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Studies on the Stress Distribution Features and Changing Rules of Surrounding Rock of Roadway under Isolated Coal Face

Pengpeng Wu *, Peng Li

School of Shandong University of Science and Technology, Qingdao, China

*Corresponding author e-mail: 810070045@qq.com

Abstract. With the development of society and the progress of science and technology, people's living standard has been raised gradually. Behind these, it the development and utilization of energy. China is a large coal production country. Coal is the basic energy in China, and will be the major energy in the current decades and even in the coming decades. As coal is a non-renewable resource, plus the irrational exploitation in the first few years, a great deal of coal resources were wasted, which is contrary to the sustainable development strategy of the country. In recent years, to respond to national policies, vigorously promote sustainable development strategy, improve energy efficiency, major mining areas are enhancing the mining of residual coal, especially in isolated island state of coal. At present, there are some effective safety measures for mining coal under the condition of isolated island in China, but most of the safety research focuses on the mining face, but only a few studies focus on the safety of roadway. Through investigation, it is found that there are a series of problems in roadway driving and working face mining, such as strip wall and coal cannon. This seriously restricts the mining speed of isolated island working face, and always threatens the safety of workers. In this paper, the stress distribution characteristics of coal body under isolated island state are analyzed by numerical simulation. On the basis of this, the stress distribution characteristics of roadway surrounding rock and working face mining are analyzed, and the stress variation law is summarized. It is found that there exists a stress concentration zone in the coal pillar under the condition of isolated island. The stress concentration zone is mainly affected by the geological conditions of isolated island. There is a second stress concentration zone 7 m away from the side of the roadway, which is smaller than the stress concentration zone in the protected coal pillar, but the dynamic change is larger and the stress concentration zone moves with the advance of the working face because of the influence of mining in the working face. Therefore, in the aspect of maintaining the stability of roadway surrounding rock, the effective maintenance mode is determined according to the stress distribution characteristics and variation law of roadway surrounding rock under isolated island working face.



1. Introduction

Based on the study of N1206 isolated island working face in No.3 coal seam of Yuwu Coal Mine and the analysis of geological data, the basic situation of N1206 isolated island working face in No.3 coal seam of Yuwu Coal Mine is obtained.

N1206 working face is adjacent to the mined-out area of N2201 working face and the mined-out area of N1205 working face, the mined-out area to the south, the Huifeng Lane at the west of west wing of Beifeng Well to the north, the N2201 mined-out area to the east, and the N1205 mined-out area to the west. N1206 working face's designed length is 254m. The mining strike length is 790m. The mining area 213,665.1m². 1.76 million tons are recoverable reserves, N1206 face elevation ranges from -447 ~ -489 m. The average thickness of coal seam 3 # is 6.65 m, and the average inclination of coal seam - 3° ~ +7°. At present, in order to mine N1206 isolated island working face, N1206 isolated island working face is regarded as long coal pillar working face, so as to arrange roadway, and arrange N1206 tunneling roadway, N1206 tunneling roadway and N2201 working face gob with 25 meters protective coal pillar[1,2,3].

2. Study on Numerical Simulation

2.1. Establishment of Numerical Model

According to the geological conditions of N1206 isolated island working face in Yuwu Coal Mine, FLAC numerical simulation software is used to simulate the study. N1206 cross-section is rectangular. The width of tunnel excavation is 5.4m and the height of tunnel excavation is 3.8m. The thickness of coal seam in the model is 6.65 m. The basic top is medium-grained sandstone with a thickness of 11.40m. The direct top is siltstone, and the thickness is 1.50m. The direct bottom is mudstone, the thickness is 0.5 m. The basic base is fine-grained sandstone, and the thickness is 1.57 m. The tensile strength, uniaxial compression strength, elastic modulus, Poisson's ratio, cohesion, internal friction angle and other mechanical parameters of the rock in each layer were obtained by splitting test, uniaxial compression test and shear test of the rock samples in the surrounding rock of Yuwu Coal Mine. The calculation parameters in the simulation are shown in Table 1.

Table 1. rock mass calculation parameters

Rock names	Density /kg.m ⁻³	Bulk Modulus /GPa	Shear Modulus /GPa	Cohesion/MPa	Internal friction angle/°	Tensile strength/MPa	Thickness/m
Medium-grained sandstone	2560	0.32	0.69	2.81	36	2.56	11.40m
Siltstone	2444	0.25	0.59	2.43	29	2.21	1.50m
Coal	1345	0.13	0.12	0.84	29	0.63	6.65m
Mudstone	2400	0.23	0.22	1.12	37	1.82	0.50m
Fine-grained sandstone	2560	0.35	0.69	2.58	28	3.01	1.57m

The model has a strike length of 225 m, a tendency length of 60 m, a vertical height of 35 m, and a total of 472500 units and 47790" nodes, as shown in Figure 1. The boundary constraint of the model is horizontal displacement. The lower boundary constraint is vertical displacement. The upper boundary

is stress boundary, The upper boundary is applied vertical load. The load size is the self-weight of overburden rock on the model, and the size is 15.0 Mpa. Numerical simulation of initial equilibrium vertical stress is shown in Figure 2.

