Available online at www.sciencedirect.com
ScienceDirect
Trans. Nonferrous Met. Soc. China 21(2011) s529−s535

Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Stress distribution rule of roadway affected by overhead mining in gently inclined coal seams group

KANG Qin-rong[1, 2], TANG Jian-xin[1, 2], HU Hai[1, 2], ZHANG Wei-zhong[1, 3]

1. College of Resource and Environmental Sciences, Chongqing University, Chongqing 400030, China;
2. State Key Laboratory of Coal Mine Disaster Dynamics and Control, Chongqing University, Chongqing 400030, China;
3. School of Safety Science and Administration, Zhongnan University of Economics and Law, Wuhan 430074, China

Received 19 June 2011; accepted 10 November 2011

Abstract: In light of the severe deformation and destruction of the district raise tunnel in the mining area at the northern part of the Lubanshan colliery, by the theoretic analysis and numerical simulation, both the mining stress distribution in seams group and the deformation and destruction mechanism of floor district raise were investigated. The results show that, at the maximum vertical distance of 40 m, the abutment stress has an influence on the recovery of 2# and 3# coal seam and 8# coal seam at distance of 30 m. As a result, the recovery of 8# is rather than those of 2# or 3# coal seam, which contributes to the deformation and destruction of the district raise surrounding rock. The major factors affecting the abutment stress include the mining depth, mining height, residual gob space, adjacent working faces and short spacing coal seam recovery.

Key words: coal seams group; stress distribution; district raise; surrounding rock deformation and destruction; abutment stress

1 Introduction

In order to lower tunnel driving rate and rational resource extraction and improve the technological and economical target of the coal seam, the overhead mining is widely adopted to support the extraction in floor district raise in most coal mines where the raise tunnels are located in the pressure-released areas. Overhead mining in the district raise is an important means for pressure-release and tunnel support. The overhead mining tunnel is subjected to the influence of such mining conditions including the mining depth, its distance from the coal seam normal and coal pillars to the location of the tunnel plane will exhibit great disparity in the coefficients concerning stability and rational support from one and another. It is only the correct analysis of the presentation of pressure of overhead mining tunnel that allows accessing to the scientific, systematic and quantitative design of support [1]. Through theoretical analysis, MENG et al [2], GUO et al [3] and ZHAO et al [4] established an elasticity model for floor stress distribution under the influence of abutment stress in the front coal surface and made systematical researches on the following aspects covering the surrounding rock stress distribution mechanism in the multi-layer co-mining field, stress concentration, displacement field, rock seam destruction and mutual influence among these relevant factors.

The spatial relationship between the working face and floor rock tunnel in overhead mining exerts tremendous influence on the surrounding rock displacement in the overhead mining tunnel. The increase of the vertical distance leads to the gradual decrease of the implication, abutment pressure derived from the upper working face extraction exerts on the surrounding rocks in the overhead mining tunnel. In overhead mining, the ceiling and floor of the tunnel as well as the two sides of the roadway are unstable [5−8]. At present, research concerns overhead mining in the coal seam abounds, while this is not the case for overhead mining in seam group, particularly for research on the influence on the stress distribution in overhead mining exerts on the stability of surrounding rock in the floor tunnel.

Foundation item: Project (51104176) supported by the National Natural Science Foundation of China
Corresponding author: KANG Qin-rong; Tel: +86-13500342123; E-mail: kang801118@163.com

Based on engineering practices, by virtue of theoretical analysis and numerical calculation, an analysis on the deformation mechanism for floor raise surrounding rock in seam group mining and overhead mining was carried out, providing theoretical basis for the resolution of tunnel support when the floor district raise is affected by the abutment pressure in overhead mining displacement.

2 Distribution of abutment pressure in recovery of floor working face

2.1 Transmission of abutment pressure in floor rock layer

The surrounding rock deformation in working face floor and stress concentration, which arise from the dynamic stress field in surrounding rock of the tunnel near the recover floor of the working face, are very important for the distribution and maintenance of the floor of the tunnel. Based on the elasticity and soil mechanics, the corresponding force model was established to research the influence law of stress and displacement of the floor rock layer on rock bottom caused by coal extraction. To simplify the calculation of the concentrated stress, the simplified supplement of abutment pressure loaded on the coal pillar is adopted to deduct the transmission mechanism of abutment pressure in the floor rock. The face on which concentrated stress p is loaded, which is viewed as a semi-infinite surface, and the influence of abutment pressure loaded on the coal pillar is viewed as the concentrated stress, exerting on every single point M is demonstrated in figure one as below [9−11].

