Study on fault slip dynamic response and rock burst potential under the influence of different horizontal stresses

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ABSTRACT

The seismic source release by fault slip under the influence of mining is an important factor to induce rock burst. In this study, the normal fault and reverse fault with different horizontal stress are constructed by numerical simulation and the fault slip law and stope dynamic response characteristics when mining the panel through the faults are compared and analyzed. Studies show that compared with mining the panel through the normal fault, the normal stress level of the reverse fault is higher, so the shear strength of the reverse fault is greater. When the fault coal pillar is small and the mining disturbance to the reverse fault is severe, the slip displacement of fault increases significantly, the shear stress drops suddenly, and the fault slip seismic source is greater. Under the influence of reverse fault slip dynamic load, the vibration velocity of coal and rock mass near the mining space, the reduction value of advanced abutment pressure and the affected range are larger, and fault slip rock burst is more likely to occur. The on-site statistical of fault slip rock burst cases are consistent with the numerical simulation results, verifying the reliability of the numerical simulation methods and conclusions.

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1. Introduction

Rock burst is one of the major disasters threatening the safe and efficient production of coal mines. It refers to the dynamic phenomenon of sudden and severe damage of the coal and rock mass around the roadway or working face due to the instantaneous release of elastic deformation energy, which is often accompanied by coal and rock mass throwing, loud noise and air wave, which is extremely harmful (Mazaira & Konicek, 2015; Jiang & Zhao, 2015; Xue et al. 2020). Fault slip rock burst is one of the typical types one, which is induced by the violent release of energy due to the sudden slip of faults caused
by mining activities. Compared with other types of rock bursts, fault slip rock burst have the characteristics of more energy released and high magnitude, and its destructiveness is stronger and the scope of influence is larger (Ortlepp & Stacey, 1994; Kaiser & Ming, 2012), which seriously restricts the safe and efficient mining of coal resources.

Field practice shows that the probability of rock burst occurrence increases significantly when mining activities are carried out near the fault. According to statistics, more than 70% of rock bursts occurred near the fault structural zone (Li et al. 2018). The 25110 panel of Henan Yuejin Coal Mine was arranged along the strike of F16 reverse fault. Affected by F16 reverse fault, multiple rock burst accidents occurred during mining of 25110 panel, and fault slip strong microseismic events were the key factors to induce rock burst. As a result, a large number of roadway support structures failed, mining equipments were seriously damaged, and the damaged roadway reached hundreds of meters (Cai et al. 2016; Li et al. 2013). The 2305S panel of Xin Julong Coal Mine is located in the wedge-shaped graben area formed by the FD8 fault and the FD6 fault (Wu et al. 2021). The mining disturbance induces fault slip and released a strong mine earthquake event, which eventually induced a rock burst accident, causing severe damage to the roadway nearly 500 m, and the hydraulic support was broken. The on-site fault slip rock burst appearance is shown in Figure 1. The energy level of the fault slip microseismic events that induced the rock burst reached $4.2 \times 10^7$ J. The large energy microseismic event released by fault slip was one of the important factors inducing rock burst disasters. To study the mechanism of fault slip rock burst, it is necessary to consider the influence of fault slip seismic source, and clarify the dynamic response characteristics of coal and rock mass under the action of fault slip dynamic load.

Fault is a common geological structure in coal mine, and the initial stress environment of different faults varies greatly. Fault characteristic parameters and fault stress state have a crucial impact on fault slip law and fault slip seismic source, so the mechanism of fault slip rock burst is very complex. Scholars have carried out a lot of research on the rock burst potential under the influence of different characteristics of faults. Based on microseismic monitoring, Mao & Chen (2013) pointed out that the microseismic energy released by fault slip is positively correlated with the length, drop, and stiffness of the fault. Xu et al. (2015) and Wu et al. (2018) used numerical simulation methods studied the influence of fault dip on fault slip activation and mining stress. Studies have shown that the larger the fault dip, the less likely it is to activate the fault, but the stress concentration of the fault coal pillar is higher. Jiao et al. (2019) used the