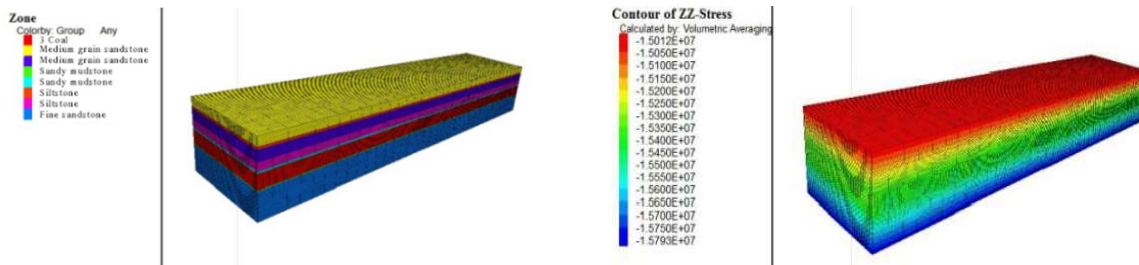


Figure 1. Numerical simulation model **Figure 2.** Distribution of initial equilibrium vertical stress

2.2. Stress State Analysis of Roadway Surrounding Rock

2.2.1. Stress Distribution Characteristics and Variation of Surrounding Rock During Roadway Excavation. Through numerical simulation software, under the condition of initial stress balance, the model is excavated to excavate the goaf of N1206 adjacent working face, and a new round of stress balance is carried out under the influence of goaf. After the stress balance of the model, the tunneling roadway of N1206 working face is excavated and simulated. The excavation model is shown in Figure 3.

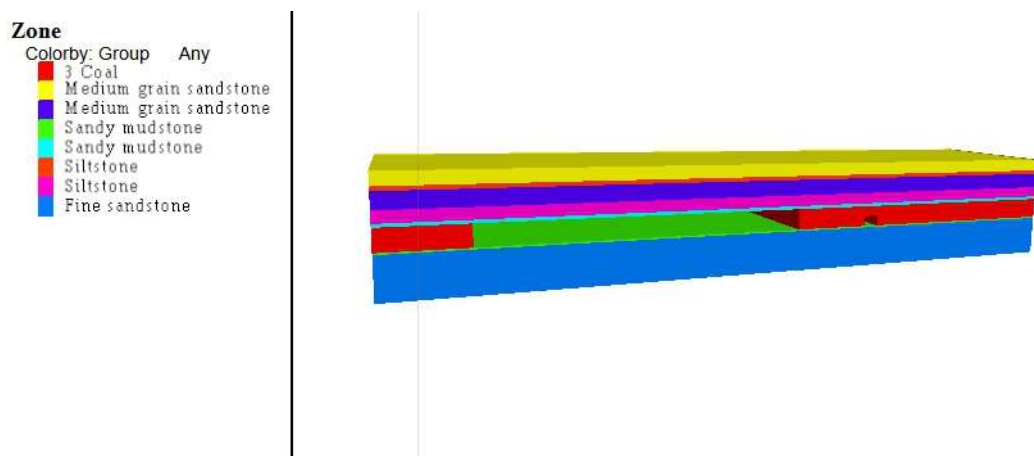
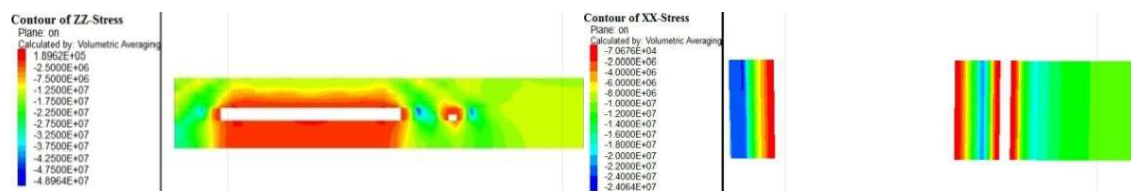


Figure 3. Numerical simulation model of drivage roadway

Numerical simulation software is used to simulate the vertical stress distribution cloud and horizontal stress distribution map in N1206 face driving tunnel, as shown in Figure 4.



(a) Vertical Stress Distribution Cloud Map

(b) Horizontal Stress Distribution Cloud Map

Figure 4. Stress Distribution Cloud during Excavation

As can be seen from the diagram, after excavation of roadway under lateral supporting stress in N1206 working face, the stress around return tunnel is re-distributed, and the depth of top and bottom plate is about 5 m, forming a low stress area similar to semi-ellipse. The vertical stress peak is formed at the middle position of coal pillar and the depth of solid coal wall at 7 m, which forms the vertical stress distribution state of the roadway with vertical stress concentration zone on both sides and stress reduction zone on and off. The horizontal stress distribution around the roadway is small, the horizontal stress in the pillar is small, the middle is large, the peak of horizontal stress is 22.32 MPa, the higher the horizontal stress of the solid coal side is, the peak value is 20.11 MPa at 10 m above the solid coal side.

By numerical simulation, the vertical stress monitoring is carried out at 30 Y coordinates, 1 m away from the roof of the tunnel, 65 measured points along the horizontal X axis of the model, and the vertical stress curve is drawn, as shown in Figure 5. Combined with the field situation, draw the schematic diagram shown in Figure 6.

