Numerical simulation study of mining process of upper and lower walls of normal and reverse faults

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Abstract. Mining coal seams near faults are prone to various mine disasters, and different mining sequences have different effects on coal seam disasters. Under this background, the numerical models of normal fault hanging wall, normal fault footwall, reverse fault hanging wall and reverse fault footwall under the same geological conditions are established. It is found that the stress concentration of coal pillar is the largest in the mining process of hanging wall of normal fault and footwall of reverse fault, and the possibility of inducing coal pillar rockburst is the largest. Affected by the fault, the coal pillar abutment stress between the working face and the fault shows an upward trend. When mining the coal seam near the fault, various methods such as hydraulic fracturing should be adopted to reduce the coal pillar abutment stress and reduce the risk of mine disasters.

Key word: fault, mining sequence, abutment pressure.

1. Introduction
As a kind of geological structure, fault is produced and developed in the crustal tectonic movement. When the stress generated in the crustal movement exceeds the strength of the rock stratum itself, the rock stratum is damaged and generates relative displacement along the fracture surface to form a fault. When the coal seam mining is near the fault, there will be obvious singular changes in the overlying strata of the goaf. Under the interaction of faults and mining, obvious ground pressure will appear, which may induce a variety of mine disasters, take for example roof caving, mine water inrush, coal and gas outburst, rock burst and so on [1-4]. In recent years, Chinese scholars have carried out research on the mining effect of fault area and achieved very important research results. DAI Jin et al [5] studied the variation characteristics of mining stress of coal pillar under different mining sequences in the upper and lower walls of normal fault. The results show that when the hanging wall of the normal fault is mined first, the hanging wall fault coal pillar pressure is smaller than the footwall coal body pressure, and when the footwall of the fault is mined first, the coal pillar pressure is related to the fault angle; WANG Xuebin et al [6-7] studied the temporal and spatial distribution of stress in the footwall of normal fault and reverse fault, and found that the possibility of rockburst in the footwall of reverse fault is higher than that of normal fault. When the horizontal distance from the working face to the fault is the same, the barrier effect of fault on vertical, horizontal and shear stress of coal seam gradually decreases; ZHANG Pingsong et al [8] combined with the geological conditions of a coal face in Huainan, carried
out real-time monitoring of rock deformation of FS2 normal fault, and found that the strain change characteristics of rock near the fault structural plane caused by mining are significant; DOU Zhongsi et al [9] studied the reasonable reserved width of protective coal pillar near the reverse fault by numerical simulation, and compared it with the actual mine, which can provide reference for the design of fault protection coal pillar under the same conditions.

At present, a large number of studies have been carried out on the mining effect of coal seams near faults, but there are relatively few studies on the stress variation characteristics under different mining sequences of the upper and lower walls of normal and reverse faults. Referring to the specific parameters of a mine, this paper establishes the numerical model of the upper and lower walls of normal and reverse faults under different mining sequences, and studies the stress variation characteristics and disaster risk under different mining sequences.

2. Establishment of experimental scheme model

The numerical model is established with reference to the actual parameters [6-7] of the working face of a mine. The length, width and height of the model are 500 m, 300 m and 109 m respectively. The fault drop is 2 m and the fault dip angle is 45°. The rock stratum not simulated in the upper part of the model applies a vertical stress of 15.7MPa. For the sake of study the stress and deformation characteristics of normal and reverse faults under different mining sequences with the same background, four numerical models of normal fault footwall mining, normal fault hanging wall mining, reverse fault footwall mining and reverse fault hanging wall mining are established based on the actual parameters of the working face [13]. In order to study the stress and deformation characteristics of overburden in goaf, the length of working face is set as 180 m, advancing from far away from fault to fault. The lateral pressure coefficient of normal fault along the vertical fault strike direction is 0.6 and that along the fault strike direction is 0.8 [11]; Since the lateral pressure coefficient of the reverse fault is greater than 1 [10], the lateral pressure coefficient along the vertical fault strike direction is set as 1.5 and the lateral pressure coefficient along the fault strike direction is set as 1.2 [11]. The numerical model of normal fault footwall mining is shown in Figure 1. The stratum properties in the model are shown in Table 1.

