Surrounding Rock Stress State Characteristics of Gob-side Entry Driving during Island Mining in Complex Condition

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ABSTRACT

Stresses, deformation and failure characteristics of surrounding rock are commonly taken into account in underground mining. At present, these characteristics are not clear in the upper and lower coal seam roadway driving along gob island, a theoretical analysis using computer numerical simulation techniques and the specific engineering practice are applied to the understanding of the roadway roof movement patterns, stress distribution and deformation of surrounding rock strata during the roadway driving and working face mining along gob island. Results show that due to effects of mining, the stress distribution characteristics are different from the normal conditions. The width of coal pillar has a great influence on the roadway deformation characteristics. The coal pillar side deformation is larger than the coal body side and the roof deformation is greater than the floor deformation during driving the gob-side roadway. During the working face mining, the roadway surrounding rock is mainly failed in shear. With the working face advancing, the dynamic pressure and influence area are increasing gradually; the convergence rate is also increasing. For the gob-side entry driving along the island mining, it should follow the surrounding rock whole section control technical approaches of Strengthen roof, Fixed side and Control floor to strengthen the supporting of roadway near the up and down corner to improve its surrounding rock strength and ensure the island working face safety in production.

KEYWORDS: upper and lower gob; island working face; gob-side entry driving; surrounding rock deformation; strata pressure characteristic
INTRODUCTION

China is the largest coal producer in the world. With the rapid development of the national economy and strong demand for energy, the coal production in China has significantly increased in recent years. As available shallow resources decrease, the coal mining gradually starts to turn to deep resources (Li et al., 2015). According to the geological condition and the coal deposit sustainable mining plan of underground mining, an alternating long-wall mining method is adopted into the production practice. In fact, the mining process around the working face has a complete mining-induced mechanics process which has three stages, initial rock mass stress, increased axial pressure and decreased confining pressure, and final destruction (Xie et al., 2012). Sometimes it is inevitable to leave two-side, three-side or four-side gobs around the working face which become the island working faces (Yang et al., 2013). During the roadway excavating and the island working face mining, roadway supporting in such seriously broken surrounding rock is of huge cost and difficulty for the influences of the lateral fractured roof and the dynamic pressure. Furthermore, the coal pillar also plays an important role in the course of protecting the roadway stability and the mining safety (Zhang et al., 2013). So it is important understand the characteristics of surrounding rock stress distribution and changes around island face. In particular, pillar size and roadway supporting are always the major considerations in island face mining design.

In recent years, many researchers have worked on the analysis of the stress distribution and deformation characteristics of surrounding rock in deep mining, there are also some technologies in the gob-side entry driving and the surrounding rock deformation control. G.X. Xie (Xie et al., 2009) found that a macro-stress shell composed of high stress exists in the rock surrounding a fully mechanized top-coal caving face. The stress of the shell is higher than its internal and external stress and the stresses at its skewback producing abutment pressure for the surrounding rock. The stress shell lies in the virgin coal and rock mass in the vicinity of the face and its sagging zone. But there are many influences on the surrounding rock stress distribution and deformation. In general, the mining sequence, the mining subsidence feature, the geological condition, the roadway layout, the working face parameter and the mining method etc. are included. The stability of mine developments with respect to mining sequence with focus on the performance of haulage drift intersection during the production plan (Abdellah et al., 2014). Ren (Ren et al., 2014) analyzed the application of a general influence function method for subsidence prediction in multi-seam longwall extraction in Hunter coalfield of in New South Wales, Australia. Adhikary (Adhikary and Guo, 2014) suggested that the systematic sub-surface and underground hydrogeological monitoring and measurements are carried out e.g. underground packer tests and piezometer, extensometer, and water inflow monitoring during mining. Their researches are helpful for the rational design of the roadway and working face position, the scientific planning of mining.

