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Feasibility Study on Continuous Mining Method in Deep Position of Jinchuan Nickel Mine, China

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Abstract: Jinchuan nickel mine is the largest nickel mine in China. Cut-and-fill mining method with high density cementing materials is used in the mine. The original mining design divided the mining operation into two steps. The first step stopped the mining rooms and the second step stopped the pillars. Because the two-step method made big trouble for finally mining pillars and strongly limited the mining speed and production, it was successfully changed to a continuous cut-and-fill method without pillars. However, the mining operation in the mine has been down to 800 m and the mining condition is getting worse and more complicated. Through systematical field investigations and 3-D FEM analysis, it is proved that the mining method without pillars is feasible for mining deeper orebodies in Jinchuan nickel mine.

Key words: Jinchuan nickel mine; deep position; continuous mining; feasibility study

1 Introduction

Jinchuan nickel mine is located in the middle of Hexi Corridor and edge of Gobi Desert in Gansu province, northwest of China. It is the second largest nickel deposit in the world with nickel metal production of 40 000 t per year at the moment. The nickel ore was borne in ultrabasic rock mass and the formation of the deposit was controlled by the regional main fault F1 which is 170 km long and strikes NW50-70°. The main orebody zone is 6.5km long, tens to about 500 m wide and more than 1 000 m deep. The NEE oriented heterotropic fault separated the main orebody zone into four independent mining areas: No.3, No.1, No.2, and No.4 from west to east. Mining Area No.2 covers 75% of the total reserve in the mine and more than 90% of rich ore is reserved there with average grade of two percent. At present, the annul ore output in Mining Area No.1 is 1.2×10^7 t and 2.5×10^7 t in Mining Area No.2. The Mining Areas No.3 and No.4 have not been excavated yet.

The mine area underwent many tectonic movements and intrusive actions of magmatic rock. So faults and joints are very developed in the rock mass which caused the rock conditions very poor and complicated. Both the contact zones between the ore bodies and surrounding rock and the contact zones between poor orebodies and rich orebodies are soft and fractured. The stability of these zones is very poor.

Cut-and-fill mining method with high density cementing materials is used in the mine. The height of descending sub-levels is 50 m. The original mining design divided the mining operation into two steps. The first step stopped the panel (mining rooms) and the second step stopped the pillars. However, after the first step, high stress concentration in pillars made them damaged seriously and difficult to be stopped. Furthermore, the two-step method strongly limited the stopping speed and mining production. Therefore, this method was changed to a continuous cut-and-fill method without pillars. Using this method, the Mining Area No. 2 has safely and successfully extracted from a stopping area of 50 000 m^2 without pillars above 1 250 m level (500 m under the ground level). However, the mining operation in Mining Area No.2 has been down to 900 m level. In deep position of the mine, in situ stress is getting higher, quality of the rock mass is worse and burring condition of the orebodies is more complicated. Therefore, it should be studied how to use the no pillar method to mine deeper orebodies whose area will be over 100 000 m^2. The study includes in situ stress measurement, investigation of engineering-geological and hydrogeological conditions, rock mass structures and quality, and systematical numerical analysis by 3-D FEM.

2 Field Investigation

2.1 In situ stress measurement

In situ stress measurement was carried out at 10 points which were distributed on 3 levels, i. e. 4 on 1 150 m level, 4 on 1 000 m level and 2 on 940 m level. Stress relief by overcoring with an improved hollow inclusion technique was used for the measurement. Details on the improved hollow inclusion technique has been reported elsewhere [1, 2]. Through the measurement, 3-D stress state at the 10 points were calculated. Using linear regression method, field stress distribution along depth was obtained as shown in equations (1)–(3).

$$\sigma_{\mathrm{h,max}} = 0.098 + 0.0507H \quad (\mathrm{MPa}) \qquad (1)$$

$$\sigma_{\mathrm{h,min}} = -0.015 + 0.0209H \quad (\mathrm{MPa}) \qquad (2)$$

$$\sigma_{\mathrm{v}} = -0.028 + 0.0254H \quad (\mathrm{MPa}) \qquad (3)$$

Where $\sigma_{\mathrm{h,max}}$, $\sigma_{\mathrm{h,min}}$ and σ_{v} are maximum horizontal principal stress, minimum horizontal principal stress and vertical principal stress, respectively; H is depth, its unit is m.