| Lithology          | Thickness (m) | Density (kg/m³) | Bulk modulus (GPa) | Shear modulus (GPa) | Cohesion (MPa) | Friction angle (°) |
|--------------------|---------------|-----------------|--------------------|---------------------|----------------|-------------------|
| Clay rock          | 14            | 2500            | 8.2                | 1.1                 | 1.8            | 30                |
| Fine silt          | 3             | 2500            | 9.6                | 3.6                 | 2.5            | 31                |
| Medium sandstone   | 8             | 2700            | 19.4               | 13.2                | 12.8           | 35                |
| Coarse sandstone   | 5             | 2600            | 16.5               | 7.8                 | 5.0            | 34                |
| Medium sandstone   | 11            | 2700            | 19.4               | 13.2                | 12.8           | 35                |
| Fine sandstone     | 13            | 2700            | 23.0               | 15.2                | 17.0           | 38                |
| Medium sandstone   | 5             | 2700            | 19.4               | 13.2                | 12.8           | 35                |
| Fine sandstone     | 20            | 2700            | 23.0               | 15.2                | 17.0           | 38                |
| Medium sandstone   | 5             | 2700            | 19.4               | 13.2                | 12.8           | 35                |
| Coal               | 5             | 1400            | 1.5                | 0.8                 | 1.1            | 25                |
| Siltstone          | 2             | 2500            | 13.1               | 4.2                 | 3.0            | 33                |
| Fine sandstone     | 6             | 2700            | 23.0               | 15.2                | 17.0           | 38                |
| Siltstone          | 12            | 2500            | 13.1               | 4.2                 | 3.0            | 33                |
3. Analysis of numerical simulation results

3.1. Stress variation characteristics of normal faults under different mining sequences

Under the same vertical and horizontal stress, the numerical model of normal fault under different mining sequences is established, the stress field distribution of normal fault during mining is observed, and the vertical stress distribution characteristics of normal fault under different mining sequences are analyzed. The vertical stress distribution of normal fault under different mining sequences is shown in Figure 2.

The analysis shows that in the process of normal fault hanging wall mining, the supporting stress of fault protective coal pillar in the working face is greater than that in the process of normal fault footwall mining. When the distance between the working face and the fault protection coal pillar is the same, the maximum vertical stress of protective coal pillar during normal fault footwall mining is 51.3MPa, the maximum vertical stress of coal pillar during hanging wall mining of normal fault is 54.2MPa, which is 106% of the mining protection pillar stress in the footwall of normal fault. This indicates that the energy accumulated in the coal pillar during the mining of the hanging wall of the normal fault is greater than that of the footwall, and the coal pillar rockburst is more likely to occur near the normal fault. When the hanging wall working face of the normal fault is mined near the fault, the fault protection coal pillars with larger width should be set up accordingly to reduce the occurrence of coal pillar rock burst.

3.2. Stress variation characteristics of reverse faults under different mining sequences

Under the same vertical and horizontal stress, the numerical model of reverse fault under different mining sequences is established, the stress field distribution of reverse fault during mining is observed, and the vertical stress distribution characteristics of reverse fault under different mining sequences are analyzed [12]. The vertical stress distribution of reverse fault under different mining sequences is shown in Figure 3.
The analysis shows that in the process of reverse fault footwall mining, the supporting stress of fault protective coal pillar in the working face is greater than that in the process of reverse fault hanging wall mining. The maximum vertical stress in front of the footwall mining face is 54MPa, while the maximum vertical stress in front of the hanging wall mining face is 51.7MPa. This shows that the vertical stress accumulation degree in the footwall mining of reverse fault is higher than that in the hanging wall mining, which shows different variation characteristics in the mining of normal fault, which may be related to the mechanical genesis of normal and reverse fault. By comparing Fig. 2 and Fig. 3, the following conclusions can be obtained: during footwall mining, the vertical stress of coal pillar of reverse fault is higher than that of normal fault; during hanging wall mining, the vertical stress of coal pillar of reverse fault is lower than that of normal fault. This is because the horizontal stress around the reverse fault is large, cause a higher degree of stress concentration in the process of footwall mining; During the mining process of the hanging wall, the stress transmission effect of the normal fault is lower than that of the reverse fault, resulting the vertical stress of the protective coal pillar in the hanging wall of the normal fault is large.

3.3. Study on mining abutment pressure of upper and lower walls of fault

For the sake of studying the variation characteristics of vertical stress of protective coal pillar in different mining processes of fault, 17 m protective coal pillar is reserved in front of the working face as the research object. A stress monitoring point is arranged every 5 m on both sides of the fault to study the stress change characteristics of 15 m on both sides of the fault and obtain the abutment stress change curve in front of the working face, as shown in Figure 4.

