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The Influence of Faults on The Deformation Law of Surrounding Rock Under Mining-induced Stress Field

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Abstract: With the continuous growth in the demand for coal resources, coal mining has become an important direction for resource development. As a typical representative of complex geological structures, faults significantly increase the safety risks and engineering difficulties during the mining process. The geological structure in the fault zone is complex, and the mining technology faces safety risks such as water inrush and instability of surrounding rocks. However, this area is rich in coal resources, and its rational development is of great significance for ensuring energy supply and improving resource utilization. This study, taking the fourth mining area of Sanyuan Coal Mine as the engineering background, through detailed geological structure detection and three-dimensional stress field numerical simulation, proposed the variation law of surrounding rock of the roadway under the influence of mining in the fault zone. The conclusion is that under the condition of being close to the fault, the maximum vertical displacement of the roadway is 111.6mm, which is approximately 58.8% larger than that in the area far from the fault; the maximum horizontal displacement of the coal pillar side and solid side of the roadway reaches 100.4mm and 55.6mm respectively, which is approximately 79.3% and 75.4% larger than that in the area far from the fault.

Keywords: Fault Surrounding; rock; Numerical simulation.

1. Introduction

China's energy structure is characterized by "abundant coal, scarce oil and insufficient natural gas". As the core of China's energy structure, coal has long played an irreplaceable role in ensuring energy security, supporting economic development and social stability. It is expected that the proportion of coal in the energy consumption structure will still exceed 50% in the short term[1-4]. As one of the main energy sources in China, coal mining faces many challenges, such as complex mining conditions, variable geological structures, and prominent stability problems of roof and surrounding rock of roadways, which seriously restrict safe production[5]. with an average annual economic loss of over 1 billion yuan, seriously restricting the high-quality development of the coal industry.

