Study on Stability of Artificial Pillar under Regenerated Mechanical Environment

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***Abstract*—In order to ensure that the ore mining stope structure stability, the artificial pillars in one gold mine were designed, their self-stability and effectiveness in supporting overburden rock of goaf were studied based on idea of regeneration of mechanical environment. This paper describes the studies of artificial pillar self- stability respectively in terms of stress changes, plastic zone distribution and displacement changes. The study results demonstrated that the designed artificial pillar can bear the weight of above overburden rock, show good stability itself, effectively prevent the destruction of surrounding rock and overburden rock of goaf and achieve the purpose of mine supporting. The designed artificial pillars can meet the needs of safety operation; however, the real-time stability monitoring should be emphasized at some key positions.**

Keywords- mechanical environment regeneration; artificial pillar;stability; stress; plastic zone; displacement

I. INTRODUCTION

A great quantity of ore mining will cause stress changes in surrounding rock environment[1]. In order to fully recover mineral resources, there is need to reclaim the left pillars but necessary measures should be adopted in supporting goaf roof after pillar recovery to prevent catastrophic mine accidents. Deshen Gu proposed an important idea, “regeneration of mining environment,” in mining science[2-3]. The idea deals with construction of artificial structure to change stress environment in surrounding rocks of goaf after mining to minimize the destruction caused by original stress changes, to reduce the difference between main tresses and to lower the stress dispersion levels in the purpose of improving stability of surrounding rock of goaf. The artificial pillars usually can’t reach desired supporting effect since their supporting capability is affected by some complicated factors such as filling construction process, characteristics of filling material and designed strength, etc[4-7]. Although some researchers have contributed their efforts and made some achievements in studies of underground support function and effectiveness, most of these studies are concentrated on areas of artificial pillar construction process and field applications, relatively less research work are reported on studies of self-stability and fracture behavior of artificial pillars[8-13]. It is found that, through literature searching and field investigation, the artificial pillars have replaced original ore pillars in many mines, however, the problems such as the self failure mechanism of artificial pillars have been puzzling the safety operations in many mines.

II. MODELLING

One gold mine in China was used as a research subject in this study; its ore body was 5m in average thickness; length was 90m; inclination was nearly horizontal; burial depth was 500m. An open-stope mining is used in this mine with natural pillars being replaced by artificial pillars to ensure the stability of surrounding rocks of goaf. The mine is divided into seven mining levels(-390m, -410m, -430m, -460m, -500m, -540m and -580m.), currently -410m level mining has been completed, -430m level is under mining and -460m level is under development.

Influenced by surface environment, the main shaft is located in the theoretical movement belt area, so it is very critical to study the influences on above overburden rocks and surface movement during mining of -430m and -460m levels. Therefore, it is necessary to study the self-stability of artificial pillars. The model is built in according to mine geological conditions, it has a bottom buried depth of 790m, a number of 124614 nodes and 117096 units, the physical and mechanical parameters of model are shown in Table 1. The research is mainly concentrated on self-stability of artificial pillars during mining process of -430m and -460 levels. The dimensions of mining room and pillar are shown in Table 2 and their layout in Fig. 1.

A gradient mode is adopted for meshing with more dense and even grids used in research areas. The model uses displacement boundary conditions: using the roll around support(u_x=0, u_y=0),bottom fixed (u_x=0, u_y=0, u_z=0）, the upper boundary is the gravity stress of overburden rock σ_{zz}=-10.92MPa, the horizontal stress in the direction of ore body tendency is 1.25 times that of vertical stress (σ_x=1.25σ_z), the horizontal stress along the ore body is 0.75 times that of vertical stress (σ_x=0.75σ_z) along the run of ore body. The Mohr-Coulomb strain softening standards are used in calculations. The model is shown in Fig. 2.

TABLE I. 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 II. PARAMETER DESIGN FOR ORE BLOCK STRUCTURE OF -430M AND -460M LEVELS

