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Research and Application of Chassis Resistance Line of Rock Breaking Mechanism

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ABSTRACT. *In order to determine the best chassis resistance line in the high-step blasting of the Bayan Oboxi mine, the stress equation under the stress wave is derived from the rock fracture mechanism. Combined with the Livingston line, the derived physical parameters were used to correct the resistance line formula proposed by Langerfors U to calculate the optimal chassis line. The finite element dynamic analysis software is used to simulate the effective stress value and rock fragmentation of the equidistant unit at the bottom of the slope under the optimal chassis resistance. Finally, the field industrial test was carried out in combination with the medium-difficulty area of the Bayan Obo West Mine to verify the rationality of the chassis resistance line. Field experiments show that the chassis resistance line after blasting is 11.5 m, and the broken block is even. After the electric shovel is excavated, the pile is loose and the lower step is flat without obvious root.*

KEYWORDS: *Chassis resistance line, rock fracture mechanism, rock yielding, effective stress value*

1. Introduction

In recent years, in the open-pit mine step blasting, the chassis resistance line is an important technical parameter. The design of the chassis resistance line is too large, which will cause the base of the front part of the explosion area to be affected, and at the same time affect the blasting throw of the rear row of rocks, resulting in the overall effect of the blasting. Poor, increase the consequences of mine production costs. In the actual production, under the condition of ensuring the safe construction of the drilling rig, in order to ensure the blasting effect, the minimum chassis resistance line is adopted as the conservative design parameter. However, the size of the chassis resistance line is affected by a series of complicated factors such as the height of the step, the strength of the rock mass, the slope angle of the step, and the power of the explosive. So far, there is no accurate theoretical calculation formula. Due to the large-scale trend of modern mining equipment and the inherent

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requirements for efficient production of open pit mines, the height of the steps in open pit mines will increase. It is especially important to determine the maximum chassis resistance line that explosives can overcome under certain working conditions. The existing research on the analysis of open-pit blasting effect is mainly for the study of the dynamic response of open-pit blasting under the action of explosion shock wave. Lan Dun, Wang Desheng, Huang Wei, et al. Analysis of stress variation during 24 m and 12 m step blasting of continuous charge structure and hole bottom detonation method using ANSYS/LS-DYNA [1]; Zhou Nan, Wang Desheng, Wang Hua, et al. Comparing the current stress field change trend of the difficult part of the step in the ordinary step blasting and high step blasting by numerical simulation method, it is concluded that the high-step blasting can obtain the blasting effect equivalent or better than the ordinary step blasting [2] Huang Yonghui, Liu Dianshu, Li Shenglin, etc., through the simulation of high-step blasting, studied the high-step throwing blasting speed law and achieved remarkable results [3]. In actual production, the blasting parameters are determined according to theoretical research and field tests, which cannot reflect the influence of the engineering suitability of the maximum chassis resistance line on the explosive stress wave [4-6]. In the open-pit blasting, a reasonable blasthole chassis resistance line can effectively use the energy of the explosive to work on the bottom rock mass to obtain the crushing effect in accordance with the production requirements, and ensure that the bottom plate of the stope does not leave the root, and the unreasonable blasting scheme of multiple tests will inevitably cause Increase in blasting costs and reduction in mining production efficiency. Therefore, the simulation simulation software [7-9] is used to numerically simulate the blasting of different chassis resistance lines. According to the stress distribution law of the rock mass at the bottom of the step, the theoretical maximum chassis resistance line under the model condition is obtained. The theoretical results of the field industrial test verification analysis, to achieve the purpose of comprehensive use of computer analysis methods and blasting theory knowledge to guide production practice.

