NUMERICAL STUDY OF THE INFLUENCE OF COAL SEAM MINING UNDER RESERVOIR ON DEEP OVERSIZE FAULT DEFORMATION

by

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Ground surface in Yonglong coal mine is hilly terrain. There is a Yinshigou reservoir on minefield. Deep coal seam mining under the reservoir has an influence on the deformation of oversize normal fault, and can cause severe mine water-inrush. Using numerical simulation software UDEC, the paper studied the characteristics of plastic zone and stress field in front of coal face in the hanging wall of the fault, while the coal face advance distances from setting-up room to coal face line were different. The results showed that while the distance from coal face to the fault i. e. the width of fault-protected pillar, was 80 m, the front abutment pressure had less influence on two sides rock mass of the fault, the fault reduced the vertical stress of its surrounding rocks; The surrounding rocks in the vicinity of fault were in a same vertical displacement contour, whose displacement was very smaller. Reasonable fault-protected pillar width of the numerical study was much closer to the average water-proof coal pillar width based on coal mines water prevention regulations of China. Consequently, while the width of fault-protected pillar is more than 80 m, coal seam mining in hanging wall of fault has no influence on the fault, and coal seam safely mining under the reservoir could be carried out.

Key words: *coal mine, coal seam mining under reservoir, oversize normal fault, safely mining, stress field*

Introduction

The reasonable retaining of fault-protected coal pillar and coal seam mining under a reservoir have been one of the important problems that affect the safety of coal mine production. Many scholars have done a lot of researches on this problem, and have achieved some research results [1-4].

On the theoretical side, Peng *et al.* [5] established the formula for calculating the width of waterproof coal pillar, which not only ensuring the safety production, but also increasing the recovery ratio of coal seam. Meng and Zhu [6] improved the formula of calculating fault-protected coal pillar, which guarantee the safely mining, and avoid fault water inrush ef-

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fectively. Song *et al.* [7] established the mining across fault and control mechanical model. Setting-up room should be layout in *internal stress field*, and coal face should be advanced to the fault with the shortest distance. Dai *et al.* [8] studied the laws and differences on the load transmission of the basic roof over the gob area under different conditions of mining sequence with hanging wall and foot wall. Differently mining sequence influences the width of fault-protected coal pillar. From the two aspects of coal safely mining under the water reservoir and mining-affected on the reservoir dam, Zhang *et al.* [9] concluded that the safety coal pillar widths of F37 Fault and F38 Fault in Shenjiazhuang mine were 87.3 m and 129.0 m, respectively, which safely mining could be realized and would not influence on the safety of reservoir dam.

On the numerical simulation side, Lu *et al.* [10] simulated the influences of coal seam and fault in front of coal face with software ANSYS under different protected pillars, and the rational protected pillar was gained. By software FLAC^{3D} numerical simulation, Gao *et al.* [11] concluded that when hanging wall is advancing to normal faults, the abutment stress increases gently and partial stress can transfer to footwall, then a smaller stress concentration zone on the footwall is developed. Used similar material tests and numerical simulation, Zhang *et al.* [12] studied the regular pattern of fault activation during coal seam mining, main conclusions were that a higher burial depth of coal seam, confined water pressure and throw of fault promotes more chances for water-inrush, while a larger width of waterproof coal pillar at fault could avoid water-inrush. Using micro-seismic monitoring, numerical simulation and theoretical analysis, Zhu *et al.* [13] researched the mechanism of the fault activation of extremely-thick coal seam in deep shaft, the main conclusions were that: the process of fault activation is divided into a stress appearance stage, an energy storage stage, and a structure activation stage. Using FLAC^{3D}, Li *et al.* [14] analyzed the changing of the plastic zone and the smallest main stress, the rational waterproof coal pillar was 60 m. Combined Grey correlation analysis and LMBP neural networks, Lin *et al.* [15] set up integration evaluation model to evaluate the stability of fault pillar. The optimization width of fault coal pillar in Yiqiao coal mine was 10 m.

