Failure characteristics of rock mass around sublevel and shrinkage stopes in steep thick orebody using Surpac and 3DEC

Kun Ui Hong (corresponding author)
Faculty of Mining Engineering, Kim Chaek University of Technology, Pyongyang, Democratic People's Republic of Korea

Chung Song Choe, Chung Il Kim
Faculty of Mining Engineering, Kim Chaek University of Technology, Pyongyang, Democratic People's Republic of Korea

Un Chol Han
School of Science and Engineering, Kim Chaek University of Technology, Pyongyang, Democratic People's Republic of Korea

ABSTRACT: This paper assesses the fracture development characteristics of the rock mass around the sublevel and shrinkage stopes under steep thick orebody using 3DEC and Surpac, and redetermines the boundary of the protective pillar area for the dressing plant. A 3D solid model was constructed using a laser detector and Surpac, transformed it into a 3DEC numerical model, and then the settlements and failure zones of the rock mass around the stopes were analyzed using generalized Hoek–Brown failure criterion. At that time, the mining characteristics of the orebody are 50–100m long, the bed height is 50m, the ore body thickness (M) is 10–30m and the slope angle is 60°. From the simulation results, the relative error between the simulated and the measured data was less than 10%. Finally, the mineable reserves of more than about 2 million tons in the protective pillar area can be obtained.

Keywords: Fracture development characteristics, Stope stability, 3DEC, Surpac.

1 INTRODUCTION

The target mine is extracting the apatite, a raw material for the production of phosphorus fertilizer. The deposit region is widely exposed to sedimentary rocks, basic and ultramafic rocks and granitoids, mostly consisting of biotite schist, metaclastic gneiss, garnet biotite gneiss, hornblende schist, quartz schist, etc. In addition, this region has developed faults in the northwest and northeast directions, and the northeast faults cut and transformed the northwest faults and ore bodies.

At present, production activities are not properly carried out in this mine due to the collapse of stopes and the stability problem of the dressing plant by surface subsidence in the area of the mine's protective pillar.

There are many mining space areas due to the production activities of more than 10 years in the area, which deteriorates mining conditions and causes deformation failure of rock mass around the stopes. Hence, the maintenance of stopes and openings is difficult and there is a risk of subsidence even to the surface buildings such as the dressing plant.

Therefore, the exploration and stability of the mined-out spaces (i.e. gobs) is of great importance in ensuring the normal productivity of the mine.

In recent years, many researchers have performed the stability analysis of the stopes and underground cavities, and determined the rational parameters of the geotechnical structures, using numerical simulation tools such as FLAC3D and 3DEC, and made a lot of progress in research to apply the results to engineering practices (Zhang et al. 2018, Sun et al. 2018, Wang et al. 2015, Abousleiman et al. 2020).

Traditional methods to explore the shape and size of the gobs are not able to obtain 3D shape information of the low efficiency and accurate spatial domain since the accuracy of shape and size of the gob is low and the measurement method is complex, due to the characteristics of the measuring tool and limitations of the survey method.

Recently, 3D cavity detection methods based on laser range finding techniques have been widely used in the field of the civil and mining engineering around the world as a method to overcome the limitations of conventional methods. As early as 1989, a laser scanning system was tested by a mining company, its detection range was limited with 60 meters, and the system was not automated in any way (Liu et al. 2015).

Fardin et al. (2003) scanned the rock mass joint surfaces and created 3D solid model of underground space by installing laser probe equipment on a platform. Also, Meng et al. (2020) obtained accurate 3D models of underground cavity and analyzed its stability using 3D laser scanning technique and FLAC3D.

At present, there are two kinds of laser detection system in the world which are designed to be suitable for surveys of inaccessible cavities: Optech's CMS (Cavity Monitoring System) and MDL's C-ALS (Cavity Auto-scanning Laser System) (Liu et al. 2008). However, these systems are expensive and their application is limited in developing countries.