Supposing that the displacement is inversely proportional to the radius and positively proportional to the cosine of coordinate angle β in point M as caused by the concentrated stress p, ε_R, the strain of point M in the direction of the radius, matches Eq. (1)

$$\varepsilon_R = \frac{A}{R^2}\cos\beta \tag{1}$$

where A represents the proportional coefficient.

Supposing that the whole situation is in a state of elasticity, σ_R, the radial stress fits Eq. (2)

$$\sigma_R = B\varepsilon_R = B\frac{A}{R^2}\cos\beta \tag{2}$$

where B represents the proportional coefficient.

A hemisphere surface with R representing its diameter, as depicted in Fig. 1(b), is needed to research. Supposing σ_R is constant within the ranging field of dβ,

$$\mathrm{d}F_R = (2\pi\sin\beta)(R\mathrm{d}\beta) \tag{3}$$

$$p - \int_0^{\frac{\pi}{2}} \sigma_R \cos\beta \mathrm{d}F_R = 0 \tag{4}$$

In both equations, F_R represents the surface area of the hemisphere.

The integral after Eqs. (2) and (3) are put into Eq. (4) goes as

$$p = \frac{2}{3}\pi AB \Rightarrow AB = \frac{3p}{2\pi} \tag{5}$$

By putting A and B into Eq. (2),

$$\sigma_R = \frac{3p}{2\pi R^2}\cos\beta \tag{6}$$

Supposing σ_z represents the stress in the surface F_R, if σ_R is replaced by σ_z as demonstrated in Fig. 1(c), as the relationship between F_W and F_R matches

$$F_R / F_W = \cos\beta \tag{7}$$

$$\sigma_z = \frac{\sigma_R \cos\beta F_R}{F_W} = \sigma_R \cos^2\beta \tag{8}$$

$$\sigma_z = \frac{3P}{2\pi R^5}\cdot\frac{z^3}{R^5} = k\frac{P}{z^2} \tag{9}$$

In Fig. 1(c), r represents the diameter to point M in the surface F_W, and $k = \frac{3}{2\pi}(\frac{z}{\sqrt{r^2+z^2}})^5$.

According to Eq. (9), σ_z is available if the pressure loaded on the coal pillar, the concentrated stress and the

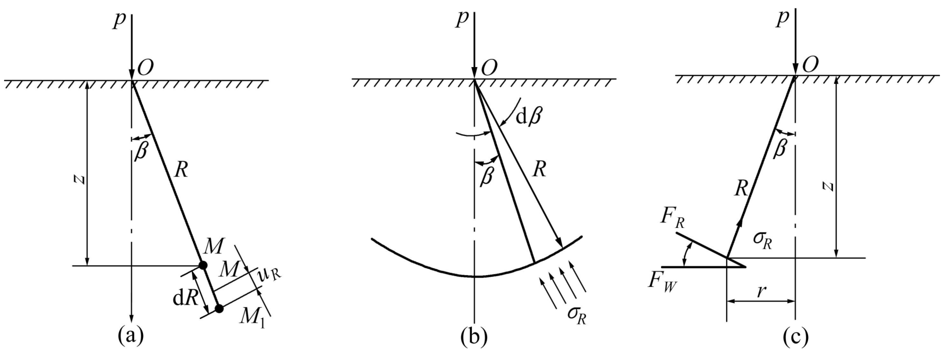

Fig. 1 Single force influence on point M in floor (p—Concentrated stress, β—Coordinate angle; z—Mining depth)

location of point M are determined. By changing the location of point M, the vertical stress of floor rock in different depths under the influence of coal pillar load can be identified.

2.2 Stress distribution in floor rock layer

Under the influence of the concentrated stress p, a pressure bubble resembling an egg, as demonstrated in Fig. 2, if the points at which the same vertical stress σ_z is identified are linked together.

