

Slope stability analysis and prediction based on the limit equilibrium method of Luming Molybdenum Mine's West-I and North Region

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ABSTRACT

Slope stability is directly related to the safety of mine production, which is one of the key factors influencing the mining production benefit. The present study used China Railway Resources Group Co., LTD Luming Molybdenum Mine's west-I and north area as the main research background and established a numerical simulation model for the selected profile according to the slope engineering geological conditions and mining design of Luming Molybdenum Mine. The profiles included three profiles from the West-I region and three profiles from the North region. The safety factor was calculated and analyzed by the limit equilibrium method and Geo-Slope software. Slope stability was evaluated. An optimization design was carried out on the sections not meeting the requirements, and afterwards the safety factor met the requirements, with the slope being generally stable.

KEYWORDS: surface mining; slope stability; limit equilibrium method; Geo-Slope

1. INTRODUCTION

The proportion of coal mining at home and abroad has increased in the last century. In recent years, with the continuous development and utilization of resources, there has been an overall trend towards deep sunken open pit mining. The deep mining process has led to increases in slope height and mining depth, resulting in poor slope stability and safety. In addition, for large open-pit mines, the optimization of slope angle is one of the important means to make full use of resources, and could reduce production costs and increase mining benefit. According to Sun (1988), with the increase of the slope angle, billions or trillions could be saved in stripping rock costs. Therefore, in the process of deep mining in open-pit mines, there is a prominent contradiction between ensuring the slope safety and improving the economic benefit.

Luming Molybdenum Mine is an open-pit mine that was designed with steep slope mining and relief for the stripping process, with the stripping direction going from the plate to the footwall of the ore body. Luming Molybdenum Mine is a typical high and steep slope strip mine, therefore it is of great significance to China to ensure safe and efficient production to meet demands for molybdenum resources.

Based on the above requirements, the early field engineering geological investigation and field data gained by the rock physics mechanics test are analyzed, and the impact exerted on the slope stability by the geological conditions of Luming

Molybdenum Mine West-I area and North area are studied using the limit equilibrium analysis method, slope stability analysis, and the numerical simulation software Geo-Slope. Finally, optimization measures are put forward.

2. LIMIT EQUILIBRIUM ANALYSIS THEORY

The limit equilibrium method design procedures are an important and most commonly used method for the analysis of slope stability. Broadly speaking, the method also belongs to a kind of numerical analysis method, but due to its generality and practicability, it is often listed as a separate class of methods. The limit equilibrium method is comprised of cutting the soil along a slip surface within the scope of the sliding trend into a bar or oblique, establishing the equilibrium equation of all the sliding soil based on the analysis of the stress of the blocks, and on this basis, determining the safety factor of slope stability (Li, 2010). These methods assume that soil rigid sliding or rotating occurred along a potential slip surface, and sliding soil mass is the ideal rigid-plastic body (Zhou, 2004). The method does not consider the soil stress-strain relationship. It assumes that the safety factor of the degree of shear strength mobilization and the shear strength of the various points along the sliding surface are the same, and assumes its safety factor expression with the deformation characteristics of the landslide area in addition to the landslides regional geological conditions and stress conditions. The differences

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between the Fellenius, the Bishop, and the Janbu are only the assumptions for interslice force or sliding surface interaction force to eliminate the static indeterminateness and the method of deriving the safety factor. Limit equilibrium methods are widely used in engineering due to their advantages such as the easy model and the convenient and easy to understand formula.

An early limit equilibrium method was presented in 1916 by Peterson, and followed by many scholars such as Fellenius, Taylor, Bishop, Janbu, Morgenstern and Price, Spencer, Sarma (Sarma, 1979; Chen and Morgenstern, 1983) who were devoted to improving the method. At present, the rigid-body limit equilibrium method has been developed from two-dimensional to three-dimensional. The greatest benefit of this solution is the constitutive relation expression in engineering, and thus it has a clear physical concept, giving it the advantage of a simple and rigorous solution. There are several methods to calculate slope stability based on the principle of limit equilibrium method. The present study mainly uses the Swedish article points method, Janbu method, Bishop method, Spencer method, Sarma method, and Morgenstern - Price method

