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Mineral

Feasibility study of highwall mining in north surface mine of Yima Coal Corporation, China

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Abstract: Yima Coal Corporation is considering to adopt highwall mining method with auger machine to recover coal from north surface pit that has reached final highwall position. The major geomechanical issues associated with auger mining are highwall and pillar stability. Based on the field investigation and laboratory test results of mechanical parameters, numerical modeling is carried out to assess the stability of highwall and pillar. Field measurements of highwall deformation have been used to validate and ensure the confidence for the development of realistic models. The results of numerical modeling show that the mining method is feasible for mining the seam of 10 m thickness in north surface coal mine.

Key words: highwall mining; surface mine; stability evaluation; feasibility study

1 Intorduction

The north surface coal mine is located 55 km east to Luoyang city, Henan province, China. It is operated by the Yima Coal Corporation (YCC). The mining operation began in 1959. The shape of the mine is approximately elliptical in plan. The overall slope angle is about 30°. The western slope has reached the final highwall position which is about 200 m away from the mine boundary. Only one part of the southern slope is being extracted, while its other part has also reached the final highwall position.

The overburden is comprised of loess and mudstone. The lithology consists of No.2-1 seam, sandstone, No.2-3 seam and the blending layer of coal and rock. The No.2-3 seam with the average thickness of 10 m is the main mining seam. The rock is strongly fractured due to blasting operation.

Highwall mining has emerged as a safe and profitable method of extracting coal resources to extend the life of existing open cut mines which otherwise could not be reached by open-cut or underground operations [1, 2]. This method uses remote control to extracts coal from the base of an exposed highwall to a significant penetration depth within the seam horizon through a series of parallel entries. Two types of highwall mining systems have been used, *i.e.* the continuous highwall mining system and the auger system. The latter is more suitable for highwall mining of a pit with unfavorable roof and floor conditions.

With the depletion of north surface coal mine, YCC is therefore looking forward to the implement of highwall mining with auger machine due to the poor quality of roof and floor.

No highwall mining with auger machine is used in the Chinese surface mines at present, and the thickness of the coal seam (10 m) to be mined at the north surface pit is bigger than that of the coal seam (no more than 6 m) in foreign countries. This situation has led to the study presented in this paper which assesses the feasibility of adopting highwall mining with auger machine at the north surface pit.

Highwall stability and pillar stability are the two major geomechanical issues associated with the auger mining.

Numerical analysis allows the effect of shape and width to the height ratio of pillar cross-section, in situ stress conditions, coal strength and interaction with roof and floor to be incorporated into the design. In this case, numerical modeling is regarded as the most effective method of assessing highwall and pillar stability [3]. The objective of this paper is to evaluate the feasibility of applying highwall mining with auger machine at the north surface pit using numerical modeling based on the investigation of engineering geology and test results of mechanical properties of the rock.

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2 Zoning and evaluation of engineering geology

The investigation of engineering geology was conducted in three zones, *i.e.*, the eastern zone, the middle zone and the western zone. Influence factors on slope deformation and structures of rock masses as well as space, length and roughness of fractures were investigated. On the basis of the results of the investigation, the geological characteristics of different zones are as follows.

(1) The eastern zone.

The layer of sandstone is thinner than 12.5 m, the thickness of No.2-3 coal seam is thicker, the structure of fault and fold is developed in the coal seam, and the rock mass is broken. The overall geological condition is relatively poor.

(2) The middle zone.

The layer of sandstone is thinner than 15 m, and the No.2-3 coal seam is thicker. The layer of sandstone is seriously broken with local discrete structure because the scale of waste in the top of No.2-3 seam is big and the spontaneous combustion is serious. The dip angle of No.2-3 seam is about 5°-8°. The integrity of the coal seam and the overall geological condition are better than that in the eastern zone.

(3) The western zone.

The overall geological condition in this zone is obviously different from that in the eastern and middle zones. The layer of sandstone is sharply getting thicker, with the thickness of 15 to 30 m from the east to the west. The thickness of No.2-3 seam is gradually getting thinner from 13 to 6 m. The angle of the coal seam is about 3°.

The structure of fault in the coal seam is not developed, but the spontaneous combustion is serious, the distribution of waste is concentrated. Therefore, the coal seam is seriously broken.

3 Test of mechanical properties of rock and monitoring of slope

Different test instruments and test methods were used to investigate the mechanical properties of different types of rocks, including cohesion, internal friction angle, bulk modulus and Poission ratio. The test was conducted both in field and in laboratory. Many types of rock of slope were tested in the field, and the rock of floor of the No.2-3 coal seam was tested in laboratory [4].