Currently, a large number of theoretical researches and field practices had been carried out under the waters, reservoirs at home and abroad, many results had been made. However, the main research questions on coal mining under the reservoirs have been the height of the water-flowing fractured zone of overlying strata and the reasonable retaining of the waterproof coal pillar after coal mining, In particular, in conditions of complex geological structures and the faults development in minefield, there are many questions in coal mining under reservoir. According to the geological conditions of Yonglong coal mine, the related problems of coal mining under the influence of fault were studied in this paper. By software UDEC, the actors simulated coal face into the hanging wall of Guo fault in Yonglong coal mine, studied the characteristics of moving abutment pressure and mining influence on Guo fault in front of coal face with its different advance distances from setting-up room to coal face line. The conclusions provide reference for layout protected pillar on Guo fault in the future.

Basic characteristics of Yonglong coal mine

Yonglong coal mine is located in Dengfeng city of Henan province, China. The mine design production capacity is 0.6 million tons per year. The mine has mined the coal seam B_1 of Permian. Currently, No. 1 mining level is production one, No. 2 mining level has been developed and mining district 21 in No. 2 mining level has been mined. The mine surface topography is hilly, the surface elevations of minefield approximately is +406-+524 m. The shaft-mouths elevations of main shaft and auxiliary inclined shaft are +468 m. Minefield belongs to Ying river system of Huaihe Basin, and the ground position of Yinshigou reservoir is located in the west wing of mining district 21 in the coal mine. Figure 1 showed the dam and water surface of the reservoir. The average water level on the reservoir generally is about +420-+425 m, whose water depth is 20m. The floor elevation of coal seam B_1 under the reservoir approximately is –280-–370 m, the average is –325 m. Therefore, the average thickness of overburden strata of coal seam under the reservoir is 725 m.

Figure 1. Dam and water surface of Yinshigou reservoir

Main fracture under the reservoir in the mining district is Guo fault F_2. The fault is high angle normal fault with northeast strike and southeast dip. The fault, extending 2.0 km into minefield, is situated in northwestern border of minefield. And its strike direction is 50°-85°, its dip direction is 140°-175°. Inclination angle and fall of the fault approximately are 70° and 100-200 m, respectively. The fault has the large extension. Therefore, while the shallow coal seam mining, fault-protected pillar was lay out to safety production. With the mining scope and mining depth increasing, the fault may be contacted with the reservoirs through mining-induced fissures, and could become a hydraulic conductivity fault. Since the fall of Guo fault is 100-200 m, the horizon of coal seam B_1 may be contacted with limestone aquifer of seam floor through the fault, while coal seam B_1 under the reservoir was mined out. Difference lithology between the strata of fault two sides and the lithology of hanging wall blocked water relatively makes relatively richer water of the footwall. Therefore, the mining-induced fissures were relative growth along the fault strike, which may form groundwater runoff zone. When coal seam mining is close to Guo fault, the count measures should be taken in advance. Reasonable width of waterproof pillar should be layout to ensure coal seam safely mining.

Calculation model of numerical simulation

The boundary conditions of calculation model

In order to study the influence of coal seam B_1 mining in the hanging wall of Guo fault, on the fault and its two sides' strata, the authors, according to the synthetic histogram of the mine, established the mechanical model of numerical calculation with plane strain, as shown in fig. 2. The thickness of coal seam B_1 is 5.1 m, whose roof is sandstone with thickness 8.5 m. The immediate floor of coal seam is sandy mudstone of thickness 6 m and its main floor is thick 10 m medium sandstone. The physical and mechanical parameters of roof and floor strata around coal seam were shown in table 1. The length and height of calculation model were 400 m and 230 m, respectively. In order to study characteristics of the overburden strata movement, deformation and failure after coal seam mined out, the different strata were divided into different units, whose division ra-

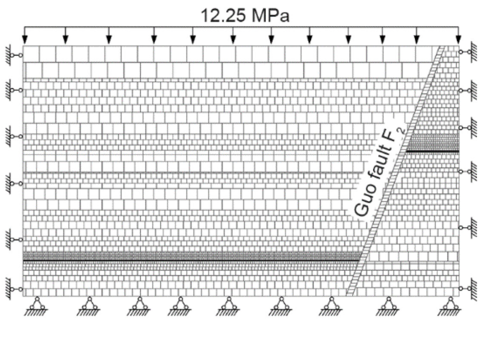

Figure 2. Mechanical model of numerical calculation

tio of length to width was 1.3- 2, the ratio of maximum volume of unit to minimum one was usually less than 4, and the grids in the main research areas were divided intensively.

