THE MINING SEQUENCE OF XISHIMEN MINE USING ORTHOGONAL TEST DESIGN AND 3-D FINITE ELEMENT METHOD①

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ABSTRACT

This paper, combining microcomputerized FEM modelling with orthogonal test design that is a widely used mathematical statistics method, presents the optimization of the panel mining sequence of the Xishimen Iron Mine in Northern China at the objective of rock mechanics. The results shows that the mining sequence between the panels has a great influence on the stability of the draw openings on near footwall, and the optimum mining sequence may be advancing in the benched working line which is oblique to the strike of the orebody.

Key words: mining sequence orthogonal test orebody

1 INTRODUCTION

There is a flat-dipping middle-thick orebody in the southern part of the Xishimen Iron Mine in Hebei Province, Northern China. As shown in Fig. 1, the whole mining range has divided into four long parallel panels without pillars so that the stopping area is increased. Mining is by a sub-block caving method with slusher draw openings on near footwall. Present mining is being carried out to the rise on all four panels. In practice, it has been shown that on the condition of poor hanging wall, the above mining method is applicable, but the stability of the draw openings on near footwall is a dominant problem which is related to safety, economy, and production efficiency.

In general, the factors influencing the stability of the draw openings on near footwall can be classified as two types, that is natural factors and engineering factors. The former, including rock mechanical properties, rock mass structure, initial stress field, groundwater, and deposit position, is uncontrollable by an artificial way; but the later, including mining sequence, mining velocity, support system, and blasting vibration etc, is controllable by people. As will be seen in the later of this paper, if optimizing the designs of those factors in rock mechanic

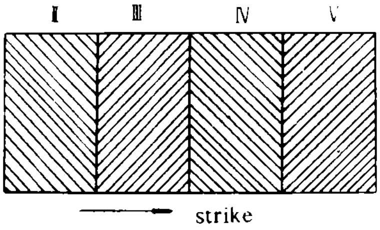

Fig. 1 Layout of the panels in the Xishimen Iron Mine

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s, the stability of the draw openings on near footwall can be improved great ly so that mining costs may be lower markedly.

With the development of electronic computer, numerical methods, e. g. FEM, BEM, DEM, etc, have become powerful tools for mining rock mechanics. In recent years, especially, the advancement in high-performance mirocomputers and microcomputerized practical program for numerical methods have made it possible that a large amount of mining simulating calculations are carried out in engineer's designing office. This will not only offer a great convenience to the user, but also decrease the calculation fee considerably.

By combining microcomputerized FEM modelling with orthogonal test design method, the following sections present the optimization of panel mining sequence of the Xishimen Iron Mine at the objective of rock mechanics, exactly, the stability of the draw openings on near footwall.

2 GEOLOGOCAL CONDITIONS OF THE XISHIMEN IRON MINE

The orebody which consists of octahedral iron ore, is bedded on the interface of ordovician limestone and diorite; located underground at the depth of 150～200 m; dips at approximately 12° to the southwest; is 500～600 m long in the strike, and 300～400 m wide in the dip; has an average height of 12 m. The country rocks have ordovician limestone (hanging wall), lime rudyte (immediate roof), Skarn (immediate bottom), and diorite (footwall). There is no large scale of fault near the orebody. The in—situ state of stress of this mine has been determined by using the Triaxial Strain Cell. Based on the laboratory tests and the geomechanics classification of rock mass[1], the mechanical parameters employed in the later calculations is listed in Table 1.

Table 1 Mechanical parameters of the ore and rocks

Name of Rocks	Compressive strength (MPa)	Tensile Strength (MPa)	Young's Modulus (MPa)	Poisson's Ratio
Limestone	38.5	2.23	27800	0.20
Rudyte	10.9	0.88	10200	0.25
Iron ore	42.6	2.13	32100	0.23
Skarn	29.7	1.85	16300	0.26
Diorite	73.7	3.54	66500	0.26

3 NUMERICAL MODELLING OF THE PANEL MINING SEQUENCE

3.1 *Schemes of the Panel mining Sequence*

In this paper, the panel mining sequence is defined as a sum of the relative space relation formed among all working panels. There are three possible states usually for the relative relation between any two neighboring panels. That is Front, Back, or Identical, as shown in Fig. 2.

