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Optimization and application of blasting parameters based on the "pushing-wall" mechanism

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Abstract: The large structure parameter of a sublevel caving method was used in Beiminghe iron mine. The ores were generally lower than the medium hardness and easy to be drilled and blasted. However, the questions of boulder yield, "pushing-wall" accident rate, and brow damage rate were not effectively controlled in practical blasting. The model test of a similar material shows that the charge concentration of bottom blastholes in the sector is too high; the pushing wall is the fundamental reason for the poor blasting effect. One of the main methods to adjust the explosive distribution is to increase the length of charged blastholes. Therefore, the field tests with respect to increasing the length of uncharged blastholes were made in 12# stope of −95 subsection and 6# stope of Beiminghe iron mine. This paper took the test result of 12# stope as an example to analyze the impact of charge structure on blasting effect and design an appropriate blasting parameter that is to similar to No.12 stope.

Keywords: iron mines and mining; excavation; blasting; optimization

1. Introduction

Beiminghe iron mine with the skarn magnetite bed type is located in Hebei Province in north China. The degree of ore hardness index is of medium-scale. The production in Beiminghe iron mine is started on April 2002. The sublevel caving method with a height of 15 m is adopted, the width of slice is 18 m, and the ring burden is 1.7 m. A SimbaH1354 hydraulic drill is used for drilling vertical fan-shaped blastholes with a diameter of 80 mm; an electronic scraper with a capacity of 4.0 m^3 is used for carrying out iron ores, and the annual production is kept at about 23×10^5 t [1-3]. The large structure parameters and great intensity of mining require the high-qualitative blasting effect. However, for a long time, the blasting effect in Beiminghe iron mine is not ideal. The blasting problems, including high boulder yield, accidents of the blasting bulkhead, and destruction of the eyebrow line [4-7], make the exploitation economically unprofitable due to the need of extra time for secondary blasting and all other expenses related to this. The security issue is another factor that influences the working conditions negatively. Therefore, the blasting problem has become one of the most significant technical issues that need to be faced urgently [8].

2. Mechanism of fan-patterned blasting holes

2.1. Model test

Many works were made to improve the blasting effect in Beiminghe iron mine, including increasing the number of blastholes and explosives, spreading the blasting way of holes bottom widely, and using the detonating tube and cable dual blasting. Although those methods increased the reliability of blasting and the quantity of explosives, the effectiveness was not ideal. In this situation, the main cause of blasting problems needed to be identified. For this purpose, the blasting test was done with a low-strength cement mortar model [9-10]. The model consists of cement Portland 425 and sand from Beiminghe River, as shown in Table 1. The blasthole diameter is 5 mm and the space of the bottom blasthole is from 8.67 to 9.33 cm, as shown in Fig. 1. The model parameters of cement mortar are shown in Table 1, the burden of blastholes are defined as 3 and 7 cm for each ratio of cement and sand to observe the holes density coeffi-

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Table 1. Model parameters of cement mortar

Number	Ratio of cement and sand by mass	Cement / kg	Sand / kg	Water / kg	Uniaxial compressive strength / MPa
I	1:3	76	230	30	9.764
II	1:5	50	250	30	3.320
III	1:7	38	267	30	1.453

