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Study on stope and slope stability of Yangla Copper Mine

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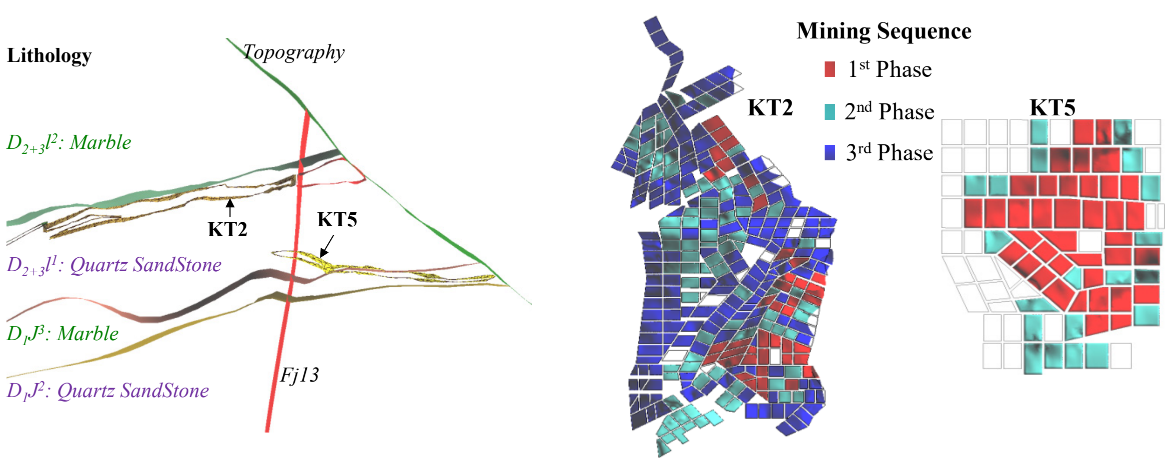
1 INTRODUCTION

Yangla copper mine is located in the northwest of Yunnan province, China. Copper exploration began in 1965 and by 2003, it was preliminarily determined that the mining area is 8 kilometers long from north to south, 3-5 kilometers wide from east to west, with an area of 35 square kilometers and 1.2-1.3 million tons of copper deposit. From north to south, Yangla copper mine consists of seven mining sections, namely, Beiwu, Nilu, Linong, Lunong, Jiangbian, Tongjige and Jiaren. All mining sections are characterized by strong topographic cutting with high mountain and narrow valley.

According to the geological conditions and characteristics of the deposit, the Linong section was designated as the first mining area, and stope and fill was adopted as the mining method. There are many vein-like ore bodies with different scale in the slope of Linong section. KT2 and KT5 are the key and largest ore bodies among them, and the mining sequence for these two ore bodies was divided into three phases, named 1st, 2nd and 3rd phase. Figure 1 summarizes the geology conditions and mining sequence for the Linong section.

The 1st phase of mining is mainly aimed at the shallow part of ore body in the slope. On January 19, 2012, slope collapse accident occurred in the 1st phase of mining the Linong section (Fig. 2), which had a serious impact on the underground stope. It can be seen that the stope and slope show prominent deformation due to mining disturbance, which brings serious safety hazards to the continuation of the project. Thus, it is necessary to predict the stability of the stope and slope in the engineering area based on obtained field data and experience, and form suggestions for optimizing design to improve safety in subsequent mining phases.



(a) Ore body shape, stratum and lithology (b) Top view of mining sequence for Linong section

Figure 1. Summary of geology conditions and mining sequence for Linong section.

Figure 2. Slope collapse occurred in the 1st phase of underground mining in Linong section.

2 CONTENTS AND WORKFLOW IN THE STABILITY ANALYSIS

According to the basic geological conditions and engineering characteristics of the Linong mining area, the following research content and workflow for the stability analysis was formulated. As shown in Figure 3, the main steps of this project were:

- Building the 3D geological model.
- Generating the *FLAC3D* (Itasca 2017) model.
- Calibrating mechanical parameters.
- Stability analysis.
- Optimizing the mining design.

2.1 *FLAC3D Model*

Figure 4 shows the complex *FLAC3D* mesh model of the Linong mining section. The model consists of a slope and nearly 4 hundred stopes within underground mine orebodies KT2 and KT5. *GoCAD* and *Griddle* (Itasca 2016) were also used in to create the model.

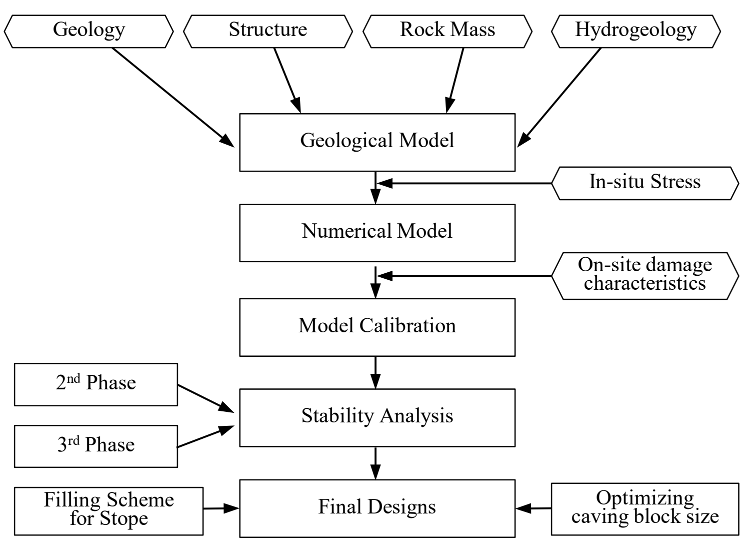


Figure 3. Contents and workflow in the stability analysis.

