Stability Analysis and Reinforcement Treatment of Open Pit Slope

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Abstract. The construction of mine surface facilities shall be carried out according to the scope of mining rights and ease of use. The underground mining of Shirengou Iron Mine uses filling method mining, and the filling station needs to be built on the surface. According to the design, it is constructed near the open pit. Based on the protection of the filling station system, the stability analysis of the open slope is needed. The failure mode of iron ore open slope is circular arc sliding failure mode. The calculation model of the stability analysis is calculated by the residual thrust method. The maximum residual thrust of the I-I section is 128.9 tons/meter, and the maximum residual thrust of the II-II section is 75.39 tons/meter. According to the calculation results, the safety measures such as slope dressing and masonry retaining wall are carried out on the open slope, and the grouting prestressed anchor cable is selected to reinforce the slope. The anchor cables are connected by reinforced concrete frame and beam, and the concrete is used. The beam acts as an anchor pier. In order to effectively consolidate the slope stability, the grouting method is combined to effectively treat the slope. After a series of slope reinforcement measures, the stability of the open slope and the safety of the filling station can be guaranteed.

Keywords: Open slope; stability analysis; safety factor; prestressed anchor cable; grouting reinforcement

1. Introduction

The Shirengou iron ore mine was originally exploited by open pit method, and the open pit was converted to underground mining in the later stage of the mine. At present, the third phase of underground mining adopts the filling mining method. The surface filling station is built on the east side of the auxiliary well, and the west side of the filling station is the large open pit of the mine. The bottom elevation of the pit is about +39.9m and the slope height is about 60m. The upper part of the slope is mining slag. The slag is mainly composed of gravel. The diameter of the gravel is about 0.2~1m. There is no filling between the gravel voids. The local thin layer contains crushed silty clay, construction waste, etc. The thickness ranges from 7.0m to 17.0m. There is a small amount of residual soil in the local part of the lower part of the pile slag, and the rock drilling equipment is easy to drill,
and contains the gravel that is not completely weathered. The rock mass of the slope is mainly strong weathered or moderately weathered gneiss, and the cracks are relatively large, resulting in relatively broken rock mass [1-2].

The open pit on the west side of the filling station has been closed, and a large amount of gravel is piled up on the periphery of the stope. The slope can be roughly divided into 3 steps, 39.9m~+81.1m for the stop slope, at +51.6m There is a wide platform; +81.1m is the slope formed by the slag. At present, the +81m platform is already full of gravel. The surface plan of the mine is shown in Figure 1.

![Figure 1. Mine Surface Plane Map](image)

2. Slope Stability Analysis

2.1. Geological Conditions
At present, the bedrock exposed on the slope is mainly composed of strong weathered and moderately weathered gneiss. The joint development is carried out, and the ore layer is exposed at the bottom of the pit. The strike of the rock stratum is consistent with the slope. The dip angle of the rock is basically the current step slope angle. According to the survey line of the treatment scope, the overall inclination of the rock formation is about 65°.

2.2. Slope Failure Mode
The lithology of the open pit slope on the west side of the filling station is slag and gneiss. According to the experience, the slope failure mode of this area is the arc-shaped sliding failure mode.

2.3. Slope Stability Calculation Model
As one of the basic methods of slope stability analysis, there are many methods for limit equilibrium analysis, such as Fellenius method, Bishop method, Janbu method, Spencer method, Morgenstern method, Sarma method and residual thrust method. These methods vary depending on the type of landslide and the assumptions used, but they are based on the principle of limit equilibrium. This slope stability analysis is calculated using the residual thrust method.