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

Insert Fig.1 here

Insert Fig.2 here

III. RESULTS AND DISCUSSIONS

A. *Stress changing process of artificial pillar itself*

The stress has great changes in the mining process, especially concentrating on the areas of surrounding rocks outside both ends of mine room, the stress value reaches 61.03MPa at lower surrounding rocks outside mine room (Fig. 3). Although this stress is less than the maximum compression strength of 75 MPa of surrounding rocks, safety monitoring should be emphasized and reinforcement measures adopted to ensure the safety. It is shown in maximum principle stress diagram that the stress of artificial pillar is relatively stable and there is no stress concentration phenomena, the applied stress is less than its compression strength. It is known from the minimum main stress diagram that the tensile stress is very small, not even existing; considering the compression-resisting and non-tension-resisting characteristics of rock material, the artificial pillar is in a stable state. While looking at whole minimum stress diagram, it is shown that the maximum tensile stress are located on the mine room roof at -430m mining level and in the middle of floor of two mining levels of goaf. The closer is the mine room to middle area of goaf, the higher the tensile stress value, the maximum tensile stress reaching 3.54 MPa which is still much lower than the tensile strength 7.5 MPa of surrounding rocks and thus surrounding rocks destruction will not occur which accounts for that the designed artificial pillars can meet supporting requirements. All material destruction starts from plastic zones occurred in the material, there is no plastic destruction zones appeared in artificial pillar itself after completion of mining, only small plastic zones appeared during the mining process of two levels(Fig.4). After the mining operation of two mining levels, the artificial pillars are in stable state of stress, this shows that the designed artificial structure parameters can effectively prevent the formation and destruction of plastic zones in overburden rocks in the goaf. It is shown in stress diagram and plastic zone distribution diagram of artificial pillars that the applied compression stress or tensile stress is less than its instability and failure strength, which results no fracture and instability of overburden rocks and causes no failure of artificial pillar itself. The plastic zone distribution diagram of mine room and surrounding rocks can also reflect good supporting of artificial pillars and stable state of the stope structure supported by artificial pillars.

Insert Fig.3 here

Insert Fig.4 here

B. *Analysis of Artificial Pillar Displacement Change*

In the mining process of two mine levels, the stress environment variation have led to changes of corresponding outside load exerting on the artificial pillars. The direct result of this load variability is the changes of pillar shape, i.e. displacement occurring in vertical direction. The magnitude of displacement is one important parameter in determination of pillar stability. In order to study the artificial pillar support effect and it stable situation, we set up No.1~5 displacement monitoring points at surrounding rocks on top of mine room and No.6~10 displacement points in each middle section of mine room roof at -430 m mining level, No.11~14 displacement points on top of artificial pillars and No.15~18 displacement points in the middle section of each mine room at -460m mining level (Fig. 5).

As shown in Fig. 6 that there is displacement changes occurring in surrounding rocks on top of mine room at -430 mining level after completion of two mining levels with a maximum displacement of 3.17mm at No.3 monitoring point and a minimum displacement of 2.52mm at No.5 monitoring point. The displacement change data explains that the supported surrounding rocks are in a stable state and there is very small displacement change. When -460m level had been mined out, the maximum displacement settlement, 8.02mm, occurred at No.8 monitoring point (Fig. 7), and relatively small displacement settlement, about 4.86mm, on the roof of mine rooms that are most close to the boundary at both ends of the goaf. Through comparison of displacement changes and analysis of plastic zone distribution diagram, it is deduced that, although the settlement in the goaf roof is relatively higher, the roof stability is not significantly affected.

Insert Fig.5 here

Insert Fig.6 here

Insert Fig.7 here

From No.11~14monitoring point displacement diagram (Fig.8), it is known that vertical displacement of the artificial pillar (beam) is within a range of 3.5 to 3.7 mm. The simulation shows that the cementation strength between the artificial pillar and surrounding rocks is in sufficient, i.e. showing unsatisfactory roof-contacting effect, this kind of phenomenon fits well with actual field situations. Although there is instantaneous settlement displacement happening in artificial pillar during mining process, the displacement finally converges to about 3.5mm, which will not affect the final stability of surrounding rocks but it should be emphasized to have real-time displacement monitoring of artificial pillar during mining. As shown in Fig. 9, a relatively large goaf roof displacement settlement, about 7.76mm, and a minimum value of 5.40mm occur at monitoring pints No.16 and No.17 after mining of -460 m mining level. In comparison with the maximum displacement of 8.02mm in goaf roof at -430m mining level, we can infer that there is close interrelationship between the goaf roof displacement settlement and mining level span, the wider span will cause a larger displacement in goaf roof (the span is 85m at -430 mining level and 65m at -460m mining level).

Insert Fig.8 here

Insert Fig.9 here

In order to compare the relationship between field measurement and numerical simulation at different level, the subsidence of the goaf roof was measured using a multiple point displacement meter(Fig. 10) with the observation stations No. 6-10 and No. 15-18 in mine room roof at the mining level of -430 m and -460m, respectively (Fig. 5). Fig.11 shows the result of the comparison , from which we can see the same subsidence regularity for the field measurements at different mining levels. The subsidence is higher near the middle of the stope while lower around the goaf. The maximum subsidence about 7.2mm, is located at goaf roof at-430m mining level, close to the numerical simulation. The maximum subsidence about 6.1mm in goaf roof at mining level of -460m,is very close to the maximum of field measurements. By comparing the two different settlement curves, due to larger span for goaf at mining level of -430 m, the subsidence is higher in the goaf roof, resulting in the instability of overlying strata.