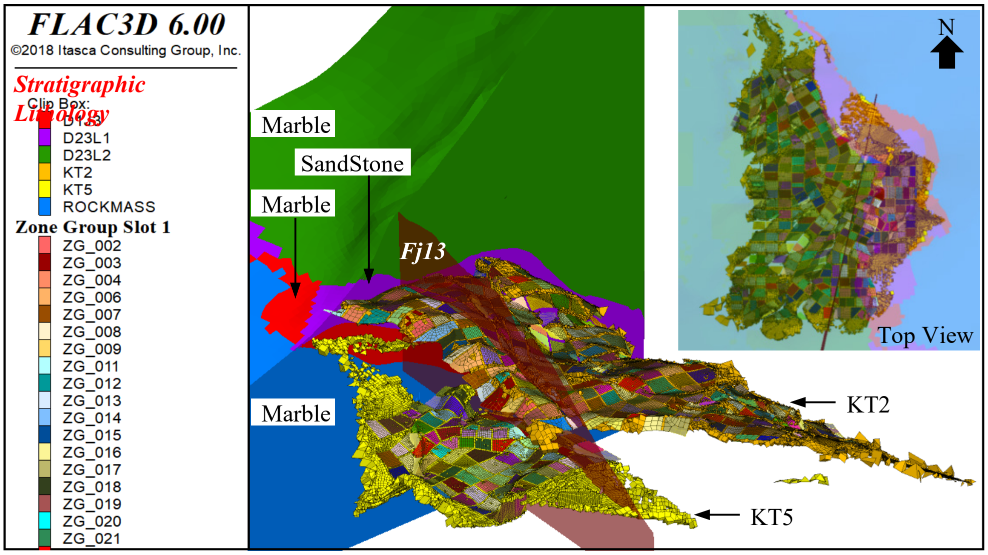


Figure 4. *FLAC3D* model for stability analysis of Yangla copper mine.

2.2 *Rock mass property estimate*

Back analysis of the failure phenomenon at the slope (Fig. 2) has been performed to obtain a set of proper mechanical properties. A Hoek-Brown constitutive model with residual strength was introduced in this study to simulate the mechanical behavior of the rock mass. After running a number of numerical tests, the properties selected to represent rock masses are listed in Table 1.

Table 1. Model property for Yangla rock mass.

Index		Marble	Sandstone	Ore
ρ (kg/m^3)		2710	2740	3500
E/GPa		1.29	5.33	6.31
v		0.26	0.25	0.25
GSI_{peak}		43	48	48
$GSI_{residual}$		25		
m_i		9	20	20
D		0.5		
σ_c/MPa		80	90	140
H-B Peak Strength	mb	0.596	1.681	1.681
	s	0.001	0.001	0.001
	a	0.509	0.507	0.507
H-B Residual Strength	mb	0.517	1.149	1.149
	s	0	0	0
	a	0.511	0.511	0.511

In Table 1, E and v are Young's modulus and Poisson's ratio of the rock mass, respectively; GSI_{peak}, $GSI_{residual}$, m_i, D and uniaxial compressive strength of rock sample tested in laboratory are input parameters for obtaining H-B model parameters.

In addition to the rock mass, the geological structural plane *Fj13* and filling materials are also included in the model. *Fj13* is simulated by using interface and Mohr-Coulomb slip model, and the filling material is simulated with the M-C constitutive model, respectively. Their mechanical parameters are mainly determined by empirical estimation.

2.3 *Model validation*

Model validation was performed to verify if the model properties discussed above reproduce the on-site failure. The study indicates that the predicted slope failure based on the set of chosen properties corresponds closely with the reality observed in the field. It is shown that the deformation and failure of the slope in the Linong section induced by the 1st phase of mining is the result of the comprehensive action of in-situ stress, rock mass quality and local geological structure, and the geological structure *Fj13* plays a controlling role.