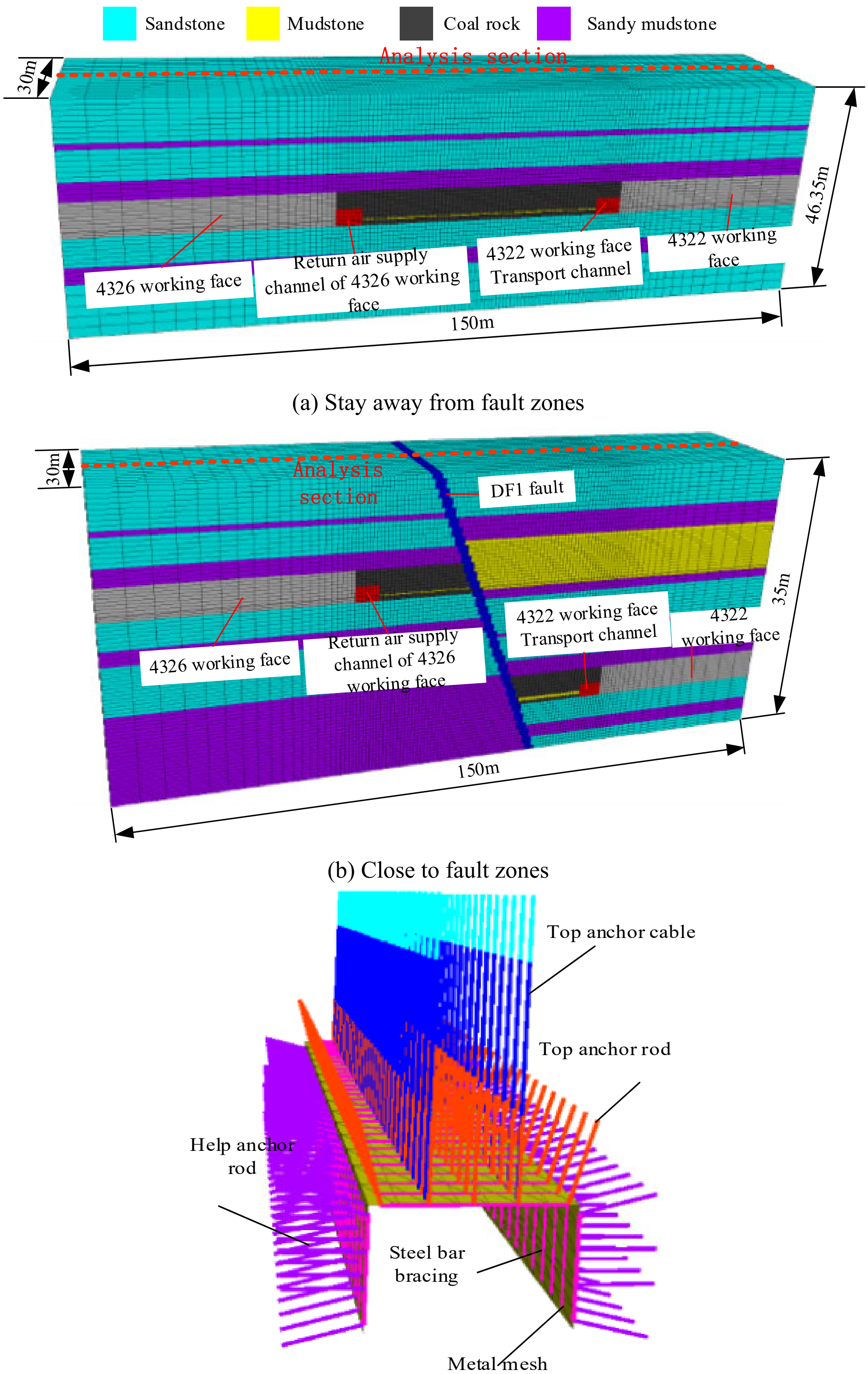
Faults, as typical weak tectonic surfaces, significantly alter the distribution characteristics of the stress field of the original rock, forming local stress abnormal areas. Under the superimposed action of mining stress, the fault zone is prone to slip activation, inducing progressive failure of coal and rock masses, and may evolve into chain disasters such as rock burst and roof cutting. It is particularly worth noting that the coal and rock masses in the fault-affected area have been subjected to tectonic stress for a long time, and their mechanical behaviors show obvious anisotropic and nonlinear characteristics. Under mining disturbance, it is more likely to form a vicious cycle of "stress concentration - energy release - structural instability", eventually leading to a progressive disaster development model of "coal wall flaking - roof collapse - fault activation"[6-10].

According to the existing data level, it is difficult to apply the research on the development of overlying rock fractures and the law of ore pressure near faults to guide engineering practice, and it is far from sufficient to provide a general qualitative description of the stress law near faults. This paper will provide a preliminary quantitative analysis by applying comprehensive analysis methods such as similar simulation, numerical simulation and field measurement. Under the condition that the assigned parameters are accurate and reasonable, similar simulation and numerical simulation can also obtain quantitative analysis results with a certain degree of reliability.

2. Numerical Simulation

(1) Numerical model establishment

To further study the influence of the changes in the mechanical properties of the rock mass near the fault on the support of tunneling and the mining of the working face, along the mining direction of the 4326 working face and considering the location of the fault, two areas close to the fault and far from the fault were selected for numerical simulation analysis. The numerical simulation model of roadway excavation and mining in the 4326 working face established by $FLAC^{3D}$ is shown in Fig.1. The modeling consists of five parts: the 4322 working face, the transport channel of the 4322 working face, the coal pillar reserved between the 4322 working face and the 4326 working face, the return air channel of the 4326 working face and the 4326 working face. Among them, the length, width and height of the model far from the fault area are 150m, 30m and 46.35m respectively, including a total of 81,075 elements and 89,088 nodes. The model of the adjacent fault area has a length of 150m, a width of 30m and a height of 66.35m respectively, and includes a total of 139,725 elements and 152,192 nodes. The boundary conditions of the model are set as the bottom surface is fixed, the normal displacement around is constrained, and the stress on the top surface is applied at 7.89MPa. The rock mass constitutive model adopts the molar Coulomb model. For the supporting structures of the rubber transport channel and the return air channel, the structural units in the $FLAC^{3D}$ software are proposed for simulation (see Fig.1 (c)).