In recent years, as deep mining has developed, many new mining technologies and methods have been widely promoted. In the aspect of gob-side entry driving, some research results have showed that bending and folding floor heave is the main factor in the stage of the first panel mining; squeezing and fluidity floor heave plays an important role in the maintaining the stability at gob-side entry; The side corners of solid coal body are a key part in the case of floor heave controlling of gob-side entry retaining (Chen et al., 2012). Researchers have analyzed the effects of using roadside cables to reinforce supporting in gob-side entry surrounding rock controlling based on elastic-plastic theory and material mechanical behaviors (Deng et al., 2010). According to the special engineering conditions, they have analyzed the feasibility of gob-side entry retaining on a working face in steep coal seam (Deng and Wang, 2014), the coupling mechanism
of roof and supporting wall in gob-side entry retaining in fully-mechanized mining with gangue backfilling (Ma et al., 2011), the structural effect of a soft-hard backfill wall in a gob-side roadway (Wang et al., 2011), the spontaneous caving and gob-side entry retaining of thin seam with large inclined angle (Zhang et al., 2014), etc. But there is little in depth research into the surrounding rock stress, deformation and failure characteristics of gob-side entry driving during the island working face mining with the upper and lower coal seams partly mined.

In this paper, the specific engineering conditions of island working face mining are considered after the upper coal bed and the lower coal bed partly mined. The combined research methods are adopted: theoretical analysis, numerical simulation and engineering practice, to analyze the surrounding rock stress distribution, deformation and failure laws and the working face abutment pressure characteristics during the roadway excavating and the island face mining. This paper can be used as a reference for theory and support parameters of gob-side entry driving with complex condition coal mining.

BACKGROUND

As a major coal producer, the Huainan Mining Industry has 11 active coal mines producing more than 15 million tons of coal annually in China. These mines drain about 50 million cubic meters (nearly 1.8 billion cubic feet) of methane annually. Guqiao coal mine is one of them, located within a coal field of 106.7 square kilometers with the geological reserves of 1870 million tons and the recoverable reserves of 968 million tons. And the designed production is 5 million tons per year. The main mining coal beds in the first level are the coal seam 13-1# and 11-2#.

The 13-1# coal seam thickness ranges from 0.90 m to 9.39 m with a mean thickness of 3.56 m, the relatively simple geological structure, the dirt bands from 1 to 2 layers and the variable coal quality. The 13-1# coal seam is relatively stable with the roof of clay rock, the floor of mudstone or sandy mudstone. There are two thin coal layers which are 13-2# and 12# coal seam between the 13-1# and the 11-2#, and the two layers are unrecoverable. There is a layer of graniphyric mudstone with the mean thickness of 12 m at the bottom of 13-1# coal seam.

The 11-2# coal seam thickness ranges from 1.0m to 3.4 m with the mean thickness of 2.6 m and fine geological conditions. The dip angle ranges from 3° to 10° with the mean value of 5°. In addition, its immediate roof is composited and the roof and floor characteristics are shown in Table 1.

Working face No. 1116 (3) of Guqiao mine is an island working face in the 13-1# coal seam above the 11-2# coal seam. The vertical distance is 75 m between the two coal seams. The working face No. 1116 (3) is partly excavated, and the upper and lower sides (those are the working face No. 1115 (3) and No. 1117 (3)) have been excavated. Working face No. 1116 (1) is buried in depth from 650.1 m to 782.7 m in main mineable coal seam 11-2#. For the upper and lower sublevels (those are the working face No. 1115 (1) and No. 1117 (1)) are previously excavated in the 11-2# coal seam, the working face No. 1116 (1) is an island working face with the upper side coal pillar width of 8m and the lower side coal pillar width of 20m, but its excavating direction is opposite to the working face No. 1116 (3). The special spatial location relationship is shown in Fig.1.
Table 1: The roof and floor rock characters of 11-2# coal seam

<table>
<thead>
<tr>
<th>Rock name</th>
<th>Rock properties</th>
<th>Thickness (m)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper roof</td>
<td>Middle-fine sandstone</td>
<td>16.9~24.0</td>
<td>Offwhite~milk-white, thick-stratiform, fine-medium grain structure, calcite cementation, contains dark mineral, parallel bedding and cross bedding</td>
</tr>
<tr>
<td>Immediate roof</td>
<td>Mudstone, 11-3 coal seam, sandy mudstone, siltstone</td>
<td>0~4.5</td>
<td>Gray~ dark gray, sliding surface, contains 11-3 coal seam and coal line</td>
</tr>
<tr>
<td>False roof</td>
<td>Carbonaceous mudstone</td>
<td>0~0.3</td>
<td>Black, dye hand, broken</td>
</tr>
<tr>
<td>Immediate floor</td>
<td>Mudstone</td>
<td>0.95~4.05</td>
<td>Gray~ dark gray, argillaceous cementation, contains phytolith and 1-2 layers thin seam</td>
</tr>
</tbody>
</table>

Figure 1: The relationship between the two coal seams and working spaces

This paper presents a three-dimensional numerical model experimental research into the surrounding rock stress distribution, deformation and failure pattern, and the working face pressure characteristics during the gob-side entry excavating and the working face No. 1116 (1) mining. It is intended to resolve those problems and difficulties encountered in field excavating and supporting by considering geological conditions of the gob-side entry driving of working face No. 1116 (1).