The annual average water level elevation on the reservoir was about +420-+425 m, whose water depth was 20 m; the elevation of coal seam floor under the reservoir approximately was –280–-370 m, the average elevation was –325 m. Therefore, the average thickness of overburden strata of coal seam under the reservoir was 725 m. According to the occurrence conditions of calculation model, the gravity stress of overburden strata on the model upper boundary was exerted; the mechanical boundary conditions of calculation were as follows:

The upper boundary of model was free one, which belonged to the stress boundary condition. Its distribution load was simplified as a uniform load. The value of distribution load, q, was relevant to the weight of overburden strata, *i. e.,*

$$q = \gamma H = 0.025 \cdot 525 = 13.125 \text{ MPa} \tag{1}$$

where, γ is the average bulk density of overburden strata, 0.025 MN/m^3, H – the vertical distance from the model surface to the ground, the average value was 525 m.

Table 1. Physical and mechanical parameters of coal seam and its roof-floor strata

Lithology	Density [kgm^{-3}]	Bulk modulus [GPa]	Shear modulus [GPa]	Cohesion [MPa]	Internal friction angle [°]	Tensile strength [MPa]
Sandy mudstone	2536	2.57	1.72	3.25	27	1.18
Medium-grained sandstone	2600	4.34	2.83	4.56	30	3.53
Coal seam B_1	1300	0.84	0.46	0.27	18	0.81
Fine-grained sandstone	2500	2.81	4.42	4.83	29	2.92
Limestone	2700	5.33	3.45	2.45	39	1.54
Mudstone	2000	1.32	2.33	1.21	23	1.12
Guo Fault F_2	1200	0.65	0.51	0.14	15	0.51

The floor boundary of the model was fixed hinge bracket, simplified to the displacement boundary condition, *i. e.*, the displacements in the X- and Y-direction were equal to zero. Boundary conditions of model two sides were all the solid coal-rock mass, simply supported edges. The displacements in X-direction of two sides of model were zero, but the displacements in the Y-direction could be changed.

The numerical calculation process

Using software UDEC, the movement, deformation, and failure laws of overburden strata were simulated while coal seam B_1 mining.

Setting-up room of the coal face was located in the hangingwall of the Guo fault, whose distance away from the model left boundary being 150 m. The coal face was advanced continuously, and stopped until the distance from the coal face to fault was 30 m, *i. e.*, the minimum width of protected fault pillar was 30 m. Figure 3 showed the vertical stress and displacement contours of surrounding rocks of coal face with its different advance distances. Stress contours in Y-direction were represented by different colors.

