reflection has slight interference to the stress cloud, and the interference mainly shows the difference of the stress cloud at the near reflection boundary. There is no difference at the non-near boundary, and the boundary reflection interference is basically negligible.
However, in simulating the propagation of waves in large vibration structures, it is necessary to strike a balance between reducing the size of the computational domain and reducing the reflection of the surface boundary, making the stress cloud more realistic.

![Figure 7. Contrast between reflective and non-reflective boundaries](image)

(a) a non-low reflection boundary  
(b) a low reflection boundary

Under the condition of non-low reflection boundary, the stress of the z component diffuses from the lower boundary corner to both sides and is distributed in layers. When the position is about 3 meters on the lower boundary, the stress is highly concentrated and reaches the extreme value, similar to the flow waterfall type. Under the condition of low reflection boundary, the upper boundary stress is stronger than the lower boundary, and spreads from the upper boundary corner point to both sides. It is also distributed in layers, and the force is relatively divergent. The whole model stress is trapezoidal in the interior and Concentration within the upper boundary.

![Figure 8. Total displacement cloud map](image)

The change of the stress along the z component of the total displacement is very strong in the displacement of the relatively concentrated stress.

![Figure 9. Z- Direction velocity cloud](image)
In terms of speed variation, whether it is a non-low reflection boundary condition or a low reflection boundary condition, its velocity change is based on the stress variation distribution. The velocity change is opposite to the stress variation, that is, the velocity of the stress concentration point is low, and the location of the stress is small.

4. Conclusion

Based on the specific mining engineering practice, using COMSOL Metaphysics simulation software, the variation law of the blasting wave in the rock is obtained by constructing the transient force variation model of the blasting rock. According to the simulation results, the explosives release huge energy when they explode, and the explosion shock wave propagates outward to the surrounding rock mass medium. The stress wave propagates from the explosion source. The stress wave appears as the distance between the fulcrum in the medium and the explosion center is different. The stress cloud diagrams exhibited by the low-reflection boundary conditions and the non-low-reflection boundary conditions are different; the difference of the stress clouds at the near-reflection boundary is not different at the non-near-boundary boundary, and the boundary reflection interference is basically negligible. Under the condition of non-low reflection boundary, the stress of the z component diffuses from the lower boundary corner to the two sides and is distributed in a layered manner. Under the condition of low reflection boundary, the force of the whole model is approximately trapezoidal and internally at the upper boundary.

Acknowledgments

This study is supported by Hunan Province Science Foundation for Youth Scholars of China fund (2018JJ3510) & Beijing Natural Science Foundation (No.9194027).

References

[1] Ti Z, Feng Z, Jin P, et al. Permeability enhancement of deep hole pre-splitting blasting in the low permeability coal seam of the Nanting coal mine. Plos One, 2018, 13(6): E0199835.
[2] Hong L, Chi MA, Chen S. Layout parameters numerical simulation in carbon dioxide blasting. Journal of Liaoning Technical University, 2017, 36(10): 1026-1030.
[3] Zhang YJ, Fan C. Seepage Field-Strain Field Coupling Analysis for Rock Masses of Coal Seam Floor during Mining Based on COMSOL. Advanced Materials Research, 2014, 1010-1012: 1467-1470.
[4] Zhang Q, Yang J, Gong W, et al. Numerical simulations of seepage flow in rough single rock fractures. Petroleum, 2015, 1(3): 200-205.
[5] Shen-Ju LI, Wang LG, Yin-Long LU, et al. Slurry diffusion within cracked wall rock during the bolt-grouting process. Journal of China University of Mining & Technology, 2011, 40(6): 874-880.
[6] Ma G, Yun C, Yan J, et al. Modelling temperature-influenced acidizing process in fractured carbonate rocks. International Journal of Rock Mechanics & Mining Sciences, 2018, 105: 73-84.
[7] Muuri E, Sorokina T, García D, et al. The in-diffusion of 133 Ba in granitic rock cubes from the Olkiluoto and Grimsel in-situ test sites. Applied Geochemistry, 2018, 92:188–195.
[8] Jiang R, Mei L, Zhang Q M. COMSOL Multiphysics Modeling of Architected Acoustic Transducers in Oil Drilling. Mrs Advances, 2016, 1(24):1755-1760.
[9] Hassani F, Nekoovaght PM, Gharib N. The influence of microwave irradiation on rocks for microwave-assisted underground excavation. Journal of Rock Mechanics and Geotechnical Engineering, 2016, 8(1): 1-15.