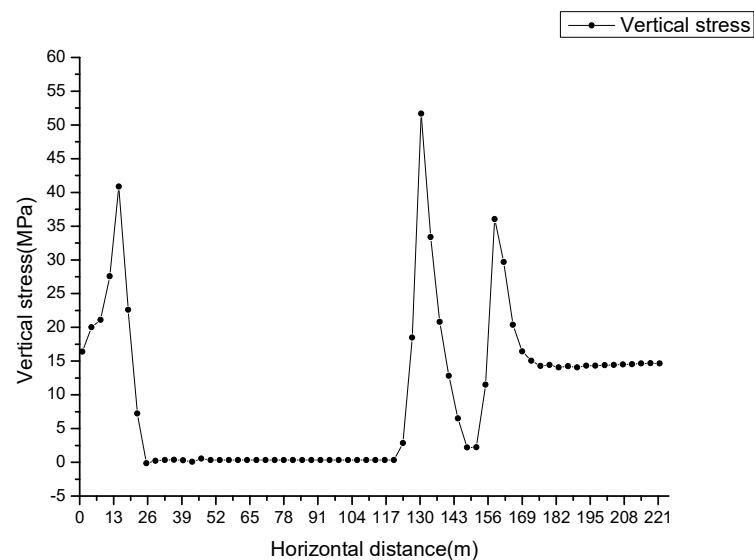


Figure 5. Vertical Stress Distribution Curve of Model

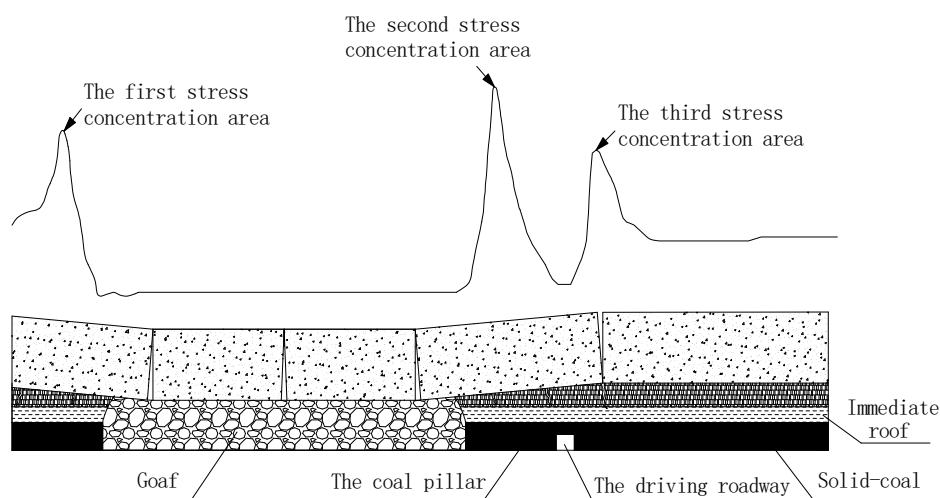


Figure 6. Vertical Stress Fractal Graph of Model

As can be seen from Figure 5 and 6, three stress concentration zones can be obtained by numerical simulation[4,5,6], which form the first stress concentration zones at the edge of the upper goaf, and the second stress concentration zones in the coal pillar (25 m wide) between the other edge of the upper goaf and the N1206 tunneling roadway. The third stress concentration zone is formed on the side of solid coal in N1206 tunneling roadway. The maximum vertical stress in the first stress concentration area is 42MPa, which occurs at 11m on the left side of the goaf in the upper section. The maximum vertical stress in the second stress concentration area is 52MPa, which produces in the coal pillar between the goaf in the upper section and N1206 driving roadway, which is 17m away from the left side of N1206 driving roadway. The maximum vertical stress in the third stress concentration area is 36 MPa, which is produced in the right side coal of N1206 driving roadway, 7 m away from the right side of N1206 driving roadway.

