A rock burst comprehensive prediction method: Application in West AnShan iron mine

Gang Li [a], Qingwen Li [b]

University of Science and Technology Beijing, Beijing 100083, China

[a]lgdiv5@163.com, [b]qingwenli@ustb.edu.cn

Abstract

It's inevitable that the West Anshan Iron mine comes to deep mining. Therefore, the prediction of rock burst is necessary to the project. Rock samples from the underground -600 to -1100m depth for predicting the tendentious of rock burst. Combined the laboratory tests with field measurements, preliminary evaluation, the rock burst can be classified into four grades. Then, the author adopts the fuzzy comprehensive evaluation theory to synthetically analyze the possibility and intensity of rock burst. At last, the result of the prediction of rock burst is application in the West Anshan iron mine.

Keywords

rock burst, laboratory tests, prediction, criterion, fuzzy comprehensive evaluation.

1. Introduction

Rock burst is one of the most common geological disaster in deep mining or other underground space engineering. So far, lots of studying had been done on rock burst prediction. The theoretical analysis and field measurement are the main prediction methods, both of them have their advantage and disadvantage. The theoretical analysis includes stress criterion, lithology criterion, energy criterion, the critical depth criterion, etc. which is applicable to the early stage of engineering. For the study of rock burst mechanism is far from enough, a variety of indicators should be considered. Compared with the theoretical method, the field measurement has a relatively high accuracy, but there are some problem with measuring method and equipment.

After decades of exploration, the mining area of West Anshan iron mine is completely detected. The large and thick rock ore underlay to the deep underground and much of their depth buried within the range of 600 meters to 1000 meter. With the mining depth increasing, the better integrity of rock mass, the higher geo-stress, and the hard brittle rock are the precondition of rock burst forming. In the view of rock ore hasn't yet been developed, the field measurement is not feasible. The author adopt the way of theoretical analysis , and draw a comprehensive conclusion of the rock burst orientation from the rock experiment by a variety of criteria evaluation standard. On the basis of combining the measured geo-stress data to predict the possibility and intensity of rock burst in deep mining, the value of critical depth of rock burst will be calculated.

The theoretical analysis method mainly analyzed from three aspects: lithology, host rock and geostress. According to the experiments results, the rock brittleness criterion, tangent stress criterion, the rock integrality modulus and RQD evaluation index are chosen.

1.1 Rock brittleness criterion

Jiayou Lu [1] proposed that the uniaxial compressive strength and uniaxial tensile strength have a significant impact on the rock burst. And the ratio of uniaxial compressive strength (σ_c) to uniaxial tensile strength (σ_t) is defined as B, which is called brittleness criterion.

$$B = \sigma_c / \sigma_t \quad (1)$$

The dividing of B based on rock burst intensity is listed as Table1:

Table 1 Coefficient B and discrimination of rock burst

Coefficient B	discrimination of rock burst
≤10	no
10~14	week
14~18	moderate
>18	high

1.2 The rock integrality modulus

The imperfect structure properties of rock mass had influence on rock burst. Thus, the rock mass integrity modulus (K_v) is an important index determines the rock burst. The K_v can be calculated from the following equation:

$$K_v = \left[C_{pm}/C_{pr}\right]^2 \tag{2}$$

Where: C_{pm}=Rock mass elastic P-wave velocity;

C_{pr}=Rock mass elastic S-wave velocity

According to the engineering rock mass classification standard in China (GB50218-94), complete rock mass refer to K_v >0.55. The probability of rock burst moved up sharply. The critical regions show as Table 2.

Table 2 Rock mass integrity modulus and discrimination of rock burst

K_v	< 0.55	0.55~0.60	0.60~0.75	> 0.75
bust intensity	no	week	moderate	high

1.3 Tangent stress criterion

Stress distribution in rock mass and mechanical properties of rock combined to impact on rock burst, the tangent stress (σ_θ) divided by uniaxial compressive strength (σ_c) is defined as tangent stress criterion (T).

$$T = \sigma_\theta / \sigma_c \tag{3}$$

Rock burst is divided into four grades on the basis of the values of T:

T<0.3, no burst;

T=0.3-0.5, week burst

T=0.5-0.7, moderate burst;

T>0.7, strong burst.

1.4 Rock mass RQD criterion

The fracturing degree of rock mass shows the level of concentrating high stress and accumulating high energy. And rock quality designation index is an important parameter for evaluating the quality of fractured rock mass. Therefore, the value of RQD can be used to predict liability of rock burst.