NUMERICAL MODELLING

Model design

In order to simulate the surrounding rock stress distribution and displacement during the gob-side roadway excavating and the island face mining, the numerical software FLAC3D 3.0 is used. The FLAC3D can be used to simulate the behavior and stress changing of rock materials. According to the practical geological conditions and the working face layout parameters, a large-scale 3-dimensional model is created. In the model, the tectonic stress induced by tectonic movement is not considered for simplification, and the three-dimensional isobaric self-weight...
stress field is adopted for the in-situ vertical and horizontal stress. The mesh size should be large enough so that the external boundary can represent an infinitely extended medium. Otherwise, the presence of the artificial boundaries will induce a significant influence on the stress-strain field around the working face (Zhao et al., 2014).

As the surrounding rock areas which are influenced by excavating after both side working faces being mined in the upper and lower coal seams are approximately large scale, the parameters of island face, the distances between coal seam 11-2# and 13-1# and the pillar width are taken into account. Emphasis is placed on the excavation order of these working faces and on the interaction between the gob-side entry driving and the island face mining. The external boundary is set to a distance of 50m between the bottom boundary and the 11-2coal floor, of 50m between the left and right boundary and the working face roadway. The parameters are adopted on the thickness of 2.5m of coal seam11-2#, the thickness of 3.5m of coal seam 13-1#. Because of the mean dip-angle of coal seam is very low (only 5°), the coal seam can be regarded as the horizontal coal seam.

Once the 3D model is created, the following boundary conditions are imposed:

1. The left and right boundaries are defined as the single constrained boundaries, set to $u=0$, $v=w\neq 0$.

2. On the bottom boundary, the displacements of the X,Y and Z direction are much smaller than the gob overlying rock displacements, so it is defined as the full constrained boundary, set to $u=v=w=0$.

3. On the top boundary, the X and Y direction displacements are larger, so it is defined as the free boundary, no constraint.

4. It can apply the uniformly distributed load to simulate the overlying rock gravity on the top of the model.

The excavation distances of 310 m in working face No. 1117 (1) and No. 1117 (3), of 330 m in working face No. 1115 (1) and No. 1115 (3) and the boundary size are taken into account. In this paper, the model dimensions (length × width × height) are 500 m × 588 m × 180 m and mean of the direction of X, Y and Z. In this model, it is composed of 167400 3D units and 177769 nodes. The model mesh grid and size are shown in Fig. 2.
Calculation parameters

According to the mechanics experiment results of the field sampling, when the loads reach the ultimate strength, the core sample would deform and fail gradually. In the process of plastic flow after the peak, the residual strength of rock mass would decrease gradually with the extension of deformation. Therefore using the Mohr-coulomb criterion for calculation, we have the following failure criterion shown in formula (1):

\[
f_s = \sigma_1 - \sigma_3 \frac{1 + \sin \phi}{1 - \sin \phi} - 2c \sqrt{\frac{1 + \sin \phi}{1 - \sin \phi}}
\]  

(1)

where \( \sigma_1 \) is the major principal stress, \( \sigma_3 \) is the minor principal stress, \( c \) is the cohesion, \( \phi \) is the internal friction angle.

