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Mining optimization in Lift 410 m of Tongkuangyu copper mine and application study of hydraulic fracturing pre-conditioning at start mining area

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ABSTRACT

Tongkuangyu copper mine was the first block caving mine in China and has produced for nearly 40 years. It is currently entering a transition period from Lift 530 m to 410 m in the Phase II project. The Lift 410 m has a block height of 120 m, and extraction and undercutting levels are located at the 434 m and 447 m, respectively. Post undercut strategy is adopted for mining. In order to reduce damaging effects of ground pressure on bottom infrastructures, the height and support type of bottom infrastructures in Lift 410 m were optimized. The height of major apex was increased by 3 m, and a combined support measure of spraying anchor mesh, anchor rod and cable, concrete steel arch was adopted. In order to ensure stable production capacity of Tongkuangyu copper mine during the transition period, rock mass pre-conditioning by hydraulic fracturing was implemented at the start mining area of No. 5 and 4 orebodies in Lift 410 m. Six vertical boreholes were drilled for hydraulic fracturing preconditioning at each start mining area of two orebodies, and segmented fracturing operations by high pressure water injection were conducted for about 30 minutes. The results show that orebody cavability at the start of a mining area was effectively improved, and an increase of about 3 times in caving rate was achieved, and a decrease of about 20.4 percentage in large block rate, which effectively ensure the production target of 9 million tons of ore per year at Tongkuangyu copper mine.

1 INTRODUCTION

Block caving has received increasing attention worldwide, mainly due to its advantages such as large production capacity, low mining cost, and easy implementation of automation and intelligence. It is an underground mass mining method which can be compared favorably with open-pit mining (Chitombo, 2010). At present, there are over 50 block cave mining projects in various stages of studies and development in countries such as Chile, Australia, South Africa, Indonesia, the United States, and China. Two operations in China are Tongkuangyu copper mine and Pulang copper mine. Several other mines in China are under construction or designed including block cave mining: West Section of Yanqianshan iron mine, PT iron mine, Shuangjianzishan silver mine, Yandong copper mine, etc.

Block cave mining not only has significant advantages, but also comes with high technological risks. A large amount of basic research work needs to be carried out before or during mine development feasibility stage to determine the applicability of block cave mining method. Otherwise, it will result in a significant loss or waste of upfront investment. Rock mass cavability and bottom infrastructure stability are focus for attention in design and production stage of block caving mines (Cuello & Newcombe, 2018), which determine the successful application of block cave mining. In order to ensure continuous and stable caving of the rock mass in block caving mines and formation of appropriate ore fragmentation, it is necessary that a well-developed fracture system within the orebody and a capping material that is weak enough to cave long with the orebody. The bottom infrastructure is the output channel of ore in block caving mines, characterized by frequent production operations and long service cycles, usually requiring service for 10 years or more. The long-term stability of bottom infrastructures is of great significance for the production safety and stability of block caving mines (Flores & Catlan, 2019). Building a long-term stable bottom infrastructure under conditions of poor rock mass stability requires a reasonable design of bottom infrastructure type and support measures.

Tongkuangyu copper mine is a typical project of successful application with block cave mining in China. China ENFI Engineering Corporation undertook consulting design and research work of the Phase II project of Tongkuangyu copper mine in the past few decades. Rich lessons and experiences have been accumulated during the mine´s production of Lift 530 m, effectively addressing issues such as bottom infrastructure damage and ground support. In the transition period from Lift 530 m to Lift 410 m, in order to ensure stable production capacity, research on application of rock mass pre-conditioning technique with hydraulic fracturing (Catalan et al., 2012; Katsaga et al., 2015) was carried out. By summarizing the achievements of design optimization and new technology application at Lift 410 m in Phase II project of Tongkuangyu Mine, guidance could be provided for the design and production of similar mines.

2 BASIC OVERVIEW OF MINE

Tongkuangyu copper mine, located in Yuanqu County, Yuncheng City, Shanxi Province , is the first underground metal mine in China that has successful application with block cave mining technique. It has been mined for nearly 40 years. There are two main orebodies (No. 4 and No. 5) in the mine district, with an average thickness of 95 m and a strike extension of about 1000 m, an average grade of 0.61%, and resources accounting for over 90% of the total reserves. The orebodies mainly exist in the metamorphic potassium basic volcanic rock layers, and the ore-bearing rock types are mainly metamorphic quartz crystal tuff and metamorphic quartz porphyry. The occurrence of orebodies is basically consistent with the host rock, with a northwest inclination and a dip angle of 40 ° to 60 °. The orebodies appear as a huge lens on the plane, inclined to a plate-like shape. The two orebodies are located parallel in space, with a relatively consistent spacing, mostly ranging from 110 m to 130 m.

The Phase II project of Tongkuangyu copper mine mainly recovers orebodies between 410 m and 690 m level (Figure 1), and block cave mining method was adopted with a designed annual production capacity of 600×104 t. The mine developments consist of belt transportation inclined shaft, auxiliary inclined ramp and blind mixed well. Construction of Lift 530 m of Phase II project began in 2008, and undercut blasting began in June 2010. In 2013, ore production of the mine reached 639×104 t, achieving full production. The designed production capacity of Lift 410 m in Phase II project of the mine was still 600×104 tonnes per year, the block height was 120 m, and extraction and undercutting levels were located at 434 m and 447m, respectively. Construction of Lift 410 m began in 2018 and production has begun at the present stage.