(a) Stay away from fault zones

(b) Close to fault zones

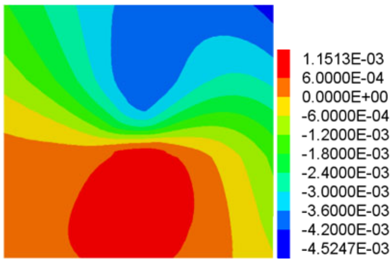
(c) Schematic diagram of roadway support

Figure 1. Numerical simulation model of tunneling and mining in the 4226 working face

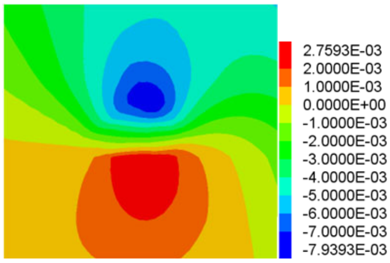
(2) Research on the deformation law of Surrounding rock in roadways Far from faults

(a) Vertical displacement

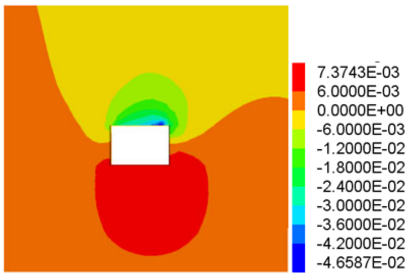
During the excavation process of the return airway in the 4326 working face, the vertical displacement changes of the surrounding rock of the roadway at the analysis section far from the fault area (the analysis section is perpendicular to the mining direction of the working face and located in the middle of the model, as shown in Figure 2) are illustrated in Figure 3. When the excavation face of the roadway is 4 meters away from the analysis section, the vertical displacement of the surrounding rock at the analysis section caused by the excavation of the roadway is very small. At this time, the vertical displacement of the surrounding rock of the roadway at the analysis section is basically caused by the mining of the adjacent 4322 working face, and its maximum displacement value is only 3.0-4.5mm. When the tunneling face is close to the analysis section, the tunneling excavation will cause a certain displacement of the rock mass near the tunneling face at the analysis section, and the maximum value is approximately 7.9mm. When the roadway excavation passes through the analysis section, due to the removal of the rock mass at the roadway location, the radial stress of the rock mass around the roadway begins to be unloaded, and the closer to the surface of the roadway, the greater the unloading amplitude. Therefore, the closer the rock mass is to the surface of the roadway, the greater its vertical displacement will be. That is, from the shallow part to the deep part, the vertical displacement of the rock mass at the cross-section of the roadway will decrease exponentially. At this point, the maximum vertical displacement of the surrounding rock of the roadway at the analysis section occurs at the position close to the coal pillar side at the top of the roadway, and its value is approximately 46.6mm. Thereafter, as the tunneling face gradually moves away from the analysis section, although the vertical displacement value of the surrounding rock of the tunnel at the analysis section will still gradually increase, the rate of increase will become smaller and smaller, and eventually tend to stabilize. When the tunneling face exceeds the analysis section by 14m, the maximum vertical displacement of the surrounding rock of the tunnel still occurs at the position near the coal pillar side at the top of the tunnel, but its value increases to 70.3mm.



