

# Study on failure law of rock mass and slope stability by open-pit combined mining

Feng Shaojie<sup>1,\*</sup>, Gao Chen<sup>1</sup>, Liu Wenbo<sup>1</sup>

<sup>1</sup>School of Civil Engineering, North China University of Technology, Beijing 100144, P.R. China

**Abstract:** With the continuous downward mining, more and more attention has been paid to the problem of slope stability under open-pit combined mining. Taking Zijinshan gold and copper mining as an example, the failure properties of overlying rock mass and slope stability under open-pit combined mining under different mining methods are studied by numerical simulation method, and the failure law of overlying rock mass is proposed. Combined with the geological structure distribution of 5-5 section and the influence of different mining stages, the slope stability is evaluated by slip field theory. Relevant reinforcement measures are proposed.

## 1 Introduction

Slope stability has always been the most concerned issue in the field of slope engineering, especially the slope stability under the condition of open-pit to underground mining. There are many mining areas in China that use open-pit to underground mining<sup>[1]</sup>. In the process of open-pit to underground mining, the slope will be affected by two mining actions (open-pit mining + underground mining) before and after, and the second disturbance will induce sliding deformation or failure of the slope. The comprehensive superposition effect of slope affected by two mining is called the composite mining effect<sup>[2]</sup>. Under the influence of composite mining effect, the comprehensive effect of two mining operations should be fully considered in the stability analysis of slope<sup>[3]</sup>. In the open pit combined mining, with the increase of mining depth, the slope stability coefficient is gradually decreasing, and the slope also begins to lose stability. The deformation mechanism is more complex than the single open pit mining, and the stability of the slope is more difficult to control. Once the instability is bound to threaten the safety of production and personnel in the mining area. In order to ensure the stability of the mine slope and save the cost of protection and treatment, it is of great significance to study the deformation mechanism of the slope under open-pit combined mining<sup>[4]</sup>.

## 2 Project profile

Zijinshan gold and copper mine is located about 15 kilometers northwest of Shanghang County, Fujian

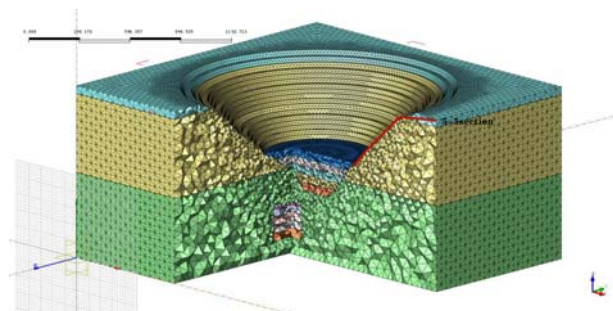
Province. It is the famous home of Zijin mining industry and the most important mine. It is a large gold and copper mine in China<sup>[5]</sup>. The terrain of the mining area belongs to the middle-low mountain tectonic erosion mountain, and the mountain system belongs to the southern section of Wuyi Mountains. Mountain toward the northeast, the terrain from northwest to southeast tilt, the highest in the central area, elevation +1063 meters, the west side of the Tingjiang River, the east side of the old county river minimum elevation +198 meters, the maximum height difference 865 meters. Zijinshan mining area is located in the middle of the ore field, with an area of about 4.37 km<sup>2</sup>. The copper reserves of 205 million tons have been found in the northwest ore section of the mining area, with an average of 1.09 %. The symbiotic gold deposit has reached the medium-sized scale, with an average of 4.69 g/t. It is accompanied by silver, pyrite, alunite and other beneficial minerals. The copper ore body in the copper belt of Zijinshan mining area mainly occurs in the primary belt below 650m elevation, which is a concealed ore body. The ore belt is mainly composed of a series of dense vein copper ore bodies. 41 copper ore bodies have been preliminarily delineated, with an overall trend of 320°, a tendency to the northeast and an inclination of 20°~50°. Zijinshan ore refers to the copper-gold ore body in the northwest section of the mining area. The two sides are accompanied by Guanzhuang-Shanhu and Miaoqian-Jiuxian synclines, and the NE trending faults parallel to the folds are well developed. The Zijinshan ore field is located in the southwest end of the core of the anticline. Faults are mainly NE-trending faults with strikes of 40°~50°, and tend to NW or SE, belonging to basement faults<sup>[6-9]</sup>.