Because of the orebody being divided into four panels on the mining area, the optimization of the panel mining sequence can be considered as a multifactors test problem in mathematics. It has been mathematically proven that arranging a multifactor test using the orthogonal design matrix will not on-

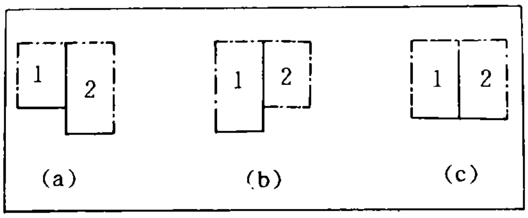

Fig. 2 Three types of relation between two neighboring panels
(a)—Front; (b)—Back; (c)—Identical

ly minimize the test times, but the estimates for the test results be also the optimum statistically[2].

Suppose A, B, C to be the factors denoting the relative relation between Ⅱ and Ⅲ, Ⅲ and Ⅳ, Ⅳ and Ⅴ respecitvely; and +1, 0, −1 to be the levels denoting the above three states of each factor respectively. Then, $L_9(3^4)$, a four factors and three levels orthogonal test design matrix, can be used to design the schemes of the panel mining sequence, as listed in Table 2. The front or back gap between two neighboring panels is supposed to be seventy metres in the modelling.

Table 2 The panel mining schemes

Scheme Number	Factor A	Factor B	Factor C
1	+1	+1	+1
2	+1	0	0
3	+1	−1	−1
4	0	+1	0
5	0	0	−1
6	0	−1	+1
7	−1	+1	−1
8	−1	0	+1
9	−1	−1	0

3. 2 FEM *Model*

Obviously, the above panel mining sequences are not unable to be simulated by using a two dimensional FEM model. Thus, a three dimensional FEM model has to be adopted. Based on the estimate of the stress influencing zone, the 3-D FEM model has been given: 1200 metres long, 800 metres wide, and 300 metres high; and divided into 1296 isoparametric elements with the sum of 1729 nodepoints.

The boundary conditions of the model is that the front, back, left, right, and bottom bounds are fixed at the direction of their normal line, while the top bound is free (to ground surface). In addition, the effect of the near- footwall draw openings on the stress distributions surrounding the stope is neglected in the model, since the geometric dimension of those openings is far and away smaller than that of the stope. Fig. 3 present the FEM mesh of this model.

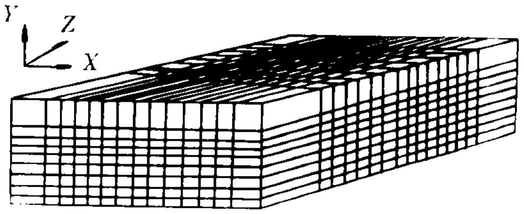

Fig. 3 Three Dimensional FEM mesh

3. 3 *A brittle Failure Condition of the Draw Openings on Near Footwall*

Although the effects of the near- footwall draw openings on the stress distributions surrounding the stope are negligible, the stress concentrations on near footwall due to mining excavation have a significant influence on the stability of those openings. From the following analysis, we can understand this point.

Fig. 4 illustrates a large diameter opening Ⅰ with a small diameter opening Ⅱ in its zone of influence. Since excavation Ⅰ is outside the zone of influence of excavation Ⅱ, a fair estimate of the boundary stresses around Ⅰ is obtained from the stress distribution for a single opening. For excavation Ⅱ, the field stresses are those due to the presence of excavation Ⅰ. An engineering estimate of the boundary stress around Ⅱ can be obtained by calculating the state of stress at the centre of Ⅱ, prior to its excavation. This can be introduced as the far field stress in the Kirsh equations[3] to yield the required boundary stress for the smaller excavation.