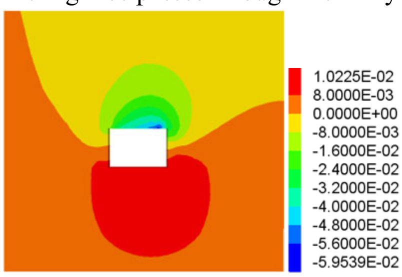
(a) The tunneling face is 4m away from the analysis section



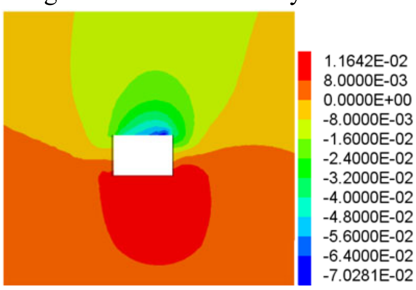
(b) The tunneling face is 2 meters away from the analysis section



(c) The tunneling face passes through the analysis section

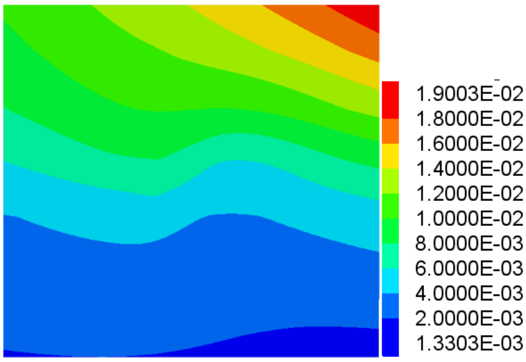


(d) The tunneling face exceeds the analysis section by 4 meters

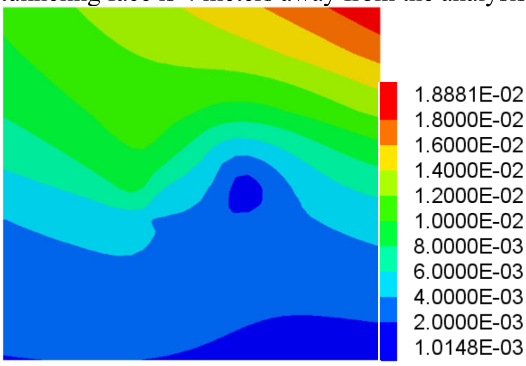


(e) The tunneling face exceeds the analysis section by 14 meters

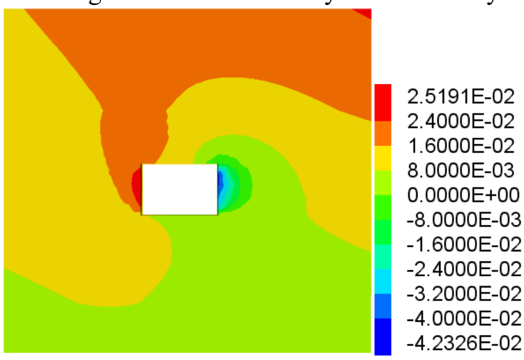
Figure 2. shows the vertical displacement changes of the surrounding rock at the analysis section during the tunneling process far from the fault area



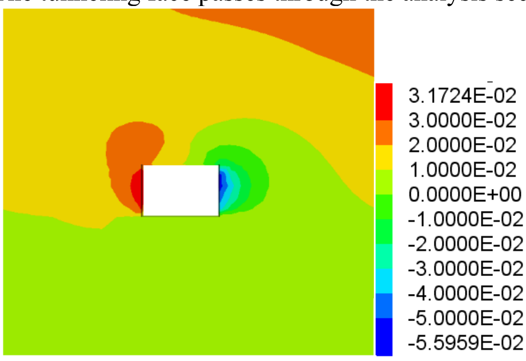
(a) The tunneling face is 4 meters away from the analysis section



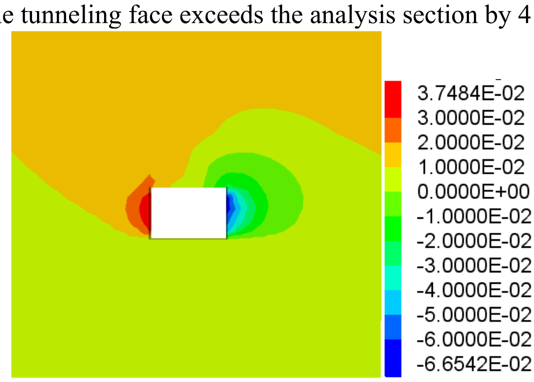
(b) The tunneling face is 2 meters away from the analysis section