\*Corresponding author: [fsjice@163.com](mailto:fsjice@163.com)

### 3 Numerical simulation of Zijinshan gold-copper mine slope

#### 3.1 computation module

The modeling mainly uses the discrete element simulation software 3DEC for simulation calculation. Due to the complex terrain, the pre-processing function of 3DEC is weak, and the geometric modeling needs to be processed by self-programming. Firstly, the elevation of the open-pit slope, the height of the step and the slope function of the open-pit slope step are defined. According to the actual situation, the boundary function of the slope step is fitted by arcs with different radii. The slope gradient of the step is  $69^\circ$ , the slope gradient is about  $39^\circ$ , and the step height is 72 m. According to this method, the coordinates of key points are extracted according to the data of different steps, and the geometric model of the three-dimensional slope of Zijinshan gold-copper mine can be established, as shown in Fig.1<sup>[10]</sup>.



**Fig.1** Three-dimensional discrete model of Zijinshan gold-copper ore

#### 3.2 Selection of geotechnical parameters

The parameters used in the numerical simulation process are selected from the experimental results of rock mechanics. Due to the influence of the combined mining effect, the stress field in the slope of the mining area changes and concentrates, and the movement and deformation of the slope forms three regions : caving zone, bending subsidence zone and fracture zone. Therefore, in the process of numerical simulation, the physical and mechanical parameters of rock mass obtained by indoor rock experiments and engineering analogy should be corrected to a certain extent<sup>[11]</sup>. The elastic modulus  $E$  and density  $\rho$  of the material in the caving zone and the bending subsidence zone are corrected to 0.85 ~ 0.90 times of the original rock and soil mass, and the Poisson ' s ratio is 1.1 ~ 1.2 times of the original experimental value. Finally, the mechanical parameters of slope slope in Zijinshan Gold-copper Mine are calculated and determined as shown in Fig. 1.

**Table 1** Mechanical parameters of rock mass in Zijinshan gold-copper deposit

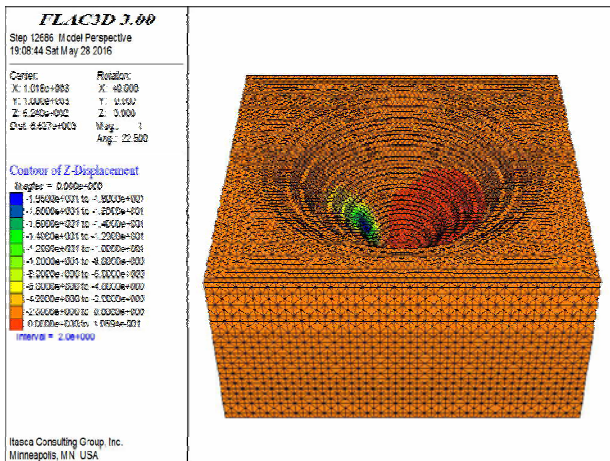
stratum	elastic modulus E/GPa	poisson ratio $\mu$	volumetric weight $\gamma/(\text{kN}/\text{m}^3)$	force of cohesion C/MPa	angle of internal friction $\psi/(\text{°})$
granite (Hard fracture structure)	37.5	0.30	28.4	0.65	38.08
granite (The structure of softer fragmentation splinter)	27.3	0.23	26.2	0.15	33.04
granite (Extremely soft bulk structure)	32.8	0.22	25.2	0.114	30.45
Loose waste slag	7.2	0.4	15.0	0.001	15.0
The cryptoexplosive hornblende rock	20.6	0.29	26.9	1.11	33.7
dacite porphyrite	37.9	0.26	26.4	1.26	32.96
copper ore body	94.3	0.23	27.5	2.26	35.59

#### 3.3 Deformation prediction analysis and calculation of Zijinshan gold-copper mine under underground mining

##### 3.3.1 Displacement vector diagram analysis of Zijinshan gold-copper mine slope

He slope stability analysis is simulated by 3DEC software, as shown in Figure 1. The underground mining area excavation is divided into four stages : from + 30m mining to 0m stage, -50m stage, -100m stage and -150m stage ; Considering the spatial distribution and time effect of excavation, a prediction model of rock movement of open-pit combined mining slope considering the time-space effect of slope rock mass is proposed on the basis of the two. The change of excavation space has different influences on the movement of slope rock mass. The slope velocity vector diagram of different excavation stages is shown in Figure 2.

As shown in Figure 2, with the increase of mining depth, it can be seen from the displacement vector diagram that the slip trend of the top and bottom of the slope in D area is obvious, and the slope is in a slip state. B, C slope local area also occurred larger movement.