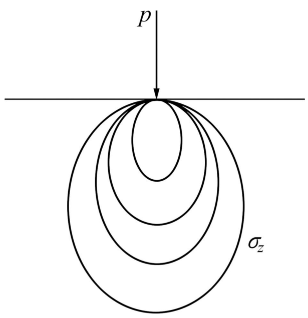

Fig. 2 Contour line of σ_z

As the pressure bubble shows that as the transmission of upper abutment pressure loaded on the coal pillar goes in the floor rock, its stress distribution exhibits the following characteristics: 1) The stress varies with depth and does not remain constant even in the same depth level. The direction of the concentrated pressure witnesses the maximum stress which expanses to the two sides of the concentrated pressure direction gradually weakens. 2) Increasing the distance from the loaded point leads to the expansion of stress distribution field. The stress varies with depth in the same vertical direction. After a certain depth, the stress rapidly declines with the increase of depth.

Supposing h represents the rock falling height, when $H>L\cdot\cot(\delta/2)$ (H represents the mining depth and L the gob width), then the aggregate load on coal pillars on both sides of the gob can be calculated by:

$$p = k[(B+L)H - L^2\cot(\delta/4)]\gamma \tag{10}$$

The average load on each coal pillar is available by:

$$\sigma = p/B = k\{[(B+L)H - L^2\cot(\delta/4)]\gamma/B\} \tag{11}$$

Supposing the width of coal pillar on the edge of either side of the gob B, the aggregate load on the coal pillar on the edge of the coal seam goes as:

$$p = k[(B+L/2)H - L^2\cot(\delta/8)]\gamma \tag{12}$$

the average load on corresponding coal pillar can be achieved by:

$$\sigma = p/B = k\{[(B+L/2)H - L^2\cot(\delta/8)]\gamma/B\} \tag{13}$$

In the above equations, p represents the aggregate load on the coal pillar, kN; k is the load coefficient; B is the coal pillar width, m; d is the falling angle of rock above the gob; γ is the average bulk density of rock above the gob, kN/m^3.

3 Research on stress distribution in seam group mining

3.1 Engineering project introduction and model establishment

In the northern part of the Lubanshan colliery, long wall mining along the strike is adopted. Among the extractable coal layers, 2# and 3# layer both adopt retained roadway mining without coal pillar as support, while the 7# and 8# coal pillar were being co-mined. The coal pillar is about 20 m in width in the retained roadway. The district raise recovery is adopted in the working faces with no pillar left. The extraction goes from the second to the third and the 8# coal seam in Fig. 3 demonstrates the sectional drawing of the whole space. The mining district raise is distributed in the soil and rock 30 m from the floor of the 8# coal seam shaped in as a straight semicircle arch section. The tunnel is 3.4 m in width, and the height for the wall and arch is 1.8 m and 1.7 m, respectively. Anchor spry is designed for the support. The after the district raise recovery, that of the 8# coal seam in particular, surrounding rocks in the district raise suffered severe deformation. According to measurement, the severest deformation is spotted in a tunnel whose width shrinks from 3.4 m to 1.5 m. The displacement on the two sides of the tunnel, the celling and the floor is too much to meet the criteria for raise design and utility.

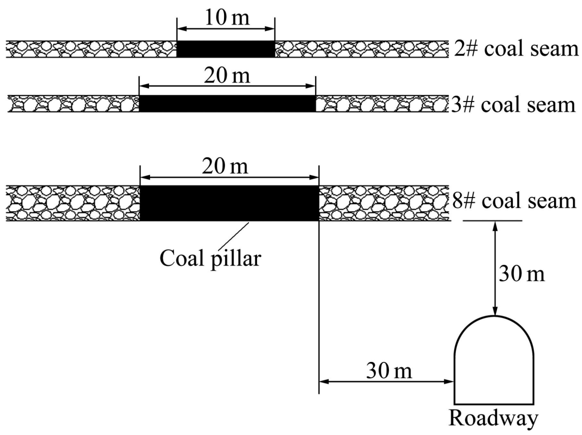

Fig. 3 Sectional drawing for coal seam and district raise

By virtue of separated elements simulation software UDEC, a numerical model is established to analyze the influence, stress distribution in coal seam overhead mining has on district raise surrounding rock stability.

The model is 250 m in length and 140 m in width as demonstrated in Fig. 4.

In this model, the horizontal displacement on the edge of both its sides is set up as a fixed boundary. The horizontal displacement is zero. In the vertical direction, the horizontal displacement is hinged, while the vertical movements are allowed. The bottom of the model is fixed, allowing no vertical movement downwards. At the top of the model, an evenly-distributed load of 12.5 MPa is added. The mechanical parameters of stratum of simulation model are shown in Table 1.