The aim of this study is to build a 3D solid model of the sublevel and shrinkage stopes using a self-developed laser detection system and mine design software Surpac, and analyze its stability with 3DEC. First, based on the data of the stopes and gobs measured by the laser detection system, 3D model of distribution state of the stope in the protective pillar area for the dressing plant is constructed by Surpac. Then, the numerical analysis using 3DEC is carried out to assess the stability of surface buildings and underground structures, and to ensure that mineable reserves in the target area are available to normalize mineral production in the mine. Finally, a total of 2 million tons of mining potential was obtained by newly setting the protective pillar boundary for the dressing plant and forming 43 stopes at the lower level.

2 3D SOLID MODEL FOR THE PROTECTIVE PILLAR AREA

We built an integrated 3D solid model of the protective pillar area for the dressing plant with a laser detection system (Figure 1).

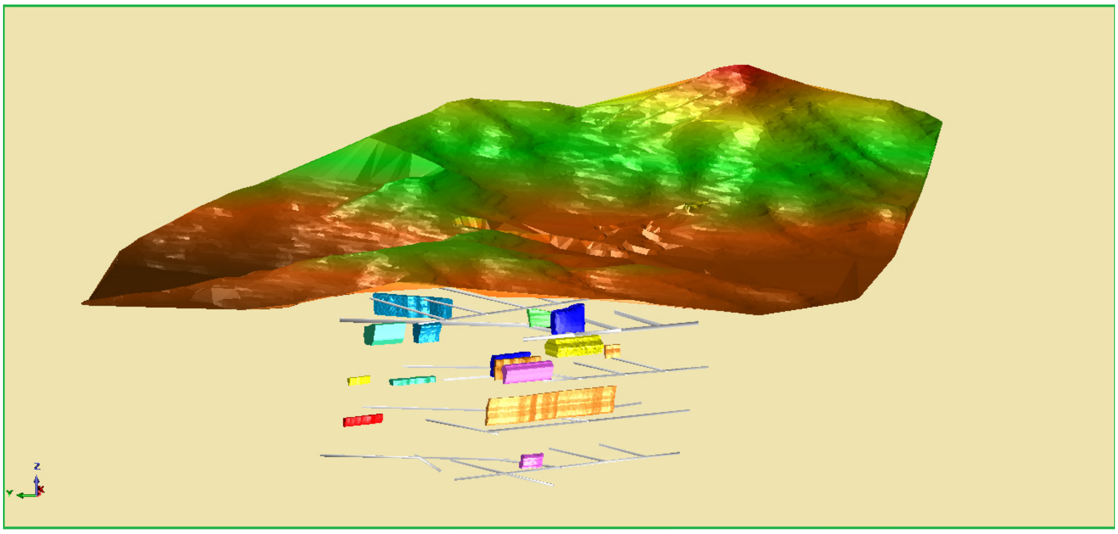
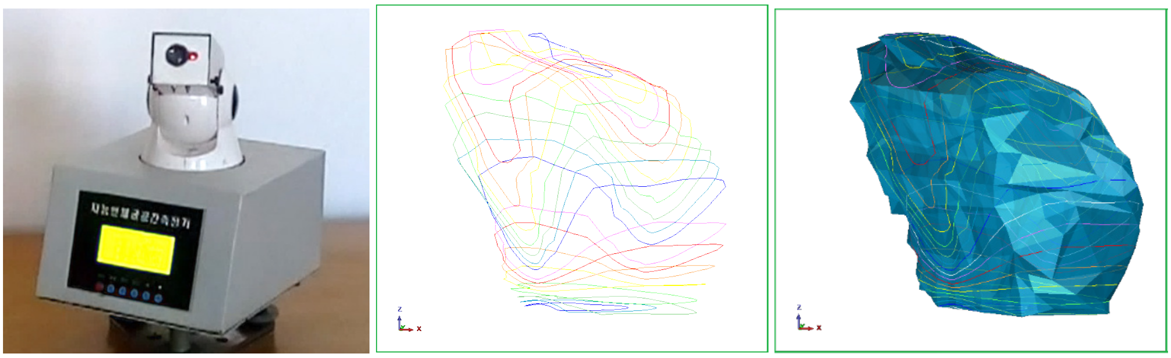


Figure 1. 3D model for the terrain and gobs of the protective pillar area.