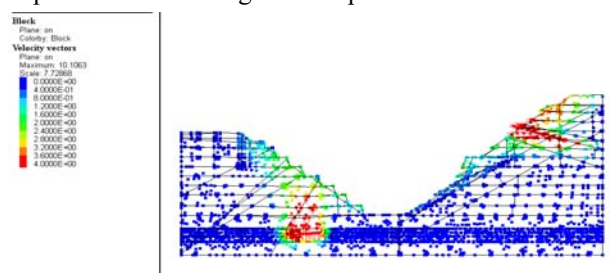


**Fig.2** Distribution of displacement vector from +30m to -150m

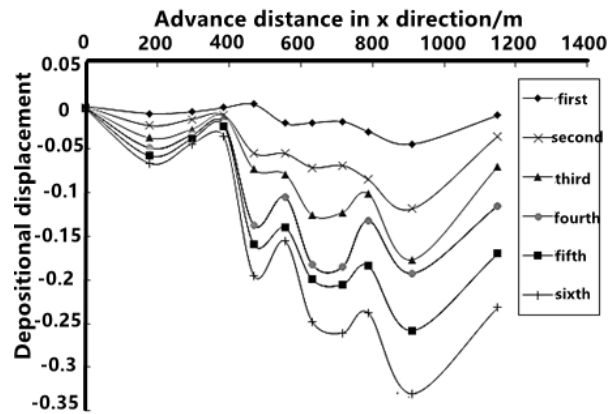
### 3.3.2 Velocity vector variation analysis of 5-5 section in goaf filling mining

With the increase of mining depth, the slip area of each zone increases, and the slip velocity also increases accordingly. The slope slip trend analysis is shown in Fig. 3 for the velocity vector diagram of section 5 -5 of overlying rock mass on goaf. According to the velocity vector diagram of overlying rock mass from mining to each stage, it can be seen that when mining by filling goaf :

- (1) When the underground mining is from + 30m to 0m, the velocity vector of the slope rock mass is mainly controlled by the slip field generated by the slope excavation, and the slope is sliding failure, and the slope is in a stable state.
- (2) When the underground mining is from + 30m to -50m, the sliding of slope rock mass is controlled by underground mining and open-pit excavation. The slope speed is large, and the large speed area above the goaf increases in a large range. The control of underground mining on the movement of slope rock mass is enhanced, and the slope rock mass belongs to sliding-collapse failure.
- (3) When the underground mining is from + 30m to -100m, the failure of the slope rock mass is further increased and the control is further strengthened. The slope failure type is still sliding-collapse failure.
- (4) When the underground mining is from + 30m to -150m, the sliding of slope rock mass is mainly controlled by underground mining, and the overlying rock mass in goaf is almost vertical subsidence, and the slope rock mass belongs to collapse failure.



**Fig.3** + 30m Excavation to - 150m Stage Profile 5-5 Velocity Vector Distribution



**Fig.4** + 30m filling mining to -150m stage along section 5-5 mining subsidence curve

The vertical displacement values of the key points from the top of the slope to the foot of the slope after each excavation are extracted along the 5-5 section, and the subsidence curve of the slope rock mass in the underground mining process is drawn as shown in Figure 4. According to the displacement curves of each monitoring point at the top of the filled slope, it can be concluded that when the filling mining is adopted, the open-pit excavation plays a controlling role on the movement of the slope rock mass, and the underground mining has little effect on the slope. The maximum subsidence value of the slope rock mass is - 0.34 m, which is located at the top of the slope. + 30m mining to -150m stage, the local failure of slope rock mass, need to be reinforced.

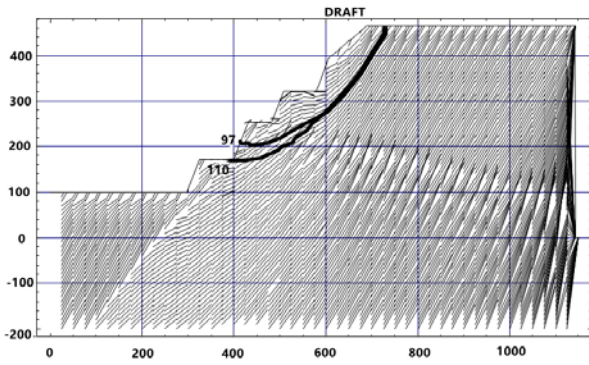
## 4 Slope stability calculation of 5-5 section in Zijinshan gold and copper mine

In view of the mining process of Zijinshan gold and copper mine, the slip field theory is used to search the sliding surface of the main control section and calculate the sliding area of the slope at different mining stages. Then Morgenstern-Price method, JanBu method, Bishop method and residual thrust method are used to determine the slope stability coefficient. The slip surface distribution of 5-5 section is shown in figure 5 and figure 6, and the slope stability calculation results are shown in table 2 and table 3.