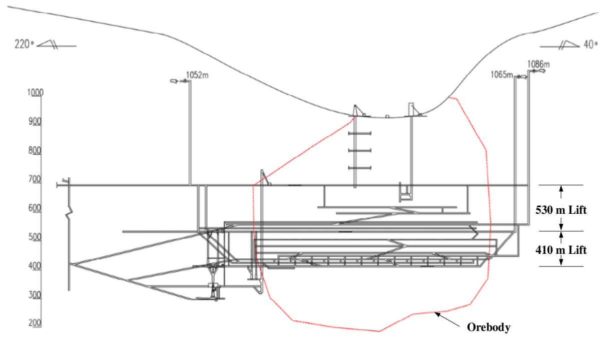

Figure 1 Lift layout in Phase II project of Tongkuangyu copper mine.

3 OPTIMIZATION DESIGN IN LIFT 410M OF TONGKUANGYU COPPER MINE

During the production period of Lift 530 m in Tongkuangyu copper mine, there were collapses and damages at bottom infrastructure roadways. By analyzing roadway damage patterns and taking appropriate measures, the production safety and stability of Lift 530 m was effectively ensured, and rich experiences had been accumulated for the design of Lift 410 m in Phase II project.

3.1 Production Experience in Lift 530 m

3.1.1 Failure mode of bottom infrastructure roadways in Lift 530 m

With undercut advancement in Lift 530 m of Phase II project, damage began to appear in early 2013, and some areas experienced severe damages. With the progress of undercut blasting, ground pressure became increasingly high, causing the damaged area to expand gradually. According to mine statistics, at the end of 2018, the area affected by ground pressure in Lift 530 m had accumulated to 34875 m2 over the years. After continuous treatment, the severely affected area was still 4625 m2, seriously affecting mine production and safety. The main location of ground pressure damages was at the extraction level. Typical failure sites of bottom infrastructure roadways in Lift 530 m were shown in Figure 2.

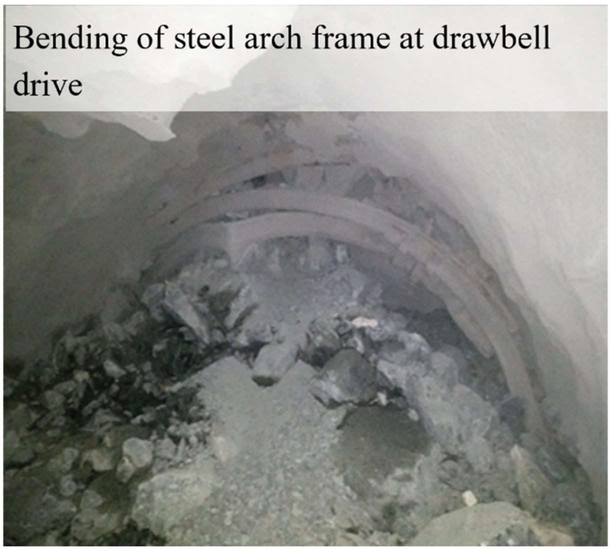

Figure 2 Typical failure of bottom infrastructure roadways at Lift 530 m.

3.1.2 Failure analysis of bottom infrastructure roadways in Lift 530 m

The on-site damage situations and patterns of bottom infrastructure roadways in Lift 530 m of the mine were analyzed. It was preliminarily believed that there were several main reasons for the damages.

(1) Increased in-situ stress

According to previous in-situ stress tests, the maximum principal stress gradually increases with depth, from 10-14 MPa at 800-870 m level to 37.83 MPa at 340 m level, an increase of about 2 times. There was no significant ground damage during the production period of Lift 810 m, while serious ground pressure damages occurred during the production of Lift 690 m. Currently, there were even more severe ground pressure damages in undercut level of Lift 530 m. Therefore, it can be considered that current phenomena of roadway roof subsidence, bottom bulge, cracking, spalling, collapse, etc. during the undercutting process were closely related to the gradual increase of in-situ stress.

(2) Stress concentration zone

The manifestation pattern of ground pressure in Lift 690 m and Lift 810 m both occurred within a range of about 20 m in front of undercutting advancement line. In Lift 530 m, the distance between the area of ground pressure damages and undercutting advancement line significantly increased, and the impact range was within 70-80 m, while the particularly severe damage was within 20-30 m, which was also the place with highest stress concentration. Based on this pattern, it can be preliminarily judged that the increase in influence range of undercutting advancement line was related to the increase of depth and in-situ stress.

(3) Undercut area and span

The earliest occurrence of ground pressure damage in Lift 530 m of No. 5 orebody occurred when the undercut area was about 20000 m2. From the on-site situation, it was found that the areas damaged by ground pressure mostly occurred at a distance of 70-80 meters from footwall contact and gradually developed towards hanging wall. It can be considered that this phenomenon was related to the undercutting sequence from footwall to hanging wall.

