Research on Mining Technology of Steeply Inclined Thin Ore Body in High-grade Content Mine

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Abstract. In view of the problems of poor mining safety, low recovery efficiency, high cost, low recovery rate and few recovery options in steeply inclined, extremely unstable thin to medium-thick ore bodies, especially there are no economically feasible mining options for low-grade resources of this type of deposit. The paper proposes a safe, high-efficiency and low-cost mining technology suitable for steeply inclined thin ore bodies-segmented empty field subsequent filling mining method combined with 3Dmine and ANSYS to establish a FLAC3D numerical model to obtain a stope production capacity of 180t/d and a loss rate of 7.40%, the expected effect of the dilution rate of 14.96%.

Keywords: High-grade mine, steeply inclined thin ore body, ore body mining technology, segmented empty field and subsequent filling mining method.

1. Introduction

The rapid increase in the consumption of mineral resources has forced mining to deepen, residual, and difficult-to-mine bodies. Steeply inclined thin ore bodies occupy a large proportion in China's non-ferrous metal mines. When the ore body is unstable or extremely unstable, the rock mass has poor self-stabilization ability, difficult to excavate and support tunnel engineering, low efficiency, and high cost; complex mining technology; The mining safety is poor; the blast hole formation is difficult, the utilization rate is low, and it is difficult to achieve high quality and large-scale blasting and mining; the low resource utilization rate is one of the difficult ore bodies. In the past, the layered caving method and the downward filling method were mostly used at home and abroad, which are mainly suitable for mining high-value ore bodies [1]. Among them, the layered caving method has a tendency to be replaced by the downward approach filling method. In recent years, scientific researchers have tested the pillarless sublevel caving method in this type of ore body, which has effectively improved the mining production efficiency and realized the recovery of this type of ore body. However, because the tunnel engineering is located in the vein, construction and support The problem of protection is still very difficult; and the amount of a single caving is small, and the working area is small at the same time, and the production capacity is still small; the loss rate of dilution is large, and the recovery space is small, which is easy to cause the phenomenon of making dumplings, leading to problems such as failure to release the caving ore.
The segmented empty field subsequent filling mining method arranges the ore blocks along the strike. The ore blocks are 50m long, 50m wide as the thickness of the ore body, and 50m high. They are generally divided into 2 to 3 segments with a height of 14 to 20m. After the completion of the phase transportation roadway of the mining standard project, the ore body shall be driven into the ore body for the ore loading access road, the patio connection road, and the patio; the bottom roadway is arranged at the bottom of the ore body, and the segmented rock-drilling roadway is arranged along the direction of the ore body. In the centre of the ore block, a scraper is used for ore extraction, and the secondary crushing is in the exit path. After mining in the mine room, the pillars are recovered according to the situation, and waste rocks are used to fill the goof. A typical scheme is shown in Figure 1.

![Figure 1. Subsection empty field subsequent filling and mining method.](image)

2. Primary selection of mining methods

The main factors affecting the choice of mining methods include the geological conditions of the deposit and the technical and economic conditions of mining. The commonly used methods for mining steeply inclined and thin ore bodies in China include shallow hole retention method, upward layered filling method, and medium deep hole retention method. Although the shallow hole retention method is simple in technology, it has poor operational safety and large mining and cutting works. The upward stratified filling method has good safety, and the loss of ore dilution is small, but the mining cost is high, the stopping and filling process is complicated, and the mining operation is greatly affected by the time and intensity of the filling body [2]. The medium and deep hole retention method has high production efficiency, simple technology, low mining cost, but large dilution rate, high mechanization investment, and high technical and management requirements; medium and deep hole subsequent waste rock filling mechanized mining method has not been adopted in China Ore bodies with similar occurrence conditions, but similar mining methods in Australia are more mature, mainly used for safe and efficient mining.