![Figure 1. Site of fault slip rock burst accident in Xin Julong Coal Mine.](image)
method of numerical simulation to study the influence of fault parameters on fault slip. The research showed that the influence of fault dip and friction angle on fault damage variables is highly significant, and the influence of fault drop and fault cohesion on fault damage variables is slight. Jiang et al. (2020) research shows that the friction angle and the stiffness of the fault have a greater influence on the seismic moment of the fault slip under the influence of mining, and the characteristic parameters of the fault are inverted based on the microseismic events monitored on site. However, there are few studies on mining induced fault slip law and stope dynamic response under different fault stress conditions, and further research is needed.

The essence of fault slip is that the shear stress of the fault reaches the shear strength, which is a mechanical response process. The initial in-situ stress state of the fault is different, and the stress evolution process and the shear slip law of the fault affected by mining will also be quite different (Chen et al. 2020; Wang et al. 2021; Zhao et al. 2019; Zhao et al. 2021). Therefore, studying the laws of fault slip and the source characteristics under different in-situ stress levels is of great significance for revealing the mechanism of fault slip rock burst. In this study, numerical simulation was used to study the law of fault slip and the seismic source characteristics under different horizontal stress conditions. Based on the dynamic analysis module, the dynamic response characteristics of coal and rock masses near the stope under the fault slip dynamic load were studied. The fault slip rock burst hazard under different horizontal stress conditions of fault is comparatively analyzed, and the on-site monitoring data is combined to reveal the impact of horizontal stress on the fault slip rock burst.

2. Case study

2.1. Engineering background

The stratum occurrence characteristic of the Dongtan Coal Mine 14310 panel is shown in Figure 2. The average thickness of the coal seam is 8 m, and the immediate roof of the coal seam is mudstone with an average thickness of about 4 m. The basic roof is dominated by siltstone and medium sandstone, and the roof is relatively hard, especially the average uniaxial compressive strength of the sandstone in the roof reaches 102 MPa. The layout of the 14310 panel is shown in Figure 3. The coal seam floor elevation is about −550 m, the ground elevation is about 50 m, the width of the panel is 230 m, and the strike length is 1000 m. The geological structure of the panel is complex, in which the NF6 normal fault passes through, with a fault dip of 60° and a drop of 6~10 m. The working face was mined through the fault from the footwall and NF6 normal fault has a great impact on mining.

2.2. Distribution of microseismic events when mining the panel

Figure 4 shows the distribution of microseismic events when mining the panel through the NF6 normal fault. Where $L$ represents the distance from the working face to the fault, and $H$ represents the distance from the microseismic event to the coal seam. As can be seen from the figure, the number and energy level of microseismic events near the roof fault are much greater than those near the floor fault,
indicating that the roof fault was more active than the floor fault under the influence of mining. The distribution height of microseismic events and the energy level of microseismic events near faults were obviously higher than those in other areas. Most of the microseismic events with the energy level greater than $5 \times 10^3 \text{J}$ occur near the roof fault plane and are induced by fault slip.

3. Simulation methodology

3.1. Model establishment

Taking 14310 panel of Dongtan Coal Mine as engineering background, a numerical calculation model was established to compare and analyze the fault slip law and fault slip seismic source of working face mining across fault under different horizontal stress conditions, and analyze the dynamic response characteristics and rock burst.
potential of stope under the action of fault slip dynamic load. The numerical calculation model is 710 m long, 450 m wide and 180 m high (Figure 5). The simulated mining depth of coal seam is 600 m, and the width of the panel is 230 m. In order to eliminate the boundary effect of the model, the width of the distance between the panel and the model boundary should not be less than 100 m. In the model, the ubiquitous-joint model was adopted to simulate the fault. The dip angle of the fault was 60° and the drop was 8 m. Two numerical calculation models were set. The fault in model 1 was a normal fault, and the lateral pressure coefficient along the dip direction of the fault was 0.6, and the lateral pressure coefficient along the strike direction of the fault was 0.8. In model 2, the coefficient of pressure measurement along the dip direction of the fault was set as 1.5, and that along the strike direction of the fault was set as 1.2. In general, fault with lateral pressure coefficient greater than 1 are reverse faults (Anderson 1951; Byerlee 1978) so the fault in model 2 is reverse fault.