The residual thrust method, also known as the balanced thrust transfer method, is a practical method in engineering under the condition that the direction of the resultant force of the first block is
parallel to the bottom surface of the previous block, and the safety factor under the limit equilibrium state is obtained. As shown in Fig. 2, $W_i$ is the weight of the block $i$, $c_i$, $\phi_i$ is the adhesion force and friction angle of the bottom surface of the bar, $l_i$ is the length of the bottom surface of the bar $i$, $U_i$ is the water pressure of the bar, and $P_i$ is the thrust between the bars. $N_i$ is the positive pressure on the sliding surface, and $T_i$ is the sliding resistance on the sliding surface [3-10]. The residual thrust method is shown in Figure 2.

$$F_i = W_i \sin \alpha_i + \psi_i P_{i-1} - [C_i L_i + (W_i \cos \alpha_i - U_i) \tan \phi_i] / F_s$$

(1)

Where: $\psi_i$ — Force transmission system, the value is:

$$\psi_i = \cos(\alpha_{i-1} - \alpha_i) - \sin(\alpha_{i-1} - \alpha_i) \tan \phi_i / F_s$$

(2)

Fs - Safety factor
When there is no external force, $P_0=PN=0$, so the calculation first gives different Fs values, and $P_i$ is calculated from top to bottom. When $PN=0$, Fs at this time is the required safety factor.

2.4. **Allowable Safety Factor**
According to the classification of safety grade of slope engineering in "Technical Specifications for Building Slope Engineering", the open slope of Shirengou Iron Mine is a first-grade slope. Combined with the engineering practice of the slope, the allowable safety factor of slope is $Fs=1.3$.

2.5. **Calculation of Section**
According to the engineering geological conditions, the geometric characteristics of the slope, two typical sections were selected for stability calculation and analysis, which are I-I and II-II sections respectively, and each section is basically perpendicular to the slope line.

2.6. **Mechanical Parameters**
The mechanical parameters are shown in Table 1.
Table 1. Rock mechanics parameter table

| Rock mass     | Cohesion C (KPa) | Friction angle φ (degree) | Volumetric weight γ (KN/m³) |
|---------------|------------------|---------------------------|-----------------------------|
| Waste stone   | 0                | 33                        | 21.0                        |
| Gneiss        | 90               | 33                        | 26.0                        |
| M1 Ore body   | 140              | 38                        | 28.0                        |

2.7. Calculation Results
The calculation results of each section are shown in Table 2. From the calculation results in Table 2, it can be seen that the safety factors of each section cannot meet the stability requirements, and engineering reinforcement measures must be taken to achieve slope stability.

Table 2. Each section calculation result table

| Section | Calculation range | Earthquake | Safety factor | Maximum remaining thrust tons (tons per meter) |
|---------|-------------------|------------|---------------|-----------------------------------------------|
| I-I     | +39.9m-+99.3m     | 0          | 1.164         | 128.9                                        |
|         |                   | 0.025      | 1.117         |                                               |
| II-II   | +39.9m-+99.3m     | 0          | 1.242         | 75.39                                         |
|         |                   | 0.025      | 1.195         |                                               |

The calculation results of each section are shown in Figure 3 and Figure 4.

![Figure 3. I-I sectional view](image)
3. Initial Slope Treatment
The slag slope between +81.1m and 99.4m is trimmed. The slope trimming consists of two parts. First, the excess part of the slope is removed, and then the retaining wall and the masonry slope are carried out. The slope dressing construction is carried out in two stages. In the first stage, a small amount of slag is removed below +81.1m (water pipe) and the retaining wall is constructed. In the second stage, the slag slope above +81.1m is trimmed and then blocked. The earth wall and the masonry stone slope protection slope, the height of the upper slurry block stone slope is 8.3m, the thickness is 50cm, the slope is calculated according to the natural rest angle of 35°, and the design below the height of +91.1m is the retaining wall, the outer wall of the retaining wall The slope angle is 45°; the platform is set at +91.1m and +81.1m, and the platform width is 2m. Appropriate adjustments are made according to the status quo under the principle of ensuring the step-slope ratio parameter.

A row of anti-slide piles is constructed at the bottom of the retaining wall. The anti-slide pile spacing is 2.0m, the length is 7.0m, and the underground depth is 5.0m.

