Numerical Optimization of Broken and Difficult for Stope Mining in Underground Metal Mines

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Abstract. In a metal mine, there is a great risk of mining hidden resources caused by unreasonable mining in the early stage. In order to effectively and safely mine this part of the resources, it is based on investigating the current status of mining and delineating the area of instability and collapse, the area is firstly grouted and strengthened and temporarily supported, and then the first mining site and its mining method in the hidden danger area are given. The 3D model of the original goaf was constructed, and the numerical analysis model was introduced and numerical simulation was carried out, the results show that: 1) grouting reinforcement treatment and temporary support measures can effectively control the surrounding rock to continue collapse; 2) the original three-dimensional visualization model of the original goaf can reflect the real situation of the first mining stope; 3) based on the results of comprehensive numerical analysis, the stope structure parameters of the first stope are obtained, the length, width and height are 31×7.5×28.8m and 36×7.5×28.8m, respectively. The optimized result realizes the safe mining of the stope and provides reference and reference for the mining of similar stope.

1. Introduction

Mineral resources are non-renewable necessities for economic construction and development. Due to historical and technical conditions, most of the mined mineral resources in the prior mining of mines are of high grade and easy to mine [1~2]. In the continuous innovation of technical conditions, in order to meet the stable development of mineral resources, The exploitation of mineral resources should be extended to the deep, and the hidden danger resources left by the mining process due to various reasons should be fully recovered [3~4], especially a series of complex engineering problems, which will bring significant safety hazards to further mining. For example, the surrounding rock gangs, the structural damage of the rock mass and the instability of the chamber caused by the instability and collapse of the stope in the early stage mining [5~6]. Due to the particularity of this kind of hidden danger resources, the stope range affected by the instability of the stope is often large, and the geological conditions and
mining conditions of the ore body will become extremely complicated. Based on previous research and engineering examples, when mining hidden resources, it is based on the situation on the site to determine a reasonable and safe mining method, which is a specific analysis of the specific situation [7~8]. There is no fixed method for the recovery plan, and there is no standard to follow. The general idea of mining hidden resources is to continuously improve its mining plan during exploration, including determining the approximate instability collapse range and ensuring the stability of surrounding rock. In the case of effective control of ground pressure is the key to solving such problems [9].

2. Difficult Mining and Mining Status
According to the site investigation, after the mining of the 22.5m high orebody in the lower part of the 0# stop of a metal mine, The collapse of the goaf caused the filling bodies of the two working slope to rush into the goaf, and the upper orebody slinked as a whole, affecting the range wave and its adjacent six stopes. According to the drilling results, the N2-3# stope is located outside the slip line, and the instability and collapse area has less influence on it, while the S1-2 stope belongs to the edge stope in the collapsed area, and the risk of mining is also greater. The mining method commonly used in the metal mine is a bottomless column deep hole back-recovering and post-filling mining method. The method is characterized by high working efficiency and large amount of collapse, and the disadvantage is that the amount of primary detonation is large. This method is still used to mine the 55m S1-2 stope. For safety reasons, the mining sequence is from bottom to top, and the lower part of the 22m high orebody, the first mining stope in Figure 1 is in the virtual coil, needs to reduce the blasting vibration, so as to protect the two working slope surrounding rock as much as possible during the mining process.

3. Environmental Management for Underground Stope before Numerical Optimization
The first step is principle of grouting reinforcement to control the surrounding environment. Before the hidden danger mining, the grouting method can be used to effectively improve the filling body strength in the unstable collapse area and improve its overall stability. The following four basic principles for controlling surrounding rock in the collapsed area are proposed: first, the water in the roadway in the collapsed area should be treated, the second pre-reinforcement treatment should be applied to the surrounding rock in the collapse area, third advanced support and temporary support bottom mining roadway, fourth to further improve the stability of the overall filling body. The second step temporary support measures to control the surrounding environment. As shown in Figure 2 below, after the collapse of the goaf, in order to prevent further instability and damage of the roof and surrounding rock within the influence range of the collapse area, the mine site technicians used different technical precautions to effectively seal the lower ore discharge chamber through field survey and observation. Anchorage support, flexible support and rigid support for the access diversion of each stop in the affected area (Figure 1).