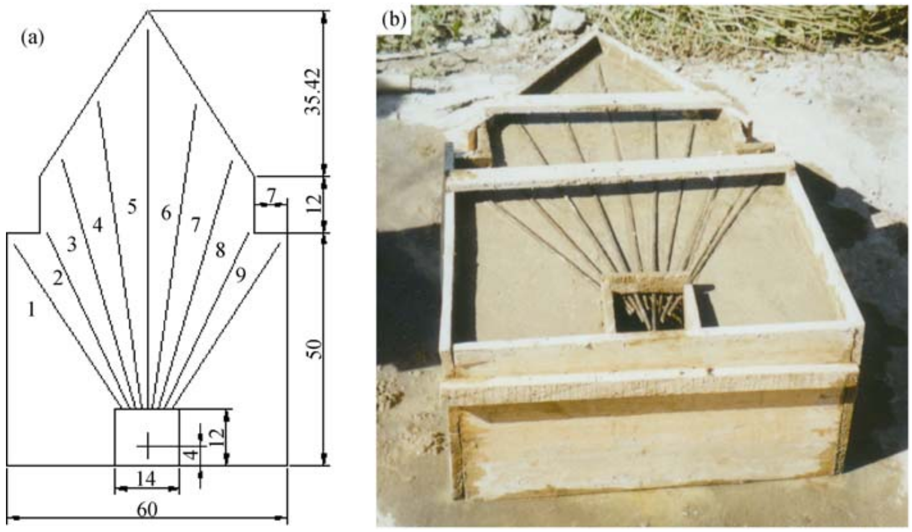

Fig. 1. Blasting model of cement mortar: (a) schematic diagram (unit: cm); (b) physical map.

cient of blasting effect, respectively.

First, a test pit was formed with 2.2 m×0.8 m×1.2 m. Next, the detonation cords were loaded into the blastholes of the model and tied with blasting caps. Red lines were drawn on the fore end surface in every 10 cm to observe and describe blasting effect. Crushed stones, not more than 10 mm in grain size, were filled into the pit and moved for less void areas until the height of heap was 50 cm, which was more than the model's, to simulate overburden. Then, the crushed stones were drawn out from the drift of the model until there was an incompact concave on the top of the heap. After blasting, the cover was peeled off from the top to the bottom by hand. The blasting effect and blasting boundary of each test were measured every 10 cm.

2.2. Mechanism of "pushing-wall"

As shown in Fig. 2, the "pushing wall" phenomenon happens in the lower part, and the top of the model, which is broken into fragments, is called the effective blasting area. With the increasing of intensity and burden of the model, the effective blasting area has the decreasing tendency; that is, the pushing wall degree tends to increase. The blasting stress wave of blastholes forms cracks around the blastholes and the explosive gas makes the rock fully blasted after blasting. The blasting stress is isotropic, while the emission of explosive gas has obvious directivity, which is always toward to the minimum resistance direction. Because the fan-patterned lower hole distance is relatively small and the distribution of explosive density is higher, the cracks in lower part of blastholes in the ore body can easily be held through each other by the explosive gas. When the explosive gas accumulates along the blasthole row, it may push forward the whole explosive ore body and emit from the drift and both sides of the ore body. When the explosive power is not enough to break the ore bodies that have detached from the main ore body, the "pushing-wall" phenomenon [11] will happen. When the blasting burden is bigger and the intensity of the model is higher, the resistance of explosive gas from the direction of the resistance line will be bigger. It is more difficult for the explosive gas to break the ore bodies that have detached from the main ore body. The higher the pushing wall is, the smaller the effective blasting area is.

Every row of fan-pattern holes contains 11-12 blastholes, the space of the adjacent porthole is 0.4-0.8 m, the space of blastholes bottom is 2.2-2.6 m, and the length of burden is 1.7 m. The original design of charging structure is shown in Fig. 3; several blastholes that are fully charged cause a big charge density of the orifice in the practical production. The above analysis shows that the concentration degree of explosive charge, which is not distributed evenly, is caused by the unreasonable explosive structure and the explosive parameter. If the charge concentration degree of a lower