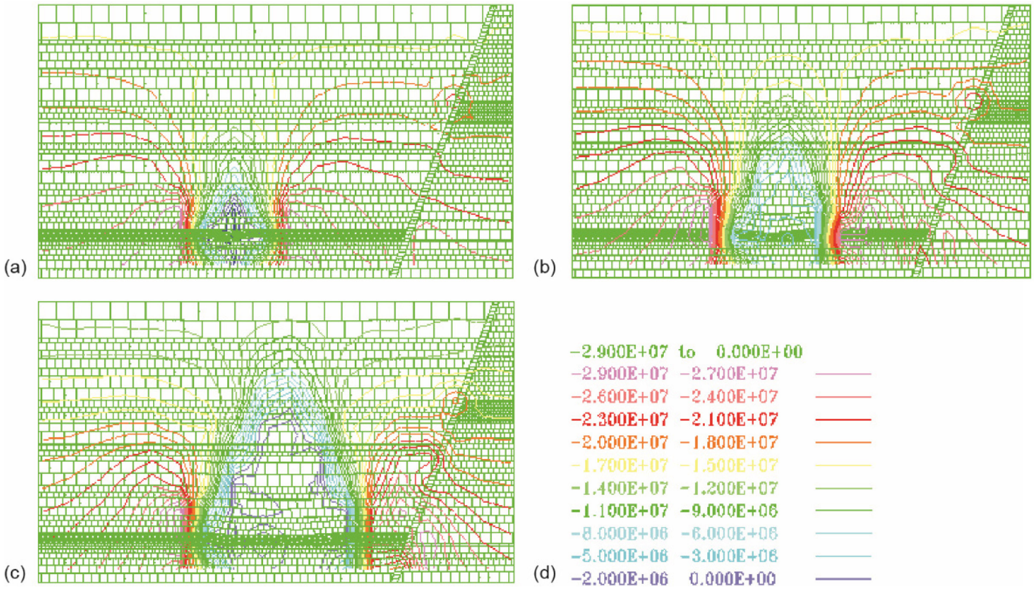

Figure 3. The displacement field and vertical stress contours of overburden strata of coal face with its different advance distances; (a) the coal face advance distance 40 m, (b) the distance 80 m, (c) the distance 120 m, (d) block plot YY stress contours [Pa] (*for color image see journal web site*)

Analysis on numerical simulation results

In the process of coal seam mining, there were subsidence, separation and broken, *i. e.*, deformation movement, failure and collapse into overburden strata, and many mining-induced fissures were generated also. The fissures could be divided into vertical-broken fissures and layers-separated ones. So, there were the mining-induced fissures field and mining stress field in surrounding rocks at coal face. With coal face advance distance increasing, there were caved zone, fractured zone and bended zone on overburden strata of coal face.

Figure 3 showed the deformation and movement rules on overburden strata in the process of coal face advance. While coal face advance distance from setting-up room to coal face line was 10 m, mining-induced fissures began to appear in immediate roof strata, but no separation. While the distance was 20 m, the fissures in immediate roof strata increased and the separation phenomena appeared obviously. While advance distance was 30 m, there was arched caving in immediate roof strata, then roof caving followed coal seam mining. When advance distance was 70 m, the gob was gradually filled with the caved strata, in which a range of strata began to subside gradually and separated along the bedding planes, and many mining-induced fissures generated were perpendicular or oblique to bedding planes under the tensile stress. When the advance distance reached to 120 m, *i. e.*, the distance from coal face line to the fault was 30 m, the heights of the caved and fractured zones were basically stable, the upper strata above fractured zone would be of entire deformation and movement, and these strata no longer be shifted each other, only smaller bending deformation under the gravity stress were produced; the upper strata maintained basically the original integrity and continuity of rock mass. Therefore, this zone was known as the bended zone. From above stress contours on the roof starta with different coal face advance distances, the front abutment pressure peak moved continuously to the farther coal mass with coal face advance, but abutment pressure decreased rapidly nearby fault. When the advance distance reached to 120 m, *i. e.,* the distance from coal face to fault was 30 m, the position of abutment pressure peak was still in hangingwall of Guo fault, and the vertical displacement of strata nearby fault was much smaller and there was no severe deformation failure.

According to the results of numerical results, the paper, using TECPLOT software to extract the data on the observation lines, imported EXCEL and drew a series of values of moving abutment pressures in front of the coal face with different coal face advance distances, which were shown in fig. 4. Starting from the setting-up room, the influence zone scope of abutment pressure in front of the coal face was smaller while coal face advance distance was 15-60 m, and the influence of coal face mining on fault F_2 was inconspicuous. However, when the coal face advance distance was 75-105 m, the peak stress of abutment pressure and the maximum stress concentration coefficient increased significantly, The scope of plastic zone expanded and gradually tended to Guo fault, and the mining influence on the fault increased. Distance of the peak stress position for abutment pressure was about 14-20 m away from the coal faceline. The influence zone scope of front abutment pressure was 70-80 m, and further away from coal faceline, abutment pressure reduced gradually and tended to be the in-situ stress value 17.5 MPa.