Figure 1. Collapse within the scope of the impact zone Chamber Control Measures
Method for grouting reinforcement to control surrounding environment
Because there is no engineering practice experience in the treatment of collapsed areas before the mine, similar mines have not found relevant treatment methods. Using N2-3# stope H=−250.4m to set up grouting holes in the existing chamber, which can fill and compact N2# stope, N1-2# stope and N1# stope within a certain range of voids and fissures (Estimated by the grouting diffusion radius), and using the S2-3# stope H=−239.9m, the existing chamber is arranged to grout holes, which can be filled and compacted S2# stope, S1-2# stope, S1# stope and S1# auxiliary -1# are within a certain range of cavity and fissures. For the N0-1# stope, the 0# stope and the S0-1# auxiliary stope for grouting reinforcement treatment, because the depth of the grouting hole is too large (greater than 40m), the ideal grouting reinforcement effect cannot be achieved, therefore, it is considered to use the digging chamber to arrange the grouting holes, and grouting and strengthening the N0-1# stope, 0# stope and S0-1# auxiliary stope, before the mining S1-2# stope and N1-2 #stope. That is to make full use of the existing or designed tunneling engineering layout, from the outside to the inside, the cavities and cracks must be taken during the drilling process, and grouting reinforcement measures must be taken until the safe mining of the 0# stope in the center of the collapsed area is completed (Figure 2~3).

![Figure 2](image1.png)

**Figure 2.** Use existing stope disposed of grouting hole.

![Figure 3](image2.png)

**Figure 3.** 3-D model of the original goaf.

### 4. 3-dimensional Model for Segmentation Length Optimization of the First Mining Section

#### 4.1. Construction of Three-dimensional Model

The assumption of grouting process and effect: 1 The precipitation and precipitation of cement particles are not considered in the grouting process; 2 The influence of groundwater on the diffusion and coagulation of the slurry can be neglected without affecting the grouting; 3 The time effect of grouting is not considered. The experimental results of petro physical mechanics (see Table 1), the elastic model of grouting material is selected, the mechanical parameters of grouting are realized by re-evaluation, and the physical and mechanical parameters such as collapse and backfilling slag are strengthened.

| Name         | E/MPa | µ  | ρt/m³ | c/MPa | φ°  | rm /MPa |
|--------------|-------|----|-------|-------|-----|---------|
| Filling body 1 | 2750  | 0.19 | 2.11  | 0.74  | 38.0 | 2.39    |
| Ore body     | 19760 | 0.30 | 3.80  | 2.45  | 40.3 | 2.4     |
| Filling body 2 | 2080  | 0.21 | 2.23  | 0.56  | 37.7 | 1.96    |

Table 1. Rock mass mechanical parameters.
The surrounding rock of S1-2# stope on the edge of the collapsed area is mainly filled body and part of backfilled slag. Based on the mining design data and actual measurement results, the influence of S1-2# mining field on the two-filled backfill is calculated and analyzed. If the model size is too large, it will affect the accuracy of the calculation and take a long time. Therefore, the geometric dimensions of the calculation model range and the three-dimensional model (including the S1# and S2# stope) are determined as shown in Table 2.

**Table 2. Model of geometry calculation and 3-D stope geometry.**

| Coordinate | X         | Y                | Z         |
|------------|-----------|------------------|-----------|
| Min        | 2596/2620 | 8293/8328.5      | -296/-286 |
| Max        | 2720/2715 | 8340/8305.5      | -229/-239 |

The block generator model is automatically generated by the developed grid generation program. As shown in Figures 4~5, the model has 195,415 units and 205,980 nodes. The initial stress field is generated by extracting the stress values at the corresponding positions in the final numerical calculation results in Chapter 3.

**Figure 4.** After the conversion of the 3-D block model

**Figure 5.** Overall calculation model

4.2. *Optimization Analysis of Segment Length of the First Mining Section*

The stope adopts a bottomless deep-hole retreat and a post-fill mining method. The width and height of the first mining section of S1-2# are known, but the length of the stope is long. The selected section length of the stope is important for segment mining. In order to determine the approximate segmentation position of the stope, firstly, the mining simulation of the entire stope is carried out. By analyzing the stress-displacement field characteristics of the S2# and S1# fillings after mining, the most severely damaged areas in the goaf are divide the basis of the east-west boundary, and then formulate three kinds of segmentation schemes to determine the optimal length of the stope.
The minimum principal stress is affected by the deformation of the self-heavy stress field (Figure 6~7), mining unloading and grouting reinforcement on the backfill slag in the filling body. At this position, a relatively obvious stress concentration phenomenon occurs, and the maximum stress value is 19.8 MPa. The top plate and the two gangs of the goaf show a significant pressure relief zone, and the minimum principal stress is the tensile stress, which is between 0 and 1.12 MPa. The tensile stress zone of the top plate and the two-layer filling body is larger. Although the grouting reinforcement improves the stress, the rest of the force still has a large concentration and unevenness, and the tensile stress reaches a maximum of 0.8 MPa.