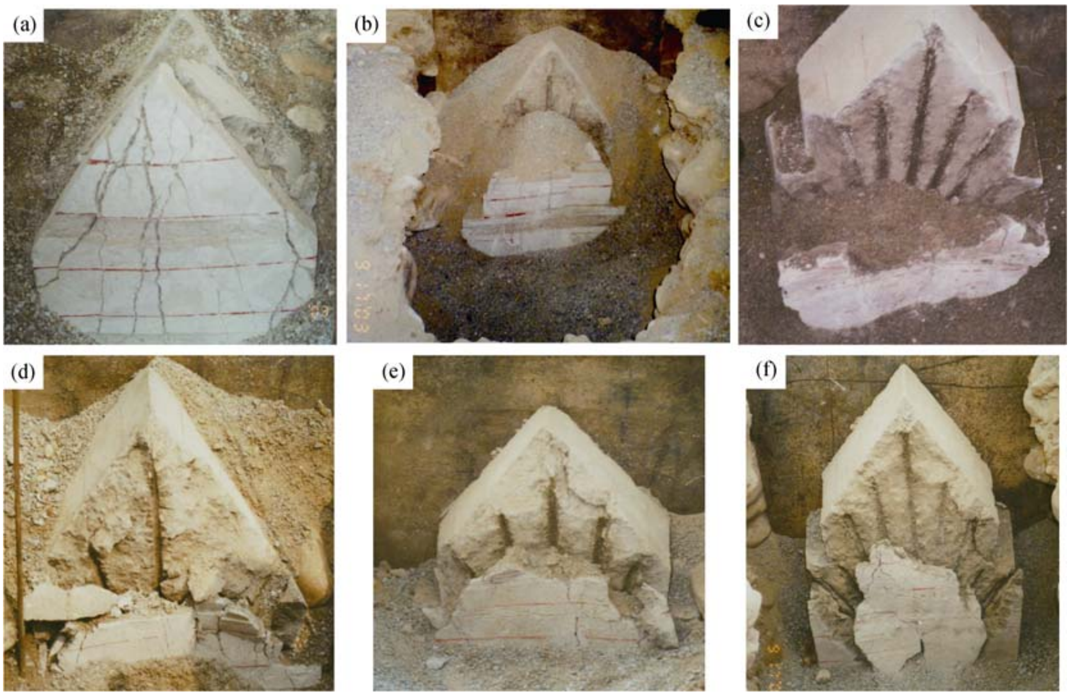

Fig. 2. Blasting result of models with different ratios of cement and sand by mass: (a) 1:3, burden of blasthole 7 cm; (b) 1:5, burden of blasthole 7 cm; (c) 1:7, burden of blasthole 7 cm; (d) 1:3, burden of blasthole 3 cm; (e) 1:5, burden of blasthole 3 cm; (f) 1:7, burden of blasthole 3 cm.

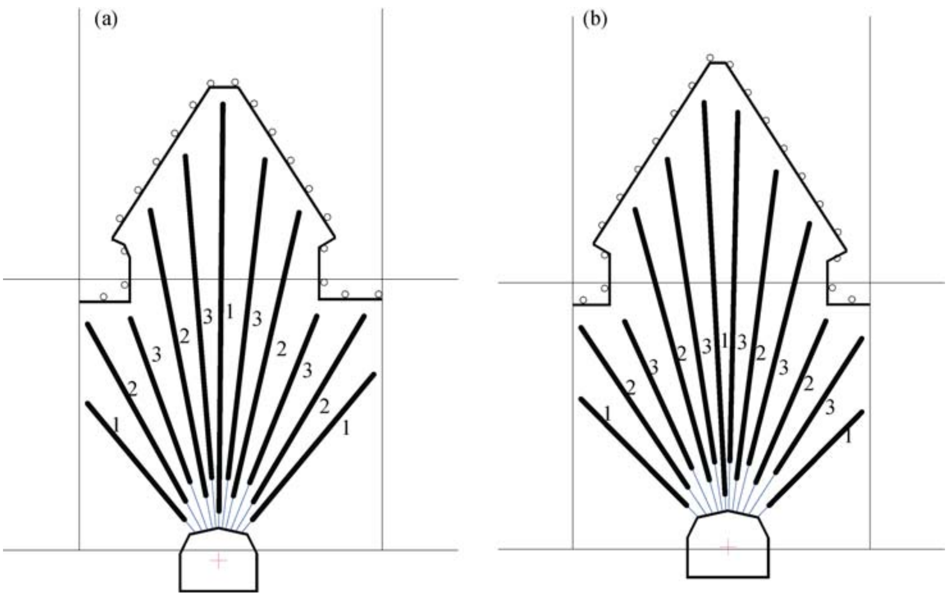

Fig. 3. Current charging structure at Beiminghe iron mine of 11 blastholes (a) and 12 blastholes (b), where 1, 2, and 3 stand for the length of uncharged holes (unit: m).