3. THE GEO-SLOPE SOFTWARE

3.1 GEO-Slope software introduction

The SLOPE/W module of Geo-Slope software was used for the calculations. SLOPE/W has become the most widely used software in geotechnical engineering professional slope analysis. It includes a variety of methods (Morgenstern-Price, GLE, Spencer, Bishop, Ordinary, Janbu, Sarma, Corps of Engineering, and Lowe-Karafiath) to analyze geotechnical engineering problems, such as shape change of the slip plane, condition of pore water pressure, soil properties, and different loading ways. Finite element method can be combined with the theory of limit equilibrium to calculate and analyze the slope stability. It can also use the parameters to analyze the stability. SLOPE/W software can analyze almost all of the SLOPE problems in geological structures, such as civil engineering and mining engineering

3.2 Selection of study section

Preliminary was completed concerning the Lumeng Molybdenum Mine engineering geological conditions, rock mass structure characteristics, the physical and mechanical properties and quality of the rock, and the rock mass mechanics parameters. This laid the foundation for the simulation. For the sake of convenience, the field engineering geological zoning, and the early stages of the rock mass quality

evaluation results, three sections of West-land three sections of North were chosen to evaluate the slope stability. The optimization of design was carried out for the instability profiles.

According to the actual situation of the field, the principles of the selection profile are as follows:

(1) Close to or through the drill as far as possible, to ensure the accuracy of the research.

(2) Set the section vertical to the slope strike in order to simplify the problem about analyzing the slope stability to plane strain problem, and reduce the calculation error.

(3) Ensure the selected profile through the F3 and F4 fault, in order to research how the faults affect the slope stability of the region.

(4) Make the profile through the fracture zones as far as possible, in order to study how the fracture zones affect the slope stability.

Based on the above principle, six representative profiles were ultimately chosen to research the slope stability of the West-I and the North area. The locations are shown in Figure 1, labeled clockwise as sections 1-1, 2-2, 3-3, 4-4, 5-5, and 6-6.

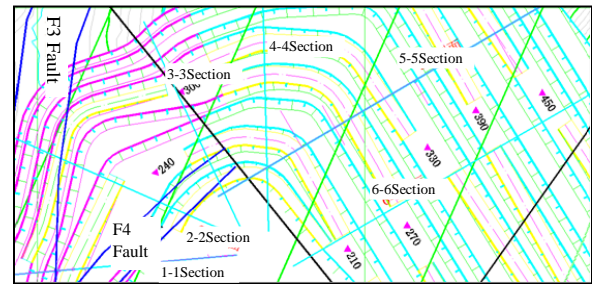


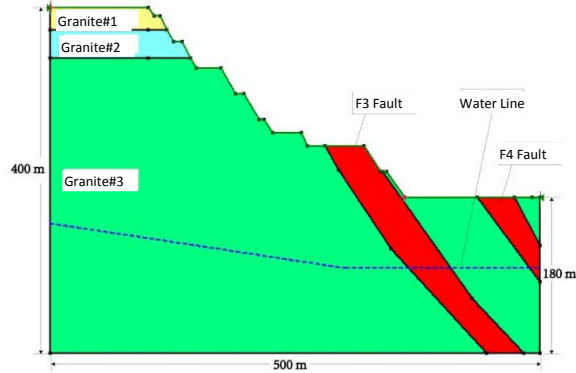
Figure 1: The research section of the west-I district and the north district.

3.3 Establishment of the calculation model

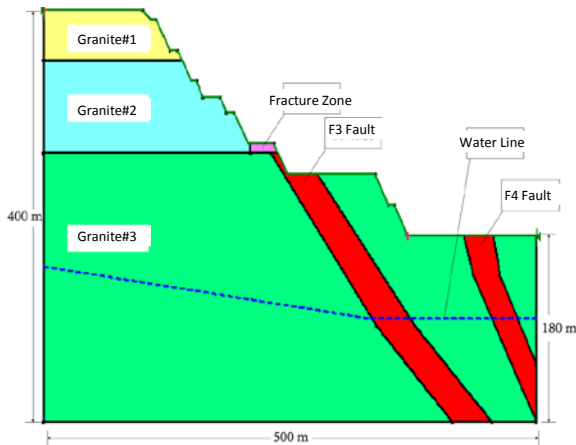
According to the above theory combined with Lumeng Molybdenum Mine's actual situation and the engineering geological zoning information, sections 1-1, 2-2, 3-3 of West-land sections 4-4, 5-5, 6-6 of North were selected as the research areas. The slope stability was analyzed by adopting the method of limit equilibrium theory. According to the geological conditions and actual mining situation, deformation of rock mass in the vertical and profile direction is negligible. Therefore by using the plane strain model assumption, the deformation of the vertical and the calculating section direction is assumed to be zero.