2. Project Overview

Barrun Mine is a subsidiary of Baotou Steel Group, also known as Baiyun Oboxi Mine. The main mining equipment is KY-310 roller rig. The mining equipment mainly includes ER9350 large hydraulic shovel Liebherr, 4410 large electric wheel mine car, etc. It is a super large modern open-pit mine. The original designed ore production capacity is 15 million t/a, the total amount of rock-peeling is 98.5 million t/a, the total amount of mining and stripping is 113.5 million t/a, and the length of the stope is nearly 5 km, north and south. Within a range of about 1 km wide, the iron ore body has dozens of main ore bodies and more than one hundred subsidiary ore bodies. The lithology in the stope is mainly dolomite, slate, Quaternary, etc. The lithology changes greatly. The lithological weathering of the upper part of the stope is serious and the strength is low. As the mining level decreases, the lithology intensity becomes larger. After adjustment, the current stop formation is in the form of a transition from the previous upper 12 m to the lower 14 m height step.

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3. Stress wave stress theory

Assuming that the stress wave is broken in the homogeneous, continuous, and isotropic elastoplastic range, the dynamic stress equation can be listed by the theorem combined with the Coulomb limit conditions:

$$\sigma_r = \frac{E}{c(1+\gamma)(1-2\gamma)} u \left[1 + (1-2\gamma)\frac{R^2}{r^2} \right]$$

$$\sigma_\theta = \frac{E}{c(1+\gamma)(1-2\gamma)} u \left[1 - (1-2\gamma)\frac{R^2}{r^2} \right]$$

$$\mathrm{u} = \frac{D_J}{\gamma+1} \left\{ 1 + \frac{2\gamma}{\gamma-1} \left[1 - \left(\frac{p_0}{p} \right)^{\frac{\gamma-1}{2\gamma}} \right] + \frac{2\gamma}{\gamma_0 - 1} \left(\frac{p_0}{p} \right)^{\frac{\gamma_0-1}{2\gamma_0}} \left[1 - \left(\frac{p}{p_0} \right)^{\frac{\gamma_0-1}{2\gamma_0}} \right] \right\}$$

$$\tau_m = K + \bar{m}\, p \approx \frac{E}{\mathrm{c}(1+\gamma)} u$$

Where: σ_r is the radial dynamic stress, ie the tensile stress, σ_θ is the tangential dynamic stress, R and r are the fracture and failure radius, u is the wave velocity of the stress wave at any position, c is the longitudinal wave velocity, $c = \sqrt{(1-v)E/(1+v)(1-2v)\rho}$, v is the medium Poisson's ratio, ρ is the density of the medium, p_0 is 0.02 p , γ is the adiabatic coefficient, generally takes 3, the subscript 0 represents the corresponding state parameter in the air, the following table J represents the CJ state parameter, τ_m is the shear stress, p is the pressure, $\bar{m} = \tan\theta$ is the internal friction coefficient and K is the coupling coefficient. Since the internal friction in the plastic medium is small, it can be ignored. Then, $\tau_m = \sigma_s = K$, where σ_s is the shear strength limit.

The energy generated after the explosion of the explosive causes the rock of the hole wall to be displaced. The peak value of the stress wave is much larger than the compressive strength of the rock, and the crush zone is first formed. With the stress wave energy transfer, the impact stress wave is attenuated into a compressive stress wave. The peak value of the stress wave greatly exceeds the tensile strength. The ore rock mass produces radial displacement, tangential displacement and derives radial tensile stress and tangential tensile stress. The longitudinal crack is formed under the action of tangential tensile stress, and the tensile stress formed by the free surface reflection causes the ore to form a tangential fracture and form a fracture zone. The cracks are not developed, and the stress wave energy causes elastic deformation of the rear ore, and finally forms a vibration zone. According to the above-mentioned

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combination analysis, the radius of the fracture region generated by the stress wave is solved by the tensile stress failure criterion:

$$R\sqrt{\frac{(1-2\gamma)\ c\rho u}{(1-\gamma)-c\rho u}}$$

The resistance line calculation formula proposed by the Swedish Langerfors U scholar:

$$W = \frac{d}{33}\sqrt{\frac{\rho S}{cfm}}$$

Based on the theory of rock fragmentation, combined with the Livingston line, the above formula is corrected, c=0.55, s=0.9, f=1.021.