blasthole is too high, there will be the "pushing-wall" phenomenon or the "pushing-wall" tendency. No matter the degree of "pushing-wall" is severe or slight, and there will always be in the huge block of stope, which shifts down with the production of lower part ore. In the course of downshift, it may be squeezed by the bulk movement, which changes a big block into several ones. Some of them may still continue to break into some small blocks, but the main body will be the big bulk to shift down. In the stope structure of a lozenge arrangement route, the upper and lower ore discharge point aligns in the form of sublevel, that is when stoping to the third sublevel, the blocks formed by the partition will be in the top of the discharge point, which can flow to the discharge point in high speed and mostly emit in the form of boulders. The essence of improving the blasting effect and optimizing the blasting parameters is to adjust the density of explosive distribution and decrease the concentration degree of explosive charge of lower blastholes.

3. Results and discussion

3.1. Method and results

One of the main methods to adjust the density of explosive distribution is to increase the length of uncharged blastholes [12]. Therefore, the experiment of improving the charging structure is done in the representative stope to study the influence law of blasting effect by the density of explosive distribution. The standard scheme of the charging structure is shown in Fig. 4.

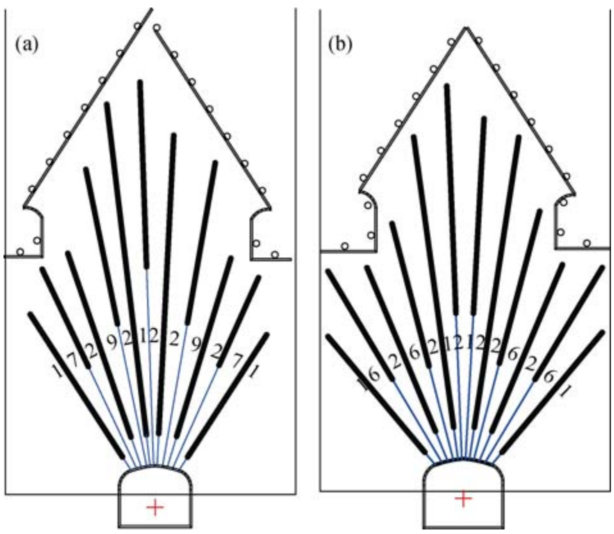

Fig. 4. Experimental scheme of the charging structure of 11 blastholes (a) and 12 blastholes (b), where the numbers stand for the length of uncharged holes (unit: m).

For this purpose, the well experienced workers in the field of charging were chosen to do the charging work to control the length of uncharged holes strictly and obtain the reliable data. The whole charging process was observed, and the consumption of explosives was written down as well as the uncharged and charged length of blastholes, respectively. The explosive was the bagged porous granular ammonium nitrate (40 kg each bag). The explosive escaped from the blastholes, accompanying by charging, the amount of escaped explosive was influenced by wind pressure and the quality of blasthole. The whole drawn process was followed and the condition of eyebrow line destruction was recorded. Subsequently, the minerals were excavated with load haul dump (LHD), and the time and location where the boulders were spotted were recorded in every five shovels. In the paper, 12# stope as a representative of experiments was discussed and analyzed. Ore of 5 ring burdens were caved in all, holes in this stope were not so completed, and the entire displacement took place in many of them at the point more than 10 ms away from the opening of holes. The testing program was adjusted according to the location where the holes were blocked. In this stope, the roof of the route was not stable enough, the ore was a little soft, and the joint extended widely. Table 2 shows the experimental results done in 12# stope. The amount of explosives in Table 2 is equal to the total amount of consumed explosive subtracted by the amount of escaped explosive in every experiment.

Table 2. Experimental results in 12# stope

Test number	1	2	3	4	5
Number of holes	10	11	12	11	11
Length of uncharged blastholes / m	23.5	28	39	36	35.5
Length of charged blastholes / m	110	113	141	103	90
Weight of charged explosive / kg	540	560	680	520	500
Consumption of explosive per ton of ore / ($kg \cdot t^{-1}$)	0.3	0.31	0.37	0.29	0.28
Height of open wire / m	0.1	0.3	0	0	0
Weight of drawn ore / t	2856	2008	1520	1936	1880
Weight of drawn ore when the first boulder exposes / t	83	169	471	566	187
Number of boulders	48	71	31	50	51
Boulders yield / %	6.8	11.1	10.2	9.1	11

