Study on Stability of Metal Mine Overlying Strata for Artificial Pillar Support

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Abstract

In this paper, artificial pillar in one gold mine is designed and the stability of overlying strata at its supporting goaf is investigated. From the perspective of stress distribution, the results show that the stress which applied to roof overlying strata and artificial pillar cannot reach damage degree of instability, and the devised artificial pillar can meet the requirement of safety production. However, the stability monitoring at some key positions on the surrounding rock of goaf should be strengthened. It is found from the displacement changes that the larger the goaf span is, the greater the subsidence of roof overlying strata is. In addition, the mining in the next mid section has a great influence on the shifting of roof overlying strata at the goaf of the above mid section.

Keywords: *Artificial pillar; Overlying strata; Metal mine; Stability*

1. Introduction

The pillar is an important, economic and effective way for maintaining stability of surrounding rock and roof control at the goaf in the underground mining support[1-3]. The pillar in the open-stope method is divided into primary ore pillar and artificial pillar. The primary ore pillar is the mineral rock left directly in the underground in ore mining, and should not be mined and reclaimed. The artificial pillar is mostly applied in rare and precious metal mine [4-8]. As mineral ores are of high-grade and valuable, the filling material constructed artificially in certain dimensions is used to replace the mined ore so that it can change the surrounding rock stress at the goaf, support overlying strata and prevent surrounding rock deformation. With ore resources being exhausted, the artificial pillar will be gradually adopted for mining in many ordinary mines in order to fully recover mineral resources and enhance economic performance. Thus, it is of practical significance to systematically study the stability of artificial pillar in supporting overlying strata.

As the artificial pillar in supporting overlying strata is affected by complex factors such as filling material proportioning, design strength and filling construction technology, its supporting effect is inferior to that of the primary ore pillar.

Although some researchers had undertaken studies on supporting role and performance of artificial pillars in underground mining in metal mines and had achieved some research results [9-14], most of researches are focused on construction technology and on-site application of artificial pillar and relatively less research are reported to concentrate on damage dynamic process and displacement changes of overlying strata under the artificial pillar supporting conditions.

2. Model Buiding

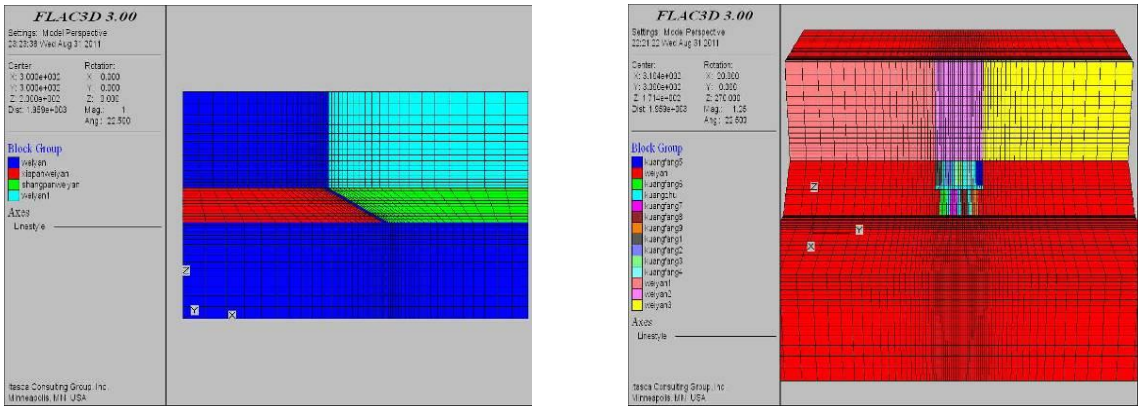
The research was done in one gold mine in China. This mine's surface was level in dip angle and +160 meters above sea level, and its ore body was 5 meters thick on average, 90 meters long, and 500 meters deep. It is mined with the open-stope method. In order to maintain production safety and to recover more metal ore, artificial pillar was used to replace primary ore one so as to guarantee stability of surrounding rock at the goaf. Seven mining mid sections were designed for mining, namely: -390m, -410m, -430m, -460m, -500m, -540m and -580m. Currently -390m and -410m mid sections have been mined out, the -430m mid section is actually mined, and the -460m mid section is being developed. As the main shaft of the mine is within the moving belt, it is very important to study on movement pattern of overlying strata in -430m and -460m mid sections with artificial pillar supporting. This will directly affect normal operation and safety of the main shaft. For this reason, based on practical engineering requirements, we devised a model with a size set at 600m×600m×400m, its specific parameters of physical mechanics are shown in Table 1. It has 124614 nodes and 117096 units. The burial depth for the model bottom is 790 meters. The stability of overlying strata under artificial pillar support is mainly studied for -430m and -460m mid sections, and the dimensions of room and pillars are seen in Table 2. Grid is divided with a gradual change mode, and the densest grids are at the center. The grids are distributed uniformly at the key research area. The model adopts displacement boundary condition: Rolling support is used around themodel($u_x=0, u_y=0$), its bottom is fixed ($u_x=0$、$u_y=0$、$u_z=0$), and gravity stress for overlying strata at the top boundary $\sigma_{zz}=-10.92Mpa$. With respect to tectonic stress, the horizontal stress is 1.25 times of vertical stress in inclination of ore body($\sigma_x=1.25\sigma_z$), while the horizontal stress is 0.75 time of vertical stress along ore body ($\sigma_x=0.75\sigma_z$). The Mohr-Coulomb strain softening principle is applied in calculation. The model is shown as Fig. 1.