3.2. Rock mass parameters and calculation method

The excavation of the working face causes the stress redistribution of the coal and rock mass around the working face, and the coal and rock mass shows the characteristics of strain softening after plastic failure. Therefore, the strain softening model was used to simulate the rock stratum, the mechanical parameters of rock mass were estimated according to the complete rock properties and the generalized Hoek-Brown failure criterion, and the mechanical parameters of each rock strata were shown in Table 1 (Hoek & Brown 1997). The fault was simulated by an improved ubiquitous-joint model. The parameters of rock mass in the fault zone were 1/5 of the parameters of sandstone in the roof of coal seam (Kong et al. 2019; Jiang et al. 2016), the dilation angle of the fault plane was 0, and the roughness value was 10. The compressive strength of unweathered joint surface can be selected as the uniaxial compressive strength of intact rock (Wang et al. 2015), so the joint wall compressive strength of the fault was 102 MPa. The basic friction angle of fault plane was determined to be 30° by direct shear test. Because the double yield model can accurately reflect the
mechanical characteristics of rock mass in the collapse zone during compaction, so the caving zone of the panel was simulated by the double yield model, the mechanical parameters of the double yield model were shown in Table 2.

During the numerical calculation, the length of each excavation of the working face is 10 m. After the excavation of the panel, static calculation was adopted until the model reaches equilibrium. The seismic moment of fault slip is used to represent the magnitude of fault slip seismic source. The seismic moment of fault slip was shown in formula 1, where $G$ is the stiffness of fault plane, $A$ is the fault area where shear slip occurs, and $D$ is the amount of fault shear displacement (Domański & Gibowicz 2008; Sainoki & Mitri 2014). After the static calculation, the seismic moment of fault slip under the influence of mining is monitored, and then the dynamic calculation was started. In order to avoid the emission and refraction of vibration wave at the model boundary and affect the dynamic calculation results, the boundary condition of the model was set as viscous boundary during dynamic calculation. In the process of dynamic calculation, the damping form adopts local damping. The research showed that the local damping of rock is generally 2%–5% (Sainoki & Mitri 2014). Therefore, 5% was selected for local damping in the process of dynamic calculation. The seismic moment of fault slip was applied to the fault element in the form of force couple (Wang & Cai 2017), and the dynamic response characteristic of stope under the fault slip dynamic load is studied. After the dynamic calculation was completed, the next step of excavation was continued, and the cycle was repeated until the panel is mined through the fault. The numerical simulation process of fault slip dynamic calculation was shown in Figure 6.

\[ M_0 = GAD \]  

(1)
4. Fault slip evolution under different horizontal stress conditions

4.1. Fault slip seismic source under different horizontal stress conditions

Figure 7 shows the evolution law of fault slip seismic moment under different horizontal stress conditions. It can be seen from Figure 7 that there are great differences between normal and reverse fault slip seismic moment affected by mining. For normal faults, when the working face advanced to 40 m away from the fault, the fault begins to slip and releasing the fault slip seismic source under the influence of mining, but the energy level of the fault slip seismic source was small. As the working face approaches the fault, the seismic moment of fault slip increases. When the working face advanced to the fault position, the seismic moment of fault slip reaches the maximum value of $9.9 \times 10^{11}$. When mining the panel through the reverse fault, the fault starts to release the fault slip moment source when the working face advances to

### Table 2. Parameters of caving zone.

| Parameters       | Density (kg/m³) | Bulk modulus (GPa) | Shear modulus (GPa) | Friction angle (°) | Cohesion (MPa) | Dilation angle (°) |
|------------------|-----------------|--------------------|--------------------|-------------------|----------------|-------------------|
| Value            | 1700            | 21                 | 15                 | 20                | 0.001          | 0                 |

Figure 6. Flow chart of dynamic calculation.
20 m distance from the fault. When the working face advanced to 10 m distance from the fault, the fault slip seismic moment increases significantly to $1.45 \times 10^{12}$. By comparing the seismic moment of normal fault and reverse fault, it can be seen that the normal fault is more likely to slip and release seismic source after mining, but the energy released by normal fault slip is less than that of reverse fault.