When \( f_s > 0 \), shear failure occurs. In general, the stress state and tensile strength of rock mass is very low, the strength criterion of extension (\( \sigma_1 \geq \sigma_3 \)) is adopted into determining the rock damage or not. On the process of analog calculation, the mechanical parameters of rock mass are shown in Table 2.
**Table 2:** The mechanical parameters of rock mass

<table>
<thead>
<tr>
<th>Rock name</th>
<th>Unit weight $d$/(kg·m$^{-3}$)</th>
<th>Bulk modulus $E$/MPa</th>
<th>Shear modulus $G$/MPa</th>
<th>Cohesion $c$/MPa</th>
<th>Internal friction angle/($^\circ$)</th>
<th>Tensile strength /MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siltstone</td>
<td>2460</td>
<td>$10 \times 10^3$</td>
<td>$8.4 \times 10^3$</td>
<td>3.75</td>
<td>36</td>
<td>1.84</td>
</tr>
<tr>
<td>Mudstone</td>
<td>2460</td>
<td>$9 \times 10^3$</td>
<td>$6 \times 10^3$</td>
<td>1.2</td>
<td>32</td>
<td>0.88</td>
</tr>
<tr>
<td>Sandy mudstone</td>
<td>2510</td>
<td>$5.1 \times 10^3$</td>
<td>$4.5 \times 10^3$</td>
<td>2.45</td>
<td>38</td>
<td>2.1</td>
</tr>
<tr>
<td>Packsand</td>
<td>2870</td>
<td>$13 \times 10^3$</td>
<td>$10 \times 10^3$</td>
<td>3.2</td>
<td>40</td>
<td>2.3</td>
</tr>
<tr>
<td>Sandstone</td>
<td>2480</td>
<td>$12 \times 10^3$</td>
<td>$9.2 \times 10^3$</td>
<td>2.5</td>
<td>40</td>
<td>3.6</td>
</tr>
<tr>
<td>Coal</td>
<td>1380</td>
<td>$4.9 \times 10^3$</td>
<td>$2.4 \times 10^3$</td>
<td>1.25</td>
<td>32</td>
<td>0.35</td>
</tr>
</tbody>
</table>

**Simulation process**

The rock mass mechanical behaviors are mainly related to the mining history and the mining progress. In order to correctly simulate the stress distribution and the displacement field of the surrounding rock. The modeling process is divided into the following steps:

Firstly, to calculate the model initial stress states under the given boundary conditions. Secondly, according to the working face excavating sequence, to simulate the excavation of working face No. 1117 (3), then one by one to excavate working face No. 1115 (3), No. 1117 (1) and No. 1115 (1). Thereafter, to simulate the excavation and support return roadway and transportation roadway of working face No. 1116 (1). Lastly, to excavate the island face No. 1116 (1) of coal seam 11-2#, step by step.

**SURROUNDING ROCK MECHANICAL CHARACTERISTICS DURING THE GOB-SIDE ENTRY EXCAVATION**

After removal of the coal from underground, considerable cavities are created, the state of stress in their surroundings changes significantly. Meanwhile, the displacements around the roadway also develop. The vertical stress and failure state distribution of surrounding rock is shown in Fig. 2 after the upper and lower levels of the 11-2# and 13-1# coal seams have been mined. The rock mass radical pressure disappeared in result of coal seam mining, so the rock mass can’t keep the triaxial compression stress state yet. In addition, the values of coal and rock mass volume on the edge of roadway and gob decrease first and then increase. At the same time, the displacement and fractures of surrounding rock increase gradually. So that, the mechanical property of surrounding rock also changes.
The vertical stress distribution of No. 1116 (1)’s return roadway surrounding rock is shown in Fig. 2 (a). It shows that the maximum vertical stress ($\sigma_z = 45$MPa) among 8m width pillar is 2.5 times higher than the initial stress ($\sigma_z = 17.5$MPa), which is effected by the dip abutment pressure.
of gob No. 1115 (1) and the accessional stress during the No. 1116 (1)’s return roadway being excavated. But in Fig. 2 (b), the maximum vertical stress ($\sigma_z=35$MPa) among the 20m width pillar is 2 times higher than the initial stress, which is effected by the dip abutment pressure of gob No. 1117 (1) and the accessional stress during the No. 1116 (1)’s transport roadway being excavated. As the width pillar between the gob and the roadway increases from 8 m to 20 m, the stress state in the middle of coal pillar also changes from plastic to elastic. And when the pillar width is 20 m, the elastic zone width in the middle of 20 m coal pillar is around 10m. It is shown in Fig. 2 (c).

In addition, we obtain the deformation data of roadway during the simulation. It is shown that the roof subsidence is 1.5 times larger than the floor heave and the pillar side deformation is 1.45 times larger than the coal side deformation in return roadway. Meanwhile, the roof subsidence is 1.5 times larger than the floor heave and the pillar side deformation is almost same as the coal side deformation in transport roadway.