(4) Post undercut strategy

Post undercut is also known as traditional undercutting method. The advantage of this method is that ore blocks can be put into production faster than other methods. At the undercut level, there is no need to arrange a specialized reverse chute for undercutting, and only rock drilling and blasting are needed to maintain a distance of 30 m between undercutting advancement line and production advancement line. The possibility of ore fragmentation been compacted at undercut level is very low. The main disadvantage is that the formed bottom infrastructures need to withstand high stress effects generated by undercutting front line (Figure 3), which can damage the overall integrity and stability of bottom infrastructures. Therefore, undercutting strategy has a significant impact on bottom infrastructures especially on drawbell drives, ultimately leading to large-scale damages.

(5) Passive support method

Support methods used for bottom infrastructure roadways were mainly plain concrete and steel arches, and similar support methods were also used for roadway repairment. These belong to passive support methods and cannot fully utilize the bearing capacity of surrounding rock. When ground pressure is high or surrounding rock is broken, it easily cracks, falls off or is even destroyed completely.

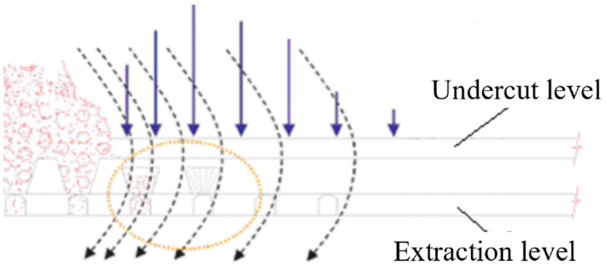

Figure 3 Stress distribution of bottom infrastructure with post undercutting.

(6) Rock boulders caused by poor undercutting

Layout of undercut roadways in the early stage of the mine made it difficult to control downward blast-holes during undercutting, and after undercut blasting, it could not penetrate the drawbells, making it easy to leave rock boulders at the top of drawbells. Treatment of rock boulders had negative impact on the integrity and stability of peach-shaped pillars. In addition, due to high rate of large blocks released from ore drawpoints, the main method for on-site secondary breaking was blasting. Original bare blasting method had significant impact on ore drawpoints. Rock drilling and blasting was used to reduce the impact, but it still posed certain risks to the stability of bottom infrastructures.

(7) Small parameter of bottom infrastructure

At the early stage of Lift 530 m, the undercutting roadways were arranged above the peach-shaped pillars, with a vertical distance of 16 m from extraction level. Due to the frequent occurrence of rock slabs during the undercutting process, a double undercutting roadway layout was adopted in production, which meant that the undercutting roadways were moved from the top to the two shoulders of peach-shaped pillars. At this time, the vertical distance between undercutting roadways and production roadways was 10 m. According to the degree of damage at the bottom infrastructures on site and the design parameters of block caving mines abroad, this parameter was still small and should be increased.

3.2 Optimization Design in Lift 410 m of Tongkuangyu copper Mine

In order to ensure the safety and stability of bottom infrastructures in Lift 410 m of Tongkuangyu copper mine, optimization of the designs for the bottom infrastructures and support methods were carried out based on experiences gained from Lift 530 m production and other block caving mines (Muhlenbrock et al., 2020).

3.2.1 Optimization of bottom infrastructure

The schematic diagram of bottom infrastructures in Lift 410 m is shown in Figure 4. Compared to the bottom infrastructures in Lift 530 m, the following optimizations have been made.

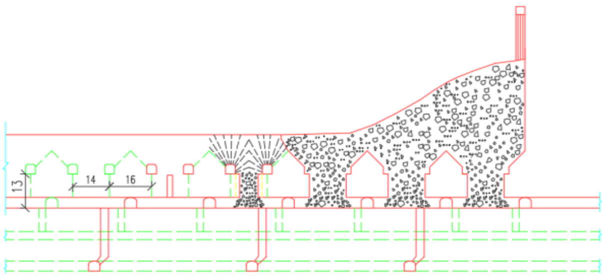

Figure 4 Schematic diagram of bottom infrastructures in Lift 410 m.

(1) Height and width of peach-shaped pillars were increased. The undercut level was raised by 3 meters and the height of undercut level from extraction level was adjusted to 13 m. Additionally, the width of peach-shaped pillar was increased from 15 to 16 m. The overall size of peach-shaped pillar was increased, which could improve ground pressure bearing capacity and the stability of peach-shaped pillars.

(2) In response to the frequent occurrence of rock slabs at the top of the drawbells during undercut blasting, undercut roadways at the top of peach-shaped pillar were moved to the shoulders, replacing the original one undercut roadway with two (Figure 4). The upward hole undercutting method with double undercut roadways avoided drilling downward holes, improving the efficiency of undercut blasting, and completely solving the rock slabs problem at the top of the drawbells, ensuring the quality of undercutting and reducing stress concentration. To some extent, the bottom infrastructure stability was increased.

3.2.2 Optimization of support measures

(1) Extraction drive

Extraction drives are important engineering in bottom infrastructures, and they are highly susceptible to damage and seriously affect production. Therefore, support should be strengthened for the extraction drives. Active support method was mainly used in Lift 410 m, using a combined support method of spraying anchor mesh and long anchor cable (Figure 5).