3.2 Stress distribution in second and third coal seam extraction

Figure 5 demonstrates the distribution of abutment pressure in the front of the working face. The coal stress gradually increases from a volume far lesser than that of the original rock to that of its counterpart. In this area, the coal is in a state of failure and destruction, and the coal rib scaling is readily expected. Within the distance of 2 to 7 m from the working face, the stress concentration is expected in the coal with the volume rocketing from the original rock stress. Abutment pressure reaches its peak when its location is 7 m from the coal wall, hitting 27 MPa, which is twice of the original rock stress. Within the distance of 8 to 50 m from the working face, the stress undergoes continuous decrease till the minimum 15 MPa. When the point is 50 m from the working face, the coal stress reduces roughly to its original state.

According to the internal stress evolving law for coal, the following conclusions are to be made.

1) With the failure and shear deformation of coal seam near the coal wall, the maximum abutment pressure is to be expected in deeper coal pillar.

2) Abutment pressure is the result of mining influence upon rock. Its distribution on the coal pillar is a mirror of stress concentration, which is caused by mining,

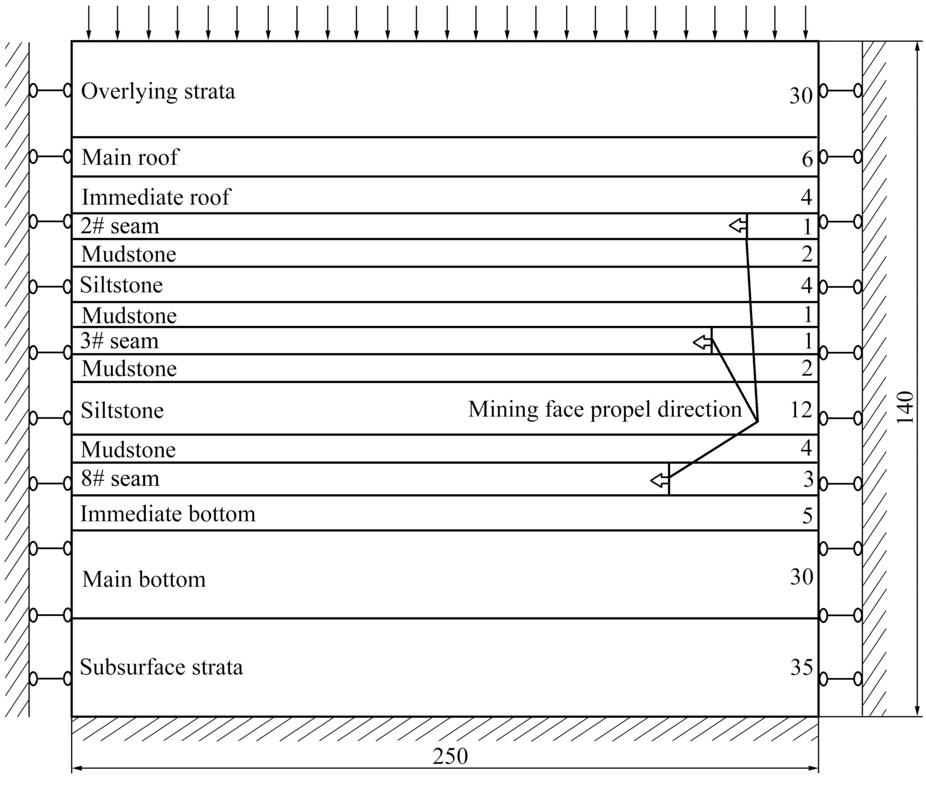

Fig. 4 Simulation model (unit: m)

Table 1 Mechanical parameters of stratum

Terrane	Density/ (kg·m^{-3})	Bulk modulus/ GPa	Shear modulus/ GPa	Friction angle/(°)	Cohesive force/ MPa	Tensile strength/ MPa
Seam	1600	1.67	1.20	46.0	6.76	1.69
Mudstone	2350	8.49	6.47	31.5	6.85	2.70
Fine sandstone	2600	11.49	8.26	40.0	11.8	2.78
Siltstone	2550	10.11	7.27	37.0	12.12	5.10
Shaly sandstone	2400	9.34	6.98	27.0	9.83	1.87

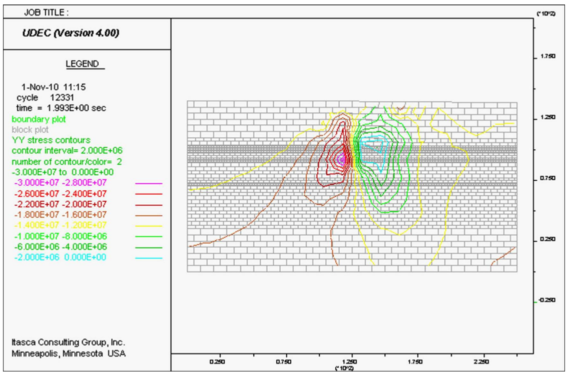

Fig. 5 Vertical stress state distribution of recovery in 2# coal seam

in the coal pillar and immediate ceiling. This concentrated stress, in turn, affects the stability of the floor of the tunnel.