Based on the above understanding,

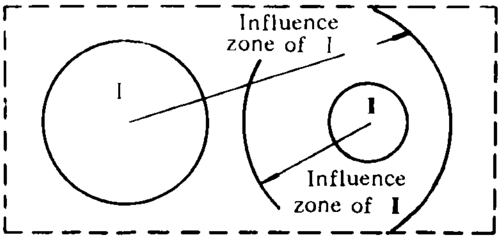

Fig. 4 The illustration of the effect of contiguous openings of different dimensions

$R_{\rm I}$ —"radius" of influence zone of Ⅰ;
$R_{\rm II}$ —"radius" of influence zone of Ⅱ

here, a hyperbolic equation is used for estimating the instability of the draw openings on near footwall, which was derived jointly from the kirsh equations, Mohr-Coulumb criterion, Maximum tensile stress condition [4] That is:

$$F = \frac{\tau_m^2}{a^2} - \frac{(\sigma_m - c)^2}{b^2} \qquad (1)$$

in which:

$$a = \frac{\sigma_c + \sigma_t}{\sqrt{32(1+K)}}$$

$$b = \frac{\sqrt{2(1-K)} \times (\sigma_c + \sigma_t)}{\sqrt{32(1+K)}}$$

$$c = \frac{\sigma_c - \sigma_t}{4}$$

$$K = \cos(\pi . \eta)$$

σ_m, τ_m — maximum shear stress and mean normal stress respectively at the center of an opening, prior to its excavation.

σ_c, σ_t — uniaxial compressive and tensile strength of rocks respecitvely.

$\eta = \varphi/360$ — the Boundary Failure Degree(BFD) of an opening,

φ — the sum of the central angles corresponding to the shear and tension failure boundaries.

This equation has the following uses:

(1) For a given BFD, if $F > 1$, the instability of the opening takes place; opposite, the opening is in safety.

(2) If the stress state is given at the centre of an opening, prior to its excavation, its BFD can be obtained from equation(1).

3.4 *The Calculation Results*

The simulation calculations of nine schemes listed in table. 1 were performed on a COMPAQ—386/16 personal computer with 80387 coprocessor. For each scheme, the mining excavations were simulated in ten steps; and linecar elastic constitutive model was employed. After each mining excavation finished, the BFD of the openings beneath the ore elements to be excavated next step were calculated by using equation (1) and the stresses at the central points of those openings, prior to its excavation.

For convenience of analysis, we may divide the BFD of an opening into five grades below 0%, 0~20%, 20~50%, 50~80%, above 80%; and call them No Failure (NF), Light Failure (LF), Middle Failure (MF), Serious Failure (SF) and Destructive Failure (DF) respectively. Then, for a mining scheme, the percentage of number of the openings at different BFD grade to the sum of the openings on the whole area is called Opening Failure Percenatge (OFP).

Fig. 5 shows that the distributions of OFP on the different grade for each scheme listed in table. 2. The weighted mean OFP of those schemes, with the weight of mean BFD at different grade except for No Failure, are presented in Fig. 6. They will be taken as the examined index in next section.