The schematic diagram of the developed laser detector and 3D solid modeling is shown in Fig. 2. The maximum measuring distance of the laser detector is 100 m and the angular resolution is 0.5°.



a) b) c)

Figure 2. Measuring device used for stope measurement and 3D model of a gob based on measurement data: a) laser detector; b) gob profile from measured data, c) 3D gob model.

It can be found that the 3D model of the stope based on the data measured by the laser detection system is very similar in shape and size to the actual one due to the large number of measurement points compared to the traditional method of the cavity survey and modeling, and the measurement method is very easy and the measurement time is very short.

In the present study, 18 gobs were surveyed by two researchers, setting two or three measurement origins for each stope. Finally, the relative error between the measurement results was less than 8%, and the measurement time was only 24 h.

3 STABILITY ANALYSIS OF SURFACE BUILDING

3.1 Analysis of surface settlement due to the formation of existing stopes

In the 15-year period from 1993 to 2008, the mine had mined approximately 15 million tons of ore at B1# to B3# levels and 18 mining stations already completed in 2020. Based on the terrain data before the development of the deposit, 3D solid models are constructed by Surpac, and was transformed to numerical model of 3DEC. At that time, the material model used the Hoek–Brown failure criterion and the initial stress considered gravity.

We conducted a comparative analysis between the simulated settlement and the current survey data for 24 major reference points in the study area (Table 1).

Table 1. Comparison between simulated and measured results for surface subsidence.

№	Reference points		Z directional settlement, mm		Relative error, %
	X	Y	Simulated result	Measured data,	
1	28151.57	58608.65	27.23	25.62	5.91
2	28223.88	58608.65	18.44	17.24	6.51
3	28151.57	58646.23	23.83	24.89	4.26
4	28223.88	58646.23	17.93	19.68	8.89
5	28187.73	58627.44	24.76	23.03	6.99
6	28048.29	58686.21	24.17	24.33	0.66
7	27986.71	58559.64	23.66	24.79	4.56
8	28184.04	58585.26	23.48	24.59	4.51
9	28075.87	58527.85	24.46	25.51	4.12
10	28020.62	58760.30	25.04	25.91	3.36

№	Reference points		Z directional settlement, mm		Relative error, %
	X	Y	Simulated result	Measured data,	
11	28182.37	58580.98	16.54	18.05	8.37
12	28098.73	58609.22	17.14	18.71	8.39
13	28069.01	58696.14	21.60	19.82	8.24
14	28050.48	58806.90	24.80	26.63	6.87
15	27917.72	58375.38	23.94	25.09	4.58
16	28030.47	58756.79	24.94	26.15	4.63
17	28241.54	58456.40	21.56	23.47	8.14
18	28095.16	58763.43	21.36	19.76	7.49
19	27916.98	58708.70	22.52	21.80	3.20
20	28141.22	58732.20	24.32	23.40	3.78
21	28220.15	58530.04	16.32	18.12	9.93
22	27945.48	58511.17	24.25	23.36	3.67
23	27939.95	58655.42	19.41	20.81	6.73
24	28214.01	58614.28	24.32	22.33	8.18

As shown in Table 1, it can be seen that the accuracy of the 3DEC analysis method based on the 3D solid model proposed in this study is guaranteed for engineering applications, with the relative error values between the simulation and the actual results less than 10%.

3.2 Securing of mineable reserves in the protective pillar area

In order to ensure the normal production activity of the mine, we must identify the mineable region in the previously established protective pillar area.

In this paper, we preliminarily identified the mineable region while preventing surface subsidence based on conventional protective pillar design methods such as vertical section method, vertical line method and elevation projection method (Figure 3).