The analysis shows that when the working face is 17 m away from the fault, the abutment pressure of the protective coal pillar in the working face increases, and the abutment pressure increase zone appears. With the distance between the measuring point and the fault increases gradually, the bearing pressure generally shows a decreasing trend. Affected by faults, when mining the working face on one side of fault, the supporting pressure of coal pillar in front of the working face increases gradually. However, due to the blocking effect of the fault on the stress transmission, the abutment pressure of coal pillars on the other side of the fault generally shows an increasing trend, but the range of abutment pressure increase is obviously lower than that on the mining side of the working face [14]. Under the four different fault mining sequences, the abutment pressure of the coal pillar in the working face increases obviously under the influence of the fault. When the work faces the coal seam mining near the fault, for the sake of reduce the impact of the fault structure on mining, drilling pressure relief and hydraulic fracturing should be adopted near the fault to reduce the abutment pressure above the coal pillar, so as to avoid various mine disasters such as fault activation and fault water inrush.
4. Conclusion
(1) Based on the same geological conditions, four numerical models under different mining sequences of normal fault hanging wall, normal fault footwall, reverse fault hanging wall and reverse fault footwall are established. The vertical stress concentration of the fault protection coal pillar is the largest in the mining process of the hanging wall of the normal fault and the footwall of the reverse fault, and the coal pillar rockburst is most likely to occur.

(2) It is found that when the working face is mining near a fault, the supporting pressure of the coal pillar in front of the working face rises, which becomes the key prevention and control area of fault disaster.

(3) The fault has a certain blocking effect on stress transmission. When one side of the fault is mined, the other side is less affected by the fault than the mining side of the working face.

5. References
[1] LAI Xingping, ZHENG Jianwei, JIANG Xinjun, et al. Influential range assessment of dynamic pressure in fault zone with broken rock masses [J]. Journal of Mining & Safety Engineering, 2016, 33(02): 361-366.
[2] LUO Hao, LI Zhonghua, WANG Aiwen, et al. Study on the evolution law of stress field when approaching fault in deep mining [J]. Journal of China Coal Society, 2014, 39(02): 322-327.
[3] JIANG Jinquan, WANG Pu, ZHENG Pengqiang, et al. Evolution characteristics of mining-induced fracture and abutment stress under high-position hard thick stratum and its effect on gas migration [J]. Journal of Mining & Safety Engineering, 2017, 34(04): 624-631.
[4] ZHANG Kexue, HE Manchao, JIANG Yaodong. Mechanism research of roadway pressure bump induced by fault slip and activation [J]. Coal Science and Technology, 2017, 45(02): 12-20+64.
[5] DAI Jin, JIANG Jinquan. Influence of mining sequence of hanging wall and foot wall on mining-induced stress of fault coal pillar [J]. Journal of Mining and Safety Engineering, 2016, 33, (01): 35-41.
[6] WANG Xuebin, GUO Changsheng, DENG chaoqun. Numerical simulation of spatiotemporal distributions of stresses on the fault and coal seam in the vicinity of the fault for mining in the footwall of the normal and reverse fault [J]. Progress in Geophysics, 2020, 35(05): 1993-2000.
[7] WANG Xuebin, GUO Changsheng, DENG chaoqun. Numerical modeling of fault barrier effects on three kinds of stresses: a case of footwall mining on the normal fault [J]. Progress in
[8] ZHANG Pingsong, LU Haifeng, HAN Biwu, et al. Monitoring and analysis of deformation characteristics of fault structure under mining condition [J]. Journal of Mining & Safety Engineering, 2019, 36(02): 351-356.

[9] DOU Zhongsi, TIAN nuocheng. Study on Reasonable Setting-up of F25 Reverse Fault Pillar in Zouzhuang Deposit [J]. Journal of East China University of Technology (Natural Science), 2020, 43(03):257-262.

[10] SUN Zongqi, ZHANG Jinghe. Variation of in-situ stresses before and after occurrence of geological fault structure [J]. Chinese Journal of Rock Mechanics and Engineering, 2004(23): 3964-3969.

[11] KONG Peng. Research on Mining Induced Faults Slip Dynamic Response and Rockburst Mechanism [D]. Shandong University of Science and Technology, 2020.

[12] ZHOU Rui, QIN Yujin, ZHANG Zhizhen. Distribution and Variation on Mining-Induced Stress in the Reverse Fault-Affect Coal Body [J]. Advances in Civil Engineering, 2021.

[13] JIANG Lishuai, WANG Pu, ZHANG Peipeng, et al. Numerical analysis of the effects induced by normal faults and dip angles an rock bursts [J]. Comptes Rendus Mecanique, 2017, 345(10): 690-705.

[14] DU Beiju, LIU Changyou, YANG Jingxuan, et al. Abutment pressure distribution pattern and size optimization of coal pillar under repeated mining: a case study [J]. Arabian Journal of Geosciences, 2020(13): 1261.