The threshold values of the four criterions are corresponding to four levels of rock burst intensity, which is shown on table3.

Table3 rock burst intensity evaluation standard

classify / Parameter	Rock burst intensity			
	no burst	Week burst	moderate	strong
B	≤ 10	10~14	14~18	>18
T	<0.3	0.3~0.5	0.5~0.7	0.7
K_v	<0.55	0.55~0.6	0.6~0.75	>0.75
RQD	<25	25~50	50~75	>75

2. Experimental investigations

Combined with the field construction, all the rock samples tested were taken from West Anshan mining area in the west of Anshan (Liaoning Province, China). There are four kinds of rock, i.e., phyllite, magnetite, granite and carbonatite. All samples were prepared in accordance with ISPM suggested shape and size.

2.1 Uniaxial compressive test

We processed all samples into cylinders with a diameter of 50mm, and the ratio of length-to-diameter is 2.The flatness of the top and bottom is less than 0.02mm, and the parallelism between them is less than 0.05mm after grinding with grinder and sandpaper. The uniaxial compressive strength (σ_c) was collected in the rigid machine and under static load, and the results are listed in Table4.

2.2 Brazilian test

The Brazilian test is an indirect method that used in measuring the tensile strength of rock. This method required the disk- shaped specimen's diameter was once or twice of its thickness. A pair of linear load is acted on the disk oriented along the direction of a diameter, and the specimen will be broken. Uniaxial tensile strength (σ_t) can be calculated as follow:

$$\sigma_t = 2P/(\pi dl)$$

Where: d= specimen's diameter; l=specimen's thickness

The result of uniaxial compressive strength is listed in Table4.

2.3 Filed measurement

Combined with practical engineering, the geostress was measured by hydro-fracturing technique. The hydro-fracturing consists of six parts[2], i.e. high-pressure pump, control system for hydraulic fluid, data recording system, power supply system, watertight drilling rods and straddle packers.

Based on the data of drill cores, the RQD and rock mass elastic wave have been recognized.

The physic-mechanical parameters of the rocks are listed in table 4.

Table 4 Physico-mechanical parameters of the rocks

No.	depth/m	Rock type	σ_c/Mpa	σ_t/Mpa	σ_θ/Mpa	C_{pm}	RQD
a-1	601	phyllite	52.7	4.7	34.5	4272	83
a-2	736	phyllite	32.3	3.1	27.7	4153	76
a-3	782	phyllite	52.8	3.6	36.3	4555	96
a-4	802	phyllite	59.4	5.3	37.2	3937	52
a-5	851	phyllite	60.2	5.1	48.4	4387	84
b-1	930	magnetite	106.0	7.3	70.2	4001	65
b-2	940	magnetite	150.9	8.2	91.3	4610	90
b-3	1025	magnetite	173.3	8.5	131.6	4527	99
b-4	1028	magnetite	182.3	8.8	140.2	4582	99
c-1	610	carbonatite	46.7	4.2	16.5	3775	33
c-2	616	carbonatite	43.3	4.7	16.8	3804	28
c-3	625	carbonatite	41.5	3.9	16.2	3777	30
d-1	770	granite	152.1	8.6	95.7	3968	69
d-2	858	granite	96.0	6.1	64.3	4062	65
d-3	903	granite	110.5	6.5	69.6	4123	63

According to the equation (1), (2), (3), we can figure out the single parameter values of each sample. The results are listed in table 5.

Table5 the single parameter value of the rocks

No.	depth	B	T	Kv	RQD
a-1	601	11.2	0.65	0.73	83
a-2	736	10.4	0.86	0.69	76
a-3	782	14.7	0.69	0.83	96
a-4	802	11.2	0.63	0.62	52
a-5	851	11.8	0.80	0.77	84
b-1	930	14.5	0.66	0.64	65
b-2	942	18.4	0.60	0.85	90
b-3	1025	20.4	0.76	0.82	99
b-4	1028	20.7	0.77	0.84	99
c-1	610	11.1	0.35	0.57	33
c-2	616	9.2	0.39	0.58	28
c-3	625	10.6	0.39	0.57	30
d-1	770	17.7	0.63	0.63	63
d-2	858	15.8	0.67	0.66	65
d-3	903	17.0	0.63	0.68	69

3. Synthetical Analysis and Prediction

Four kinds of methods are used to discuss the possibility of rock burst, but it's limited if only individual index was considered [3]. On basis of existing research fruit and all the analysis results contrast, this article adopts fuzzy comprehensive evaluation theory to evaluate rock burst.