Monitoring of the western highwall with EDM (remote Electronic Distance-Measuring) stations was conducted in 2001. Field monitoring and measurement of the overall slope movement with EDM stations provided the information on slope deformation.

4 Highwall stability

Highwall stability is essential to ensure the safety of mining person and equipment as the mining operation is beneath the highwall. The highwall mining system has a basic protection shield built above the working area of the launch vehicle. The shield reduces the risk of damage or injury caused by small block falls from the highwall face. However, the shield cannot provide protection from the larger block falls or overall highwall instability. Therefore, it is necessary to identify the risk of any highwall stability before mining and take proper preventive measures during mining operation.

4.1 Setting of the computational model

The finite-difference method (FDM) was selected for numerical modeling of the problem. FLAC version 3.30 was employed for the analysis. The model is presented in **figure 1**, which includes 5000 elements and 5151 nodes. In the model displacement in the vertical direction is allowed and the horizontal direction is fixed along the left and right boundary, whereas the bottom is fixed in horizontal and vertical directions. The Mohr-Coulomb plasticity constitutive relation was used for the analysis. The mechanical properties of each material layer are listed in **table 1**.

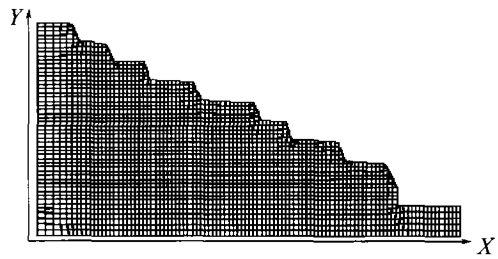

Figure 1 Mesh of highwall model.

4.2 The analysis of numerical results

The modeling results [5] showed that the upper section of the slope was dominated by downward displacement with the lower section of the slope associated with a generally upward elastic response. The mid-section was associated with right-lateral movement into the mining face, whereas the lower section was subjected to a consequence of overburden pressure release. The maximum displacement (11.6 cm) occured in the No.2-3 seam. The results of modeling fit well with the in-situ observation, which validates and ensures confidence in the design of hole and pillar layout.

No yielded surface was formed in the model, only the yielded zones in the past occurred near the modeled ground surface.

From the modeling results, it can be concluded that the highwall is stable.

Table 1 Mechanical properties of each material layer

Rock types	Volumic weight/ ($kN \cdot m^{-3}$)	Bulk modulus/ GPa	Shear modulus/ GPa	Internal friction angle /(°)	Cohesion/ MPa	Tensile trength/ MPa
Loess	19.0	0.4	0.2	20	0.25	0.05
Conglomerate rock	23.6	23.3	14	42	1.92	1.3
Mudstone	19.1	24	11.1	24	0.37	0.3
No.2-1 seam	16.1	3.5	1.2	26	0.6	0.43
Sandstone	23.6	15.62	12.7	40	1.8	1.1
No.2-3 seam	15.0	4.6	1.3	30	0.8	0.4
Floor of seam	19.0	13.0	9.1	32	1.1	0.7

5 Stability of coal pillar

5.1 Setting of the computational model

An auger machine has been designed for drilling 1.5 m diameter holes in 60 m length. As shown in **figure 2**, the model of hole and pillar layout is 30 m in width and 50 m in height, while the height of the coal seam bench is 10 m. The model includes 7200 elements and 7371 nodes. The horizontal displacement of the two sides and the vertical displacement of the bottom are limited.

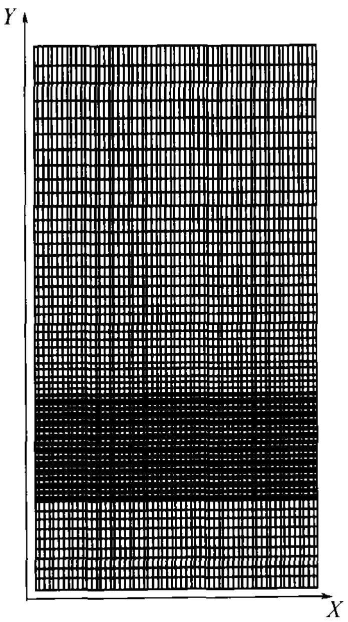

Figure 2 Mesh of scheme model.

Pillars are left between the highwall entries to support the overburden during and after highwall mining, and no any artificial support is used. Safe pillars are essential for a successful highwall mining operation. If the pillars collapse during mining, the overburden will cave into the mining entry and may injure the mining equipment.

Mining proceeds are descending from the roof. Because the pillar width and the vertical separation between passes (septums) have great effects on pillar stability, three models are considered.

