Model Construction of Blasting Vibration Reduction to Protect Surrounding Rock in Open-pit Mining Under Complex Environmental Conditions

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Abstract

Drilling and blasting method is the main method of breaking rock for open-pit excavation. The blasting vibration generated leads the slope rock mass to dynamically respond, which affects the stability of the slope. In order to reduce the blasting damage of slope remaining rock mass caused by conventional blasting, the calculation method of the dynamic load of the decoupled charge structure on the blast hole wall is proposed, and the blast dynamics process of the vibration reduction and rib protection is analyzed. The three-dimensional model of open-pit slope was established by the finite element software of Midas GTS, and the static stability evaluation of open slope was carried out. The research showed that the impact of blasting vibration on the slope was effectively reduced by the blasting vibration blasting method. For the stress or vibration velocity distribution of the open slope, the field test was difficult to measure, and the finite element numerical simulation could be quickly obtained.

Keywords

Complex environmental condition, stope mining, blasting damping, blasting of rib protection.

1. Introduction

Blasting mining is the primary link in the total cost control of open pit mining. The cost of drilling-and-blasting is relatively low, accounting for only about 1/15 of the total cost of mining [1]; however, the effect of blasting will directly affect the production efficiency and energy consumption of shoveling and loading, transportation ,crushing and other processes [2]. Therefore, the blasting stage can increase the damage crushing degree of the ore rock and reduce the unfavorable factors such as bulk, rock and dike wall by changing the blasting parameters, which the production efficiency of the subsequent processes can be improved [3]. Among them, in the blasting construction of Geotechnical Engineering, the damage of remaining rock mass out of the contour caused by the blasting can not be ignored [4]. A variety of blasting methods have been proposed and adopted by domestic scholars and numerous engineers and technicians , which have achieved certain effects in damage reduction of rock mass beyond the contour line [5].In recent years, smooth blasting technology had been widely used in (open-pit mine) slope blasting. However, there were still serious over-excavation, under-excavation and rock mass damage out of contour, which affected the final stability of the slope [6].

Based on the existing controlled blasting, the vibration reduction blasting for rib protection was proposed. Compared with the conventional engineering blasting, the directional blasting with vibration relief isolation blasting reduced the over-excavation and under-excavation out of boundary contour [7], a relatively flat excavation surface was obtained, and the damage of remaining rock mass is reduced to the greatest extent [8].The slit-charge directed fracture blasting method precisely controls the directional propagation of blasting cracks [9], which can effectively reduce over-excavation and under-excavation, greatly improve the blasting effect, and is widely applied to rock blasting engineering [10].

Numerical simulation is an effective method for optimization of the design in explosive surface mining and analysis of blasting effect . In this paper, the explosive process and dynamic mechanical parameters of common charge and slotted charge in rock are studied, and the blast of an surface mine is simulated with numerical simulation method, which provides theoretical reference for the study of slotted charge mechanism and field application.

2. The calculation method of the dynamic load of the decoupled charge structure on the blast hole wall

2.1 Air-deck Charge

After explosive detonation, explosive blast was generated in the intervallic air of the blast) hole , and transmission phenomenon occurred when the blast wave reached the hole wall, and the transmission pressure is

$$P_T = K_0 P_R \tag{1}$$

In the formula, P_T is the transmission pressure of the hole wall; P_R is the incident pressure of the hole wall; K_0 is the transmission coefficient.

$$K_0 = \frac{2\rho_1 C_1}{\rho_1 C_1 + \rho_0 V_0} \tag{2}$$

Where,$\rho_1 C_1$ represents the wave impedance of the rock mass; C_1 is the longitudinal wave velocity of rock mass,ρ_1 is the density of rock mass;ρ_0 is the wave impedance of explosives,ρ_0 for the density of explosives,V_0 is the speed of explosives

Since the hole wall deformation of air-deck charge is small, it is generally considered that: K0≈8.

Where, the incident pressure P_R can be calculated by two methods:

$$P_T = \mathrm{P}_1 \left(\frac{\mathrm{r}_0}{R_1 + U_0} \right)^6 \tag{3}$$

Where, $P_R \geq 200$MPa,r_0 is charge column;R_1 is the charge column,$P_1=1/8(\rho_0 V_0^2)$,U_0 is certain instantaneous displacement of the bore hole's wall, and

$$U_0 = \int_0^T \mathrm{v}_0(\mathrm{t})\mathrm{dt} \tag{4}$$

Where $v_0(t)$ is the particle velocity of the hole wall, and t is time.