4.2. Shear stress and shear displacement of fault under different horizontal stress conditions

In order to further reveal the rule of fault slip activation, the shear displacement and shear stress evolution under the influence of mining were studied. Figure 8 shows the fault shear displacement and shear stress when mining the panel through the normal fault. When the working face advanced to 30 m from the fault, the fault slip area was located at 52~68 m above the coal seam. The fault area close to the working face keeps good stability, the shear stress level was high, and the fault accumulates a lot of elastic energy. As the working face advanced to the vicinity of the fault, the degree of mining disturbance increases, and the fault slip area extends from the high fault plane to the fault plane near the roof of the coal seam. When the working face advanced to 10 m or 0 m away from the normal fault, the slip range of the fault under the influence of mining expands sharply, and the shear stress in the fault area near the coal seam drops suddenly and released a lot of energy, resulting in a large fault slip seismic source.

Figure 9 shows the shear stress and shear displacement of the fault when the panel mined through the reverse fault. It can be seen from Figure 9 that when the working face advanced 20 m away from the reverse fault, the shear stress level of the roof fault increases continuously, and the reverse fault shear stress level was much higher than the normal fault. Although the shear stress level of the fault was high, the fault stability was good, and the shear displacement of the fault was very small, indicating that under the condition of high level stress, the reverse fault is less prone to slip and can accumulate more elastic energy. When the working face advances to 10 m away from the reverse fault, the fault shear stress in the range of 28~96 m above the coal seam...
decreased suddenly, the shear displacement of fault increased rapidly. Although the high position of fault slips and the shear stress drops suddenly, the low position of fault still maintains a high shear stress level, the fault slip displacement was small and the fault stability was good. When the working face advances to the position of the fault position.

Figure 8. Shear stress and shear displacement of the fault when mining the panel to different positions. (a) The working face is 30m away from the fault (b) The working face is 20m away from the fault (c) The working face is 10m away from the fault (d) The working face mined to the fault position.
reverse fault, the slip of the low position fault occurred under the influence of mining, the shear displacement of the low position fault increased rapidly, and the shear stress dropped suddenly to release the fault slip seismic source.

**Figure 9.** Shear stress and shear displacement of the normal fault when the working face advanced to different positions. (a) The working face is 30m away from the fault (b) The working face is 20m away from the fault (c) The working face is 10m away from the fault (d) The working face mined to the fault position.
Based on the above analysis, it can be seen that if the working face is mined near the reverse fault, and the fault coal pillar is wide, the disturbance degree of mining to the fault is small, and the shear strength of the fault is larger due to the high normal stress of the reverse fault, so the fault is not prone to shear slip but continuously accumulates energy. When the fault coal pillar is small and the mining disturbance to the fault is severe, the shear displacement of fault increases suddenly and the shear stress drops suddenly. Therefore, the fault slip seismic source is significantly larger than that when the working face mined through the normal fault.

5. Dynamic response of fault slip under different horizontal stress conditions

5.1. Evolution law of stope vibration velocity under fault slip dynamic load

The propagation process of fault slip seismic source will cause vibration of coal and rock mass, and damage will occur when the vibration velocity of coal and rock mass
is large. Therefore, the vibration velocity is an important index to evaluate the degree of dynamic load disturbance of coal and rock mass (Mutke et al. 2008, 2015; Wang et al. 2022). Figure 10 is the cloud diagram of vibration velocity distribution when the panel mined through the normal fault, in which Figure 10(a) was the vibration velocity of the stope at different times when the working face advanced to 30 m away from the fault. It can be seen from Figure 10(a) that when the working face advances to 30 m away from the fault, the high position of fault was first activated by slip, but the fault slip seismic source was small, and the vibration velocity near the fault was small. The fault slip seismic source propagates to the surrounding coal and rock mass in the form of vibration wave, and the vibration velocity decreases continuously during the propagation of vibration wave. After 0.06 s of fault slip, the vibration wave propagates near the coal and rock mass in front of the work face, but the vibration velocity was small, so the disturbance degree of fault slip vibration wave to the mining coal and rock mass was slight. When the working face advanced to the fault position, as shown in Figure 10(b), the fault slip range expands and the fault slip position shifts from high to low. The fault at the basic