2.2 Evaluation of engineering geological conditions

The investigation of engineering geological conditions was carried out in the three deeper levels of the mine, i.e. 1 150 m, 1 000 m and 940 m levels. Length of openings investigated was more than 2 000 m. The content of the investigation included distribution and structures of rock masses, and strike, space, length, roughness and filling condition of joints, etc. Based on the results of the investigation, classification of rock mass structures was made by fuzzy discrimination method, as shown in **table 1**.

Table 1 Classification of rock mass structures

Rock mass group	Code	Structure of rock mass
Fractured rock mass around F1 fault	I_1	Loosing (granular) structure
Migmatite with inter-stratified extruding	I_2	Stratified cataclastic structure
Migmatite without obvious fractures	I_3	Inlaid structures
Gneiss rock mass with coarse grains	II_1	Stratified cataclastic structure
Fractured rock mass around F16 fault	II_2	Loosing (granular) structure
Schist gneiss	II_3	Stratified cataclastic structure
Middle thick or thin layer marble with various magmatic intrusion	III_1	Stratified structures
Thick layer marble	III_2	Block structures
Fractured middle thick or thin layer marble with frequent inter-penetration of various magmatite	III_3	Cataclastic structures
Homogeneous stripped migmatite	IV	Stratified structures
Granite	V	Inlaid structures
Ultrabasic rock with ore	VI	Cataclastic structures

Using dynamic fuzzy clustering analysis, stability zoning of rock mass was made. This zoning attached importance to major factors which influence the stability of rock mass. Based on the results of CSIR classification and NGI classification, the rock mass in Jinchuan mine was divided into 4 zones, as shown in **table 2**.

Table 2 Zone dividing of rock mass stability

Zone No.	Rock mass groups	Q	RMR	Grade
1	III_2, V	2.630	47.8	Fair
2	I_3, IV, III_1, VI	0.611	41.7	Fair
3	I_2, II_1, III_3, II_3	0.293	39.1	Poor
4	I_1, II_2	<0.1	<10	Very poor

Note: Q is the index value of NGI classification; RMR is the index value of CSIR classification.

3 Mechanical Properties of Rock Material

3.1 Basic mechanical parameters of intact rock

More than 200 tests were carried out to get basic mechanical parameters of intact rock. Test results are shown in **table 3**.

3.2 Mechanical parameters of weakness in different house rock

Tests of mechanical parameters of weakness (weak planes) were carried out in a traditional shear box. Test number (specimens) for each type of house rock was 9. Test results of cohesion (c_{w}), internal frictional angle (ϕ_{w}), normal stiffness (k_{n}), shear stiffness (k_{s}) of weakness are shown in **table 4**.

3.3 Creep characteristics of rock

Some types of rock in Jinchuan mine showed remarkable creep effect. To determine the creep parameters, 4 types of creep tests were carried out. The total test number was 109, i.e. 55 uniaxial compressive creep tests, 27 bending creep tests, 18 shear creep tests and 9 torsion creep tests. Six types of rock were tested which included lherzlite, marble, migmatite, lamprophyre, lean ore and rich ore. Among the 6 types of rock, marble and lean ore showed quite strong creep characteristics, and creep effect of lherzlite and rich ore was not serious.

Based on the test results, a rheological model for rock in Jinchuan mine was established, as shown in **figure 1**. The values of k_1, k_2, η_1, η_2 and σ_{f} could be deter-

Table 3 Basic mechanical parameters of intact rock

Rock type	σ_c / MPa	σ_t / MPa	E / GPa	ν	c / MPa	ϕ / (°)
Lherzolite	114.7	7.0	61.0	0.18	11.5	40.0
Marble	104.0	11.0	64.0	0.16	7.4	42.6
Migmatite	148.0	15.2	79.0	0.21	10.5	43.2
Lean ore	137.9	11.9	52.0	0.23	9.0	39.9
Rich ore	151.5	6.0	57.0	0.30	7.2	41.4