(c) The tunneling face passes through the analysis section



(d) The tunneling face exceeds the analysis section by 4 meters



(e) The tunneling face exceeds the analysis section by 14 meters

Figure 3. shows the horizontal displacement changes of the surrounding rock at the analysis section during the tunneling process far from the fault area

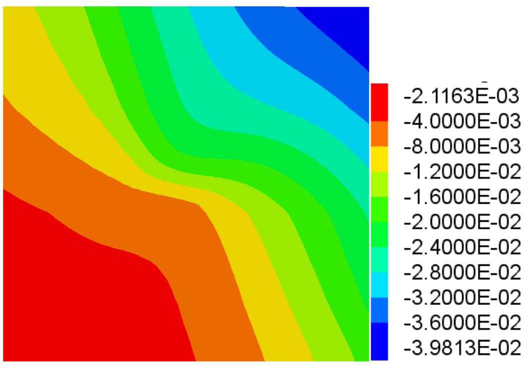
(b) Horizontal displacement

During the excavation process of the return airway in the 4326 working face, the horizontal displacement changes of the surrounding rock of the roadway at the analysis section far from the fault area are shown in Fig.3. When the excavation face of the roadway is more than 4 meters away from the analysis section, the horizontal displacement of the surrounding rock at the analysis section caused by the excavation of the roadway is very small. At this time, the horizontal displacement of the surrounding rock of the roadway at the analysis section is basically caused by the mining of the adjacent 4322 working face, and its maximum displacement value is only 4.0-6.0mm near the roadway. When the excavation face of the roadway is close to the analysis section, the excavation of the roadway will cause the rock mass near the excavation face of the roadway at the analysis section to have a horizontal displacement into the roadway, and its value is approximately 3.0-5.0mm. When the roadway excavation passes through the analysis section, due to the removal of the rock mass at the roadway location, the horizontal displacement of the surrounding rock of the roadway begins to increase significantly, especially on both sides of the roadway. At this time, the maximum displacement of the surrounding rock of the roadway occurs at the middle-upper position of the surfaces of both sides of the roadway. Its value is approximately 42.3mm on the coal pillar side and approximately 25.2mm on the solid side. And from the position where the maximum displacement occurs towards both sides, the horizontal displacement of the surrounding rock of the roadway gradually decreases to 0. As the tunneling face of the roadway gradually moves away from the analysis section, although the horizontal displacement value of the surrounding rock of the roadway at the analysis section will still gradually increase, the rate of increase will become smaller and smaller, and eventually tend to stabilize. When the excavation face of the roadway exceeds the analysis section by 14m, the maximum horizontal displacement of the surrounding rock of the roadway still occurs at the middle-upper position of the surfaces of both sides of the roadway. However, its values will increase to 66.5mm and 37.4mm respectively on the coal pillar side and the solid side.

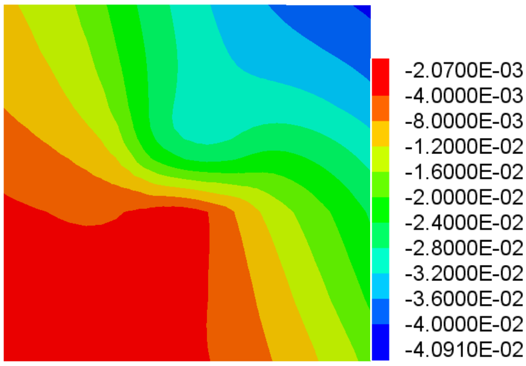
(3) Research on the Deformation law of Surrounding rock in Roadways near fault zones