The total deformation of transport roadway is smaller than return roadway’s. That is because the bigger size pillar can support the roof pressure enough and decrease the surrounding rock concentrated stress.

As mentioned above, pillar width is the direct reason for the different characteristics of deformation, plastic zone and concentrated stress zone between the transport roadway and the return roadway during the gob-side entry driving. But it means not the bigger the better of the pillar width. It is therefore necessary to design the economic and scientific pillar width when the roadway safety size, air demand, fire preventing and safe production are taken into account.

SURROUNDING ROCK MECHANICAL CHARACTERISTICS DURING THE ISLAND FACE EXCAVATION

Surrounding rock stress distribution

*Vertical stress distribution of overlying rock*

As the coal seams are excavated, the overlying rock appears subsidence, bend and caving. From there, it can be seen that the stress redistribution occurs within the damage area. And in the different position along strike direction, the stress distribution features are also different. While the excavating distance is 40 m, the vertical stress reduces above the gob ranging from 0 m to 15 m. At the edge of gob, the overlying rock above the caving wall is broken by pulling cut and the shear failure occurs easily.

In addition, during the coal seam 11-2# excavating, the size of concentrated stress zone in front of working face is larger than back of open-off cut.

*Surrounding rock dip section stress distribution in front of working face 10m*
(a) Excavating 40 m

(b) Excavating 80 m

(c) Excavating 120 m
In the different position along strike direction, the stress distribution features are also different. According to the practical experience in Huainan coal field, the concentrated stress peak zone in front of working face ranges from 5 m to 20 m. So in this article, the surrounding rock dip sections in front of working face 10 m are chosen in different excavating distance to analyze the stress distribution. It is shown in Fig. 3.

The stress distribution states around the transport and return roadway are obtained from Fig. 3 in different excavating distance. With the working face advancing continually, the value of peak stress increases gradually in the middle of return roadway pillar. When the face excavating distance ranges from 120 m to 140 m, the value of peak stress increases to 50 Mpa, the stress concentration factor is 2.86 in the 8m pillar, and the value of peak stress increases to 45 Mpa, the stress concentration factor is 2.57 in the 20 m pillar respectively.

**Main stress distribution of coal seam11-2#**

As the coal seams are excavated, not only the upper and lower surrounding rock stress redistribution occurs, but also in the coal seam around the gob the stress redistribution occurs. Furthermore, the coal seam stress distribution features are also different in different stope structures and parameters. In the course of excavating, the position of island face changes as shown in Fig. 4.

When the both sides of working face are entity coal seam, the stress distribution shape is the basic symmetry ranging from upper to lower. When the both sides of working face are gob, the stress value shows a decline trend from upper to lower caused by the different pillar width.

In the process of the working face being excavated from entity coal to both side gobs, the concentration stress is obvious on the pillar which is in front and in the rear of working face. The conditions and peak positions of vertical stress are shown in Table. 3 with the excavating distance 40 m and 120 m respectively. With the island working face excavating, the maximum vertical stress changes among the coal pillar and the coal body, the stress peak zone is located in front of working face ranging from 5m to 20 m. When the excavating distance is 120 m, the stress concentration factor is the biggest than others in upper side pillar of return roadway.
Excavating 40 m

(b) Excavating 80 m

(c) Excavating 120 m
Excavating 160 m

**Figure 4:** The coal seam stress distribution in different excavation distance

**Table 3:** The maximum vertical stress and position at coal body and coal pillar in different excavation distance

<table>
<thead>
<tr>
<th>Distance /m</th>
<th>Range</th>
<th>Peak stress/MPa</th>
<th>Stress concentration factor</th>
<th>Distance between peak stress position and rib/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>Upper side pillar of return roadway</td>
<td>60</td>
<td>3.43</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Lower side coal body of return roadway (6.5m)</td>
<td>65</td>
<td>3.71</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Lower side pillar of transport roadway</td>
<td>43</td>
<td>2.46</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Upper side coal body of transport roadway (6.5m)</td>
<td>43.5</td>
<td>2.49</td>
<td>10</td>
</tr>
<tr>
<td>120</td>
<td>Upper side pillar of return roadway</td>
<td>78</td>
<td>4.46</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Lower side coal body of return roadway (6.5m)</td>
<td>63.2</td>
<td>3.61</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Lower side pillar of transport roadway</td>
<td>43</td>
<td>2.46</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Upper side coal body of transport roadway (6.5m)</td>
<td>56.2</td>
<td>3.21</td>
<td>5</td>
</tr>
</tbody>
</table>