Table 1 mechanical parameters of rock mass

Constituent	***Density (kN/m^3)***	***Elastic modulus (MPa)***	***Cohesion (MPa)***	***Friction angle(°)***	***Poisson's ratio***	***Tensile strength(MPa)***
Surrounding rock	28	60000	15	45	0.2	7.5
Ore body	27.1	65000	15	42	0.19	7.5
Artificial pillar	21	230	0.171	35	0.25	0.01

Table 2 Parameter design for ore block structure of -430m and -460m mid sections

Mid section	***Ore block structure parameter***			
	Number of pillars per section	Pillar width (m)	Number of rooms per section	Room width (m)
-430m	4	6.6	5	11.7
-460m	3	5.8	4	11.9



(a) Division of grids for the model (b) Cutaway view for the model

Fig. 1 Model diagram of overlying strata with artificial pillar support

3. Results and Anlysis

3.1 Distribution and changes of stress for overlying strata

It is known from the maximum main stresses in Figure 2 that stresses are centralized mainly at the boundary of the mining zone, especially in the surrounding rock area outside of the room at two ends. The centralized stress is 61.03MPa at the lower part of surrounding rock outside of the room of the -460m mid section, the compressive strength is around 75MPa for the surrounding rock. Though it is less than the standard surrounding rock compressive strength, these areas should be monitored in stability and the effective reinforcement measures should be taken. The load-carrying capacity for the artificial pillar itself is also less than compressive strength, the artificial pillar is in a relatively stable state. It is known from minimum main stress in Figure 3 that tensile stress occurs mainly at the top of the room in -430m mid section and in the middle of the baseboard at mining areas of two mid sections. The closer to the mid section at the goaf the room is, the larger tensile stress its top (bottom) board receives, and the bigger the high stress area with a maximum tensile stress at 3.54MPa, which is far less than the tensile strength 7.5MPa of the surrounding rock itself. So the surrounding rock will not be damaged. In addition, it is known from the figure that there is no tensile stress in artificial pillar, which ensures the artificial pillar is in a stable supporting state. It is known from distribution of plastic areas at the goaf roof (Fig. 4) that only sporadic plastic areas exist in the stope after -430m and -460m mid sections are mined out. Artificial pillar itself has no plastic breakdown area, few plastic areas occur in artificial pillar only during process of mining. But artificial pillar gradually enters in a stable stress state with mining, which indicates the structural parameters for devised artificial pillar can be used to effectively prevent plastic area forming and damaging of overlying strata at the goaf. Through analysis of force diagram and distribution diagram of plastic area of overlying strata and artificial pillar itself at goaf, it is known that their compressive stress or tensile stress is less than damage strength in instability and failure strength, which doesn't result in rupture and instability of overlying strata and failure of artificial pillar itself. However, the areas where there is the larger stress at two sides of surrounding rock at the goaf should be monitored in stability, and the reinforcement measure should be taken as necessary.