(a) Vertical displacement

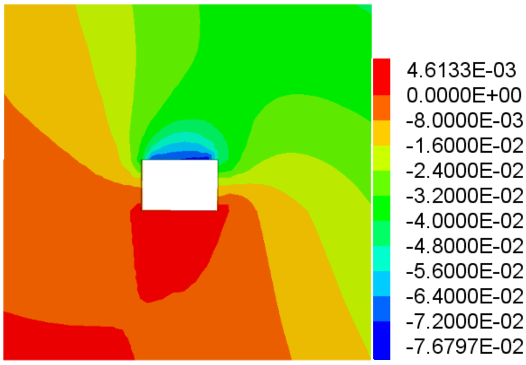
During the excavation process of the return airway of the 4326 working face, the vertical displacement changes of the surrounding rock of the roadway at the analysis section near the fault area are shown in Fig.4. When the excavation face of the roadway is 4 meters away from the analysis section, the vertical displacement of the surrounding rock at the analysis section caused by the excavation of the roadway is very small. At this time, the vertical displacement of the surrounding rock of the roadway at the analysis section is basically caused by the mining of the adjacent 4322 working face, and its maximum displacement value is approximately 8.0 to 24.00mm. When the tunneling face is close to the analysis section, the tunneling excavation will cause the roof near the tunneling face at the analysis section to have a vertical displacement into the tunnel, with a value of approximately 8.0mm. When the roadway excavation passes through the analysis section, due to the removal of the rock mass at the roadway location, the radial stress of the rock mass around the roadway begins to be unloaded, and the closer to the surface of the roadway, the greater the unloading amplitude. Therefore, the closer the rock mass is to the surface of the roadway, the greater its vertical displacement will be. That is, from the shallow part to the deep part, the vertical displacement of the rock mass at the cross-section of the roadway will decrease exponentially. At this point, the maximum vertical displacement of the surrounding rock of the roadway at the analysis section occurs at the position near the coal pillar side at the top of the roadway, with a value of approximately 76.8mm, which is approximately 64.8% higher than that far from the fault area. Thereafter, as the tunneling face gradually moves away from the analysis section, although the vertical displacement value of the surrounding rock of the tunnel at the analysis section will still gradually increase, the rate of increase will become smaller and smaller, and eventually tend to stabilize. When the tunneling face exceeds the analysis section by 14m, the maximum vertical displacement of the surrounding rock of the tunnel still occurs at the top of the tunnel near the coal pillar side, but its value increases to 111.6mm, which is approximately 58.8% higher than that far from the fault area.



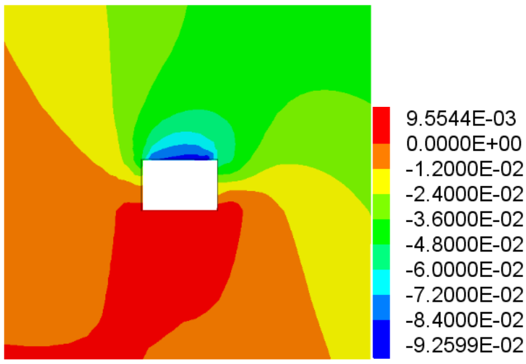
(a) The tunneling face is 4 meters away from the analysis section



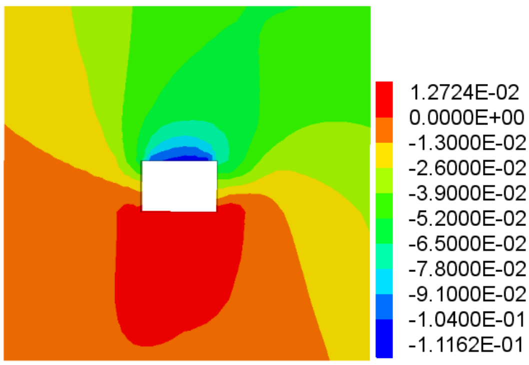
(b) The tunneling face is 2 meters away from the analysis section