Table 4 Mechanical parameters of weakness

House rock	c_w / kPa	ϕ_w / (°)	k_n / (MPa·m^{-1})	k_s / (MPa·m^{-1})
Migmatite	15.2	29.0	915	559
Rich ore	24.5	27.1	639	352
Lherzlite	31.5	27.4	1 544	772
Marble	46.4	29.8	753	378
Diabase	62.9	26.0	1 717	916
Lean ore	18.4	26.9	1 596	818

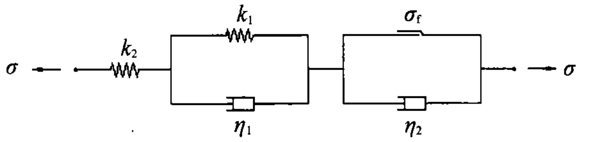

Figure 1 Rheological model of rock in Jinchuan mine.

mined by polynomial regression, as shown in **table 5** for marble and lherzlite.

3.4 Swelling characteristics of rock

The distribution of chlorite schist in Jinchuan mine is quite large. Chlorite contains montmorillonite and possesses remarkable swelling characteristics. Through field investigation and laboratory analysis, it was determined that the content of montmorillonite in chlorite schist was 17.95% and 11.48% in the west and east part of the mine, respectively.

From 10 swelling tests, the swelling parameters were obtained as follows:

Maximum swelling stress = 2.174 MPa;

Minimum swelling stress = 0.03 MPa;

Maximum swelling rate of volume = 4.47%;

Minimum swelling rate of volume = 0.05%.

Table 5 Creep parameters of marble and lherzlite

Rock	k_1 / GPa	k_2 / GPa	η_1 / (×10^{-9}MPa·s)	η_2 / (×10^{-9}MPa·s)	σ_f / MPa
Marble	24.03	52.78	3.472	2.262	39.34
Lherzlite	29.81	42.72	2.611	3.460	30.32

4 FEM Analysis of Mining Design

4.1 Computing program and model

3-D large scale nonlinear FEM program "FINAL" was used for the FEM analysis. The computing was performed in a computing station of VAX system. The computing geometry model is shown in **figure 2** whose length (y direction) is 2 000 m, width (x direction) and height (z direction) are both 1 000 m. The model includes 8 000 nodes and 7 000 elements of 20-node and 3-D equal parameter. The orebody to be mined from 1 250 m level to 1 050 m level was divided into 8 sublevels. Each sublevel was 25 m high and divided into several 20 m wide drifts.

4.2 Mechanical parameters of materials

Based on the test results of mechanical parameters of intact rock and weakness, and investigation of joint condition in rock mass, the mechanical parameters of rock mass for 4 zones, as defined in table 2, were determined as shown in **table 6**. During the calculation of the mechanical parameters of rock mass, empirical reduction factors were used.

4.3 Analysis models

In order to compare the stability status of mining structures with pillars and without pillars, and to study the effect of different mining orders, following 6 models were analyzed.

Model 1: Mining with pillars, all mining rooms were successively mined from top to bottom, and, at last, the pillars were mined.

Model 2: Mining without pillars, and the other min-

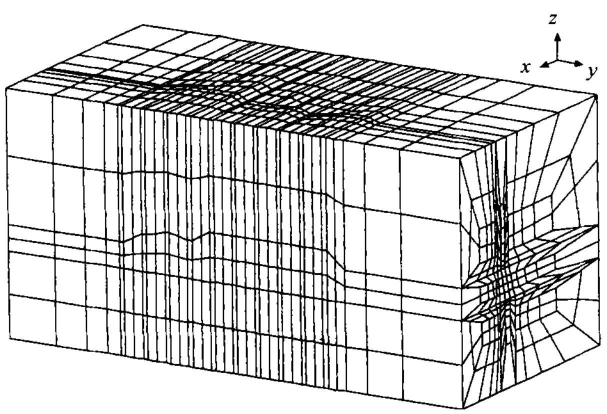

Figure 2 Mesh of FEM model.

ing structural parameters were the same as Model 1.