According to the rock properties of the gun area, the length of the blasthole packing is 6 m; the ultra-deep value of the blasthole in domestic mines[10-15] is generally 0.5~3.6 m, considering the rock properties of the blasting area and the actual experience of the Barur mine. Value, to determine the super deep value of the model blasthole is 2.5 m. limited by the function of the rig, the drilling method is vertical drilling, with a whole diameter of 310 mm and a whole depth L of 16.5 m. The current step height H of the Barrun mine is 14m, and the slope angle α=75°. According to the formula $W_d \geq H\cot\alpha + B$ (B≥3 m), the minimum chassis resistance line $W_d \geq 6.751$ of the Barun mine can be used to ensure the safety of the drilling rig. According to the revised formula, the optimal chassis line is 12.423m larger than the radius of the stress wave damage zone. In the actual open-air blasting, the stepped plate surface is restricted by the step slope surface. During the blasting process, the rock at the bottom of the step is not easily broken, combined with the actual blasting lithologyto take 12m.

Step blasting simulation, the 1/2 model is established with the z-axis as the symmetry plane. The design has a step height of 1400 cm, a width of 2 000 cm, a longitudinal depth of 1 500 cm, and a designed slope angle of 75°, using a cm-g-us unit system. . The rock selects the bilinear follow-up hardening model. The material model is suitable for isotropic, follow-up hardening or isotropic and plastic follow-up strengthening materials containing strain rate effects. It is a commonly used material model for simulating rock. . Blocking and rock materials are made of *MAT--003 material, and the solid element is *sect-lag. The specific parameter settings are shown in Table 1 and Table 2.

Table 1 Blocking material parameters

Density g/cm^3	Elastic Modulus E/MPa	Poisson's ratio v	Yield Strength MPa	Tangent modulus MPa
1.85	1.2	0.38	0.8	0.1

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Table 2 Dolomite material parameters

Density g/cm^3	Elastic Modulus E/GPa	Poisson's ratio ν	Yield Strength MPa	Tangent modulus MPa
2.63	4.83	0.26	4.3	30

Air is made of *MAT--009 material; air density is set to 1.29g/L, other parameters use default, state equation *EOS--Air (*EOS-001), the equation of state is linear polynomial and thermodynamic initial state material definition parameter.

$P=C_0+C_1\mu+C_2\mu^2+C_3\mu^3+(C_4+C_5\mu^2+C_6\mu^3)E$

In the formula: $C_0=C_1=C_2=C_3=C_6=0$, $C_4=C_5=\gamma_0-1=0.4$

The emulsion explosive is made of *MAT--008 material. The specific parameters are shown in Table 3. The solid unit of emulsion explosive and air is *sect-ale, and the emulsion explosive adopts ELFORM 11 multi-substance unit algorithm; the equation of state *EOS-Jwl (* EOS-002), this equation is used to define functional explosives. This is an unrestricted chemical reaction that accurately describes the process of the artillery product. JWL representation:

$$P = A\left(1-\frac{w}{R_1V}\right)e^{-R_1V} + B\left(1-\frac{w}{R_2V}\right)e^{-R_2V} + \frac{wE}{V}$$

Where: P---the required pressure value;

E---the internal energy of the detonation product;

V--the volume of the detonation product, that is, the ratio of the volume of the detonation product to the initial volume;

A, B, R1, R2 and w are pending coefficients.

Table 3 emulsion explosive parameters

Density g/cm^3	Detonation speed cm/us	Explosive pressure PCA	A	B	R_1	R_2	Qmeg	E_0
1.20	0.40	4e9	2.14e11	1.82e9	4.15	0.95	0.3	4.192e9

In the definition of the mesh boundary condition, the section of the model (the blasthole surface) is taken as the symmetrical boundary, and the rest of the surface is the non-projection boundary. The top, slope and slope surface of the step are set as the vacant surface; the model is drawn by Hypermesh 14.0. In the hexahedral solid element mesh, in order to facilitate the observation of the stress distribution during the blasting effect process, the mesh of the explosive and the filling material is finely divided, as shown in Fig. 1.