4. Prestressed Anchor Cable Reinforcement

4.1. Anchor Cable Selection and Design
According to the common types of anchor cables, the grouting type prestressed anchor cable is selected. The ribs are made of 8 strands of φj15 (7φ5) steel strands with a single anchor tension of 1000kN, the vertical direction of the anchoring slope is inward, and the anchoring angle is 20° (depression angle).

The anchor cables are connected by reinforced concrete frame beams and the truss beams are used as anchor piers.

4.2. Anchor Cable Arrangement
The anchor cable is arranged on the steps between +53.6m and +81.1m, and the three rows of anchor cables are arranged on the north side of the step. The horizontal spacing of the anchor cables is 4m, and the four rows of anchor cables are arranged on the south side. The horizontal spacing of the anchor cables is 3m. Each step anchor arrangement can be seen in Table 3.
Table 3. Anchor cable arrangement parameter table

| Position  | Orifice elevation | Anchor number | Horizontal spacing | Hole depth | Number of holes | Total hole depth |
|-----------|-------------------|---------------|--------------------|-----------|----------------|-----------------|
| North side | 60.6m             | MS1-MS11      | 4m                 | 36m       | 11             | 1155m           |
|           | 67.6m             | MS23-MS33     | 4m                 | 35m       | 11             |                 |
|           | 74.6m             | MS45-MS55     | 4m                 | 34m       | 11             |                 |
|           | 58.6m             | MS12-MS22     | 3m                 | 45m       | 11             |                 |
| South side| 64.6m             | MS34-MS44     | 3m                 | 44m       | 11             | 1872m           |
|           | 70.6m             | MS56-MS66     | 3m                 | 43m       | 11             |                 |
|           | 76.6m             | MS67-MS77     | 3m                 | 42m       | 10             |                 |
| Total     | -                 | -             | -                  | -         | 76             | 3027m           |

During construction, the location of the anchor cable orifice is determined from both ends, and the other anchor cable holes are determined by the horizontal spacing.

4.3. Anchor Cable Construction Requirements

(1) The anchor cable has a borehole diameter of φ130, and the vertical slope is drilled and the angle with the horizontal plane is 20° (depression angle); the slope of the borehole axis should not be greater than 2% of the length of the anchor cable, and the depth should not be less than the design length. It should not be larger than the design length of 50cm.

(2) The anchor cable body is composed of 8 high-strength steel strands (1860MPa) with φ15.24. There should be no joints between the single steel strands, which should be arranged straight; the axis direction of the anchor cable should be set every 1.5m. A centering bracket is provided with an isolating frame every 1.5m, and the two spacers are bundled in the middle.

(3) The design length of the anchor cable anchorage section is 10m. The pull-out test is carried out before construction. The length of the anchorage section is adjusted according to the test results. The construction must also be based on the drilling condition feedback design.

(4) The length of the free section of the anchor cable is 50m. A layer of 1mm thick butter should be applied first, then a polyethylene plastic pipe anti-corrosion device of φ18 should be placed, and the outer tape is fixed by the engineering tape.

(5) One time grouting pipe is tied on the anchor cable body. The head of the grouting pipe is 5~10cm away from the bottom of the hole. Before using the grouting pipe, check whether there is crack or blockage.

(6) The top of the anchored cable should be fitted with a guiding cap to facilitate the threading.

(7) The wedge-shaped anchor cable carrying the pier on the outer slope surface of the inclined beam is used as the anchor pier, and the steel backing plate is embedded therein; the steel plate should be adjusted to be perpendicular to the axis of the anchor cable when it is buried.

(8) The anchor is made of OVM type anchor, the hole anchor plate is made of A3 steel plate, 38cm×38cm×4cm; Anti-corrosion pier with C20 concrete pouring, the size is 40cm×40cm×20cm, and the thickness of the protective layer is more than 5cm.

(9) Two-pressure grouting is used for grouting of anchor cable. M30 cement mortar is used for one-time grouting. The grouting port of grouting pipe should be inserted into the bottom of the hole 30~50cm; the second high-pressure grouting should be grouted once. After the formed cement body strength reaches 5 MPa, the grouting pressure is not less than 5 MPa, and a pure cement slurry having a water-cement ratio of 0.45 to 0.50 is used.