**Roof and floor failure characteristics**

In order to analyze the surrounding rock failure during the island face excavating, the surrounding rock failure distributions are obtained in front of island face 10m, 50m and 100m respectively along the inclined section. It is shown in Fig. 5. In front of island face 10m, the surrounding rock plastic zone above the island face No. 1116 (1) extends to the coal seam 13-1#, which is caused by the shear stress around the gobs. And above the gob No. 1115 (1) and No.
1117 (1), the plastic zones extend to the 45m above the coal seam 13-1#, which are caused by the tensile stress. The block states are given in Fig. 5 (a).

With the distance from the working face increasing, the roof and floor failure zones are less than before. And the failure zones are caused by the shear stress around the roadway of island face No. 1116 (1) and near the gob. And the failure zone size of return roadway is larger than the transport roadway’s. Above the gob No. 1115 (1) and No. 1117 (1), the plastic zones extend to the 45m above the coal seam 13-1#, which are caused by the tensile stress. The block states are given in Fig. 5 (b, c). The plastic zones near the roadway gradually extend to the overlying rock above the island face No. 1116 (1), and the angle of break is about 45°.

Based on above analysis, for the working face No. 1116 (3) is located above the island face No. 1116 (1), when the position of roadway of working face No. 1116 (3) are designed, the concentrated stress distribution, failure zone and angle of break should be taken into account under the influence of island face No. 1116 (1) excavating. And if the two working faces are excavated at the same time, the horizontal offset distance should be more than 100m.

\[\text{Figure 5: The inclined section damage state of surrounding rock in front of island face}\]
Roadway deformation characteristics

As the island face No. 1116 (1) is excavated, the surrounding rock deformations of roadway are monitored. According to the deformation changing feature, it can be divided into 3 parts: the severe influence stage, the transition influence stage and the slow influence stage, as shown in Fig. 6. In the severe influence stage, the gob side roof bends and sinks gradually, the abutment pressure also increases gradually near the island face, and the surrounding rock deformation is larger than other two stages.

In Fig. 6 (a), the severe influence stage ranges from 0 m to 35 m in front of island face, it shows that the two-side convergence is obvious, the maximum deformation is 776 mm at side of pillar and the maximum deformation is 171 mm in side of coal body among the return roadway. The pillar deformation accounts for about 82%. Furthermore, among the transport roadway, the maximum deformation is 430 mm at side of pillar and the maximum deformation is 50 mm at side of coal body, the pillar deformation accounts for almost 89.5%.

In Fig. 6 (b), the severe influence stage also ranges from 0 m to 35 m in front of island face, the roof maximum deformation is 504 mm and the floor maximum deformation is 79 mm among the return roadway, the roof deformation accounts for nearly 86.4% in the floor-to-roof convergence. The roof maximum deformation is 396 mm and the floor maximum deformation is 36 mm among the transport roadway, the roof deformation accounts for about 91.7% in the floor-to-roof convergence.

![Figure 6: The roadway surrounding rock deformation characteristics during the island face excavation](image)
Based on above analysis, the deformation of roadway mainly occurs in front of island face ranging from 0 m to 75 m, and the deformation of pillar side is larger than the coal body side. So the overlying rock movement and failure features have to be taken into account, when the roadway support parameters are designed. Whereas, according to the roadway deformation characteristics, the technical method of support should be adopted such as “Strengthen Roof, Fixed Side and Control Floor”. Using the method to optimize the support parameters can improve the surrounding rock strength and keep the stability of coal pillar.

ENGINEERING PRACTICE

According to the result of simulation, we design the roadway support parameters and practice in the coal field. The engineering conditions of island face No. 1116 (1) include: the excavating length is 2687.9 m and 217.6 m along the strike and dip direction respectively, the island face No. 1116 (1) is buried in depths from 574.5 m to 714.3 m with the areas of 584618.25 m². With all other geological conditions as above.