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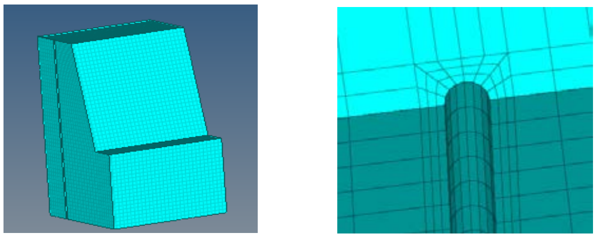
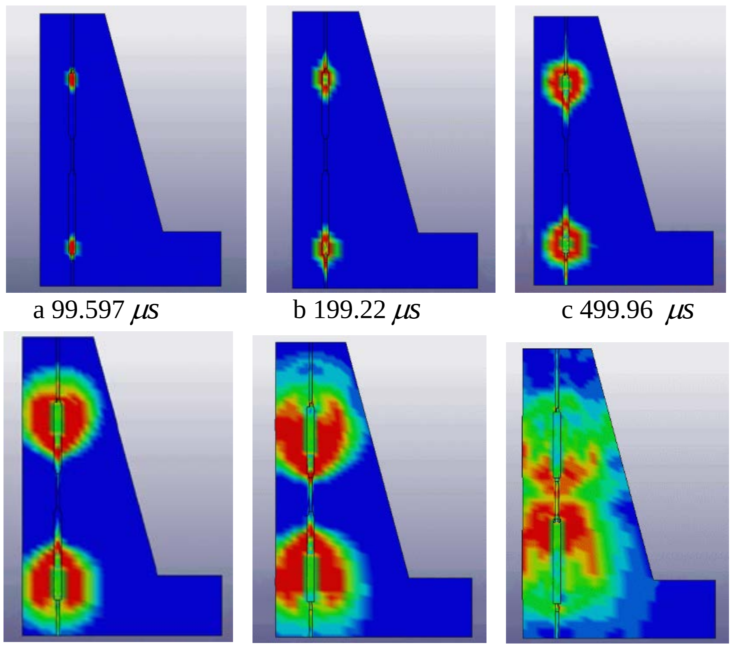


Figure. 1 Overall model and fine meshing

4. Simulation results and actual blasting effect analysis

4.1 Analysis of simulation results



a 99.597 μs b 199.22 μs c 499.96 μs

d 899.94 μs e 1298.5 μs f 2194.3 μs

Figure. 2 chassis resistance line is 10.5m, stress change diagram at different times

The parameters and conditions of the open-air step blasting are all completed, only the chassis line is 10.5m, as shown in Figure 2. It can be seen that after the detonation, the detonation wave propagates from the orifice to the shape of the water droplet at the bottom of the hole. As time passes, the wavefront of the stress wave

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forms a certain angle with the blasthole and remains substantially unchanged and propagates outward. The stress wave reaches the free surface and the pressure reflection forms a reverse stretch. The stress field in the rock is mainly generated by the reflected wave from the free surface, which is the main cause of rock damage.

From the post-processing of LS-PREPOST, the stress distribution of the model at any time is obtained, and the blasting effect is further analyzed. The four consecutive points on the bottom of the slope are taken as the stress analysis monitoring points. Figure 3 shows that this part is the place where the maximum resistance of the step blasting is easy to occur. According to the calculation results of Fig. 3, in the case of the same charge amount, the chassis resistance line is 1050 cm, which is close to the bottom surface of the slope, and the stress value of the inspection point is larger than the stress peak of the other 3 models. From the peak analysis, the stress peak of each monitoring point is above 30MPa, which exceeds the rock yield strength.