Insert Fig.10 here

Insert Fig.11 here

Overall, the pillar displacement deformation of artificial pillar is small and roof deformation of goaf being supported is also in a safe range, and the deformation is in consistent with above mentioned plastic zones (Fig. 4), all kinds of structures in the stope are stable, instability and failure will not occur. It demonstrates that the stability of the mine stope structure supported by artificial pillars and self-stability of pillar can meet the requirement of safe production in mines.

IV. CONCLUSION

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- In mining process, the artificial pillar is in a very sable state itself due to the small values of applying compressive and tensile stress, which is far less than the corresponding compression and tension strength. In consideration of compression-resisting and non-tension-resisting characteristics of rock material, the applied tensile tress conditions are especially studied in stope structures, we found a maximum tensile stress of 3.54 MPa in surrounding rocks, this stress is much less than the tension strength 7.5 MPa, therefore the destruction will not occur in surrounding rocks. In terms of stress changes in other structure of stope, it is also shown that the designed artificial pillars had demonstrated good supporting effect, the stope structure is in a stable state can meet supporting requirements.
- Based on analysis of plastic zone distribution in stope structure, it is found that there is plastic

destruction area occurring in artificial pillars, even there are some plastic zones during mining process of two mining levels. However, the artificial pillars are in stable stress state after completion of mining of two mining levels, it illustrates that the designed structure parameters of artificial pillars can effectively prevent the formation and destruction of plastic zones in overburden rocks in the goaf.

- Based on simulation research, there is instantaneous settlement displacement happening in artificial pillar during mining process due to low artificial pillar-surrounding rock cementation strength and weak roof-contacting effect, this kind of phenomenon fits well with actual field situations of the mine. However, the displacement finally converges to about 3.5mm, which will not affect the final stability of surrounding rocks. The real-time displacement monitoring of artificial pillar during mining should be emphasized.
- According to the comparison of the filed measured subsidence for the goaf roof at different mining levels, field measurements are consistent with the simulations. The larger span of goaf the higher of the subsidence. The subsidence at the middle of goaf is higher than that at the goaf surrounding rocks.

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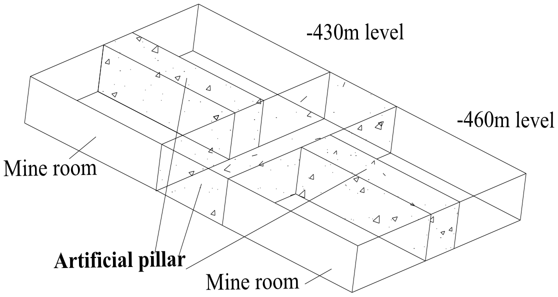

Figure 1. Layouts of mine room and artificial pillar

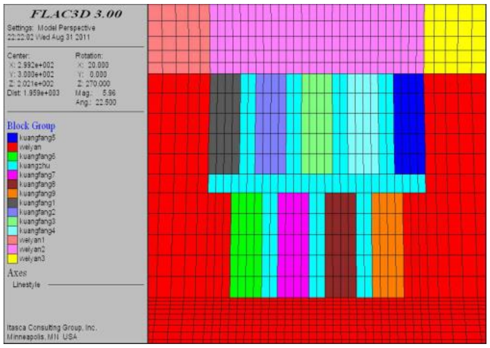

Figure 2. Model of mine room and artificial pillar

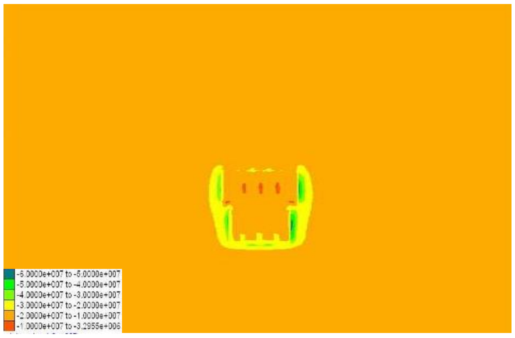

Figure 3. Contour map of maximum principal stress

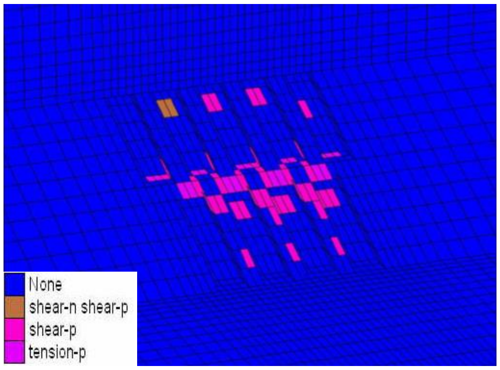

Figure 4. Plastic zone distribution in pillars

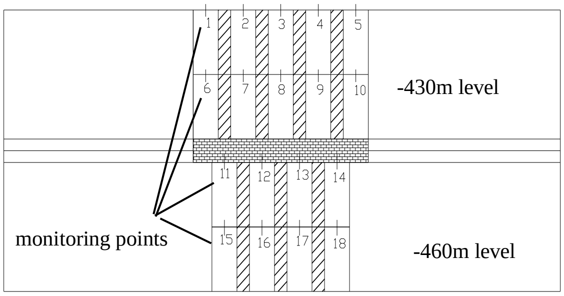

Figure 5. Different stope structure displacement monitoring point arrangement plan