3.1 fuzzy comprehensive theory

For the problem of rock burst, we will set U as the mainly control factor the strength brittleness coefficient (B), the rule of tangential stress(T), rock mass integrity coefficient(K_V) and RQD evaluation index

$$U=\{B,T,K_V,RQD\}=\{u_1,u_2,u_3,u_4\}$$

According to the four factors classify the degree of rock burst separately [4], the individual criteria were properly adjusted to four level. In that way, rock burst evaluation set V as follow:

$$V=\{no,week,medium,strong\}=\{v_1,v_2,v_3,v_4\}$$

The fuzzy relationship matrix R has lots of established methods. And on the basis of its distribution features, the selected membership function which reveals the tendency of the rock burst is the distribution of K-parabolic index. The R can be calculated as follow (Yang 2005):

$$r_1(x_i)=\begin{cases}1 & x_i\le a_i\\ \left(\frac{b_i-x_i}{b_i-a_i}\right)^k & a_i<x_i<b_i\\ 0 & x_i\ge b_i\end{cases}$$

$$r_2(x_i)=\begin{cases}\left(\frac{b_i-a_i}{b_i-x_i}\right)^k & x_i\le a_i\\ 1 & a_i<x_i<b_i\\ \left(\frac{b_i-a_i}{x_i-a_i}\right)^k & x_i\ge b_i\end{cases}$$

$$r_3(x_i)=\begin{cases}\left(\frac{c_i-b_i}{c_i-x_i}\right)^k & x_i\le b_i\\ 1 & b_i<x_i<c_i\\ \left(\frac{c_i-b_i}{x_i-b_i}\right)^k & x_i\ge c_i\end{cases}$$

$$r_4(x_i)=\begin{cases}0 & x_i\le b_i\\ \left(\frac{x_i-b_i}{c_i-b_i}\right)^k & b_i<x_i<c_i\\ 1 & x_i\ge c_i\end{cases}$$

Where: $r_1(x_i)$, $r_2(x_i)$, $r_3(x_i)$, $r_4(x_i)$ that are x_i to the four levels of the probability of rock burst by degree of membership; x_i are the index value of the ith factor. a_i, b_i ,c_i are the dividing grade of the ith factor; k is the function index, in accordance with empirical data obtained.

The four factors are different for disparity weight roles, which mean each factors should be allocated to corresponding weight. Based on the expert assessment method, the value of fuzzy weight can be calculated. Every expert redo the weight value of the factor combined with his experience of rock burst prediction. And with all opinion, we can identify main indicators of rock burst factor B, T,K_v , RQD weight distribution, thus the weight vector expressed by A:

$$A=\{0.2,0.3,0.3,0.2\}$$

Integrating the weight of each factors concentration and membership with the expert assessment, fuzzy comprehensive evaluation of surrounding rock burst (Q) can be calculated as follow:

$$Q=A\times R=\{Q_1,Q_2,Q_3,Q_4\}$$

Where: Q_1, Q_2, Q_3, Q_4 are separately corresponding to the tendency value of the four levels of rock burst. The value of Q closer to 1, the more possible of rock burst happened.

Table 6 Integrated results of rock burst prediction

	phyllite	carbonatite	granite	magnetite
601	Moderate burst			
610		Week burst		
616		Week burst		
625		Week burst		
736	Moderate burst			
770			Moderate burst	
782	Strong burst			
802	Moderate burst			
851	Strong burst			
858			Moderate burst	
903			Moderate burst	
930				Moderate burst
942				Strong burst
1025				Strong burst
1028				Strong burst

3.2 The comprehensive evaluation of rock burst

Based on the principal of the fuzzy mathematic comprehensive evaluation system, the matrix Q can be calculated. And the results of rock burst prediction in all kinds of surrounding rock are given as Table 6.

4. Conclusion

In all above, the comprehensive evaluation of rock burst are shown in Table 6. The results suggest that rock burst is almost certain to happen in the depth of -600m to -1000m. And the intensity of rock burst roughly corresponds to the buried depth which means the deeper the rock buried, the more intense of the rock burst. For the rock's lithology, the possibility of a more strong rock burst goes through stages of magnetite, phyllite, granite, carbonatite. Integrated control measures should be taken when the West Anshan iron mine comes to the process of deep mining.

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