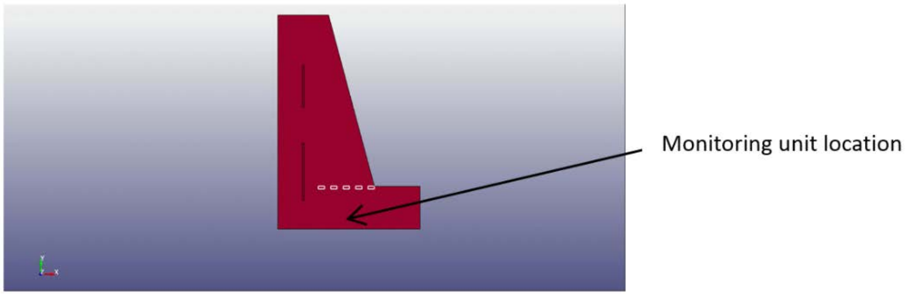

Figure. 3 monitoring point location

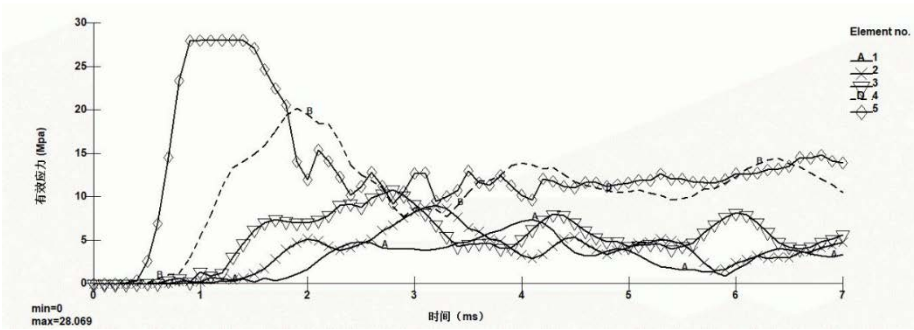

Figure. 4 monitoring unit stress time history diagram

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4.2 Analysis of actual blasting effect

The blasting area is located at the 1548 level north gang of the stope. The lithology of the blasting area is mainly fluorite dolmenite with medium strength. The aperture is 310 mm and the depth is 2.5m. The hole is arranged with a large whole spacing and small spacing. The whole network parameter is 5.5m × 15m, chassis resistance line in accordance with the aforementioned simulation results 11.5m design line field industrial test. The whole pattern is a triangular cloth hole, and the charging method is continuous charging, and the filling height is 6 m. The detonation method is detonation by hole, and the combined tube in the hole and the surface is extended. There are 115 blastholes, the rock blasting capacity is 272788.19t, the emulsion explosive is 64t, and the explosive consumption is 234g/t. The blasting parameters are shown in Table 4, and the blasting technical economic indicators are shown in Table 5. It can be seen from the field test results that when the chassis resistance line is 10.5m, the bottom plate is flat after blasting, and there is no obvious root. The overall block breaking effect of the blasting pile is better, which meets the mining requirements of the mining equipment. The electric shovel mining is shown in Figure 5. Show.

Table 4 main blasting parameter table

Rock hole(个)	Duan Gao(m)	Ultra deep(m)	Chassis line(m)	Pitch(m)	Row spacing(m)	Packing height(m)
67	16.5	2.5	10.5	15	5.5	6

Table 5 blasting technical economic indicator table

Blasting rice road(m)	Blasting volume(t)	Blasting volume(m^3)	Yanmi explosion(t/m)
1072	272788.19	73864	187
Unit consumption(g/m^3)	Unit consumption(g/t)	Number of spacers(个)	Blasting cost(元)
619	234	40	145471

Figure. 5 The field resistance map of the chassis with a resistance line of 10.5m after blasting

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5. Conclusion

In this paper, based on the actual problems in the Barur mine, the multi-group model is used to analyze the propagation law of stress wave in the step rock mass under different chassis resistance lines, and the optimal chassis resistance line value is given, and the industrial test is verified. , got the following conclusion:

(1) Through numerical simulation calculation and field industrial test verification, it is concluded that under the condition of 310 large-aperture vertical drilling mode, the maximum chassis resistance line of medium-hard rock dolomite step blasting is 10.5, which provides the step blasting of Barun Mine. Clear data indicators;

It is proved that the numerical simulation combined with the actual engineering verification is a way to solve the actual problems of the mine with low cost and high efficiency, which provides favorable technical support for the future development of the blasting work of the Barur Mine.

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