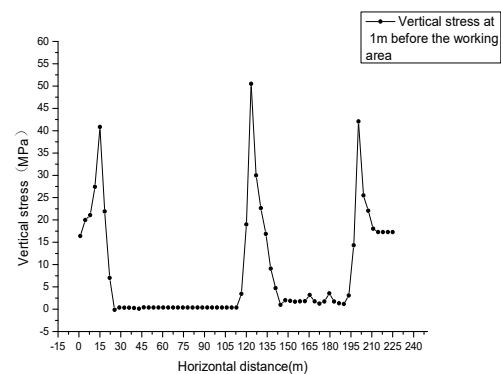
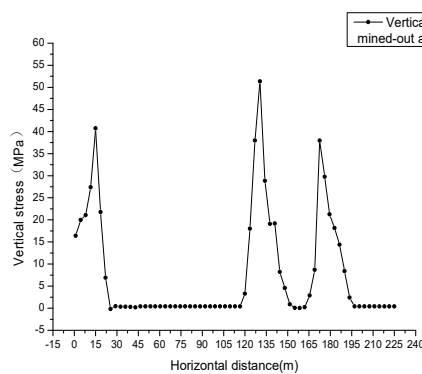
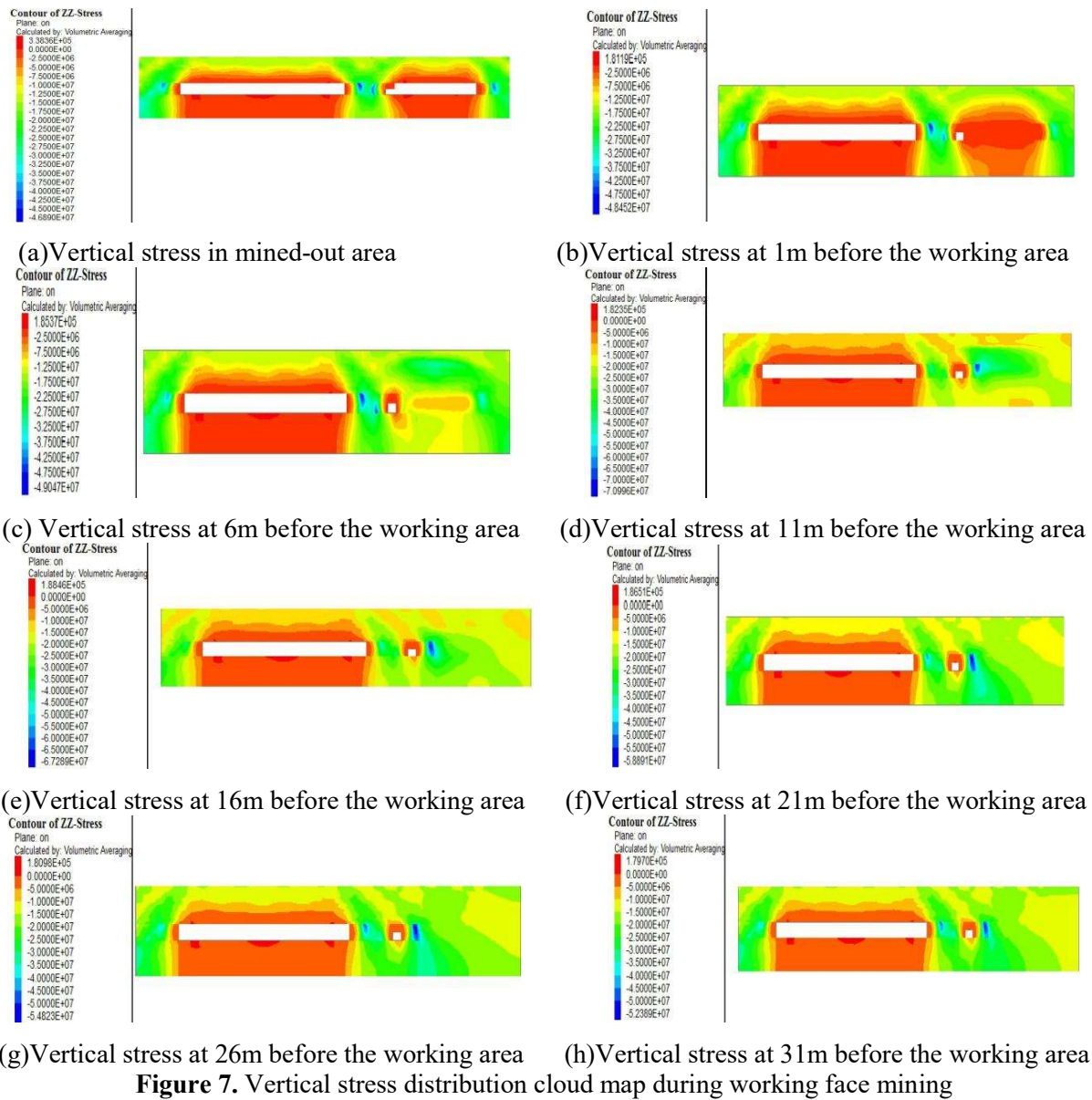
According to the data analysis of vertical stress and horizontal stress, it is found that N1206 tunneling roadway is in vertical stress unloading area, there is basically no roadway failure phenomenon. But combined with the field discovery, N1206 tunneling roadway part stage coal cannon, strip side phenomenon, especially the left side of the roadway, the vertical stress distribution map shows that although the vertical stress peak of the right side of the roadway is closer to the vertical stress peak of the left side of the roadway than that of the left side of the roadway. The vertical stress peak of the left side of the roadway (coal pillar) is larger and the influence range is wider. Therefore, the deformation of the surrounding rock of the left side of the roadway may be greater than that of the right side of the roadway. Therefore, the support of the right side of the roadway is strengthened while the support of the right side of the roadway is strengthened, and the support of the left side of the roadway is strengthened when necessary[7,8,9].

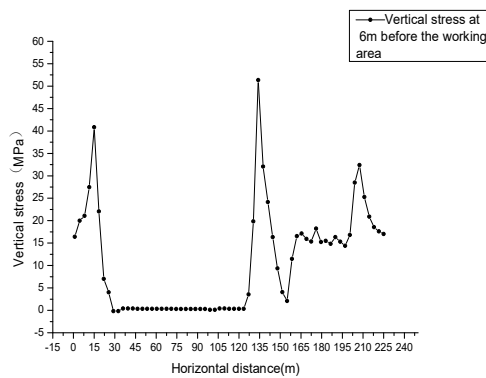
2.2.2. Stress distribution characteristics and variation law of surrounding rock during roadway mining
After tunneling, it is necessary to mine N1206 working face. Under the influence of the disturbance of mining face, the stability of surrounding rock of N1206 return wind is bound to be affected. Therefore, the roadway maintenance method is used to satisfy the stability of surrounding rock during tunneling. It also satisfies the stability of roadway surrounding rock during working face mining. Therefore, the stability of roadway surrounding rock during working face mining is simulated, and the failure mechanism and deformation characteristics of roadway surrounding rock are analyzed.