(10) When the anchor cable is stretched, the compressive strength value of the grouting body and the concrete pedestal should be 25 MPa, and the tension should be carried out in an orderly manner. The order should consider the mutual influence of the adjacent anchor cables; before the anchor cable is officially tensioned, take 100~200KN to pre-tension the anchor cable for 1~2 times, so that the anchor cable body is completely straight and the parts are in close contact; when the anchor cable is
stretched to 1050~1100KN, the load is designed to be unlocked for 10 minutes. 800kN) to lock.

(11) After sealing the anchor cable, seal the grouting, rinse the hole with high-pressure water gas before grouting, and then pour the cement thick slurry with the grouting machine. When the concentration of the slurry and the grouting are basically the same, Pressure circulating grouting, grouting time is 1h, pressure is 2MPa [12-13].

5. Grouting Reinforcement

According to the site survey, in order to effectively control the slope stability, the grouting method is used to effectively treat the slope.

In the pile slag, the method of grouting with side holes is adopted. In order to prevent the collapse of the borehole, the grouting is performed once every 1.00 m, and the borehole is drilled with a full-diameter drill bit with a diameter of 76 mm. A row of holes is drilled outside the foundation, and the spacing between the holes is 1.0m. After the peripheral grouting is basically finished, the grouting is carried out in the gap between the internal beam and the beam of the cutting board foundation and the periphery of the column. The spacing of the drilling holes is designed to be 1.0m to 2.0m according to the actual situation. The parameters of the slurry are: cement: fly ash: water ratio is 1: 1.0.5, Then add 3‰ water glass.

According to the survey report, the slag layer is medium-density. Refer to the indicators provided in the Theory and Engineering of Geotechnical Grouting, the porosity is 0.35. Calculated according to the grouting formula (3):

\[ Q = 1000vn\beta\alpha \]  

Q-Grouting amount per meter (L); 
v-Reinforced soil volume(m³); 
n-Soil porosity; 
\( \beta \)-Slurry filling factor, pile slag value 0.8; 
\( \alpha \)-Slurry loss factor, pile slag value 1.05.

According to the above formula, the grouting amount per metre is 230.9 L/m.

Grouting in this project is mainly based on controlled grouting, and grouting pressure is only used as a reference. The grouting pressure is based on the principle that the grout can be smoothly injected. When the injection rate is greater than 10 L/min, a smaller grouting pressure is used as much as possible to reduce the possibility of ground grouting. Therefore, the grouting pressure can be controlled from 0.5Mpa to 2.0Mpa [14-15].

6. Horizontal Drain Hole

Arrange a row of horizontal drain holes on the slope of 1~1.5m above the slope of the +53.6m platform. The arrangement of the horizontal drain hole is shown in Table 4.

The horizontal drainage hole position is determined according to the anchor hole position, and the drainage hole is not avoided to intersect with the anchor hole, and the drainage hole is arranged in the middle of the two anchor cables.

| Position  | Orifice elevation | Anchor number | Horizontal spacing | Hole depth | Number of holes | Total hole depth |
|-----------|------------------|---------------|--------------------|------------|----------------|-----------------|
| North side | 55.1m            | P1-P10        | 4m                 | 30m        | 10             | 300m            |
| South side | 55.1m            | P11-P21       | 3m                 | 30m        | 11             | 330m            |
| Total     | -                | -             | -                  | -          | 21             | 630m            |
The horizontal drain hole has a hole diameter of 90 mm, and the angle between the axis and the horizontal line is 10° (elevation angle). The drain pipe adopts φ80PVC pipe, the flower pipe is upward, and the plastic sand net is wrapped; the leakage hole has a hole diameter of 10 mm and the axial hole spacing is 50 mm.