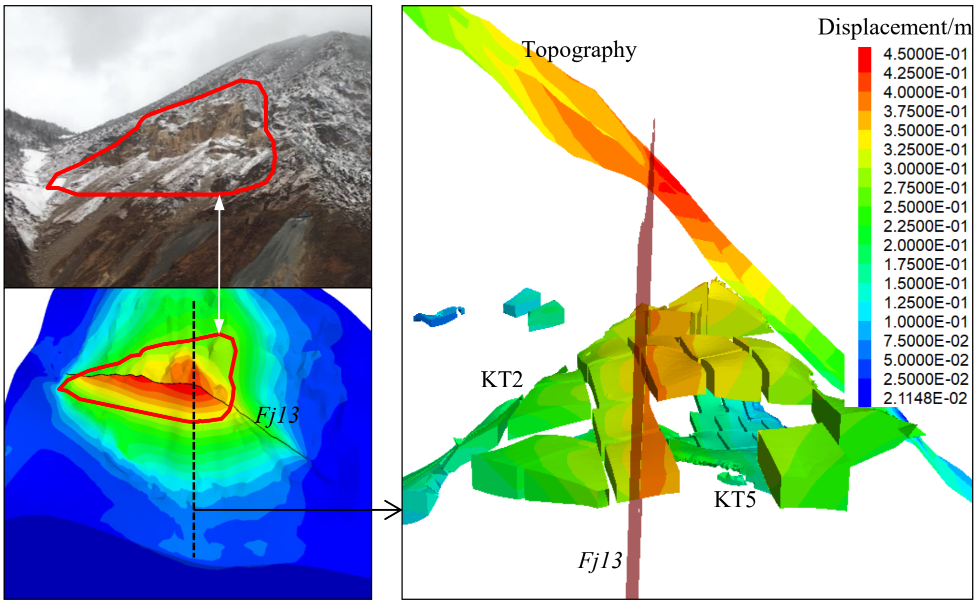


Figure 5. Landslide accident occurred in the 1st phase of mining in Linong section.

3 RESULTS AND DISCUSSION

Considering the complexity of the rock mass failure mechanism, a number of mechanical indicators such as plastic state, safety factor, velocity, deformation and stress were used in this study to identify rock mass damage.

The underground mining area of the Linong section is prominent in scale, and the safety of the project needs to take the stability requirements of the underground stope and slope into account. For avoiding overestimating the real stability condition. this analysis, based on engineering experience and numerical analysis, means to develop the following evaluation criteria for assessing stability of stopes:

- High risk of damage: large number of zones in plastic state tend to coalesce, or do not converge in velocity, or with stress-strength ratio less than 1.
- Moderate risk of damage: zones converge in velocity, and with stress-strength ratio between 1.0 and 1.2.
- Stable: zones converge in velocity, and with stress-strength ratio greater than 1.2.

The slope safety evaluation adopts a different standard, and when the velocity response converges, it is considered to have a self-stabilizing condition. Otherwise, the slope has a high risk of failure.

3.1 *Stability of stope in KT2 in subsequent mining phase*

The stability analysis for the 2nd and 3rd phases of mining is completed on the assumption of mining without filling.

It is shown that, after the completion of the 1st and 2nd phases of mining, the stope is generally in a moderately stable state, and the rock mass stability conditions shown in the simulation analysis are basically consistent with the field performance. However, a considerable part of the stopes have poor stability conditions in the 3rd phase of mining. In order to meet the safety requirements of the project for subsequent mining and long-term, it is necessary to carry out targeted treatment on the existing stopes, and the structural parameters of the subsequent stope, especially, the span need to be optimized.

3.2 *Determination of filling properties and slope stability*

After the 2nd phase of mining is completed, all unfilled stopes are filled with filling material. Stope stability improvements were compared using filling materials of different strength in order to determine the proper filling strength.

3.3 *Optimization analysis for block size*

The optimization of the structural parameters of the stope mainly refers to adjusting the span of the stope to improve its stability. In KT2, the stability characteristics of the area with the deepest buried depth are investigated under three span conditions: 24m, 30m, and 36m. The results show that the stress-strength ratio of the stope increases with the decrease of the span, and the safety improves correspondingly.

4 CONCLUSIONS

Stope and slope stability analysis of Linong section of Yangla copper mine in every mining phase were carried out in this study. Especially, it investigated the necessity of applying filling material to the existing stopes and optimizing the block size in 3rd phase of mining for improving the stability of rock mass. The overall recommendations are as follows:

- During the 3rd phase of mining, the excavation disturbance near the side of the slope may induce large-scale rock mass instability.
- It is recommended that unfilled stopes be filled with filling material of high strength before the 3rd phase of mining,
- In order to reduce the large scale of failure in the stopes due to subsequent deep mining, it is recommended to reduce the span from 36m to 24m.

REFERENCES

Earth Decision Sciences. 2003. *GOCAD 2.0 User's Manual*. France： Earth Decision Sciences.

Hoek, E., & Brown, E.T. 1980. Empirical strength criterion for rock masses. *Journal of Geotechnical and Geoenvironmental Engineering, ASCE*, 106(GT9): 1013—1035.

Hoek, E. & Bray J.W. 1981. *Rock slope engineering* (Third ed.). London: Inst. Min. Metall.

Hoek, E. 1983. Strength of jointed rock masses, 23rd. Rankine Lecture. *Géotechnique*, 33(3): 187-223.

Itasca Consulting Group, Inc. 2016. *Griddle, Ver. 1.0 User's Manual*. Minneapolis: Itasca.

Itasca Consulting Group, Inc. 2017. *FLAC3D – Fast Lagrangian Analysis of Continua in 3 Dimensions, Ver. 6.0 User's Manual*. Minneapolis: Itasca.