FLAC numerical simulation is used to simulate the vertical distribution cloud map and horizontal stress distribution cloud in the 0 ~ 30 m range before work, and then it is used to analyze the influence of vertical stress and horizontal stress on the stability of surrounding rock.

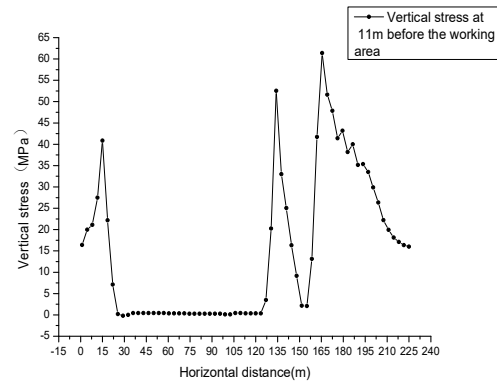
(1) Characteristics and variation of vertical stress distribution in surrounding rock of roadway

In the middle area of the working face, the vertical stress data of the middle position of coal seam are extracted from 0 ~ 30 m along the mining direction of the working face, 65 measuring points are arranged horizontally along the X-axis direction at a distance of 1 m from the roof of roadway, and data are recorded every 5 m from the side of the goaf, along the advancing direction of the working face, eight sets of data at the distance of 1 m, 6 m, 11 m, 16 m, 21 m, 26 m and 31 m are recorded respectively, which are shown in Figure 7 and Figure 8.

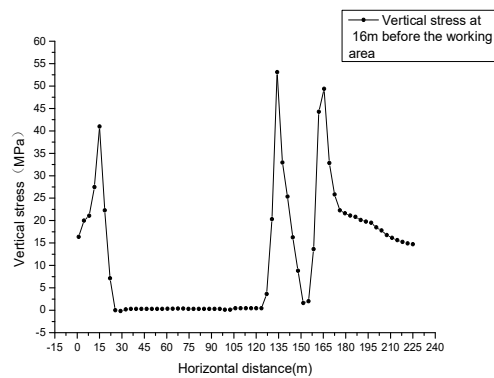




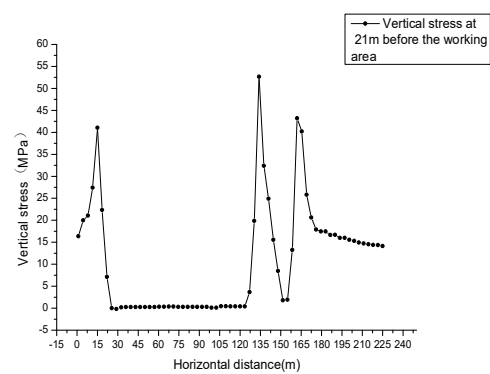
(c) Vertical stress curve at 6m before the working area



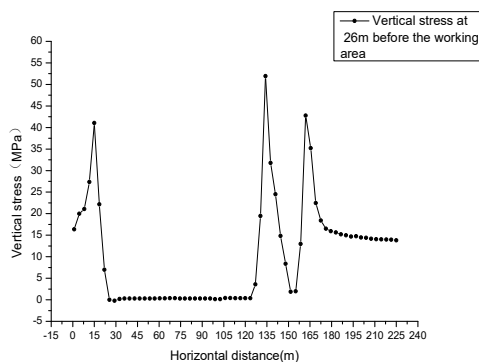
(d) Vertical stress curve at 11m before the working area



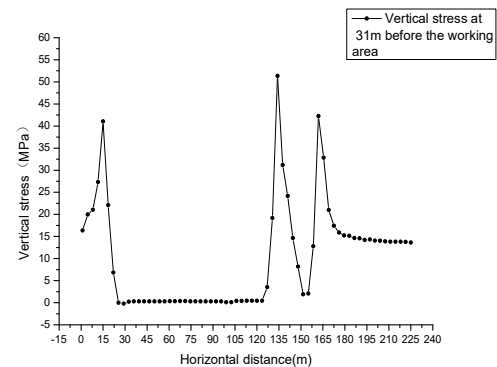
(e) Vertical stress curve at 16m before the working area



(f) Vertical stress curve at 21m before the working area



(g) Vertical stress curve at 26m before the working area



(h) Vertical stress curve at 31m before the working area

Figure 8. Vertical stress distribution curve during working face mining

According to the cloud diagram of vertical stress distribution and the curve of vertical stress distribution during working face mining, it can be seen that the change of the first stress concentration area and the second stress concentration area is smaller and the third stress concentration area is larger,

because the third stress concentration area is located on the solid coal side of N1206 working face. It is greatly affected by the disturbance of N1206 working face.