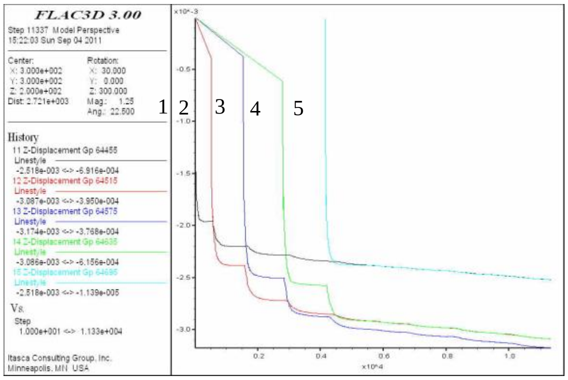

Figure 6. Displacement change at No.1~5 monitoring points

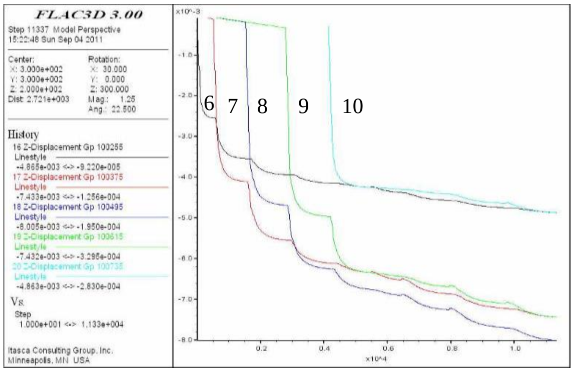

Figure 7. Displacement change at No.6~10 monitoring points

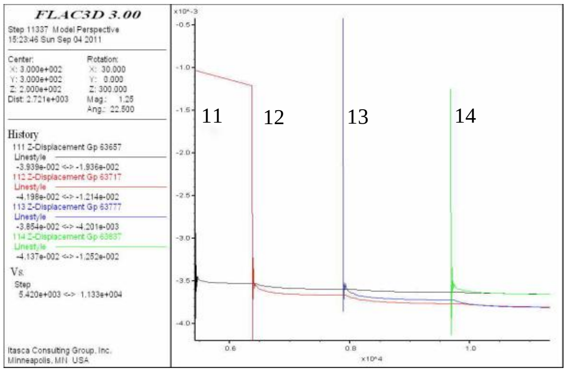

Figure 8. Displacement change at No.11~14 monitoring points

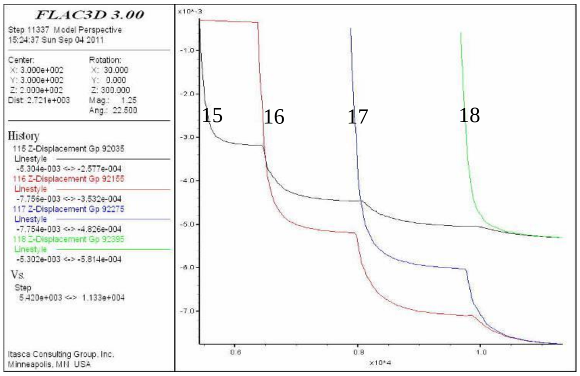

Figure 9. Displacement change at No.15~18 monitoring points

Figure 10. Field test scene of multiple point displacement meter

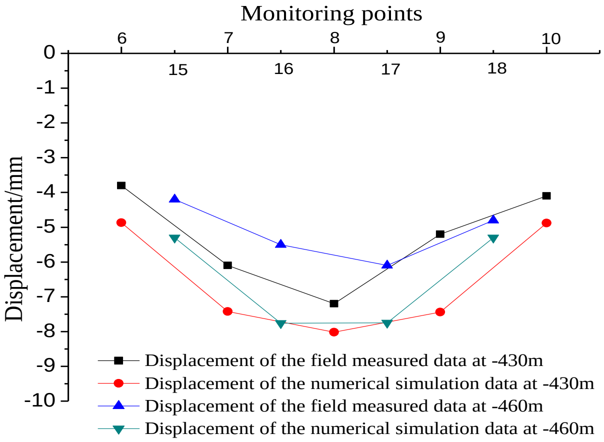

Figure 11. Comparison of displacement of the field measured and the numerical simulation data at different level