Figure 11. Cloud diagram of vibration velocity distribution when mining the panel through the reverse fault. (a) The working face is 10m away from the fault (b) The working face mined to the fault position.
roof slipped, and the fault slip seismic source was large, also the vibration velocity of square coal and rock mass in front of the working face was large. Therefore, with the continuous advancement of the working face near the fault, the disturbance effect of fault slip on the dynamic load of the working face was more obvious.

Figure 11 shows the cloud diagram of vibration velocity distribution when the panel mined through the reverse fault. When the working face was more than 10 m away from the reverse fault, the fault has maintained good stability without slip, and the fault has maintained the state of accumulated energy. When the working face advanced to 10 m and 0 m away from the fault, the fault occurred violent slip and released a lot of energy. The range of slip and released energy of reverse fault are greater than that of normal fault. After 0.08 s, the vibration velocity of coal and rock

Figure 12. Dynamic response characteristics of advance abutment stress when mining the panel through the normal fault. (a) The working face is 10 m away from the fault (b) The working face mined to the fault position.
mass near the stope was still close to 2 m/s, with high vibration velocity and long vibration duration. Therefore, when the panel mined through the reverse fault, the fault slip has the characteristics of more severe and greater energy release. The coal and rock mass near the stope was disturbed more significantly by the dynamic load of reverse fault slip.

5.2. Response characteristics of advance abutment pressure of working face under fault slip dynamic load

Stress is a necessary condition for the occurrence of rock burst and has a direct control effect on rock burst (Qi et al. 2021; Pan & Dai 2021). Analyzing the dynamic

Figure 13. Dynamic response characteristics of advance abutment stress when mining the panel through the reverse fault. (a) The working face is 10m away from the fault (b) The working face mined to the fault position.
response characteristics of advance abutment pressure of working face under fault slip dynamic load is of great significance to evaluate the potential of rock burst. Since the fault slip seismic source was largest when the working face is 10 m and 0 m away from the normal fault, so the advance abutment pressure when the working face 10 m and 0 m away from the normal fault was analyzed. Figure 12 shows the dynamic response characteristics of advance abutment pressure when the panel mined through the normal fault. It can be seen from the figure that when the working face advanced to 10 m away from the fault, the peak value of advance abutment pressure of the working face was 31.6 MPa. Under the action of fault slip dynamic load, the coal stress within 45 m in front of the working face decreases, and the peak value of abutment stress decreased by 1.1 MPa. When the working face advanced to the fault position, after the fault slip dynamic load, the stress of the coal body within 50 m in front of the working face decreased, and the stress of the coal and rock mass in the area of the peak abutment stress decreased by 5.5 MPa, indicating that the coal and rock mass near the stope was plastically damaged by the fault slip dynamic load, and the rock burst potential increased.

Figure 13 shows the variation law of advance abutment stress under the action of fault slip load when the panel mined through the reverse fault. It can be seen from Figure 13 that when the working face advanced to 10 m away from the fault, the area where the advance abutment stress decreases after the action of fault slip dynamic load was 65 m in front of the working face, indicating that the influence range of fault slip dynamic load on the working face was very large. When the working face advances to 10 m and 0 m away from the reverse fault, significant plastic failure occurs in the coal and rock mass in the peak area of abutment stress after the action of fault slip dynamic load, and the reduction range of peak abutment stress reached 4.9 MPa and 7.2 MPa respectively, which were significantly greater than that when mining the panel through the normal fault. Therefore, under the condition of high horizontal stress, the advance stress of the working face was more strongly affected by the fault slip dynamic load, the rock burst potential was higher, and the influence range was larger.