The vertical stress curve is basically the same as that of the working face when the working face has not been mined because of the new stress balance gradually. The peak stress of the third stress concentration area is gradually away from the right side of the roadway and away from the inner side of the solid coal. The peak value is about 50m from the right side of the roadway and the maximum vertical stress is 42.5MPa. At 6m ahead of the working face, the peak stress in the deep part of the solid coal gradually decreases, the stress near the right side of the roadway rises gradually, and the peak stress in the third stress concentration area gradually shifts to the right side of the roadway. But at this time, the peak stress in the deep part of the solid coal is 55m. The maximum vertical stress is 33 MPa. At 11m ahead of the working face, the stress peak in the deep part of the solid coal gradually decreases, the stress near the right side of the roadway rises gradually, and the stress peak in the third stress concentration area continues to shift to the right side of the roadway, and the stress peak is located at 13m in the right side of the roadway. The maximum vertical stress is 62 MPa. At 16m ahead of the working face, the stress peak value of the third stress concentration area continues to shift to the right side of the roadway, and the stress value of the deep part of the solid coal gradually stabilizes. The stress peak value lies at 10m at the right side of the roadway and the maximum vertical stress is 50MPa. At 21 m ahead of the working face, the peak stress in the third stress concentration area continues to shift to the right side of the roadway, and the stress value in the deep part of the solid coal gradually stabilizes. The peak stress is 7 m at the right side of the roadway, and the maximum vertical stress is 43 MPa. The stress peak of the third stress concentration zone is no longer transferred to the right side of the roadway at 26m ahead of the working face and 31m away from the working face, and the stress value of the deep part of the solid coal tends to stabilize. The stress peak is located at 7m in the right side of the roadway and the maximum vertical stress is 43MPa is no longer changed.

In a comprehensive analysis, the influence of mining on the vertical stress of the right side of the roadway during the mining period has a great influence on the vertical stress of the right side of the roadway. The maximum stress of the third stress zone in the same position is 7 MPa higher than the maximum stress of the third stress zone in the excavation period. The distribution of maximum stress in the third stress concentration region is shown in Figure 9.

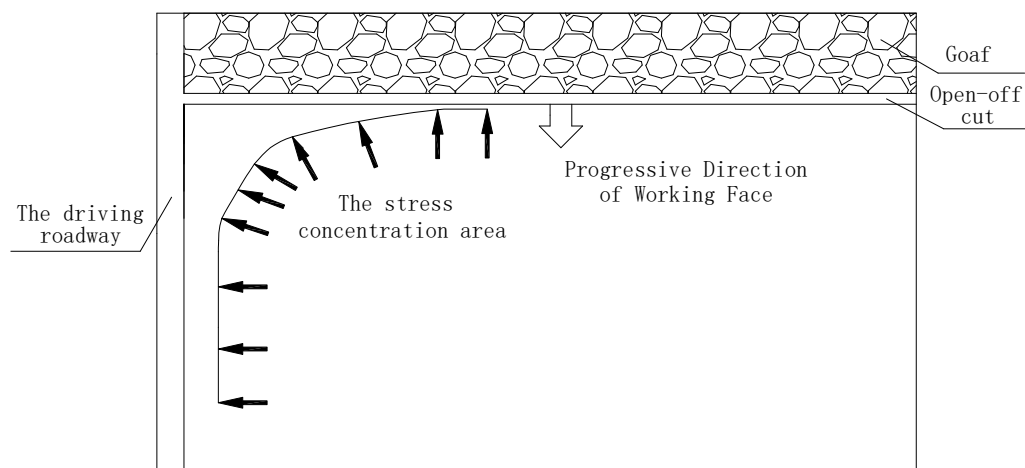


Figure 9. Distribution of the maximum vertical stress in the leading section of working face

The vertical stress change of roadway roof in goaf, working face and the unmined part of working face is observed in X coordinate of 152.5, which is the X coordinate where the roadway is located, 60 measuring points are arranged horizontally along Y axis at 1 m away from the roof of the roadway, as shown in Figure 10.