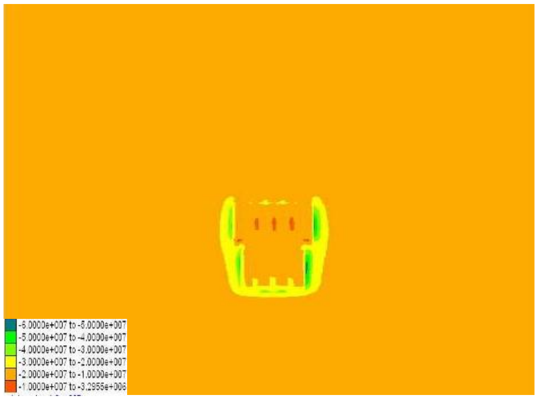


Fig. 2 Contour map of maximum principal stress

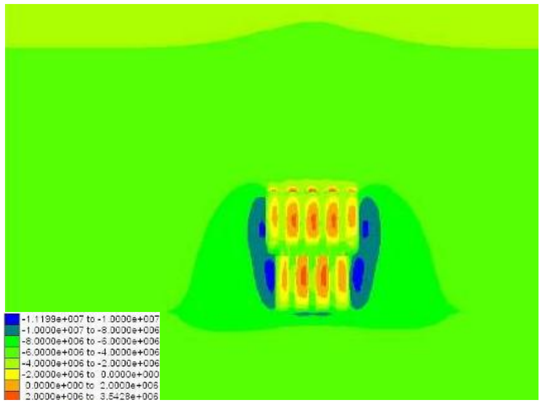


Fig. 3 Contour map of minimum principal stress

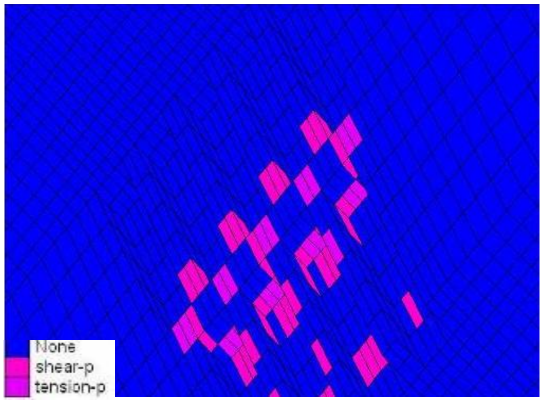


Fig. 4 Plastic zone of the room roof at the goaf

3.2Change of displacement for overlying strata

The change of displacement for overlying strata at the goaf is an important parameter reflecting its stability. Therefore, No. 1-5 displacement monitoring points are set up in the middle of room roof at the goaf of the -430m mid section, and No. 6-9 displacement points are set up in the middle of room roof at -460m mid section (Fig. 5). After the -430m mid section is mined out, the displacement changes of room roof at the goaf of the section are shown in Fig. 6. It is known from Fig. 6 that the room roof in the middle of the entire goaf, i.e. No. 3 monitoring point, presented the largest subsidence of 6.75mm. There is a small subsidence, around 4.24mm for No. 1 and No. 5 monitoring points located room roof of the boundary at two sides of the goaf. This result is consistent with distribution of maximum tension stress analyzed aforementioned. Because rock materials is characterized with compressive resistance rather than tensile resistance, the tensile stress is centralized at the same area where the overlying strata will ruptures easily and results in great displacement of overlying strata.

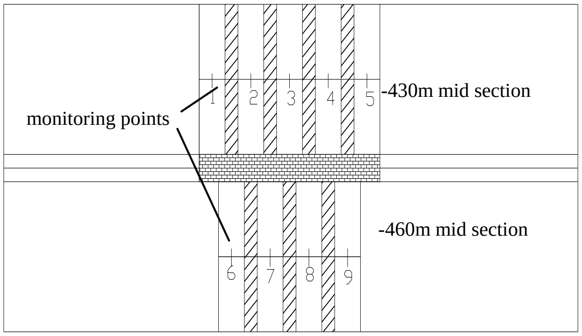


Fig. 5 Distribution of displacement monitoring points of the room roof at the goaf in different mid sections

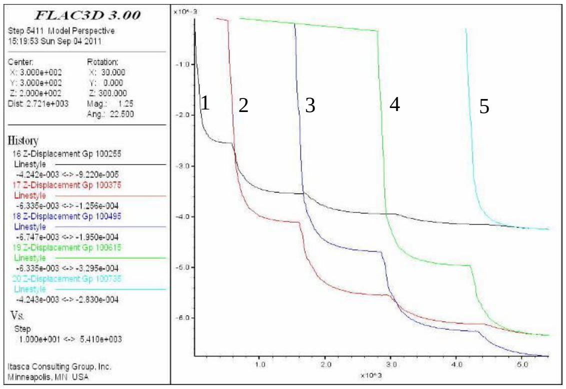


Fig. 6 Displacement change of the goaf roof at No. 1-5 points after the -430m mid section is mined out

After the -460m mid section is mined out, there is a greater subsidence of room roof at Points No. 7 and 8, i.e. 7.76mm or so (Fig. 7), which is about 1mm higher than the maximum subsidence of 6.75mm at room roof after -430m mid section is mined up. This result is caused by actions of gravity stress and tectonic stress.