The calculation model is shown in Figure 2. The length of the 1-1 and 2-2 sections model is 500 m and the height is 400 m. The 3-3 section model length is 500 m and the height is 420. Sections 2-2 and 3-3

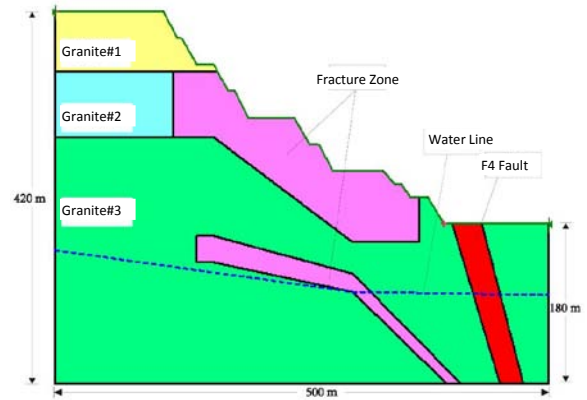
have fracture zones. Sections 1-1 and 2-2 pass through the F3 and F4 faults, the 3-3 section passes through the F4 fault, which should be considered to have an effect on the slope stability during calculations. The 4-4 section model of North length is 500 m along the horizontal axis and the height is 420 m. The 5-5 section model length is 800 m and the height is 540 m. The 6-6 section model length is 700 m and the height is 550. For the 4-4 section, there is a big range of fracture zone, which should be considered when calculating the impact on the slope stability.



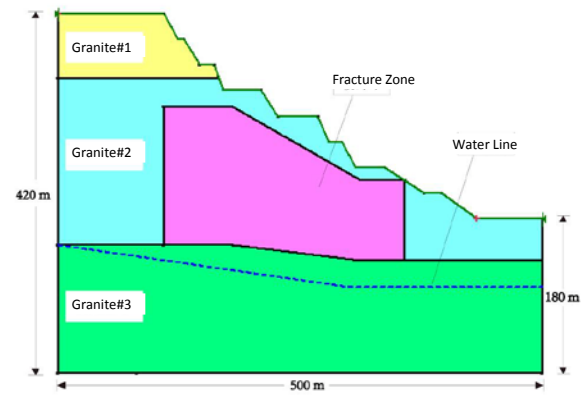
(a): West-I 1-1 section calculation model



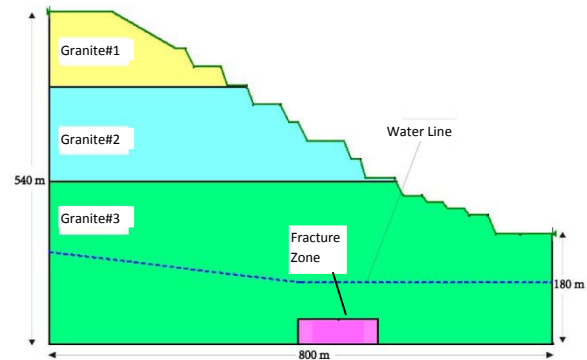
(b): West-I 2-2 section calculation model



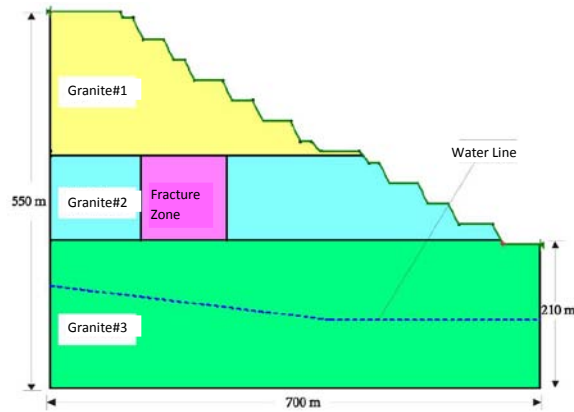
(c): West-I 3-3 section calculation model



(d): North 4-4 section calculation model



(e): North 5-5 section calculation model



(f): North 6-6 section calculation model
Figure 2: West - I area and North area of Luming Molybdenum Mine calculation model.

4. NUMERICAL SIMULATION AND ANALYZING OPTIMIZATION RESULTS

4.1 Simulation optimization analysis of West-I

(1) Simulation analysis of West-I

The safety factor with different calculation methods is as shown in Tables 1 and 2. In the 1-1, 2-2, 3-3 profile of West-I, the minimum safety factors are $F_s=1.213$, $F_s=1.202$ and $F_s=1.086$, respectively. According to the Bishop method, the safety factor is less than 1.3, so the slope is not stable.