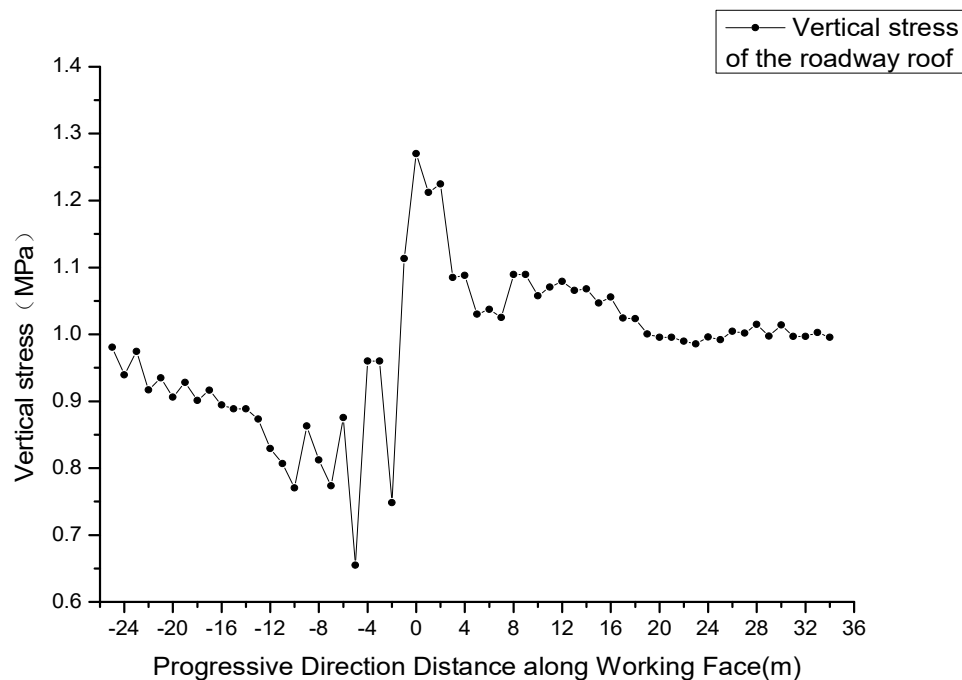


Figure 10. Vertical stress distribution curve of roadway roof during working face mining

Because the location of the roadway is not located in the stress concentration area of the roadway, the vertical stress of the roadway roof is within the controllable range, but during the working face mining, the vertical stress of the roadway roof is different at different stages. As can be seen from Figure 10, the stress increases gradually at the mining face. At the leading distance of mining face 0 ~ 6m, the roof of roadway appears stress concentration, and at the leading distance of working face 3m, the roof of roadway appears the maximum vertical stress. The actual effect of vertical stress distribution of roadway roof is shown in Figure 11.

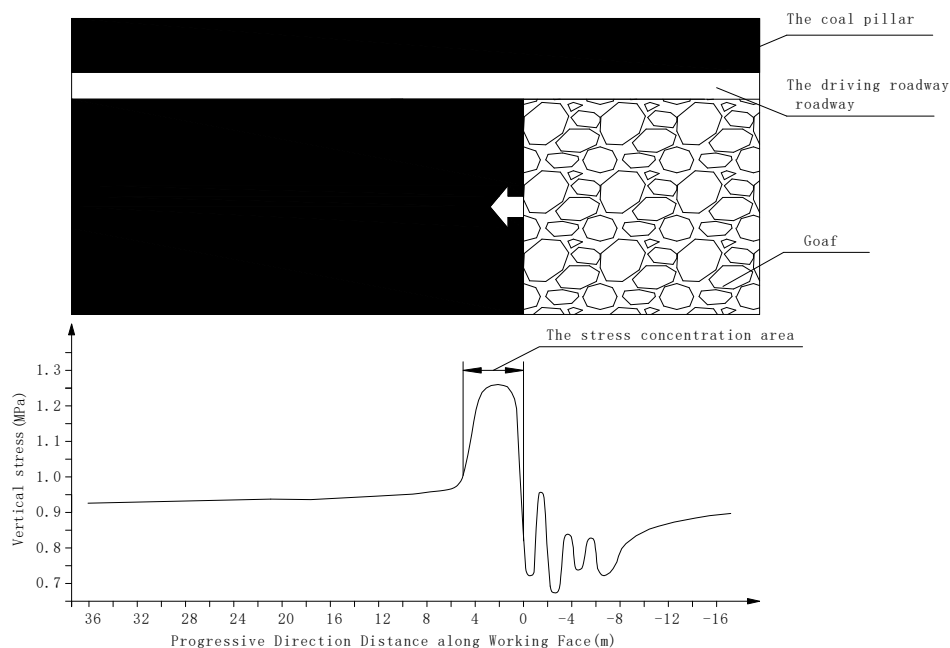


Figure 11. Vertical stress distribution of roadway roof during working face mining

(2) Characteristics and variation law of horizontal stress distribution of roadway surrounding rock

In order to observe the horizontal stress distribution characteristics of roadway affected by mining, the horizontal plane of roadway is mainly observed, as shown in Figure 12.



Figure 12. Horizontal Stress Distribution Graph during Mining

Taking the mining face as the starting point and the advancing direction of the working face as the horizontal coordinate, 35 measuring points are arranged in the middle position of the right side of the roadway respectively to record the horizontal stress data of the right side of the roadway (Figure 13a). Based on the model Y terminal, the horizontal stress data of the left side of the roadway are recorded in the middle position of the left side of the roadway (Figure 13b).