4 STATISTICAL ANALYSES OF CALCULATION RESULTS

4.1 *The Variance Analysis*

From Fig. 6, it can be seen that there

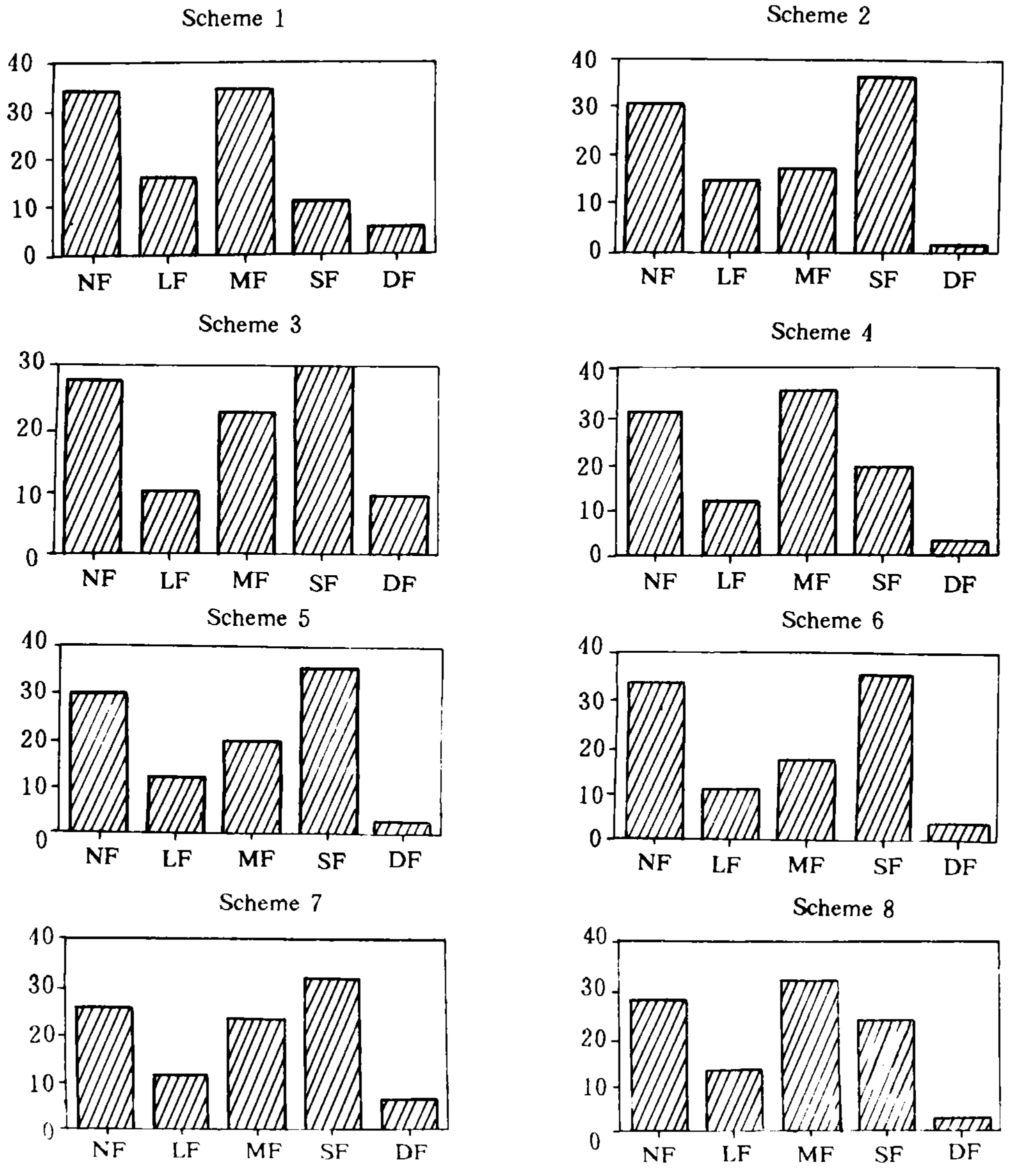

Fig. 5 OFP distribution on different BFD for the nine mining schemes

are considerable differences among the checked index of all schemes . Those differences derive from the variation of level of the investigated factors A, B, and C. Since only the notable factors have an influence on the checked index from the statistical viewpoint[5] the, objective of variance analysis is to determine which factors to be notable for a given confidence level so that the effect analysis of the notable factors will be made later . The variance analysis to weighted mean OFP are given in Table 3.

From Table. 3 it can be seen that the investigated factors, including A, B, and C, are all notable for the confidence level 95%.