Model 1: the pillar width is 1 m, 5 row layout;

Model 2: the pillar width is 0.8 m, 5 row layout;

Model 3: the pillar width is 1 m, 6 row layout.

5.2 Analysis of the modeling results

The plastic zones of three models are presented in **figure 3**. For model 1, during and after mining, the yielding zones in pillars were small and not connected together, which indicated that the pillar was stable. However, the yielding zones occurred at the septum. It showed that some minor fall of septum could happen, which was in agreement with the field situation [2]. Fortunately, the auger system can tolerate some minor roof falls [3].

For model 2, after mining the fourth row, only the local yielding zones occurred in pillars. When mining the fifth row, the fifth row pillars failed due to stress concentration at vertical direction, and subsequently the fourth row pillars also damaged due to the effects of the fifth row mining. The damage mode of coal pillars is shear failure. Yielded surface also happened in the floor due to stress concentration at horizontal direction.

For model 3, when mining the former five rows, no yielding surface occurred in the pillar, but when mining the sixth row, the yielding zones were joined together in the fifth and sixth row pillars. At the same time, tensile and shear failures occurred at the septum and the floor near the sixth row.

Comparing model 1 with model 2, when the pillar width is 1 m, during and after mining, the yielding zones in pillars were small and not connected together. It indicates that the pillar is stable. However, when the pillar width is reduced to 0.8 m, as the working face was moved to the fifth row, continuous yielding zones in the fifth pillar were formed, which illustrated that the pillar had been failed.

Comparing model 1 with model 3, when adopting 5 row holes layout, during and after mining, no yielding surface was formed in the pillars, which indicates the stability of the pillars is good. However, when adopting 6 row holes layout, during mining the sixth row, yielding zones were connected, which showed the pillar had been damaged. It can be concluded that reducing the septum thickness has detrimental influences on the performance of pillars.

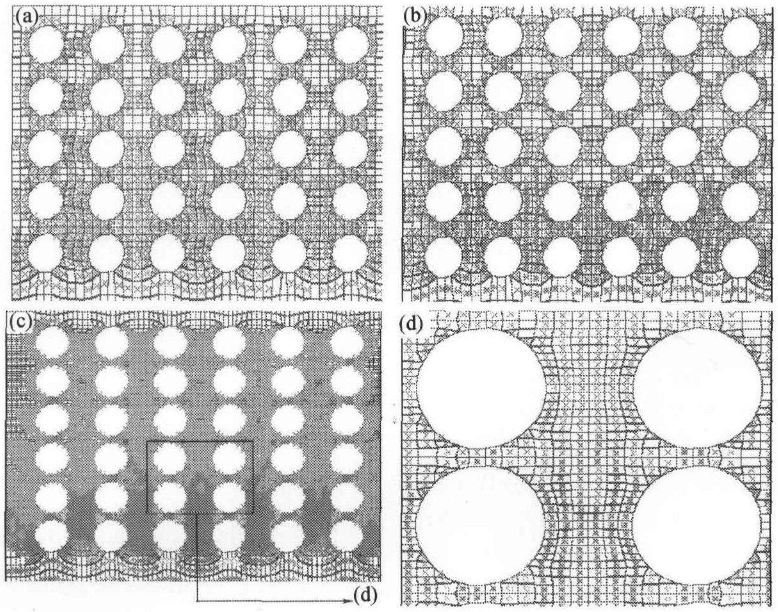

Figure 3 Plastic zones of three models, (a) model 1; (b) model 2; (c) model 3, (d) local enlargement of (c); x—elastic, at yield in past; *—at yield in shear or volume; o—at yield in tension.

6 Conclusions

(1) The highwall and pillar stability is the major geomechanical issue associated with higwall mining. The results of numerical modeling indicate that the highwall in north surface mine of Yima Coal Corporation is stable. When adopting model 1 layout, the pillar stability is good, which shows that higwall mining is feasible in north surface mine.

(2) For a given mine, the main factors affecting the pillar stability are the pillar width and the septum thickness. With the decrease of the pillar width or septum thickness, pillar failure is shear failure due to the concentration of the vertical direction stress; however, the septum failure mechanism is different, the former is shear failure, whereas the latter is both shear and tensile failures. Reducing the pillar width and the septum thickness has detrimental influences on the performance of pillars.

(3) Applying highwall mining method with auger machine, the cross-section recovery rate is 35.3% for the recovery of the coal pillars. It is estimated that a direct income of about 11.85 million yuan RMB (about 1.5 million US dollars) per year will be achieved in north surface mine.

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