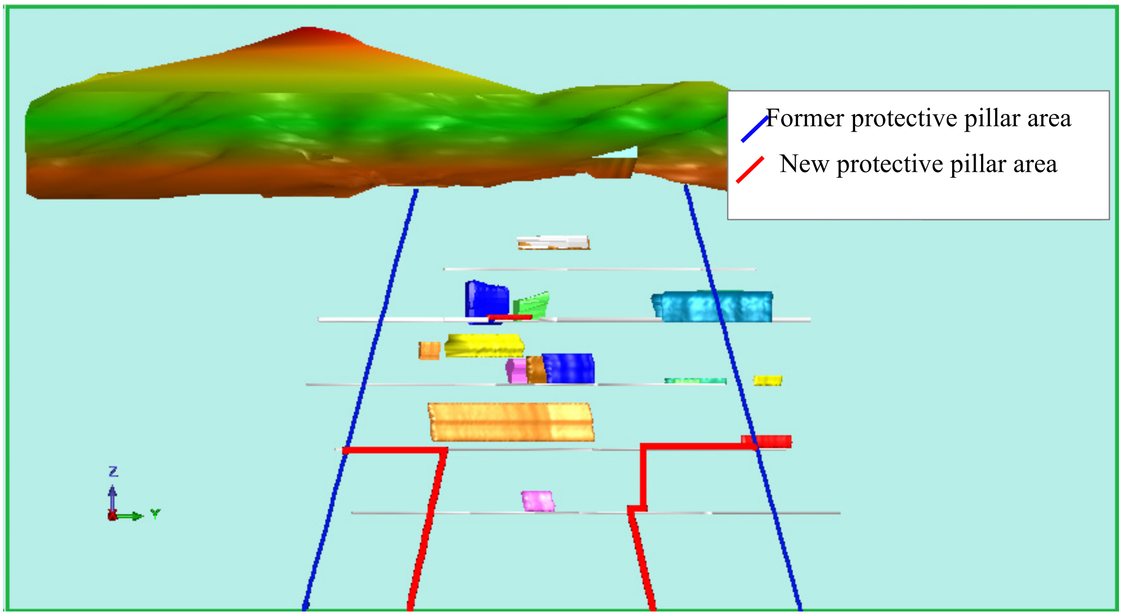
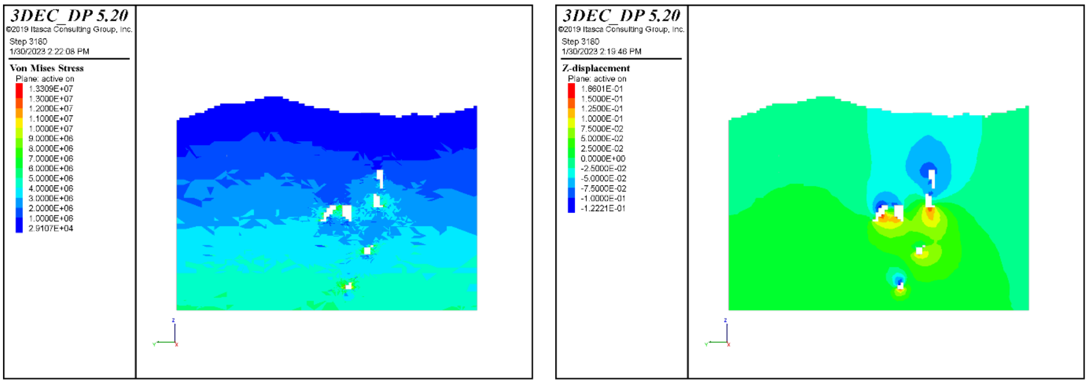


Figure 3. New boundary of the protective pillars for surface buildings.

After placing the stopes outside the guard pillar boundary, the stability analysis on the surface and the mined-out space was carried out. Simulation results of stress distribution and vertical displacement when the stopes are formed in one section (x=28112) are shown in Figure 4.



a) b)

Figure 4. a) Stress distribution and b) vertical settlement in x = 28112 Section.

We simulated the influence of them on the top-formed gobs and surface buildings, when placing 63 sublevel and shrinkage stopes at the lower B3# level. It can be found that 46 of the 63 stopes, which can be located from B4# to B7# levels, can ensure the safety of the surface buildings, since the settlement in the protective pillars is less than 8mm after mining.

From the results of the above studies, the amount of the minable ore in each stope obtained from the newly established protective pillar boundary for the ore dressing plant is given in Table 2.

Table 2. Amount of ore obtained by the newly established protective pillar boundary.