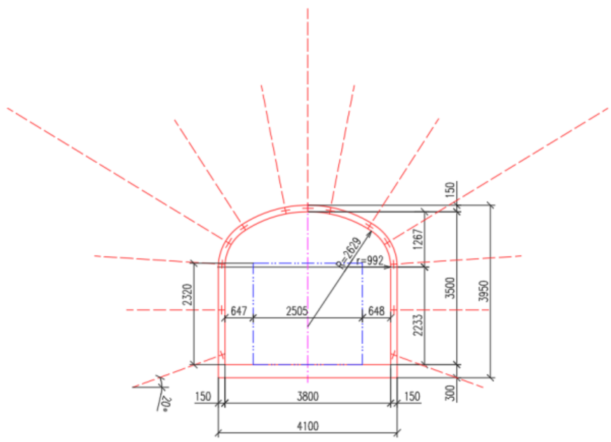

Figure 5 Support scheme for extraction drive.

Thickness of sprayed concrete was 150 mm with a strength grade of C25. Mortar anchor rod was filled with cement mortar with a cement-sand ratio of 2:1, and anchored throughout the entire length. It was required to fill the anchor hole tightly. Anchor rod was made of φ 22 mm steel bar, with a spacing of 1 m × 1 m. Length of anchor rod at roadway roof was 3.0 m, and 2.25 m at roadway two sides. The size of steel support plate was 200 mm × 200 mm × 10 mm. At conditions of fractured rock mass, the density of anchor rod could be increased (such as 0.8 m × 0.8 m). Metal mesh was made of φ 6.5 mm steel bar with a mesh size of 150 mm × 150 mm. Anchor cable support was added at the roadway arch, with a spacing and row spacing of 2 m. The top anchor cable was 8.0 m long, and the anchor cables on both sides of the arch were 6.0 m long. The anchor cable comprised of two φ15.20 mm

1×7 standard steel strands, bonded with cement mortar with a cement-sand ratio of 2:1 for the entire length, and anchored with MJ-1 anchor head. Floor of extraction drive was paved with concrete with thickness of 300mm and strength grade of C30.

(2) Drawbell drive

Drawbell drive not only needs to withstand the influence of ground pressure caused by undercutting, but also needs to withstand higher ground pressure when the drawbell is formed due to its direct connection with it. Therefore, the drawbell drive is the most affected in the entire bottom infrastructures, and a more reliable support must be adopted. Two kinds of supports were adopted at drawbell drives. The first was spraying anchor mesh support, and the second was a combination of spraying anchor mesh and medium length anchor cable support.

In order to protect the integrity of the drawpoint browline and reduce the damage to the ore drawpoint due to ore flow and impact, reinforcement was carried out at drawpoint browline (Figure 6). Two supports were used simultaneously for drawbell drive 2 m near ore drawpoint side, one was spraying anchor mesh support, and the other was steel arch pouring concrete support. The primary support parameters are described below. Sprayed concrete with a thickness of 100mm and a strength grade of C25. The size of metal mesh was 150 mm × 150 mm, and it was made of φ 6.5 mm steel bars. Mortar anchor rod was filled with cement mortar with a strength grade of no less than C20, and anchored throughout the entire length. It was required to fill the anchor rod hole tightly. The specifications of anchor rod at the roadway arch and two sides were φ 22 mm × 3000 mm, φ 22 mm × 2250 mm, respectively. The spacing between anchor rods was 1 m × 1 m, and the specifications of support plate were 200 mm × 200 mm × 10 mm. Four rows of steel arches were set up for secondary support, and the height of roadway was reduced by 500 mm. The arches intersected diagonally with drawbell drive. The arch was made of H-shaped steel with a type of HW200mm × 200mm, which was bent as a whole and installed with a spacing of 500 mm. The arches were connected by tension rods. The arch was fixed with bent hook anchor rods, with a specification of φ22mm × 2250mm and a spacing of 1m × 1m. The anchor rods were welded to the arch. Welding pad at the lower part of the arch, with a size of 200mm × 200mm × 20mm (length × width × height) and a welding height of 6mm. The top of the arch was supported by reinforced concrete, with a protective layer thickness of 50mm. The main steel bar was φ18mm@250mm, the secondary steel bar was φ12mm@300mm, and the connecting steel bar was φ8mm@500mm × 600mm. Pour concrete on both sides, with a thickness of 250mm and a strength grade of C30.

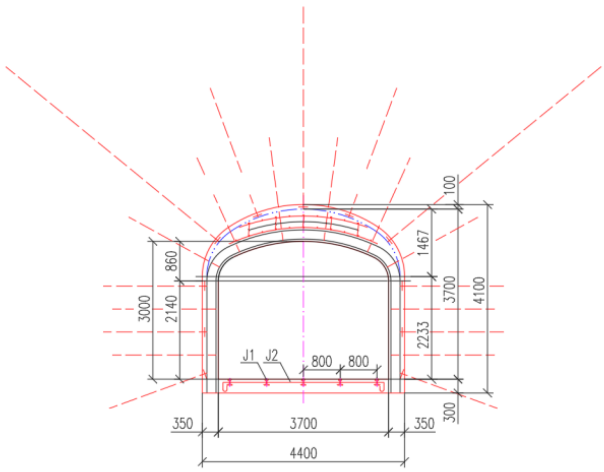

Figure 6 Support scheme for browline of ore drawbell drive.