Figure 6 demonstrates the abutment pressure distribution in the floor in the recovery of 2# coal seam. The internal stress in the area with distance between 0 to 30 m from the coal wall falls into 20 to 30 MPa, which is 1.5 to 2.3 times of the original rock stress. 30 m beneath the coal, the stress is 14 to 20 MPa. While 40 m beneath the coal, the rock stress generally falls into the range of 14 to 16 MPa, which is only a slight increase of the original rock stress. Therefore, it is believed that the abutment stress 40 m beneath the coal floor is basically the same as that of the original rock. Within the area that the gob is 0 to 45 m from the coal wall or is 0 to 50 m downward from the floor, the stress ranges from 2 to 10 MPa, roughly 0.15 to 0.75 times of that of the original rock. For rock layer 50 m beneath the gob, rock stress, in general, ranges from 10 to 14 MPa, and that for rock layer 70 m beneath the gob is 12 to 14 MPa, roughly that of the original rock. As a result, it is held that rock stress 70 m beneath the gob floor in the pressure-released area restores to that of the original rock.

Based on the above analysis, the maximum vertical

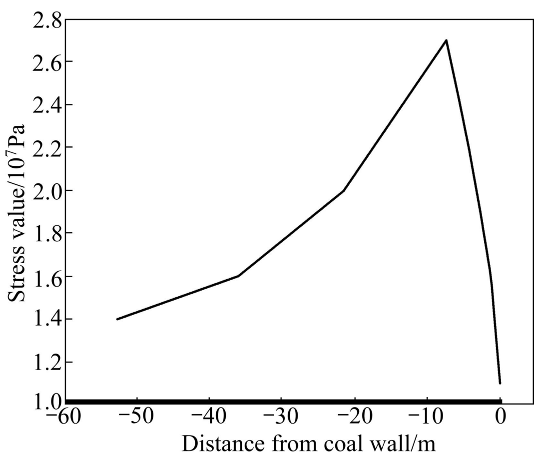

Fig. 6 Abutment pressure distribution of upper 2# coal seam

distance at which abutment pressure arises from recovery in 2# coal seam on the floor of the tunnel is 40 m, while district raise in the northern part of the Lubanshan colliery is 60 m in vertical direction from 2# coal seam. Thus, the surrounding rock stability in the raise tunnel is not subjected to the recovery of 2# coal seam.

In the northern part of the Lubanshan colliery, descending mining is adopted. Therefore, the recovery of 2# coal seam is done when recovery of 3# coalmine starts. The rock above 2# coal seam, through collapsing, crash and compaction, is basically stable. Besides, the thickness of 3# coal seam and recovery techniques taken are basically the same as that of 2# coal seam. Therefore, abutment pressure distribution in 3# coal seam recovery should roughly be in line with that of 2# coal seam. Hence, the conclusion that the maximum vertical distance at which the abutment pressure arising from recovery of 3# coal seam has an influence at the distance of 40 m. Because the vertical distance between the district raise and 3# coal seam is 54 m, the surrounding rock stability of district raise tunnel will not be subjected to recovery or 3# coal seam.

3.3 Mining stress distribution of 8# coal seam

Figure 7 demonstrates the abutment pressure distribution in the front part of working face of recovery of the 8# coal seam. The coal stress within the area 0 to 2 m from the working face gradually increases from a far lower volume than the original stress to its counterpart. The coal mine in this area is in a state of failure and destruction, and coal rib scaling is readily expected. The stress concentration is expected within the area zero to 8 m from the coal, with stress volume rocketing from that of the original rock. Stress peak (38 MPa), is to be realized 8 m from the coal wall. Within the area of 8 to 70 m from the coal wall, stress declines gradually from its peak till the minimum 15 MPa and basically restores to that of the original rock 70 m from the coal pillar.