When $P_R < 200$MPa,

$$P_R = \left(2\times10^8\right)^{\frac{1.6}{3}} \bullet \mathrm{P}_1^{\frac{1.4}{3}} \bullet \left(\frac{\mathrm{r}_0}{R_1 + U_0} \right)^{2.8} \tag{5}$$

From the law of conservation of energy

$$\mathrm{v}_0(\mathrm{t}) = \mathrm{U}_0{}' = \frac{K_0 P_R}{\rho_1 C_1} = \frac{K_0 \left(2\times10^8\right)^{\frac{1.6}{3}} \bullet \mathrm{P}_1^{\frac{1.4}{3}} \bullet \left(\frac{\mathrm{r}_0}{R_1 + U_0} \right)^{2.8}}{\rho_1 C_1} \tag{6}$$

$$P_T = \rho_1 C_1 \mathrm{v}_0(\mathrm{t}) \text{ 7-3-5} \tag{7}$$

To solve the above equation,$U_0(t)$ can be obtained.

2.2 Decked charge of river sand

When blasting was carried out by the interval charge in the blast hole, under the dynamic load of detonation wave, high temperature, high pressure and other detonation products, a shock wave was generated in the river sand medium. When the shock wave reached the hole wall of the blast hole, reflection and transmission phenomena were generated, that was, pressure was generated on the hole wall. The calculation method of its explosive dynamic load is as follows:

The stress wave at any points in the medium can be expressed as follows:

$$P_R = \Delta b_x = 880.8\overline{R} \tag{8}$$

In the formula: Δb_x (represents for stress peak in the medium where the distance from explosion center is R_0, MPa ; $\overline{R}$ is the ratio of the distance R_0 that from the charging center to the certain point to the charging radius r_0 , $\overline{R} = R_0/r_0$;

According to the continuous condition, the relation between the transmission pressure and the incident pressure on the hole wall is as follows:

$$P_R = k_2 P_R \left(\frac{2\rho_1 C_1}{\rho_1 C_1 + \rho_2 V_2} \right) \tag{9}$$

In the formula:$\rho_2 V_2$ is the wave impedance of river sand medium when the shock wave speed reached the wave speed V2,ρ_2 is the initial density of river sand. Momentum conservation can be obtained for the same reason:

$$v_1(t) = U_1' = \frac{K_2 P_R}{\rho_1 C_1} = \frac{K_2 \bullet 880.8\overline{R}^{-1.44}}{\rho_1 C_1} = \frac{K_2 \bullet 880.8 \left(\frac{r_0}{R_1 + U_0} \right)^{-1.44}}{\rho_1 C_1} \tag{10}$$

Similarly,$U_1(t)$， $v_1(t)$and $P_R(t)$ can be obtained.

3. Analysis of blast dynamics of vibration reduction to protect surrounding Rock

3.1 Blasting dynamic action of blasting hole on side with non-shielded vibration damping material

Because there is no protective PVC pipe on the side of the hole with non-protective and anti-vibration material, blast wave and explosion gas will directly load on the hole wall, which is as same as ordinary smooth blasting.The peak of the tangential and radial tensile stress that the rock mass of the hole wall subjected is both largely, namely:

$$\sigma_{\theta max} = D_0, \sigma_{rmax} = \approx P_{max} \text{。} \tag{11}$$

In the formula,$\sigma_{\theta max}$ is the peak of tangential tensile stress.D_0 is the coefficient related to poisson ratio ν and the propagation distance of stress wave R_0,D_0 is 1 at the hole wall of blast hole; σ_{rmax} is the peak of radial compressive stress.P_{max} refers to the initial radial stress peak on the hole wall when ordinary smooth blasting is adopted.

And the hole wall of blast hole will be subjected to quasi-static pressure, that is:

$$\sigma r(\theta) = P_j \tag{12}$$

Where,P_j is the quasi-static pressure of the hole wall of the blast hole under ordinary smooth blasting. The blasting gas generated after the explosion of the explosive will be directly loaded on the hole wall of the blast hole, and the gas wedge action generated will increase the damage degree of the blasting to the surrounding rock.