(3) Intersection point

At the intersection of the drawbell drive and the extraction drive, stress concentration is prone to occur during the excavation process, and it causes significant disturbance to surrounding rock. In addition, the roadway span at the intersection is large. In order to maintain stability during production, it is necessary to strengthen support measures. The reinforcement method mainly considered adding anchor cable on the basis of the support method used in the section (Figure 7). The length of the anchor cable at the roadway arch was 8.0 m, with a spacing of 2.0 m. The anchor cable was comprised with two φ15.20 mm 1×7 standard steel strands, bonded with cement mortar with a cement-sand ratio of 2:1 for the entire length, and anchored with MJ-1 anchor head.

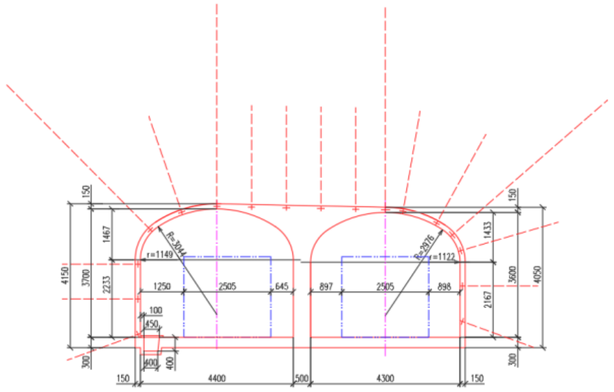

Figure 7 Support scheme for intersection part of drawbell drive and extraction drive.

4 PRE-CONDITIONING BY HYDRAULIC FRACTURING AT START OF THE MINING AREA IN LIFT 410M OF TONGKUANGYU COPPER MINE.

At present, Tongkuangyu copper mine is in the transition period from Lift 530 m to Lift 410 m of Phase II project, and the continuity of the production during this transition period is the main focus of the mine. With mining going deeper, the number of geological structures decrease, which will have an adverse impact on cavability of orebody in Lift 410 m. At the same time, the undercutting project at the start of the mining area of Lift 410 m cannot form a sufficient hydraulic radius for continuous caving of overlying orebody, making it difficult to ensure continuous caving and ensure production capacity. Therefore, based on previous experiences of foreign block caving mines, rock mass pre-conditioning technique with hydraulic fracturing (Pardo & Rojas, 2016; Nugraha et al., 2020; Rimmelin et al., 2020) was applied at the start of mining area of Lift 410 m to improve rock mass cavability. Details of field application of hydraulic fracturing pre-conditioning at start mining area of No. 5 orebody is described below.

4.1 On site testing of rock mass pre-conditioning by hydraulic fracturing

4.1.1 Engineering layout

Six vertical deep boreholes were arranged at the start of mining area No. 5 orebody in Lift 410 m (Figure 8). Among them, the boreholes #1, #3, and #5 were located at roadways of 530 m transportation level, while the boreholes #2, #4 , and #6 were located at roadways of 554 m extraction level. The bottom of the holes were all located at the boundary line of undercut blasting in Lift 410 m. The borehole depths were 95 m (554 m level) and 71 m (530 m level), and the diameter of boreholes was about 98 mm. Segmented hydraulic fracturing pre-conditioning tests were carried out based on these six boreholes.

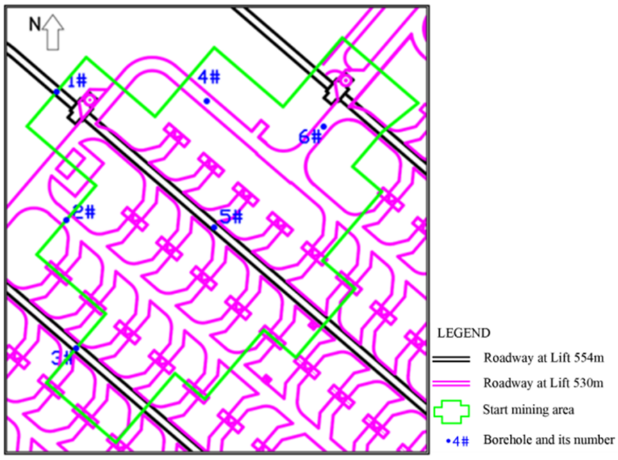

Figure 8 Borehole layout for hydraulic fracturing pre-conditioning project.

4.1.2 Equipment system

The equipment system for hydraulic fracturing pre-conditioning consisted of a water storage tank (Figure 9a), a group of high-pressure water injection pumps (Figure 9b), a pipeline collection (Figure 9c), a straddled packer (Figure 9d), a lifting tower (Figure 9e), and a monitoring system (Figure 9f). After the completion of the equipment system for hydraulic fracturing pre-conditioning, the straddled packer was assembled, debugged and lowered to the predetermined position inside the borehole. The packer was injected with water through a low flow rate pump to expand and form a fracturing section (sealing off a certain area). Then, a high flow rate pumping group was used to inject water into the fracturing section, causing the rock of borehole wall to fracture and the induced hydraulic fractures to continuously extend outward under continuous injection of high-pressure water.