2.1. Establish a set of feasible plans and a set of candidate plans

According to the mining technical conditions of the mine, the above 4 mining methods are selected as the set of options. In the program concentration, the stability of the ore rock is a qualitative indicator and needs to be quantified. The stability is divided into five levels: extremely stable, stable, relatively stable, unstable, and extremely unstable. When entering data, use "1", "0.8", "0.5" and "0.2" respectively, and "0" instead. The feasible set of primary selection schemes after the above processing is shown in Table 1.
Table 1. Set of preliminary mining plans.

| Plan number | Mining method                     | Inclination/° | Thickness/m | Stability          |
|-------------|-----------------------------------|---------------|-------------|--------------------|
| u1          | Shallow hole retention method      | 63            | 2           | 0.2 0.8 0.5        |
| u2          | Segmented empty field             | 57            | 3.6         | 0.5 0.5 0.5        |
| u3          | Subsequent Filling and Mining     | 70            | 2           | 0.5 0.5 0.5        |
| u4          | Medium and deep hole retention method | 60          | 1.5         | 0.5 0.5 0.8        |

2.2. Optional mining method equivalent matrix calculation

Based on the preliminary mining plan set, apply the maximum minimum method formula

$$\lambda_{ij} = \frac{\sum_{k=1}^{m} (x_{ik} \land x_{jk})}{\sum_{k=1}^{m} (x_{ik} \lor x_{jk})} \quad (i, j = 1, 2, ..., n) \quad (1)$$

Obtain the fuzzy similarity matrix (the symbols $\land$ and $\lor$ in the formula respectively represent the smaller and larger elements of the two elements), and then the equivalent matrix elements of the optional mining methods are shown in Table 2.

Table 2. Equivalent matrix elements of primary mining method.

| Plan number | u1  | u2  | u3  | u4  |
|-------------|-----|-----|-----|-----|
| u1          | 1   | 2/3 | 2/3 | 2/3 |
| u2          | 2/3 | 1   | 1   | 5/6 |
| u3          | 2/3 | 1   | 1   | 5/6 |
| u4          | 2/3 | 5/6 | 5/6 | 1   |

From the $\lambda$-cut matrix of the fuzzy equivalence matrix, we know that when $\lambda_{ij} = 1$, i and j should be of the same kind, otherwise they are of different kind. When $\lambda_{ij} = 5/6$, u2, u3, u4 are one type, among which u4 is the medium and deep hole subsequent waste rock filling mechanized mining method, and the other two are the upward layered filling method and the segmented empty field subsequent filling mining method [3].

3. Engineering Practice

Among the two joint veins in the mine, the V7 joint vein ore rock was the most stable and was first discovered below the 28th middle section. Therefore, engineering practice first chose the joint vein in the 29 middle section 2980 ore blocks. The mine was designed and constructed in July 2019, and it was mined for a total of 6 months. The mined ore was 7016t (monthly average of 1169t); all ore had been mined except for the loss of fine ore, which could not be calculated; consumed 552 bolts. The post-mining goof has a vertical height of 9.6m and a width of 4.5m. During the subsequent waste rock filling, the empty area did not collapse [4]. The plane of the actual stope is shown in Figure 2.
3.1. Geometric model size

In order to fully simulate the mining process, the FLAC3D simulation analysis model as shown in Figure 3 is obtained after 3DMine and ANSYS processing the geological topography map and the actual measurement plan of each stage provided by the mine. There are 226,200 structural parameter optimization model units and 924,001 nodes in the stope.

Figure 2. Stope plan.

Figure 3. FLAC3D simulation analysis model for optimization of stope structure parameters.
The test stope is selected in the middle section of 180m, and the boundary stress of this calculation model is taken as:

\[
\begin{align*}
\sigma_h &= \lambda \gamma H \\
\sigma_v &= \gamma H
\end{align*}
\]  

(2)

In the formula, \(\sigma_h\) is the horizontal boundary stress, \(\sigma_v\) is the self-weight stress, \(\lambda\) is the lateral pressure coefficient, \(\gamma\) is the bulk density, and \(H\) is the depth. The optimization calculation model range of structural parameters in the stope is \(y=500\)m (vertical to the strike direction of the ore body), \(z=0\)m horizontal to ground height (FLAC3D), and \(x=1260\)m (along the strike direction of the ore body) (FLAC3D).