Displacement distribution characteristics (Figure 8~9): The maximum displacement value of the top plate and the filling body is 5.0 cm, and the displacement of the backfilling slag position in the goaf is relatively large. Z-displacement distribution characteristics: The displacement value in the Z direction is 1.2 cm, and the deformation is also the largest at the backfill position. The shear strain incremental distribution characteristics (Figure 10): The shear strain increment area appeared near the top plate and the two gangs, and the shear strain increment was $7.51 \times 10^{-3}$. Plastic failure zone (Figure 11): The volume of the plastic zone is: $9.068 \times 10^2$ m$^3$ for shear-n, $3.06 \times 10^2$ m$^3$ for tension-n, $3.286 \times 10^2$ m$^3$ for shear-p, and $9.53 \times 10^2$ m$^3$ for tension-p. The main manifestation is shear failure, and the upper orebody has a small extent of tensile failure. According to the above analysis results, the use of non-segment mining schemes will result in excessive exposure area leading to instability and collapse of the goaf. A more prudent plan should be adopted to divide the stope into east and west respectively, first picking the east head, and then performing high-quality filling treatment before mining the west head, which can effectively control the ground pressure. The length of the stope is optimized from the length of the stope. The optimization scheme is (based on the most severely damaged position in the above simulation results): Scheme 1: The boundary line of the section mining is $Y=647$; Scheme 2: The boundary line of the section mining is $Y=650$; Scheme 3: The boundary line of the section mining is $Y=653$. 
Figure 9. Z-shift cloud map.

Figure 10. Shear strain increment.

Figure 11. Plastic zone cloud map.

Figure 12~17 is the graph generated by segmentation mining with Y=650 coordinate line as the boundary line. (The comparison is the best for this scheme, and the other schemes are slightly omitted).

Figure 12. Maximum principal stress cloud map (segmented mining).

Figure 13. Minimum principal stress cloud map (segmented mining).

Figure 14. Y-Displacement cloud map (segmented mining).

Compared with the maximum and minimum principal stress cloud diagrams of non-segment mining and section mining (the boundary line is Y=650), the values and ranges are significantly reduced. The maximum principal stress value is reduced from 2-28 MPa to 2-20 MPa. The minimum principal stress decreases from 0-1.12 MPa to 0-0.9 MPa, indicating that segmental mining has a certain effect on reducing the stress value and range of surrounding rock.
Compared with the displacement value generated by non-segment mining and section mining (boundary line $Y=650$), the $y$-direction displacement value is reduced from 5 cm to 3.5 cm, and the $z$-direction displacement value is reduced from 1.2 cm to 0.8 cm. In general, the stability of the goaf is increased due to the reduced exposed area of the goaf. Comparing the plastic zone and the shear strain increment generated by non-segment mining and section mining (the boundary line is $Y=650$), the plastic zone area has been greatly reduced ($\text{shear-n} = 5.178 \times 10^{-2} \text{m}^3$, tension-$n = 2.22 \times 10^{-2} \text{m}^3$, shear-$p = 1.44 \times 10^{-2} \text{m}^2$, and tension-$p = 3.24 \times 10^{-2} \text{m}^3$). The tensile stress failure zone of the two-side filling body is greatly reduced, the area of the shear stress failure zone of the roof is reduced, and the shear strain increment value is also reduced from $7.51 \times 10^{-3}$ to $6.37 \times 10^{-3}$. It is indicated that the section mining plays a certain role in maintaining the stability of the goaf, especially the further destruction of the upper orebody.

Based on the results of the above numerical analysis, the stope structure parameters of the S1-2# stope can be determined, with a length of 31 m and 36 m (segment mining), a width of 7.5 m and a height of 28.8 m.

5. Conclusion

Based on the location and scope of the first mining section in the hidden danger zone and its mining method, a three-dimensional model of the original mined-out area of the first mining section at the edge of the hidden danger zone was constructed, then using the 3D numerical analysis model for simulation calculation, it is possible to obtain a reasonable segment length of the first mining section. Propose the following basic principles for controlling the surrounding environment within the collapse area, including: 1 The water in the roadway in the collapsed area should be pumped and discharged; 2 Pre-reinforcement to treat the surrounding rock environment within the collapse area; 3 Advance support and temporary support at the bottom of the mining roadway and other surrounding environment; 4 further improve the stability of the overall filling body. Based on the results of comprehensive numerical analysis, the parameters of the stope structure of the first stope are obtained, and the length, width and height are $31 \times 7.5 \times 28.8 \text{m}$ and $36 \times 7.5 \times 28.8 \text{m}$, respectively.

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