Level	Block	Stope number	Ore amount, t	Sum, t
B4	13(B)	4-1, 4-3	120 000	120 000
B5	13(B)	5-3, 5-4	90 000	
	14(B)	5-5, 5-6, 5-8	135 000	
	15(B)	5-9, 5-11, 5-12, 5-13	180 000	
	19(B)	5-16, 5-17	90 000	
	20(B)	5-18, 5-19	90 000	
	21(B)	5-21	45 000	468 000
B6	13(B)	6-2, 6-3	135 000	
	14(B)	6-4, 6-5, 6-7	180 000	
	15(B)	6-8, 6-9, 6-10, 6-12	225 000	
	20(B)	6-15, 6-16	90 000	
	21(B)	6-17, 6-18	45 000	675 000
B7	13(B)	7-1, 7-2	135 000	
	14(B)	7-3, 7-5, 7-6	135 000	
	15(B)	7-7, 7-9, 7-11, 7-12	180 000	
	20(B)	7-13, 7-14, 7-15, 7-16	180 000	
	21(B)	7-17, 7-18, 7-19, 7-20	180 000	810 000
Total		46	2 073 000	

Through the present study, we identified the stable regions in the protective pillar area and obtained the mineable reserves of more than about 2 million tons.

4 CONCLUSION

In this paper, we proposed a method to construct a 3D solid model of the orebody and gobs using a laser detector and Surpac, and analyzed the stability of the surface buildings and stopes by transforming it into a 3DEC numerical model to optimize the stopes layout in the protective pillar area.

(1) The use of a developed laser detector has made it possible to reflect in more detail the shape and size of the mined-out space, thus increasing the accuracy of the modeling and analysis results for computer simulation.

(2) Comparison of simulated and measured results within the known settlement zone on the surface verified the reliability of the computer simulation analysis method and performed the simulation analysis by 3DEC to find out more than 2 million tons of mineable reserves in the protective pillar area, thus making it possible to obtain great economic benefits.

ACKNOWLEDGEMENTS

This study was financially supported by the National Science and Technical Development Foundation of DPR Korea (Grant No. 24–20211007).

REFERENCES

Abousleiman, R., Walton, G. & Sinha, S. 2020. Understanding roof deformation mechanics and parametric sensitivities of coal mine entries using the discrete element method, *International Journal of Mining Science and Technology* 30, pp. 123–129.

Fardin, N., Feng, Q. & Stephansson, O. 2003. Application of a new in situ 3D laser scanner to study the scale effect on the rock joint surface roughness. *International Journal of Rock Mechanics & Mining Sciences* 41 (2), pp. 329-335.

Liu, X., Li, X., Gong, F. & Liu, K. 2015. Safety Problem of Cavity Under Open Pit Bench. *Archives of Mining Sciences* 60 (2), pp. 565–580. DOI: 10.1515/amsc-2015-0037

Liu, X.L. 2008. Research for stability analysis and safety forewarning of cavity based on laser 3D detection. Ph.D. thesis, Changsha, Central South University, pp. 61-64.

Meng, Z., He, M., Tao, Z., Li, B., Zhao, G. & Xiao, M. 2020. Three-Dimensional Numerical Modeling and Roof Deformation Analysis of Yuanjue Cave Based on Point Cloud Data. *Advances in Civil Engineering* 2020, Article ID 8825015, 13 pages. DOI: 10.1155/2020/8825015

Sun, X.M., Li, G., Zhao, C.W., Tang, J.Q., He, M.C., Song, P. & Miao, C. Y. 2018. Numerical Investigation of Gob-Side Entry Retaining through Precut Overhanging Hard Roof to Control Rockburst. *Advances in Civil Engineering* 2018, 10 pages.

Wang, F.T., Zhang, C., Zhang, X.G. & Song, Q. 2015. Overlying strata movement rules and safety mining technology for the shallow depth seam proximity beneath a room mining goaf, *International Journal of Mining Science and Technology* 25, pp. 139–143.

Zhang, D. Y., Sui, W. H. & Liu, J. W. 2018. Overburden Failure Associated with Mining Coal Seams in Close Proximity in Ascending and Descending Sequences Under a Large Water Body. *Mine Water Environ.* 37, pp. 322-335.