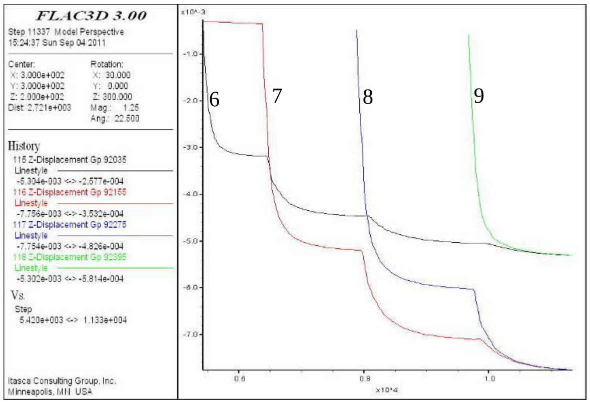


Fig. 7 Displacement change of the goaf roof at No. 6-9 points after the -460m mid section is mined out

3.3 Interaction of displacement changes for the mined overlying strata at different mid sections

After the -460m mid section is mined out, the maximum subsidence of the room roof comes to 8.02mm at No. 3 monitoring point in the -430m mid section (Fig. 8). It is known from Fig. 9 that the displacement of room roof at No. 1-5 monitoring points after -460m mid section is mined up is much larger than the displacement at the corresponding points in -430m mid section after the section is mined up. The subsidence of room roof reaches greatest value after -460m mid section is mined up. when -430m mid section is mined up ,No. 3 monitoring point’s subsidence is 6.75mm, while its subsidence goes up to 8.02mm and its displacement increases by 18.8% after the -460m mid section is mined up. In comparison to the subsidence at different monitoring points of foregoing different mid sections, it is found that the maximum subsidence of room roof at -460m mid section is less than that of the -430m mid section. This suggests that the bigger the mining mid section span is, the greater the subsidence of roof at the goaf is, and more unstable the overlying strata are.

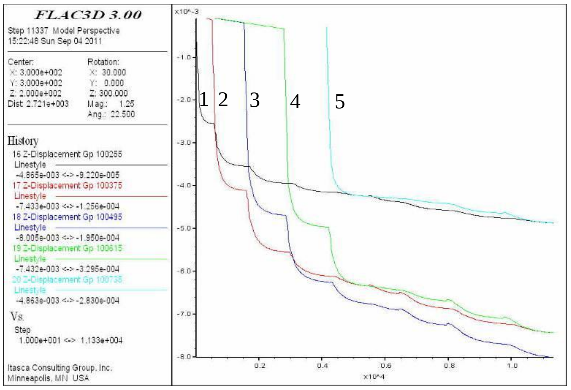


Fig. 8 Displacement change of the goaf roof at No. 1-5 points after the -460m mid section is mined out

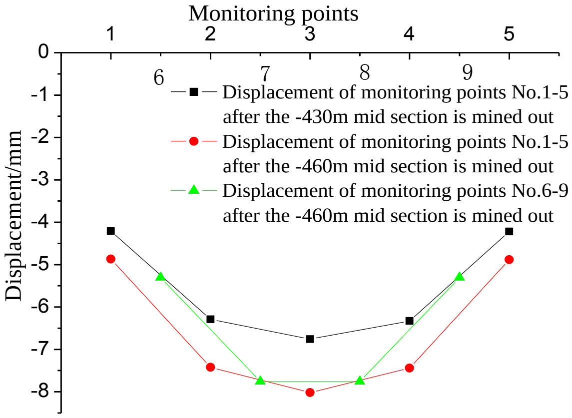


Fig. 9 Comparison of displacements of roof monitoring points at the goaf after different mid sections are mined out

Taking all the calculations into consideration, the mining out of -460mm mid section will have a greater influence on the subsidence of No. 1-5 monitoring points than the mining out of -430m mid section, and their displacement of monitoring points increases by 15.6--18.8%.