7. Conclusion
(1) By using the residual thrust method to calculate the stability of the open slope, the maximum residual thrust of the slope I section is 128.9 tons/meter, and the maximum residual thrust of the section II is 75.39 tons/meter.

(2) In the process of reinforcement of open slope, safety measures such as slope repairing and masonry retaining wall are adopted. In addition, grouting prestressed anchor cable is selected to reinforce the slope, and reinforced concrete frame girders are used to link between anchor cables. The truss beam is used as an anchor pier.

(3) In order to effectively consolidate the slope stability, the grouting method is used to effectively treat the slope, and the drilling spacing is designed to be 1.0m~2.0m according to the actual situation. The parameters of the slurry are: cement: fly ash: water ratio is 1: 1:0.5, Then add 3‰ of water glass. By adopting the above-mentioned series of slope reinforcement measures, the stability of the open slope and the safety of the filling station can be finally guaranteed.

(4) Through the construction of horizontal drainage holes, drainage and drainage can reduce the rainwater erosion of the rock mass of the northern slope of the mine, hinder the rainwater from invading the soft structural surface of the northern slope, thereby increasing the strength of the rock mass and reducing the rock mass. The impact of groundwater pressure.

References
[1] DU Ying-nan. Slope treatment plan for Shirengou iron ore filling station[J]. Science and Technology Innovation Herald, 2015(NO.21): 92-93.
[2] Li Yan-fen, Xiang Wei-hua, Guo Ming. Stability analysis of the slope along the outer side of Shirengou Iron Mine Filling Station[J]. Modern Mining, 2012(9): 150-151.
[3] Zhou Yu-xin. Numerical simulation of groundwater flow in fractured rock mass and dumping site of mine slope [D]. Nanjing, Hohai University, 2005.
[4] Shi Liang-gui. Study on the stability of the second stage dumping site and the optimization of earthmoving process in Xinqiao Mining Co., Ltd. [D], Changsha, Central South University, 2005.
[5] Luo Yi-bo. Comprehensive analysis of dumping field in the copper-tin polymetallic ore district of Shizhuyuan wild chicken tail [D]. Changsha, Central South University, 2013.
[6] Zhai Wen-long, Zhou Han-min. Application of simplified Bishop Method and residual thrust method in stability calculation of high-step dumping site [J]. Modern Mining 2015 (8): 168-170.
[7] Ren Gao-feng. Research on the mechanism and control of slope damage caused by joint mining[D]. Wuhan, Wuhan University of Technology 2010.
[8] Jia Zhu-ping, Zheng Lu-jing. Stability Analysis and Treatment Scheme of Large-scale Landslide on Open-pit Slope[J]. Metal mine, 2014(5):27-31.
[9] Liu Jie, Zhao Xing-dong, Lu Zeng-xiang. Optimization of open-pit to underground mining scheme and slope stability analysis [D]. Journal of Northeastern University (Natural Science), 2013 (9): 1327-1329.
[10] Gao Huan-ran, Lu Shu-ran, Wang Yi-qing, et al. Stability analysis and treatment measures of an open coal mine slope [J]. Modern Mining, 2018 (4): 193-195.
[11] Mao Quan-sheng. Stability Analysis of the Mountain Slope in the Ma Keng Iron Mine Medium and Machine Repair Work shop[J]. Metal Mines; 2007(8):91-94.
[12] Jiang Su-yang. Construction of Anchorage Cables for Imported High Slope at Xiaolangdi of the Yellow River[J]. Guangxi Water Resources and Hydropower 2000(3):23-25.
[13] Zhou Wei. Research on construction technology of prestressed anchor cable for underground engineering [D]. Chongqing, Chongqing University 2010.
[14] Liu Ji-feng; Lu Ming-shi; Fan Ying-jiang. Application of micro-pipe piles in foundation pit support of narrow space[J]. Journal of Henan Urban Construction Institute, 2012(5):1-4
[15] Ling Yu-bo. Application of compaction grouting technology in the reinforcement of urban culverts [J]. China Water Transport (second half), 2018 (7): 170-171.