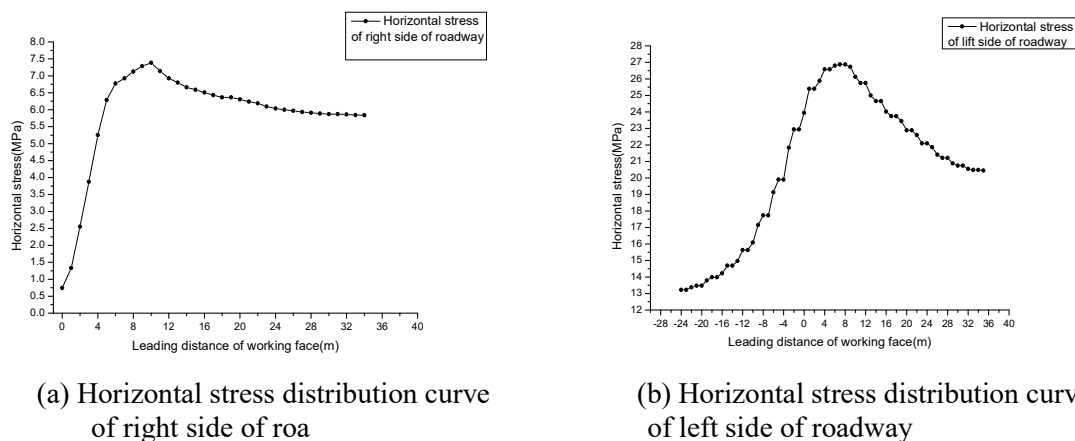


Figure 13. Horizontal stress distribution curve during working face mining

Figure 13 shows that the horizontal stress concentration exists in the two sides of the roadway at 8m lead distance, and the horizontal stress concentration area moves with the advance of the working face, among which the maximum horizontal stress on the right side is 7.5 MPa, the maximum horizontal stress on the left side is 27 MPa, and the left side is 3.6 times the right side. When the advance distance of the working face reaches 30m, the horizontal stress of the two sides of the roadway is basically stable, in which the horizontal stress of the right side of the roadway is 6MPa, the horizontal stress of the left side of the roadway is 20MPa, and the left side is 3.3 times of the right side.

According to the above data, the horizontal stress of the left side of the roadway is greater than that of the right side of the roadway, because the left side of the roadway is an island coal pillar, which is affected by the roof pressure, and the roof pressure is converted into shear stress and then into horizontal stress. Therefore, during the tunnel support period, the support management of the left side of the roadway is increased to ensure the stability of the roadway surrounding rock during working face mining [10,11,12].

3. Conclusion

By understanding the actual situation of the isolated island working face and combining with the geological condition of the adjacent mine, the paper simulates the stress distribution characteristics of the surrounding rock of the roadway when the roadway is excavated and the stress distribution of the roadway when the working face is mined, and analyzes the stability of the surrounding rock of the roadway.

Through simulation, the following rules are summarized:

(1) Stress distribution characteristics and variation law of surrounding rock in roadway excavation

Under the condition that the location of roadway has been determined, the characteristics of surrounding rock are mainly affected by isolated islands. In the aspect of vertical stress, there exists stress concentration at 17m on the left side of N1206 tunneling roadway in the coal pillar between goaf and N1206 tunneling roadway in the upper section. In the right side of N1206 tunneling roadway, there is stress concentration 7m away from the right side of N1206 tunneling roadway. The maximum vertical stress of the left side of the roadway is greater than that of the right side of the roadway. Because of the strong stress concentration of coal pillar, according to the coal seam buried geological conditions, the coal quality is brittle, so the left side of the roadway is prone to such disasters.

The horizontal stress distribution around the roadway is small, and the horizontal stress in the coal pillar is small on both sides and large in the middle. The higher the horizontal stress in the solid coal is, the higher the peak value is at 10 m above the solid coal bank.

(2) Stress distribution characteristics and variation law of surrounding rock in roadway mining face

Eight sets of data at the distance of 1 m, 6 m, 11 m, 16 m, 21 m, 26 m and 31 m are recorded. It can be seen that the stress concentration area located on the solid coal side of N1206 working face is greatly influenced by the disturbance of N1206 working face. The maximum stress of the stress zone in the same position is larger than that of the stress zone in the tunneling period. In the advanced distance section of the working face, there is always an arc-shaped vertical stress concentration zone. There is a stress concentration zone in the coal of the right side of the roadway, which is the nearest stress concentration zone to the right side of the roadway. The vertical stress concentration zone on the left side of the roadway is formed in the coal pillar 17m away from the left side of the roadway.

At 8m advance distance of working face, horizontal stress concentration exists in the two sides of roadway, and the horizontal stress concentration area moves along with the advance of working face. When the advance distance of the working face reaches 30m, the horizontal stress of the two sides of the roadway is basically stable.

(3) Stress distribution characteristics and variation law of roadway roof during mining face mining

It is easy to find that the vertical stress of the roof is different in different stages during mining, the stress increases gradually at the working face, and the stress concentration appears at the leading distance 0 ~ 6 m of the working face. And at the advance distance of 3 m, the maximum vertical stress appears on the roof of the roadway.

(4) The stress concentration area in the left side of the roadway is larger than that in the right side, so the deformation of the left side of the roadway is larger than that of the right side of the roadway. In the course of roadway maintenance, the maintenance of left side of roadway should be strengthened.

For the right side of the roadway, it is shown by simulation and research that the stress variation of the right side of the roadway is basically stable or small, and the change of the right side of the roadway is mainly occurred during the working face, and always occurs in the leading distance section of the working face. During the working face mining, the support of the right side of the roadway should be increased, the stability of the right side of the roadway should be maintained, and the influence of the mining on the right side of the roadway should be reduced.

Therefore, combining with the concrete geological conditions of Yuwu Coal Mine, the study on the stress distribution characteristics and variation law of the surrounding rock under the working face of isolated Island can be used not only to solve the practical problems on the spot, but also to ensure the stability of the surrounding rock in the driving roadway. It can also provide reference for the study of the stability of roadway surrounding rock under the condition of the same type of isolated island.

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