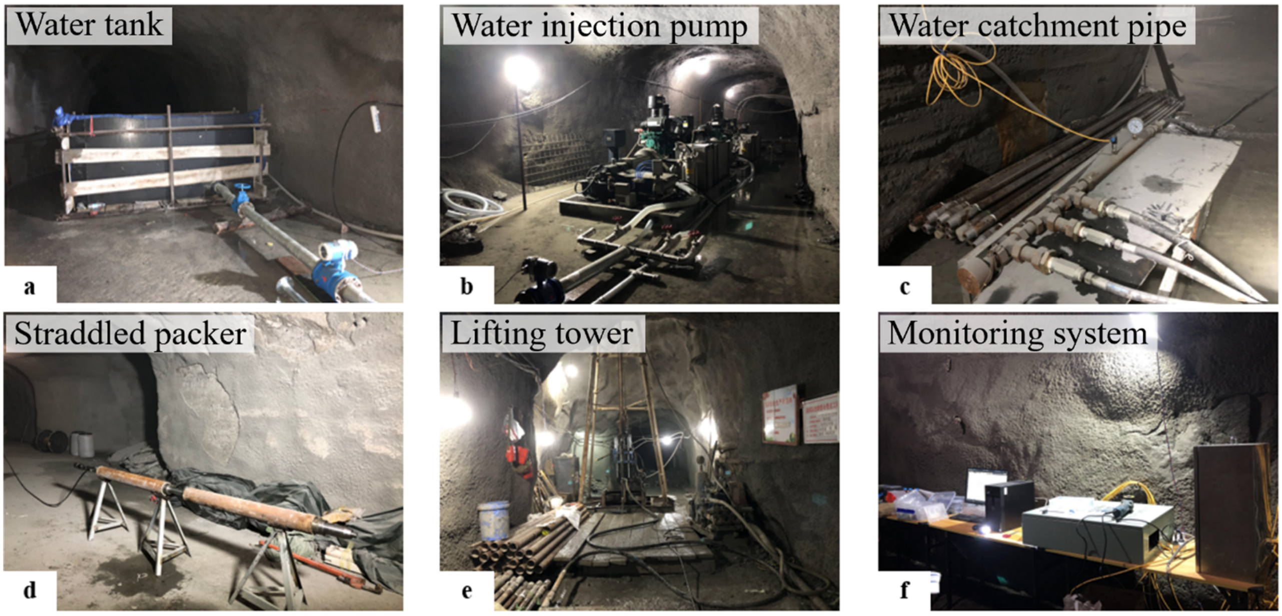

Figure 9 Equipment of rock mass pre-conditioning with hydraulic fracturing.

4.1.3 Test record

Hydraulic fracturing pre-conditioning tests were carried out at the start of mining area No. 5 orebody in Lift 410 m, and the total time spent was 53 days (December 6, 2020- January 27, 2021). The hydraulic fracturing test process adopted a section-by-section mode from the bottom to the top of hole, with a fracturing interval generally of 1.5-2.5 m. Some fractured borehole sections were verified based on borehole images and then subjected to skip processing. The process parameters of water injection pressure, flow rate, and micro-seismic signals during fracturing were real-time monitored. Scatter plots of injection pressure and flow rate were shown in Figure 10. It can be seen that the injection pressure was concentrated between 10-32 MPa, with an average of about 21.30 MPa. The water injection flow rate was mainly controlled by the number of water-injection pumps and valves opened during the on-site testing process. The water injection flow rate for most testing processes was 250-300 L/min.

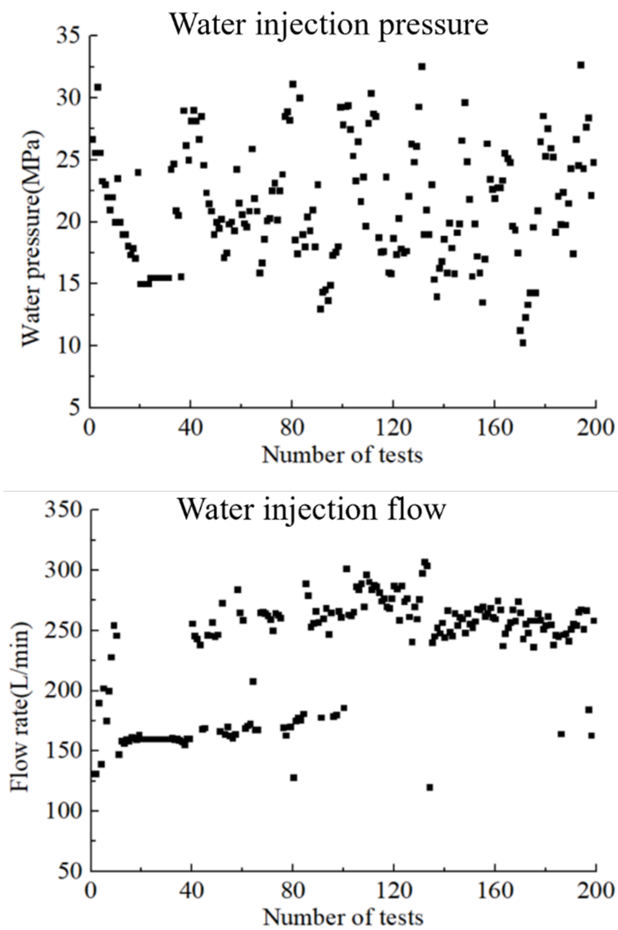

Figure 10 Scatter diagram of water pressure and flow rate during tests.

4.2 Application effect analysis

The effect of hydraulic fracturing pre-conditioning on rock mass cavability was mainly evaluated using two indicators: caving rate and ore block size.