5.3. Characteristics of elastic energy density response of advanced coal in working face under fault slip dynamic load

The dynamic response characteristics of coal elastic energy density in the peak area of abutment stress under fault slip dynamic load is an important factor to determine whether fault slip rock burst occur and the severity of rock burst. Figure 14 shows the dynamic response characteristics of elastic energy density of coal in the peak area of advance abutment stress under different fault horizontal stress conditions. It can be seen from Figure 14(a) that when the working face advanced to 20 m away from the normal fault, the elastic energy density in the peak area of abutment stress was the highest before the action of dynamic load. However, due to the small fault slip dynamic load, the elastic energy density of coal in the peak area of abutment stress was only slightly reduced. When the working face advances to 10 m and 0 m away from the fault, the elastic energy density in the peak area of abutment stress before
dynamic load was lower than that when the working face was 20 m away from the fault. However, the working face is affected by strong fault slip dynamic load, and the elastic energy density of coal decreases significantly after the action of dynamic load. Especially when the working face advanced to the fault position, the decrease of elastic energy density reached 81 KJ/m³, the coal in the peak area of abutment stress induced by fault slip dynamic load occurred significant plastic failure, released a large number of elastic energy density, so the potential of rock burst increased. After the working face mined through the fault and before the action of fault slip dynamic load, the elastic energy density of the coal in the peak area of advance abutment stress decreased significantly. Because the fault slip dynamic load was small, the fault slip dynamic load does not damage the coal in the peak area of abutment stress, the elastic energy density of coal in the peak area of abutment stress increased slightly, the weak fault slip dynamic load plays the role of energy storage, and the potential of rock burst was low.

Figure 14. Dynamic response characteristics of elastic property density of coal in the area of peak abutment stress. (a) Working face mining through normal fault (b) Working face mining through reverse fault.
Figure 15. Relationship between in-situ stress state and fault slip rock burst.
Figure 14(b) shows the dynamic response characteristics of elastic energy density of coal in the peak area of advance abutment stress when the working face mined through the reverse fault. It can be seen from the figure that when the panel mined through the reverse fault, due to the influence of the high stress level of the reverse fault, the elastic energy density of coal in the peak area of abutment stress before the action of dynamic load was significantly higher than that when the panel mined through the normal fault, indicating that the static energy accumulation level of coal near the reverse fault was higher. When the working face mined to 10 m and 0 m away from the reverse fault, the coal near the working face was affected by the strong fault slip dynamic load, the coal in the peak area of abutment stress of the working face occurs severe plastic failure, releasing a large amount of elastic energy, and the reduced values of elastic energy density reached 125KJ/m³ and 70KJ/m³ respectively. The potential of fault slip rock burst was higher.

6. Discussion

The fault activation process is extremely complex, but from a macro point of view, its essence is the friction slip caused by the increase of shear stress, and the factor controlling this failure is the normal stress perpendicular to the fault plane. Through the statistical analysis of in-situ stress data of 40 different mines, the mining depth of the mine ranges from 300 m to 1400 m, and the in-situ stress types include: \( \sigma_H > \sigma_V > \sigma_h \), \( \sigma_H > \sigma_h > \sigma_V \) and \( \sigma_V > \sigma_H > \sigma_h \) three types, combined with stress accumulation index \( \mu_m \) to analyze the stress accumulation capacity and level in the formation. If the energy accumulation in the fault area can reach the ultimate strength of the mechanical system composed of the fault zone and the hanging wall and footwall, it may cause the sudden relative dislocation of the fault, release a large amount of energy, and cause dynamic disasters such as rock burst.

\[
\mu_m = \frac{\sigma_1 - \sigma_3}{2\sqrt{\sigma_1 \sigma_3}}
\]  