(c) The tunneling face passes through the analysis section



(d) The tunneling face exceeds the analysis section by 4 meters

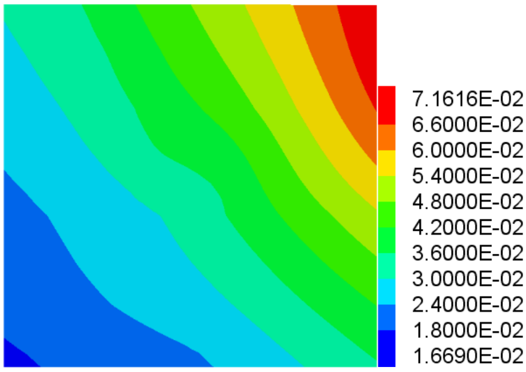


(e) The tunneling face exceeds the analysis section by 14 meters

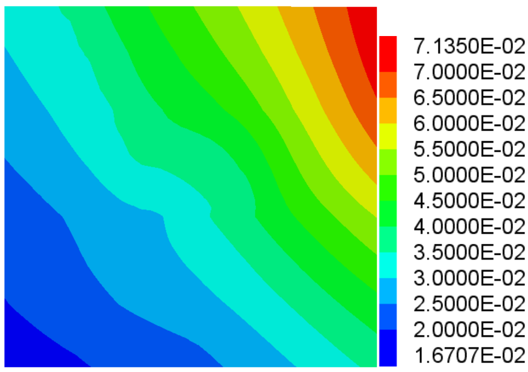
Figure 4. shows the vertical displacement changes of the surrounding rock at the analysis section during the tunneling process in the adjacent fault area

(b) Horizontal displacement

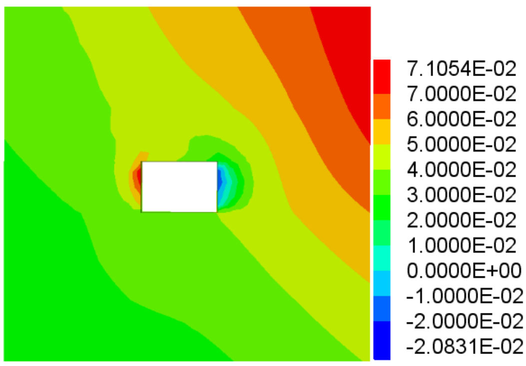
During the excavation process of the return airway of the 4326 working face, the horizontal displacement changes of the surrounding rock of the roadway at the analysis section near the fault area are shown in Fig.5. When the excavation face of the roadway is more than 4 meters away from the analysis section, the horizontal displacement of the surrounding rock at the analysis section caused by the excavation of the roadway is very small. At this time, the horizontal displacement of the surrounding rock of the roadway at the analysis section is basically caused by the mining of the adjacent 4322 working face, and its maximum displacement value is 30 to 42mm near the roadway. When the excavation face of the roadway is close to the analysis section, the excavation of the roadway will cause the rock mass near the excavation face of the roadway at the analysis section to have a horizontal displacement into the roadway, and its value is approximately 2.0-4.0mm. When the roadway excavation passes through the analysis section, due to the removal of the rock mass at the roadway location, the horizontal displacement of the surrounding rock of the roadway begins to increase significantly, especially on both sides of the roadway. At this time, the maximum displacement of the surrounding rock of the roadway occurs at the middle-upper position of the surfaces of both sides of the roadway. Its value is approximately 20.8mm on the coal pillar side and approximately 71.0mm on the solid side. And from the position where the maximum displacement occurs towards both sides, the horizontal displacement of the surrounding rock of the roadway gradually decreases to 0. As the tunneling face of the roadway gradually moves away from the analysis section, although the horizontal displacement value of the surrounding rock of the roadway at the analysis section will still gradually increase, the rate of increase will become smaller and smaller, and eventually tend to stabilize. When the tunneling face exceeds the analysis section by 14m, the maximum horizontal displacement of the surrounding rock of the tunnel still occurs at the middle-upper position of the surfaces of both sides of the tunnel. However, its value will increase to 64.4mm and 91.6mm respectively at the coal pillar side and the solid side. If the horizontal displacement caused by the mining of the adjacent 4322 working face is subtracted, The displacements of the actual coal pillar side and the solid side will reach 100.4mm and 55.6mm respectively after the roadway excavation is stable, increasing by approximately 79.3% and 75.4% respectively compared with those far from the fault area.