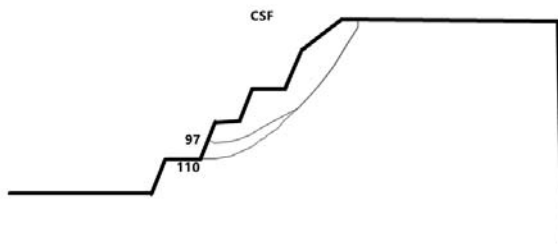
Zijinshan gold and copper mine open-pit stope design slope structure parameters are as follows :

- Step height : 12 m ( 6 steps parallel to 72 m )
- Slope angle of back steps : 70°
- Width of cleaning platform : 4-6 m
- Safety platform width : 15-20 m ( one per 72 m )
- Slope structural parameters : 4m, 4m, 15m
- Overall slope angle : 40.5°
- Slope height : 686 m





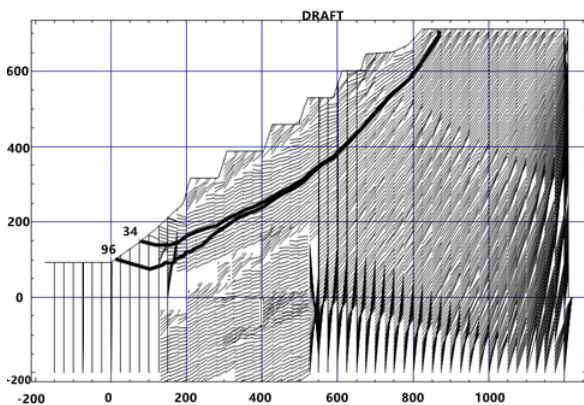
**Fig.5** Calculation of dangerous sliding surface of slope 5-5 profile slope (stability coefficient  $FS = 1.101$ )



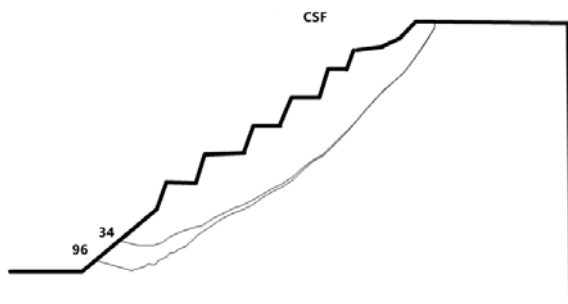
**Fig.6** Determination of dangerous sliding surface of slope 5-5 profile slope (stability coefficient  $FS = 1.101$ )

**Table 2** Calculation results of slope stability

method of calculation	Morgenstern-Price	JanBu	Bishop	remaining thrust method
stability factor	1.092	1.034	1.150	1.230



**Fig.7** Calculation of dangerous sliding surface of section 5-5 slope from +30m mining to -150m stage ( $F_s = 0.953$ )



**Fig.8** Determination of dangerous sliding surface of section 5-5 slope from +30m to -150m ( $F_s = 0.953$ )

**Table 3** Calculation results of slope stability

method of calculation	Morgenstern-Price	JanBu	Bishop	remaining thrust method
stability factor	0.954	0.942	0.971	0.973

According to the above calculation results, the average slope stability coefficient of 5-5 section is calculated as shown in table 4.

**Table 4** Calculation results of slope profile in goaf treated by caving method

district number	Stope location	section	slope stability factor	slope stability
C zone	South side of stope	Section 5-5	1.101	stabilization
C zone	-50m stage stope south side	Section 5-5	0.987	destabilization
C zone	-150m stage stope south side	Section 5-5	0.953	destabilization

According to the calculation can be seen, stope south section 5-5, in underground mining to -150m stage, slope stability coefficient decreased from 1.101 to 0.953, slope sliding surface has just begun to instability, gradually sliding surface continues to increase.

## 5 Slope engineering reinforcement measures

The essence of engineering stabilization measures is to improve the anti-sliding force, reduce the sliding force and make the slope meet the requirements of allowable safety factor. The usual engineering stabilization measures are prestressed anchor cable and anchor rod, anti-slide pile, anchor shotcrete slope protection, anti-slide retaining wall and pressure grouting.

According to the engineering geological and hydrogeological analysis of the open-pit slope of Zijinshan Gold and Copper Mine, the calculation results of slope stability and the stability analysis of the stereographic projection of slope rock mass structure, in view of the problems existing in the stability of the original design slope, the slope structural parameters are appropriately adjusted, and the engineering stability measures are carried out for the slope in the local area to achieve the slope stability.