3.2. Test result analysis

Fig. 5 shows the process of boulder exposure, taking the pieces of every twenty buckets as a unit. Every ring burden has two peaks of boulder exposure, as shown in Fig. 5(a). The drawn ore during the first peak of boulder exposure belongs to the ring burden of test. The reason for the formation of the second peak in boulder exposure is that the not-caved ore is collapsed to the discharge point, according to the analysis based on the degree of destruction holes and the amount of drawn ore. Therefore, the paper mainly discussed the first peak of boulder exposure. Based on the stochastic medium theory of ore drawing [13-15], the numerical relationship between the quantity of drawn ore and the height of drawn body is as the following equation:

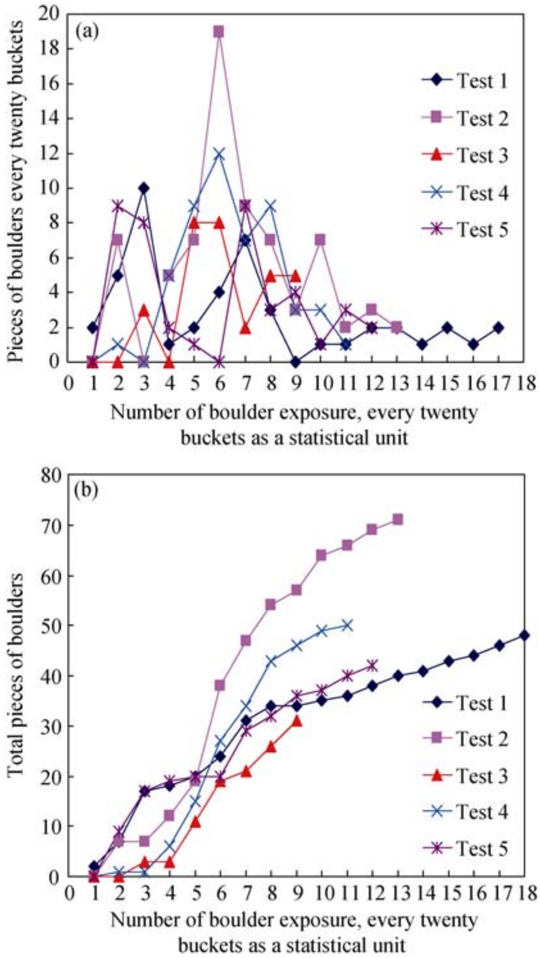

Fig. 5. Statistic result of boulders exposure: (a) variation of the number of boulder exposure in the process of drawing ore; (b) variation of the total number of boulder exposure in the process of drawing ore.

$$\begin{cases} Q = \dfrac{\sqrt{\beta\beta_1}A\pi}{\omega+1}H^{\omega+1} \\ \omega = \left(\alpha+\alpha_1\right)/2 \\ A = \dfrac{1}{2}+\dfrac{1}{\sqrt{\pi}}\displaystyle\int_0^{\frac{k}{\sqrt{\beta}}} \mathrm{e}^{-t^2}\mathrm{d}t \end{cases} \tag{1}$$

where Q is the drawn quantity, H the height of drawn body, α and β the granule flow parameters along the direction of the drift, α_1 and β_1 the granule flow parameters vertical to the direction of the drift, and k the influence coefficient of the drawing boundary, ranging from 0.10 to 0.15.

By substitution of the data of drawn body height into the drawn body equation as Eq. (2), the corresponding drawn body can be calculated and represented on the surface of holes row as shown in Fig. 6. The smaller the drawn body is in the beginning of boulder exposure, the bigger the drawn body is at the end of boulder exposure peak. Therefore, the boulders were drawn during the two-drawn body, and the region in the two-drawn body had a higher boulder yield and poor blasting effect. The smaller the area of the region in the two-drawn body is, the more superior the scheme of charging is.

$$\frac{y^2}{\beta_1 z^{\alpha_1}}+\frac{\left(x-kz^{\alpha}\right)^2}{\beta z^{\alpha}}=(\omega+1)\ln\frac{H}{z} \tag{2}$$