4.2.1 Analysis of caving rate

On July 19, 2021, borehole camera technique was used to observe the status of cave back in #5 borehole (Figure 11). It can be seen that when the camera probe was lowered to a depth of 57.63 m inside borehole, it had reached the boundary of cave back. The black area in Figure 11 was the empty space between the cave back and the top of muck pile.

Figure 12 shows the elevation of the cave back monitored in #5 borehole at different times after undercut blasting. It can be seen that the caving rate presented five changing periods. The first changing period: from March 30th to June 6th, 2021 (68 days), the caving rate was about 0.06 m/d; the second changing period : from June 7th to July 19th (43 days), the caving rate was about 0.17 m/d; the third changing period : July 20-27 (within 8 days), the caving rate was about 0.85 m/d; the fourth changing period: from July 28th to August 20th (within 24 days), there was no change in the elevation of cave back (the caving rate was zero); the fifth changing period: from August 21st to September 30th (within 41 days), the caving rate was about 1.73 m/d. The average caving rate during above monitoring period was about 0.50 m/d. By comparing with the average caving rate (0.12 m/d) at start mining area in Lift 530 m, it was found that hydraulic fracturing pre-conditioning tests at the start of the mining area in Lift 410 m increased caving rate with more than three times. Practice had shown that the start of the mining area No. 5 orebody in Lift 410 m achieved normal production throughout the year in 2021, and the production scale of the mine remained basically the same as that of 2020, effectively ensuring the smooth connection of production capacity during the transition period of the mine.

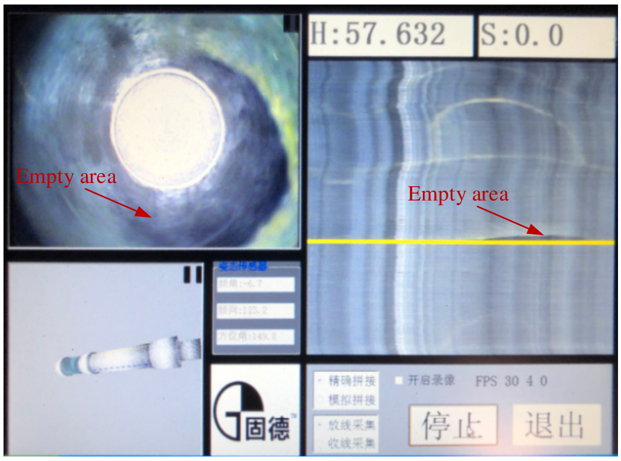

Figure 11 Observation of cave back in #5 fracturing borehole.

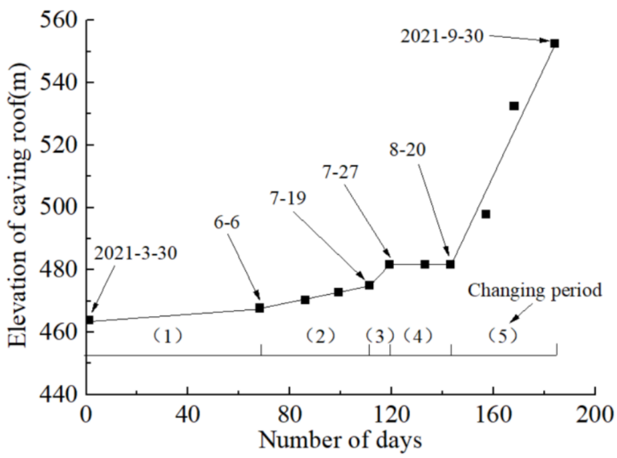

Figure 12 Monitoring records of cave back in #5 fracturing borehole.

4.2.2 Analysis of fragmentation size

On February 10, 2023, ore fragmentation images (Figure 13) were captured at the drawpoints at the start of mining area No. 5 orebody in Lift 410 m. There was a significant difference in the size of ore fragmentations at different drawpoints, with some large fragmentations ranging from 1.5 to 2 meters in size, and there was basically no phenomenon of hangups or jamming. Statistical analysis of ore fragmentation size was conducted based on image analysis technique (Gomez et al., 2017; Manzoor et al., 2022), and large ore fragmentation was defined by size greater than 1.2 m. The maximum size of the ore fragmentations at the drawpoint a-1 was about 0.72 m, and the large fragmentation rate was 0. The maximum size of ore fragmentations at the drawpoint a-2 was about 1.82 m, and the large fragmentation rate was about 22%. The maximum size of ore fragmentations at the drawpoint a-3 was about 1.85m, and the large fragmentation rate was about 28%. The average fragmentation rate of these three drawpoints mentioned above was about 16.6%. From March to May 2021, Tongkuangyu copper mine conducted an individual statistical analysis of large ore fragmentations at the start of the mining area No. 5 orebody in Lift 410 m. The results showed that the large ore fragmentation rate in the initial production stage was about 14.6% after the implementation of hydraulic fracturing pre-conditioning, which was much lower than the 35% large fragmentation rate in the initial production stage in Lift 530 m and a decrease of about 20.4 percentage points in large fragmentation rate was achieved. The reduction in large fragmentation rate was beneficial for the continuity of mining operations, while reducing the consumption of detonators, explosives and other explosive devices in secondary breaking, as well as the instability of roadways, effectively ensuring the production capacity and safety environment of the mine.