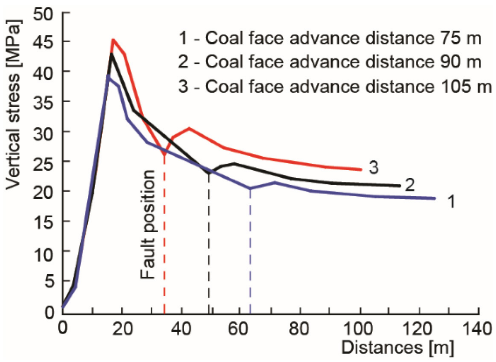

Figure 4. The distribution characteristics of abutment pressures in front of coal faces with different advance distances

Reasonable width of water-proof coal pillar

Usually, coal seam mining in one side of hydraulic conductivity fault, water-proof pillar has to be layout on the two sides of the fault shown as fig. 5. Based on *mines water prevention regulations of China* [16] and Dai *et al.* [17], the reasonable width of water-proof coal pillar of hydraulic conductivity fault could be calculated in line with the following empirical formula:

$$L = 0.5KM\sqrt{\frac{3P}{K_P}} \geq 20 \text{ m} \tag{2}$$

where L [m] is the width of water-proof coal pillar of hydraulic conductivity fault, K – the safety factor, generally taken 2-5, M [m] – the coal seam thickness or mining height, P [MPa] – the water pressure on coal seam, K_P [MPa] – the tensile strength of coal seam.

According to geological and mining conditions of coal seam in hanging wall of Guo fault under Yinshigou reservoir, coal seam thickness, M, was 5.1 m; the maximum burial depth, H, was 790 m, then water pressure on

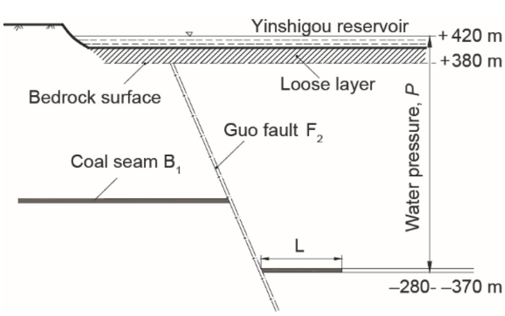

Figure 5. Calculation on water-proof coal pillar of fault under Yinshigou reservoir

coal seam at fault location was $P = \gamma H = 0.01\times790 = 7.9$ MPa. Coal seam belongs to a soft one, its compressive strength was about 3.5 MPa, its tensile strength, K_P, was taken as 0.35 MPa. Safety factor of water-proof coal pillar, K, was taken as 2-5.

Based on eq. 2, when safety factor of water-proof coal pillar, K, was 2 and 5, respectively, the calculated width of water-proof coal pillar was 42.0 m and 104.9 m, respectively. So, the width of water-proof coal pillar was about 41.97-104.92 m, with an average of 73.45 m. Therefore, while coal seam mining in hangingwall of Guo fault under Yinshigou reservoir, the resonable width of water-proof coal pillar should be taken as 105 m for prevention of water inrush.

Conclusions

- With coal face advance, its front abutment pressure peak moved continuously to the farther coal mass, but abutment pressure decreased rapidly nearby fault.
- While the coal face advance distance from coal face line to the fault, *i. e.*, fault-protected pillar width, was 80 m, the front abutment pressure has less influence on two sides' strata of the fault, while the vertical stress of surrounding rocks nearby fault decreased. At same burial depth strata, the displacements of surrounding rocks of the strata in vicinity of fault basically are in the same vertical displacements, and the displacements are much smaller.
- The reasonable fault-protected pillar width with numerical results is much closer to the average of the water-proof coal pillar width based on coal mines water prevention regulations of China. While the fault-protected pillar is greater than 80 m, the safety coal seam mining under the reservoir could be implemented.

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