3.2 Blasting dynamic action of blast hole on side with vibration damping material

After the detonation of the explosive, the shock wave would first act on the hole wall. When the blast hole had the existence of the protective material of the damper, some of the shock wave that originally acts on the upper wall of the blast hole was partly blocked by the PVC damper tube, that is, the blast wave was first loaded on the PVC pipe.The stress wave produced geometric attenuation and energy loss,when the stress wave propagation distance R0 increased, the stress wave peak value P_{max} decreased rapidly. According to the theory of elastic mechanics, the initial tensile stress peak $\sigma_{\theta max}$ and quasi-static stress on the wall of the hole can be expressed by:

$$\sigma\theta_{max} = P_{max}^2 \left(\frac{R_n}{\delta + nR_n} \right)^{2-\frac{\nu}{1-\nu}} \tag{13}$$

$$\sigma_r(\theta) = \mp \frac{P_{max}^2}{(R_n + n\delta)^2} \tag{14}$$

Where: R_n is the inner diameter of the PVC pipe; n is the number of layers of the PVC pipe, δ is the thickness of the PVC pipe; ν is the poisson ratio of the PVC pipe or rock.

The PVC guard tube also prevents the explosive gas wedging into the pore wall rock mass.That is, the rock mass is more vulnerable to high stress peaks, high temperature and high pressure, and the rock body on the side of the PVC guard tube will be protected.Because of the existence of PVC tube, the stress wave peak acting on the wall of the blast hole is significantly reduced, and the thicker the PVC tube is, the larger the Poisson's ratio is, and the smaller the peak value of the stress wave at the wall of the blast hole, the opposite side, the protection of the pit slope is more obvious. If the ratio of wave impedance of PVC pipe to the rock is more larger, the action of reflection of generated when the stress wave propagate to the rock of the hole wall is greater, and the energy transmitted into the rock mass is smaller, that is, the degree of damage to remaining rock mass of the pit slope will be smaller.

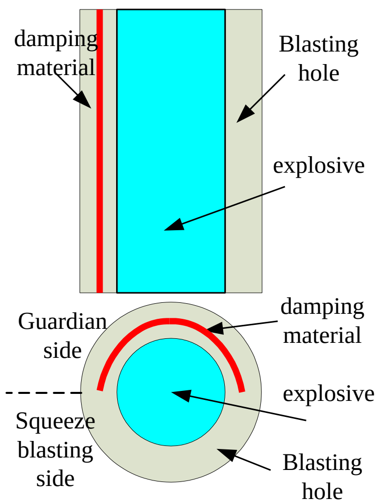

Figure.1 Schematic diagram of the position of the damping material in the blast hole

During the detonation of explosive, with the generation and expansion of blasting cracks, the load in the blasting area is released on the crack surface, and the stress concentration at the crack tip is shown in figure 1. Before the perforation of the cracks between the holes, releasing of stress is generated within a part of the range. When the cracks are perforated and the pressure of the holes is less than the load of excavation, the unloading effect will be reflected on the macro level. With the release of explosive gas, the dynamic load of blasting will continue to decrease, and the excavation load will be fully unloaded when the pressure in the hole drops to the atmospheric pressure. The purpose of using PVC pipe is to reduce the influence of stress wave of propagation on the surrounding rock on the one hand, and reduce the dynamic effect of blasting shock wave on the surrounding rock by blocking the escape of explosive gas on the other hand.

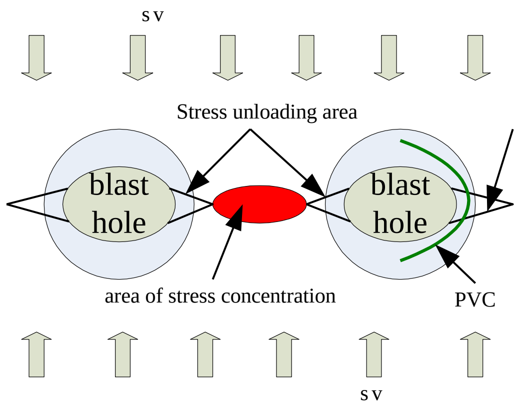

Figure 2 Schematic diagram of dynamic mechanical process of excavation

4. Three-dimensional numerical model

4.1 Model construction

The finite element calculation software was used for the numerical simulation of open air blasting construction. In the solid model, the calculation range of rock mass was 70m in length, 90m in width and 70m in height. The mole-coulomb constitutive model was used for the constitutive model, and curved springs were used for the setting of boundary rock mass. The solid model and the division of unit grid wereshown in Figure 3.

In the solid model, the blasting vibration load generated by blasting (as shown in FIG. 4) is calculated by empirical formula in combination with the design technical parameters of blasting construction scheme, and the calculated dynamic load is applied on the excavation surface in the form of triangular pulse wave, so as to realize the simulation of blasting construction process.