The overall stability of the original designed slope of Section 5-5 basically meets the requirements. With the destruction of the slope rock mass by underground mining, there are a large number of loose bodies in the upper rock mass integrity of the slope, which gradually transforms into an unstable state.

Local bench engineering treatment of section 5-5: The area to be treated is the sliding area of section 5-5 after mining. According to the size of the sliding surface, the area that may need reinforcement in the future is determined and the engineering cost is estimated. The engineering treatment range and engineering quantity are shown in Table 5. The actual cost is adjusted according to the actual situation of strata exposure.

**Table 5** 5-5 section reinforcement scope and project budget

Section name	reinforcement range	height (m)	take measures	work amount (m)	estimate cost (million yuan)
5-5	220m ~ 450m	130	Anchor cable, spray anchor net	433	888.3
5-5	480m ~ 615m	135	Anchor cable, spray anchor net	562.5	1035
5-5	697m ~ 758m	48	anchor rope	381	768.6

## 6 Conclusion

Taking Zijinshan Gold and Copper Mine as an engineering example, the rock movement law in the process of open-pit combined mining was studied by using three-dimensional discrete element numerical software. On this basis, the slope stability of section 5-5 was evaluated, and the slope reinforcement measures were proposed. The main conclusions are as follows:

(1) With the increase of mining depth, the slip trend of slope top and bottom in D area is obvious, and the slope is in slip state. B, C slope local area also occurred larger movement.

(2) Combined with the slope displacement vector diagram, it can be found that with the increase of mining depth, the slip area of each zone increases, and the slip velocity also increases accordingly. From +30m mining to -150m stage, the local failure of the slope rock mass needs reinforcement treatment.

(3) When the mining depth increases to 150m, the slope stability coefficient decreases by 13.4%, and the slope will slide.

(4) Affected by underground mining, the 5-5 section slope gradually changed from stable state to unstable state in the mining process. In the later stage of mining, a large area of fractured rock mass appeared in the upper part of the goaf. Anchor cable and shotcrete-anchor network measures were used to reinforce the unstable state and fractured rock mass.

## Acknowledgments

This work was supported by National Key Research and

Development Program of China (2018YFC0809900), National Natural Science Foundation of China (41772335), the Youth Talent Training Program and Discipline construction of high-level universities with distinctive features of North China University of Technology.

## References

1. Sun,S.G.Cai,M.F.Wang,S.J.(2000).Study of sliding mechanism for slope due to the excavation from open pit into underground mine. *J.Chinese Journal of Rock Mechanics and Engineering*,19(1): 126-129.
2. Sun,S.J. Wang,S.J. (1998) A method for evaluation of slope rock-mass stability under the combined action pit and underground mining.*J.Journal of Engineering Geology*,6(4) : 312-318.
3. Sun,S.G. Cai,M.F. Wang,S.J.(1999)Effect of combined under- ground and open pit mining and deformation mechanism of slope. *J.Chinese Journal of R ock Mechanics and Engineering*,18 (5) : 563-566.
4. Feng,S.J. Quan,J.Y. Fu,Y.G. Qiu,H.R (2016) Study on the Deformation Mechanism of Slope Body under Combined Mining of Open Well.*J.Science Technology and Engineering*,16(25):224-228.
5. Li,L.H.Zhang,Y.Cai,M.F.et al.(2008)FEM-based inversion analysis of in-situ stress field of Zijinshan Gold-copper Mining Area.*J.Metal Mine*,(7) : 1-18.
6. Cui,Y.Z.(2001)Numerical Modeling of Continuum and Discontinuous Media and Its Application to Safety Analysis of Arch Dam-foundation Systems. D.Beijing: Tsinghua University.
7. Liu,X.H.Technical research of goaf disposal in Zijinshan Gold Mine.*J.Nonferrous Mines*,31(1) : 21-43.
8. Rao, Y. Z. Chai, W. Huang, B. W. (2008) ANSYS numerical calcu- lation of ore pillar stability in Zijinshan Gold-copper Mine. *J.Gold*,29( 7) : 22-26.
9. Yuan,H.P. Wang,J.L. Zhao,K. et a1. (2011) Study on the goaf form influence on distribution of surface subsidence. *J.Metal Mine*,(11) : 25-28.
10. Sun,S.G. Guo,W.C. Liu,W.B. Guo,P. Dong,Y.F. (2015) Mechanism of High Slope Sliding Induced by Open-pit Mining.*J.Metal Mine*, (05) :162-165.
11. Wang,X.C.Guan,X.M.Wang,X.L.et al.(2011) Study on stability of open-pit mine slope and sensitivity of rock mass parameters.*J.Journal of China Coal Society*,36(11) : 1806-1811.