3.3. Optimization on blasting parameters

To further study the rationality of charging structure, the concept of distribution density of charged blastholes was introduced, which was equal to the ratio of total length of charged blastholes and blasting area. The main reason for the pushing wall proved by the model test is that the lower blasthole charging is too concentrated. The research emphasis is to discuss the relationship between the blasting effect and length of uncharged blastholes. The reasonable distribution density of charged blastholes is obtained based on the test of changing the length of charged blastholes, which is equal to the ratio of the smaller drawn body area and the length of charged holes in the drawn body in each test. The blasting parameter is improved according to the reasonable distribution density of charged blastholes. Table 3 shows the statistical results.

According to Table 3, the distribution density of charging blastholes is between 0.55 to 0.77 m/m^2, the process of ore excavation is fluent. The drawing process of the second experiment, whose density is up to 0.91 m/m^2, is not fluent and generates the phenomenon of arch twice. This sequence shows the impact of charging blastholes density on the drawn fluency; the larger the density is, the worse the blasting effect is. The conclusion matches the result of model experiment on the ground surface. Therefore, the effective method of improving the blasting effect is to decrease the distribution density of charging blastholes that can increase the area of the effective blasting zone. Statistical data in Table 3 show the superiority of the fourth ring burden experiment, whose charged holes density is 0.55 m/m^2 and corresponding drawn ore body height is 17.95 m. Therefore, the paper recommends the scheme that the height of drawn body is 18 m and the distribution density of charging blastholes should not be more than 0.6 m/m^2 when the blasting parameters of stopes is similar to 12# stope.

Optimization of blasting parameters needs to consider the size of caving ore and the quantity of drawn ore. The quantity of drawn ore of the first ring burden in this experiment