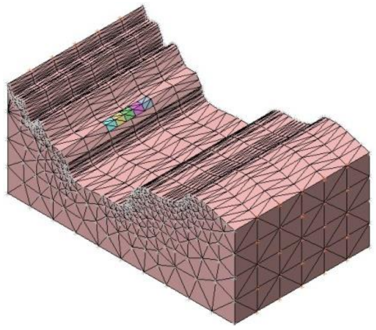

Figure 3 3-dimensional numerical model

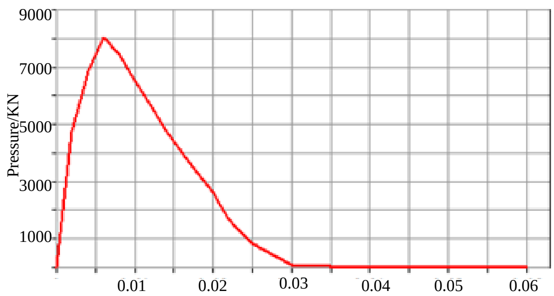

Figure 4 input of time function

4.2 Result analysis

According to the numerical calculation (combined with figure 5~7), different charging forms were simulated (ordinary charging and energy-concentrated charge packaging), corresponding to the working conditions respectively ① and ② . For construction condition ①, 0.54 s after detonation of explosive, the largest velocity of surrounding rock is 8.5 cm/s, with the transfer of blasting vibration wave in the rock mass , due to the energy dissipate to the soil layer gradually, the excavation surface of vibration velocity of rock mass fell rapidly, 1.8 s after detonation of explosive, vibration velocity of rock mass caused by blasting gradually reduced to less than 1 cm/s until zero. For construction condition ②, 0.38 s after detonation of explosive, the most vibration velocity of rock mass are 8.1 cm/s, then as the time gone by and the dissipation and damping of energy, the velocity of surrounding rock mass gradually reduced to zero. The maximum vibration velocity of the surrounding rock is distributed in the slope rock mass near the blasting face. By comparing with the two charging structures and forms, the blasting vibration of the energy-concentrated charge is reduced obviously.

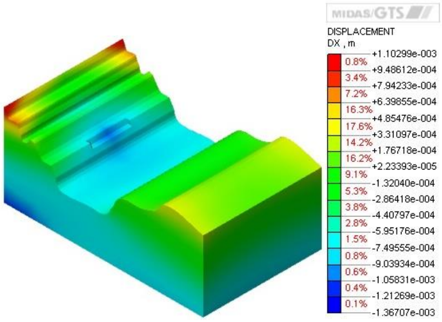

Figure 5 peak displacement x - direction displacement

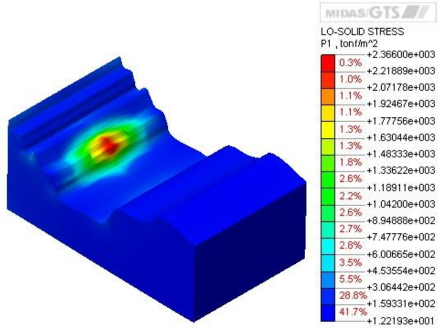

Figure 6 the maximum principal stress

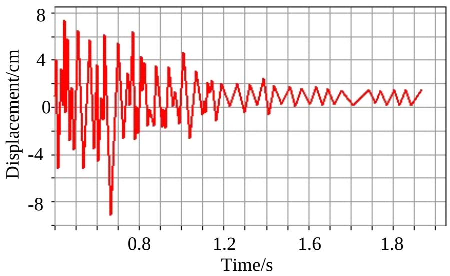

Figure 6 dynamic load 1

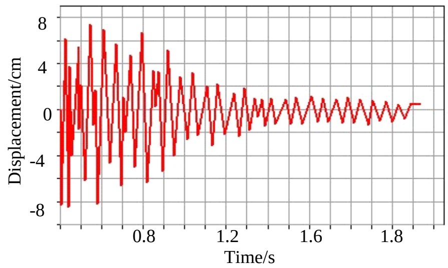

Figure 7 dynamic load 2

5. Conclusion

1) based on the functions of the binding energy blasting device, such as cavity energy guiding, uniform crushing, blasting expansion and others, adopting the binding energy technology of smooth blasting can effectively protect the integrity of surrounding rock and improve the self-bearing capacity of surrounding rock after blasting.

2) by using the finite element numerical method, the blasting vibration simulation analysis can roughly analyze the propagation attenuation law of energy in rock mass during blasting construction.

3) with the tunneling construction of the open slope, the vibration velocity of surrounding rock increases gradually during blasting, and the blasting impact load is related.

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