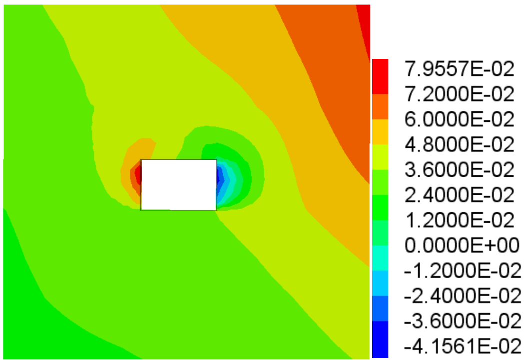
(a) The tunneling face is 4 meters away from the analysis section



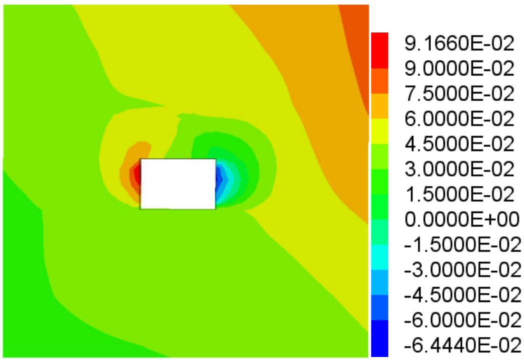
(b) The tunneling face is 2 meters away from the analysis section



(c) The tunneling face passes through the analysis section



(d) The tunneling face exceeds the analysis section by 4 meters



(e) The tunneling face exceeds the analysis section by 14 meters

Figure 5. shows the horizontal displacement changes of the surrounding rock at the analysis section during the tunneling process in the adjacent fault area

3. Conclusion

Under the condition of being close to the fault area, after the return airway of the 4326 working face was excavated, its maximum vertical displacement value was 111.6mm, which increased by approximately 58.8% compared with that far from the fault area. The maximum horizontal displacements of the coal pillar side and the solid side reached 100.4mm and 55.6mm respectively, increasing by approximately 79.3% and 75.4% respectively compared with those far from the fault area.

References

[1] Qian Minggao Scientific coal Mining [J]. Journal of China Coal Society, 2010, 35(4): 529-534.

[2] Xie Heping, Qian Minggao, Peng Suping, et al. A Preliminary Study on the Scientific Production Capacity and Development Strategy of Coal [J]. Engineering Sciences in China, 2011, 13(6): 44-50.

[3] Xie Heping, Wang Jinhua, Jiang Pengfei, et al. Research on New Concepts and Technological Changes of Scientific Coal Mining [J]. Engineering Sciences in China, 2015, 17(9): 36-41.

[4] Li Quansheng Theory and Technical System of Loss-Reducing Mining in Underground Coal Mines [J]. Journal of China Coal Society: 1-15.

[5] Yuan Liang. Innovation and Development of Safety Science and Technology in China's Coal Industry [J]. Coal Mine Safety, 2015, 46(S1): 5-11.

[6] WU Q, WANG M, WU X. Investigations of groundwater bursting into coal mine seam floors from fault zones[J]. International Journal of Rock Mechanics and Mining Sciences, 2004, 41(4): 557-571.

[7] Wang Gang, Huang Gul. Review on the Mechanism of Rock Burst [J]. China Mining, 2012, 21(S1): 400-405.

[8] Yu Guangming, Xie Heping, Yang Lun, et al. Numerical Simulation Study on the Fractal interface Effect of Mining Fault Activation [J]. Journal of China Coal Society, 1998(4): 62-66.

[9] Peng Suping, Meng Zhaoping, Li Yulin. Similar Simulation Experiment Study on the Influence of Faults on Roof Stability [J]. Coal Geology & Exploration, 2001(3): 1-4.

[10] Meng Zhaoping, Peng Suping, Feng Yu, et al. The influence of fault structure on mine pressure and roof stability in the mining face [J]. Coalfield Geology and Exploration, 2006(3): 24-27.