4. Conclusions

(1) It is shown by the stress distribution research that the strata will not reach instability state when maximum compressive stress of 61.03Mpa(Compressive strength for surrounding rock is around 75MPa) or maximum tensile stress of 3.54MPa (Tensile strength is 7.5MPa) is applied to roof overlying strata. However, the stability monitoring at some key position of surrounding rock should be strengthened and corresponding reinforcement measures should be taken if necessary. From analysis of stress strength and plastic area distribution, the designed artificial pillar is stable itself and can bear pressure forces from overlying strata and meet requirements of safety in production.

(2) It is found from displacement changes that, attributed to physical and mechanical properties of rock materials, the bigger the goaf span is, the greater tensile stress it bears, and the greater the subsidence of roof overlying strata is in the mining disturbing process.

(3) When two adjacent mid sections with different elevations are mined, the mining for next mid section has a great influence on the shifting of roof overlying strata at the goaf in the above mid section. The mining for the -460m mid section causes 8.02mm subsidence at No. 3 monitoring point, which increases by 18.8% at No. 3 monitoring point, compared with the mining of the -430m mid section.

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References

[1] A. Newman, E. Rubio, R. Caro, A. Weintraub, K. Eurek, "A review of operations research in mine planning", Interfaces 2010, Vol. 3, pp.222-245.

[2] D.R. Tesarik, J.B. Seymour, T.R. Yanske, "Long-term stabilityof a backfilled room-and-pillar test section at the Buick Mine,Missouri, USA", International Journal of Rock Mechanics and Mining Sciences, 2009, Vol. 7, pp.1182-1196.

[3] M. Najafi, S.E. Jalali, A. R. Yarahmadi Bafghi, F. Sereski, "Prediction of the confidence interval for stability analysis of chain pillars in coal mines", Safety Science, 2011, Vol. 5, pp. 651-657.

[4] Kh.I Aglyukov, "Mining of the protective pillars using a packed fill",Journal of Mining Science, 2004, Vol.3, pp.292-297.

[5] M. Monjezi, M. H. Seyed, M. Khandelwal, "Superiority of neural networks for pillar stress prediction in bord and pillar method", Arabian Journal of Geosciences, 2011, Vol.5-6, pp.845-853.

[6] O.V. Ovcharenko, I.I. Ainbinder, K.Yu. Shilin, N.P. Kramskov, "Geomechanical Substantiation of the Parameters for Underground Mining of “Mir” Kimberlite Pipe" ,Journal of Mining Science, 2002, Vol.6, pp.528-533.

[7] A. Mortazavia, F.P. Hassanib, M. Shabania, "A numerical investigation of rock pillar failure mechanism in underground openings",Computers and Geotechnics, 2009, Vol.5 pp.691-697.

[8] J. Deng, L. Bian, "Investigation and characterization of mining subsidence in Kaiyang Phosphorus Mine", Journal of

Central South University of Technology, 2007, Vol.3, pp. 413-417.

[9] A. S. Tawadrous, P. D. Katsabanis, "Prediction of surface crown pillar stability using artificial neural networks", Int. Journal for Numerical and Analytical Methods in Geomechanics, 2007, Vol. 7, pp. 917-931.

[10] Chen Q.F., Zhou K.P., Action mechanism of low-grade backfill on stability of mining environment structure. Rock and Soil Mechanics, 2010, Vol. 9, pp. 2811-2816.

[11] X.J. Wang, X. Feng, T.B. Yang, K. Zhao, K. Zhao, "Reasonable width calculation and analysis of artificial pillar in deep mining", Journal of Mining & Safety Engineering, 2012, Vol. 1, pp.54-59.

[12] J. P. Loui, P. R. Sheorey, "Estimation of non-effective width for different panel shapes in room and pillar extraction", International Journal of Rock Mechanics and Mining Sciences, 2002, Vol. 1, pp.95-99.

[13] J. Deng, Z.Q. Yue, L.G. Tham, H.H. Zhu, "Pillar design by combining finite element methods, neural networks and reliability: a case study of the Feng Huangshan copper mine, China", International Journal of Rock Mechanics and Mining Sciences, 2003, Vol. 4, pp.585-599.

[14] J. Zhou, X.B. Li, X.Z. Shi, W. Wei, B.B. Wu, "Predicting pillar stability for underground mine using Fisher discriminant analysis and SVM methods",Transactions of Nonferrous Metals Society of China, 2011, Vol.21, pp.2734-2743.

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