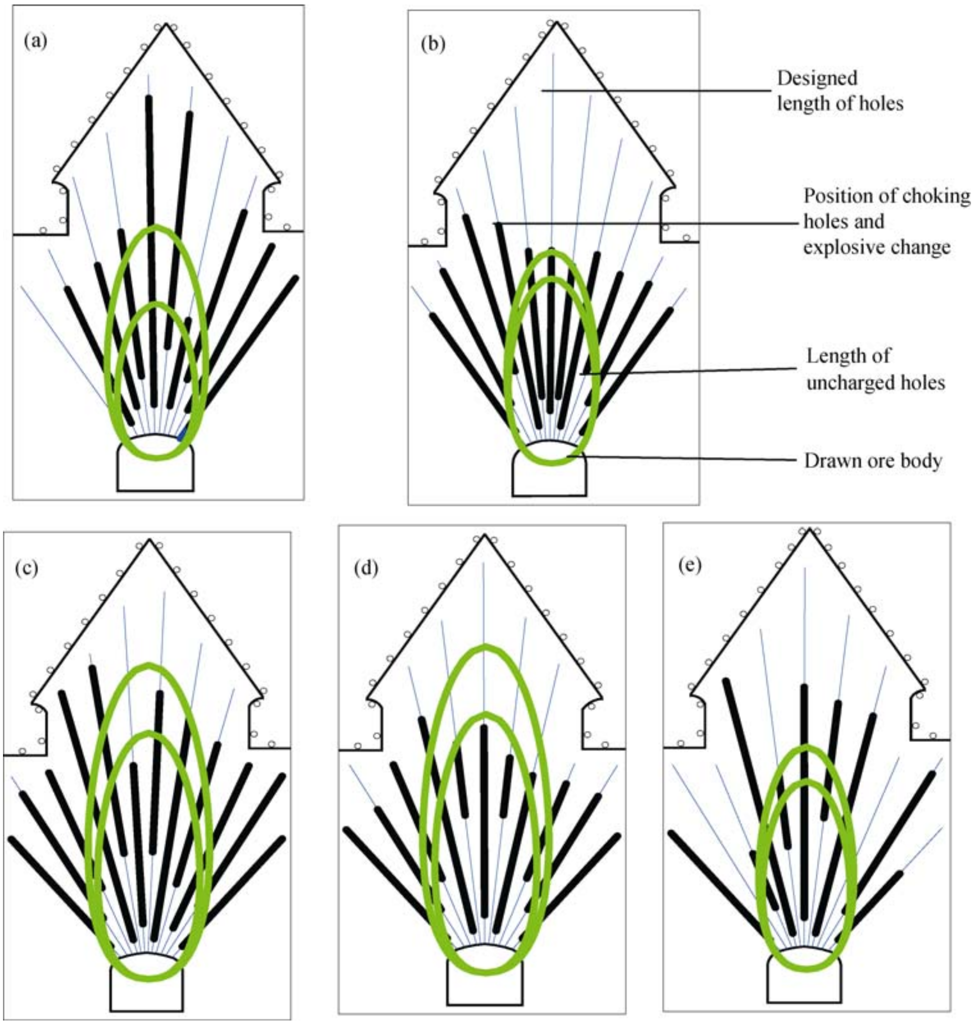

Fig. 6. Position of the boulder formation peak in the first experiment (a), second experiment (b), third experiment (c), fourth experiment (d), and fifth experiment (e).

Table 3. Statistical results of charging structure and blasting effect

Test pace	1	2	3	4	5
Estimated height of drawn body / m	10.42	12.55	17.07	17.95	13.05
Statistical area / m^2	35.0	48.3	81.2	85.4	51.4
Length of charged blastholes / m	27.09	44.09	55.54	46.65	31.70
Charged holes density / $(m \cdot m^{-2})$	0.77	0.91	0.68	0.55	0.62
Blasting effect	Blasted pile exposed 5 boulders, ore removal is basic smooth.	Destruction of the eye brow line is about 1.4 m.	Drawing process is fluency.	Drawing process is fluency.	Blasted pile exposed a boulder, ore removal is basic smooth.

was large, and the outline of blastholes distribution matched the outline of drawn ore body much better. Synthesizing the outline of blastholes distribution and the structure of charging, the paper put forward a scheme based on the layout of blastholes optimization and the charging structure of blastholes. Fig. 7 shows the scheme of optimized blasting parameters. The angle of holes side is 57º; the total length of holes is 148 m, including 114 m for the loaded length and 34 m for the unloaded length; the utilization ratio of blastholes is 77%, the density of holes distribution is 0.5 m/m^2, the total consumption of explosive is 560 kg, and the explosive consumption is 0.34 kg/t estimated according to the charge density of explosive 0.98 g/cm.

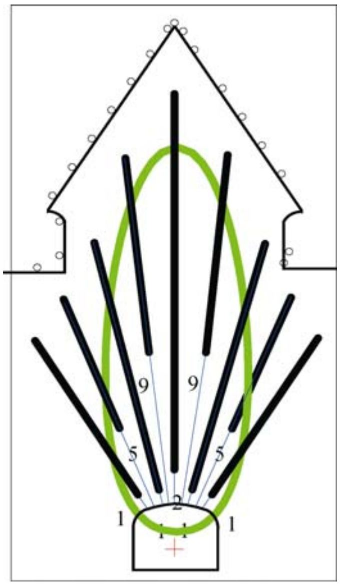

Fig. 7. Recommended layout of holes and charging structure, where the numbers mean the charged length (unit: m).

4. Conclusions

(1) In the model test, the "pushing wall" phenomenon happens in the lower part, and the top of the model, which is broken into fragments, is called the effective blasting area. With the increase of model intensity and burden, the effective blasting area tends to decrease, that is, the increasing tendency of pushing wall degree.

(2) The uneven density of explosive distribution and the high concentration degree of explosive charge in lower blastholes in Beiminghe iron mine are the main reasons of the occurrence of "pushing-wall" and high boulder yield.

(3) This sequence shows the impact of charging blastholes density on the drawing fluency; the larger the density is, the worse the blasting effect is. The distribution density of charging blasthole is better when it is not more than 0.6 m/m^2.

(4) Synthesizing the outline of blastholes distribution and the structure of charging, the paper put forward a scheme based on the layout of blastholes optimization and charging structure of blastholes. The length of uncharged hole is 1, 5, 1, 9, 2, 9, 1, 5, 1 m, respectively.

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