Table 3　The Variance analysis($\alpha = 0.05$)

Sources of deviationk	Factor A	Factor B	Factor C
Quadratic sum of deviation	64.83	60.70	72.72
Freedom degree	2	2	2
Mean quadr deviation	32.41	30.35	31.37
F-examined value	21.05	19.69	20.37
F standard value	19.00	19.00	19.00
Notability of factors	★	★	★

Notes: ★ means this factor is notable for the given confidence level.

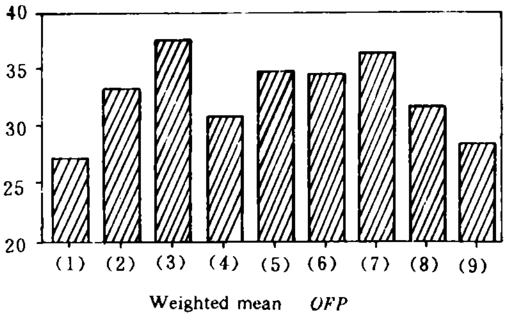

Fig. 6　Weighted mean OFP of the nine mining schemes

(1)～(9): scheme number

4.2　*The Effect Analysis*

After determining the notable factors, the optimum levels can be found in the light of the maximum or minimum main effects of those factors. Since we wish the checked index, weighted mean OFP, be small as soon as possible, it is the levels corresponding to the minimum main effect of each notable facotr that are the optimum levels we are to seek for. The effect analysis are given in Table 4, from which, it can be seen that the optimum levels of the notable factors are A1, B1, and C1 respectively.

4.3　*The Optimum Mining Sequence Between The Panels*

Based on the assembly of th above optimum levels, A1B1C1, the optimum panel mining sequence on rock mechanics can be obtained for the Xishimen Iron Mine, as shown in Fig. 7. By chance, it is identical with the scheme 1 listed in table 2. Hence, from Fig. 5, we can know that its weighted mean OFP is 27.1%.

Table 4　The effect analysis

Sources of effect	1st—level	2nd—level	3rd—level	Minimum
Factor A	−1.64	6.71	4.32	−1.64
Factor B	1.56	2.39	5.03	1.56
Factor C	0.74	3.30	5.58	0.74

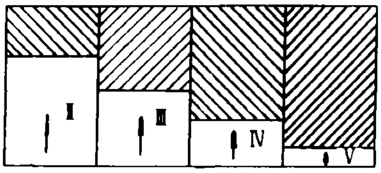

Fig. 7　The optimum panel mining sequence based on rock mechanics for the Xishimen Iron Mine

5　CONCLUSIONS

(1) The mining sequence between the panels has a siginificant influence on the draw openings on near footwall. Therefore, it is very necessary to seek for the optimum panel mining sequence based on rock mech nics.

(2) The combined method of the microcomputerized numerical modelling (e.g. FEM) with the orthogonal test design mehtod can be applied successfully to the optimization of mining design. It can not only

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tions are continuously encountered. Furthermore, employing this learning approach can reduce the difficulty of problem solving in complex rock mechanics environment where insufficient knowledge often occurs and that of knowledge acquisition.

Another more important feature of this system is its content- addressability. This property is valueable for the domain of data-limited rockburst prediction and rock opening design because it can help designer determine default values of geologic features and correct incorrect parts of the content of a pattern.

The identification of probable rockburst of new cases is made by adaptive and associative reason of neural networks. The degree of activation of an output node of a certain neural network generated by the system reflects quantitatively its relative importance. This property will allow predictors to quickly assess the best suitable measures of controlling rockbursts or the controlling parameters for further detailed analysis.

Furthermore, to the best of our knowledge this has been the first attempt at predicting the possibility of rockburst occurrence using machine learning based on neural networks. We will need to consolidate our results by further testing on a larger test set.

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be convenient to the user, but also decrease the calculation cost greatly.

(3) For the Xishimen Iron Mine, the optimum panel mining sequence at the objecitve of rock mechanics is : Panel Ⅱ front to Panel Ⅲ, Panel Ⅲ front to Panel Ⅳ, Panel Ⅳ front to Panel Ⅴ, which form the benched working line that is oblique to the strike of the orebody.

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