Model 3: Mining with pillars, mining rooms were gradually mined from central to two sides of the stope, and, at last, the pillars were mined.

Model 4: Mining without pillars, and the other mining structural parameters were the same as Model 3.

Model 5: Mining with pillars, mining rooms were gradually mined from one side to the other side of the stope, and, at last, the pillars were mined.

Model 6: Mining without pillars, and the other mining structural parameters were the same as Model 5.

Table 6 Mechanical parameters of rock mass for 4 zones

Zone No.	σ_c / MPa	σ_t / MPa	E / GPa	v	c / MPa	ϕ / (°)
1	43.8	3.6	8,81	0.25	6.5	46.1
2	35.5	3.1	6.12	0.25	5.1	45.0
3	26.2	2.6	5.35	0.22	4.1	43.9
4	10.0	1.0	5.00	0.22	2.0	30.0
Filling	4.1	0.5	1.20	0.21	0.6	33.0

Note: filling means filling material used for cut-and-fill method

4.4 Analysis of results

(1) Comparison between mining with pillars and without pillars.

Some key data of the calculated results are shown in **table 7**.

Model 1, Model 3 and Model 5 are three models with pillars, and Model 2, Model 4 and Model 6 are three models without pillars. Comparing the results of Model 1 and Model 2, Model 3 and Model 4, Model 5 and Model 6, following conclusions can be made.

1) In three models with pillars, after excavation of mining rooms, stress concentration in surrounding rock was not high, but stress at pillars was high to 90 MPa. High stress concentration will cause the pillars broken and make a big trouble for finally mining the pillars.

2) After excavation of the pillars, stress concentration in models with pillars was at the same level as in models without pillars. Stress at two ends of the stope in models without pillars was 8–13 MPa higher than that in models with pillars, but stress at two sides of the stope in models with pillars was 1–5 MPa higher than that in models without pillars.

3) The maximum horizontal displacement at right side of the stope in models without pillars was 1–8 cm higher than that in models with pillars, but at left side the situation was opposite, the maximum horizontal displacement in models with pillars was 0–5 cm higher than that in models without pillars.

4) Before excavation of pillars, yielding zone in surrounding rock in models with pillars was small and scattered. However, after excavation of the pillars, the yielding zone was joined together, and its shape and size were basically the same as that in models without pillars.

(2) Comparison between different mining orders

Table 7 Key data of calculated results

Data item	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Maximum Stress at two ends of the stope / MPa	66.0	79.0	51.0	61.0	60.0	68.0
Maximum Stress at two sides of the stope / MPa	33.0	28.0	26.0	22.0	23.0	22.0
Maximum Stress at pillars / MPa	90.0	—	80.0	—	79.0	—
Maximum Horizontal displacement at left side of the stope / cm	19.0	24.0	17.0	22.0	25.0	25.0
Maximum Horizontal displacement at right side of the stope / cm	14.0	32.0	24.0	31.0	32.0	33.0
Maximum Subsidence of the Stope roof / cm	5.2	5.9	5.6	6.4	6.2	7.8
Maximum Stress in filling / MPa	18.0	13.0	12.0	14.0	13.0	17.0

Model 2, Model 4 and Model 6 were three models without pillars, but their mining order was different. Comparing their calculation results listed in table 7, it can be seen that synthetical index of stability status in model 4 is the best among the three no-pillar models. It means mining from central to two sides of the stope is the best mining order.

5 Conclusions

(1) From comprehensive comparison of stress, displacement and yielding zones, it is concluded that stability status of mining without pillars is close to that of mining with pillars. It means that mining method without pillars is strongly feasible in the deep position of Jinchuan nickel mine.

(2) Mining method without pillars makes the management of mining operation much easier, and can significantly increase production, productivity and profit of the mine. Therefore, it is much better than the mining method with pillars.

(3) Mining from central to two sides of the stope is the best mining order in Jinchuan nickel mine.

(4) High stress concentration will occur at two ends of the stope during mining without pillars, so it is important to take measures to prevent failure of two ends of the stope and other dangerous places indicated by the FEM analysis and in situ monitoring.

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