As mentioned above, the support technologies of “Strengthen Roof, Fixed Side and Control Floor” are adopted in gob-side entry driving. The roadway dimensions (width×height) are 5000 mm×3800 mm, the field actual support parameters are given as follows: the roof anchor bolt type is Φ22×2400 mm combined with the 29# U-type shack and the anchor cable with the length of 6000 mm, the inter-row spacing is 800 mm×800 mm. And in practice, the roadway deformations are monitored during the island face excavating.

According to the engineering monitoring, the surrounding rock surface deformation and the pillar stress among the return roadway are taken into account. They are shown in Fig. 7, 8.

Figure 7: The surrounding rock surface deformation rate curve of the return roadway

In Fig. 7, the low influence stage ranges outside 78.7 m in front of the island face, the roadside displacement rate is 16 mm/d and the roof-to-floor displacement rate is 27 mm/d. The transition influence stage ranges from 39.2 m to 78.7 m in front of the island face, the roadside maximum displacement rate is 57.5 mm/d and the roof-to-floor maximum displacement rate is 68.5 mm/d. The severe influence stage ranges from 0 m to 39.2 m in front of the island face. In front of the working face, the deformations of roof and floor are very serious.

The total value of roof-to-floor convergence is 1515 mm, the total value of two-side convergence is 1224 mm, the roof-to-floor convergence is 1.24 times more than the two-side’s, the roof-to-floor maximum displacement rate is 1.67 times more than the two-side’s.
According to the stress distribution curve of coal pillar, it can be divided into four parts: the releasing zone, the obvious rising zone, the slow rising zone and the stable zone. It is shown in Fig. 8.

The stress stable zone ranges outside 81m away in front of island face and the coal pillar is relatively stable. The stress slow rising zone ranges from 42 m to 81 m in front of island face, the stress changing rate is less. The stress obvious rising zone ranges from 15 m to 42 m in front of island face, the stress changing rate is higher than other zones, and the stress reaches the peak value in this zone. The stress releasing zone ranges from 0 m to 15 m in front of island face, the stress is very low near the face wall.

As mentioned above, as the island face is excavated, the roadway deformation mainly occurs in front of the island face ranging from 0 m to 81 m, the roof-to-floor deformation is larger than the deformation of two-sides. Also, the pillar stability is very important to control the roof nearby gob. So in order to guarantee the safety production, it is necessary to adopt the technology of “Strengthen Roof, Fixed Side and Control Floor” to support the roof and strengthen the pillar.

CONCLUSIONS

This paper considers the complex engineering conditions, and applies the combined methods of theoretical analysis, numerical simulation and engineering practice to analyze the stress, deformation, failure and abutment pressure distribution characteristics of surrounding rock during the gob-side entry driving and the island face excavating. The following conclusions can be obtained:

(1) During the gob-side entry driving and the island face being excavated, the coal pillar is important to control the roof subsidence and deformation. It is necessary to design the economic and scientific pillar width when the roadway safety size, air demand, fire preventing and safe production are taken into account, i.e. wider pillar is not necessarily better in terms of stability. It is also necessary to design a suitable pillar width to control the surrounding rock mechanical behaviors.

(2) The stress distribution characteristics are analyzed in the different position around the island face, as the coal seams are excavated, not only the upper and lower surrounding rock stress redistribution occurs, but also in the coal seam around the gob the stress redistribution occurs. Furthermore, the coal seam stress distribution features are also different in different stope structures and parameters. During the working face is excavated from entity coal to both side
gobs, the concentration stress is obvious on the pillar which is in front and in the rear of working face.

(3) According to the stress and deformation changing features, the overlying rock failure characteristics are analyzed, when the position of roadway of working face No. 1116 (3) are designed, the concentrated stress distribution, failure zone and angle of break should be taken into account under the influence of island face No. 1116 (1) excavating. And if the two working faces are excavated at the same time, the horizontal offset distance should be more than 100m.

(4) The deformation of the roadway mainly occurs in front of island face ranging from 0 m to 75 m, and the deformation of the pillar side is larger than the coal body side. According to the roadway deformation characteristics, and the pillar stability is very important to control the roof nearby gob. So in order to guarantee the safety production, it is necessary to adopt the technology of “Strengthen Roof, Fixed Side and Control Floor” to support the roof and strengthen the pillar.

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