3.2. Simulation results and analysis

The space formed after the mining of the ore body disrupts the original balance state and causes the stress to redistribute. During the secondary balance process, the load imposed by the original rock on the stope or the surrounding rock and pillars of the goaf caused the deformation of the stope wall and the pillars. Move or destroy. The appearance of severe ground pressure will not only deteriorate the conditions of mining activities, affect production, and even endanger safety. This simulation was carried out in order to study the distribution of stope site pressure and its appearance during the underground mining of Silver Mine. On the one hand, based on the specific mining conditions of the mine, some measures have been explored to control the stability of the rock strata and pillars of the stope, avoid the appearance of large-scale severe ground pressure, and control the impact of the stope pressure on safe production within the allowable range; On the one hand, according to the distribution and transfer law of mining site pressure, a mining plan with high efficiency, low cost, low loss and dilution, and good economic benefits was developed [5].

4. Precautions during mining

4.1. Falling

The following points should be paid attention to during the mining operation. 1) Arrangement of blastholes. In order to prevent hidden hazards such as overhanging roof from falling mine and lower section caving, and to improve the utilization of existing equipment, the mine blasthole adopts a forward-inclined fan shape. 2) Blast hole diameter (d). The blast hole diameter is 40mm (YT-23 air-leg rock drill and YSP-45 top mining rock drill), which is conducive to the blasting of the currently used emulsion explosives. 3) Effective depth of blasthole. The effective depth of the blasthole is 3.0m. 4) The inclination of the blasthole fan (ie the inclination of the end wall). The forward-inclined fan shape is adopted when the cutting groove is drawn [6]. This method can delay the early infiltration of the upper waste rock and rubble, and can effectively control the caving boundary. 5) The side hole angle of the fan-shaped blasthole. The side hole angle is the angle between the two blast holes on the most side of the fan-shaped row surface and the horizontal. In order to reduce mining loss and ore dilution, and obtain a better recovery rate, the side hole angle should match the ore body inclination as much as possible. 6) Collapse step. The caving step should be compatible with the section height, the centre distance of the mining roadway and the mining equipment, so that the thickness of the caving ore layer is consistent with the release ellipsoid and the safety of mining is guaranteed. The step distance of ore collapse is determined by production conditions and practice as 1.5~2.0m.

4.2. Blasting

Use emulsion explosives, non-electrically conductive blast tube, detonator detonation, sub-blasting. In order to avoid excessive concentration of charge at the orifice of the fan-shaped blasthole, the filling
length of the other holes should be staggered to increase the packing length except for the side holes when the charge is full, so that the orifice spacing is (0.4~0.6) w=0.6m.

4.3. Mining
1) Mining equipment. Choose WJD-1.0 electric scraper. 2) Mining management. The ore isolation layer is used to draw ore to reduce the production of ore dilution. Strengthen ore management, control the cut-off grade of ore, and geological personnel should follow-up and guide, and promptly retreat to ensure ore grade and reduce loss and dilution [7].

4.4. Ventilation
The ventilation adopts axial-flow local fan for press-in ventilation. The fresh air flow enters the mining roadway from the ramp and connecting road, and the polluted air is discharged from the upper ventilation shaft on the 11th line through the 130m middle section.

4.5. Main technical and economic indicators
The production capacity of ore blocks is 200t/d, the cutting-to-cut ratio is 10m/kt, the mining loss rate is 8%, the ore dilution rate is 10%, the ore output efficiency of the scraper is 120t/shift, the unit consumption of mining explosives is 0.22kg/t, and the mining is direct The cost is 22.30yuan/t.

5. Conclusion
Subsection empty field subsequent filling mining method is a high-grade mining method designed according to its own ore falling and extraction conditions combined with the occurrence of the ore body, combining the respective advantages of the layered caving mining method and the pillarless sublevel caving mining method of. This mining method is still a brand-new mining method for high-grade mining methods, and there are still many shortcomings. It also needs to constantly explore, learn, summarize, and gradually improve and perfect in practice to determine more optimized ones. These parameters provide valuable experience for the mining of steeply inclined thin ore bodies in the future.

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