Xia et al. (2016) uses formula 2 to calculate the measured in-situ stress data and classify them according to different mining depths, and the results are shown in Figure 15. In formula 2, \( \sigma_1 \) and \( \sigma_3 \) represent the maximum and minimum principal stresses respectively. It can be seen from the Figure 15 that when the mining depth is greater than 300 m and less than 600 m, no fault slip rock burst has occurred in the mine within the mining depth, indicating that the occurrence of fault slip rock burst is closely related to the mining depth. When the mining depth is greater than 600 m and less than 900 m, the statistical data show that 16 fault slip rock bursts occurred, and all fault slip rock bursts occurred in \( \sigma_H > \sigma_V > \sigma_h \), \( \sigma_H > \sigma_h > \sigma_V \) these two types of in-situ stress fields, and the stress accumulation index \( \mu_m \) is greater than 0.3 and less than 0.5. When the mining depth is greater than 900 m and less than 1200 m, the six mines with the in-situ stress types of \( \sigma_H > \sigma_H > \sigma_V \) all have fault slip rock burst with \( \mu_m \) less than 0.3. However, the mine with the in-situ stress type of \( \sigma_H > \sigma_V > \sigma_H \) only has fault slip rock burst when \( \mu_m \) is greater than 0.3 and less than 0.5.
It can be seen that the occurrence of fault slip rock burst is closely related to the distribution of in-situ stress in the mining area. For the stress type $\sigma_V > \sigma_H > \sigma_h$, the fault slip rock burst will not occur even if the in-situ stress and $\mu_m$ value are very high. Therefore, the reverse fault is more prone to fault slip rock burst than the normal fault in coal mining, and the $\sigma_H > \sigma_h > \sigma_V$ stress field is more prone to fault slip rock burst under the same conditions. The results of in-situ statistics are consistent with those of numerical simulation, which verifies the reliability of numerical simulation method and conclusion.

7. Conclusion

The production practice shows that the energy level and frequency of microseismic events near the fault increase obviously when the working face was mined near the fault, and the potential of rock burst was high. Under the engineering background of mining the panel through the fault, the normal fault and reverse fault with different horizontal stresses are established by numerical simulation method, and the fault slip dynamic calculation under the influence of mining was carried out. The slip law of fault and dynamic response characteristics of coal and rock mass during mining through normal fault and reverse fault are compared and analyzed.

The shear strength of the fault is larger due to the high normal stress of the reverse fault. When the disturbance degree of mining to the reverse fault is small, the fault is not prone to shear slip but continuously accumulates energy. When the fault coal pillar is small and the mining disturbance to the reverse fault is severe, the fault slip displacement increases suddenly, the shear stress drops suddenly, and the fault slip seismic source is significantly larger than that when the panel mined through the normal fault. The coal and rock mass near the working face are more prone to plastic failure under the influence of strong fault slip dynamic load, releasing a large amount of energy to induce rock burst.

Under the influence of mining, the fault will slip and release energy. The coal and rock mass near the mining space will vibrate under the action of fault slip dynamic load. In serious cases, plastic failure will occur, resulting in rock burst accidents. Compared with the mining the panel through the normal fault, when the panel mined through the reverse fault, the vibration velocity of coal and rock mass near the mining space is greater, the reduction value of advance abutment stress and the affected range are greater, the energy level released by coal and rock mass in the peak area of abutment stress after fault slip dynamic load is greater, and the potential of rock burst is higher.

The field statistical results show that the occurrence of fault slip rock burst is closely related to the in-situ stress distribution in the mining area. For the mine with the stress type $\sigma_V > \sigma_H > \sigma_h$, fault slip rock burst generally does not occur. The fault slip rock burst mostly occurs in the mine with the stress type of $\sigma_H > \sigma_H > \sigma_v$ and $\sigma_H > \sigma_H > \sigma_V$. Under the same conditions, the fault slip rock burst is more likely to occur in the stress field of $\sigma_H > \sigma_H > \sigma_V$. The results of field statistics are consistent with those of numerical simulation, which verifies the reliability of numerical simulation method and conclusion.
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Data availability statement

The data used to support the findings of the study are available from the corresponding author upon request.

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