(2) Optimization analysis of the West-I slope

According to the calculation results for the 1-1 profile, slope overall stability is poor. The reduction of the slope angle between the 180m-210m platform should be considered. The slope angle should be optimized from 59° to 57° . The result is as shown in Table 1.

According to the calculation results for the 2-2 profile, the slope angle should be optimized between the 270m-300m platform, from 64° to 60° . The result is as shown in Table 1.

According to the calculation results for the 3-3 profile, the slope angle between 300m~330m platform should be reduced from 64° to 60° . The safety factor did not meet the requirement that $F_s > 1.3$, the slope angle should be optimized between the 330m~360m platform, and reduced from 65° to 63° . The result is as shown in Table 2.

Table 1: Safety factor summary of 1-1, 2-2 profile.

	1-1 profile 59°	1-1 profile 57°	2-2 profile 64°	2-2 profile 60°
Swedish slice method	1.247	1.316	1.217	1.333

Bishop method	1.365	1.389	1.345	1.408
Janbu method	1.213	1.278	1.202	1.317
M-P method	1.288	1.344	1.289	1.380

Table 2: Safety factor summary of 3-3 profile.

	3-3 profile 64°	3-3 profile 60°	3-3 profile 63°
Swedish slice method	1.129	1.253	1.326
Bishop method	1.143	1.299	1.367
Janbu method	1.097	1.274	1.332
M-P method	1.086	1.238	1.305
The slope angle of 300 m~330 m platform to 60° , and slowing the slope angle of 330m~360 m platform to 63°			

4.2 simulation optimization analysis of 4-4 profile of North

(1) Simulation analysis of 4-4 profile of North

The safety factor of 4-4 profile was $F_s=1.168$, so the slope angle should be optimized.

(2) Optimization analysis of the 4-4 profile

According to the calculation model of 4-4 profile, the slope angle between the 240m~270m platform should be optimized from 65° to 61° . The safety factor is as shown in Table 3.

Table 3: Safety factor summary of 4-4 profile.

	4-4 profile 65°	4-4 profile 61°
Swedish slice method	1.197	1.313
Bishop method	1.291	1.346
Janbu method	1.168	1.302
M-P method	1.276	1.378

(3) Simulation analysis of 5-5, 6-6 profile of North

According to the calculation results of 5-5 and 6-6 profile, the minimum safety factors are $F_s=1.306$ and $F_s=1.303$, respectively, which meets the requirements of the slope design specification. The safety factors are as shown in Table 4.

Table 4: Safety factor summary of 5-5, 6-6 profile.

	5-5 profile	6-6 profile
Swedish slice method	1.351	1.311
Bishop method	1.368	1.397
Janbu method	1.306	1.303
M-P method	1.359	1.352

5. CONCLUSIONS

(1) Six typical profiles of West-I and North zones were selected and studied. The principles of the selection profile are as follows: close to or through the drill as far as possible; set the profile vertical to the slope strike; ensure the selected profile through the F3 and F4 fault; make the profile as far as possible through the fracture zones.

(2) Before optimization, the safety factors of the 1-1, 2-2, 3-3 profile of West-I and 4-4 profile of North were $F_s=1.213$, $F_s=1.202$, $F_s=1.086$, and $F_s=1.168$, respectively, so the slope is not stable. The minimum safety factors of 5-5 and 6-6 profiles were 1.306 and 1.303, respectively, meeting the requirements of the slope design specification.

(3) After optimization, the minimum safety factors of the 1-1, 2-2, 3-3, 4-4 profiles were $F_s=1.307$, $F_s=1.317$, $F_s=1.305$, and $F_s=1.302$, respectively, meeting the requirements of the slope design specification. The possibility of slope instability is very small within the stable state.

According to the above analysis results, the optimization of the slope angle of the final slope has a certain effect. If the condition is permitted, the field should strengthen the construction management and monitoring in the process of mining, and take measures to control those sensitive areas using gentle slope mining and avoiding the placement of heavy objects on the top of the slope in order to reduce accidents and ensure safe production.

6. ACKNOWLEDGEMENT

It is with great pleasure that we acknowledge the generous financial support of National Natural Science Foundation of China (project number: 51474017) and Natural Science Foundation of Xinjiang Uygur Autonomous Region of China (2014211B013).

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