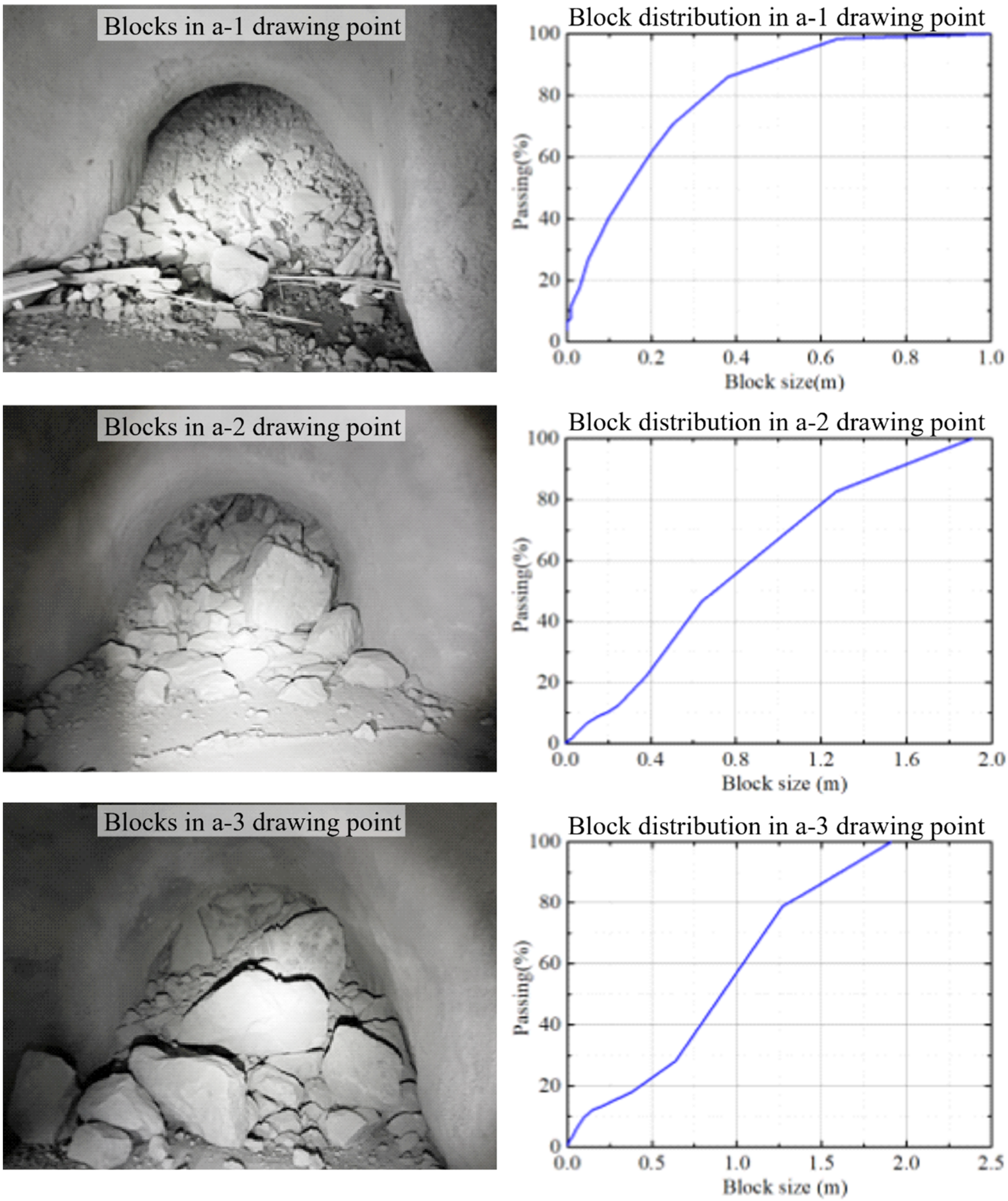

Figure 13 Images and statistical analysis of rock fragmentation at drawpoints of No. 5 orebody in Lift 410 m.

5 CONCLUSION

Block caving is a large-scale underground mining method with high production efficiency and low production cost. Tongkuangyu copper mine is the first block caving mine in China and has serviced for nearly 40 years, which has gained rich experiences during mining production in Lift 530 m of Phase II project. Nowadays, Tongkuangyu copper mine is in the transition period from Lift 530 m to Lift 410 m, and stable connection of production capacity during this period is the main focus of the mine.

(1) In order to reduce damaging effects at the bottom infrastructures caused by ground pressure, the parameters and support method of bottom infrastructure in Lift 410 m were optimized based on field experiences in production of Lift 530 m. The height of major apex was increased by 3m, the undercut roadways were arranged at the shoulders of peach-shaped pillars, and a strengthened support method with combination of spraying anchor mesh, anchor rod and cable, concrete steel arch was adopted to different roadways.

(2) Through field tests of rock mass hydraulic fracturing pre-conditioning, a fully equipped equipment were developed, new fractures were produced at the start of the mining area No. 5 orebody in Lift 410 m and the cavability of the orebody was effectively improved. The caving rate of ore and rock during production period at the start of the mining area had been increased by more than three times, and the large block rate at ore drawpoints had been reduced with about 20.4 percentage points, which effectively ensure the production target of 9 million tons of ore per year at Tongkuangyu copper mine.

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