Figure 8 demonstrates the abutment pressure distribution in the floor in the recovery of the 8# coal

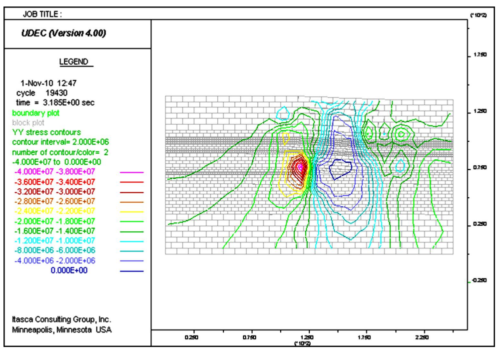

Fig. 7 Vertical stress state distribution of recovery in 8# coal seam

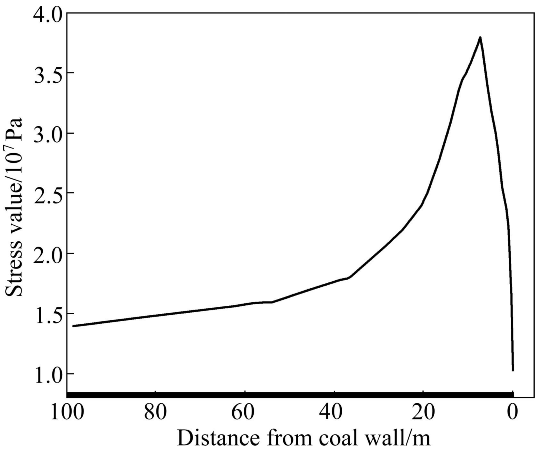

Fig. 8 Abutment pressure distribution of upper 8# coal seam

seam. The internal stress within the area which is 0 to 30 m from the coal wall and 0 to 30 m beneath the coal bed ranges from 20 to 40 MPa, which is 1.5 to 3 times of that of the original rock. While stress within the area of 0 to 20 m hits the peak, which is 2 to 3 times of the original rock stress. Rock stress at 30 to 70 m beneath the coal ranges from 14 to 20 MPa and decreases with the increase of recovery coal seam. 0 to 70 m from the gob and beneath the floor are pressure-released area with stress ranging from 0 to 12 MPa, roughly 0 to 0.9 times of that of the original rock, among which, stress within the area 0 to 30 m from the gob and beneath the floor is less than 4 MPa.

District raise is distributed in the soil and rock 30 m beneath the floor of the 8# coal seam where the maximum stress in overhead mining is between 20 to 22 MPa, about 1.8 times of that of the original rock. Anchor spry, which lacks strength, is applied in the district raise. The negligence of overhead mining dynamic pressure implication and untimely inefficient support reinforcement, the very reasons for district raise deformation in the northern part of Lubanshan colliery, contribute to severe tunnel deformation, which in turn seriously affects the production. Therefore, the dynamic pressure and guarantee tunnel stability is very important to optimize the support coefficient design for the district raise tunnel.

According to stress distribution in recovery of the 8# coal seam, the following laws can be reached [12−13]:

1) Rock 0 to 20 m beneath the coal floor is not proper for district raise distribution. Overhead mining exerts great influence in this area where the stiffness, strength and contractibility of the support are very demanding, which results in high cost and technology.

2) Rock 20 to 30 m beneath the coal floor, with dynamic pressure implication coefficient as high as 1.8, requires certain specific support. Within the area, the overhead mining dynamic pressure, such as support strengthened by pre-stress anchor, is a must for improvement of tunnel surrounding rock strength, integrity and self-loading capacity to improve district raise surrounding rock stability.

3) Rock 30 to 70 m beneath the coal floor, proper for raise, with stress in overhead mining ranging from 14 to 20 MPa, roughly 1.1 to1.5 times of that of the original rock, is relatively stable, and requires less sophisticated supporting technology.

4 Surrounding rock deformation mechanism in overhead mining

As recovery working face of the 8# coal seam advancing towards the district raise, stress concentration in the district raise surrounding rock on the two sides of the tunnel becomes obviously great and the ceiling stress is relatively weak. In the overhead mining working face 10 to 20 m horizontally from the district raise, the maximum surrounding rock stress in district raise at 22 MPa, about 1.7 times of that of the original rock, as demonstrated in Fig. 9, is expected. In recovery of the 8# coal seam, elastic failure diameter of the ceiling ranges from 1.5 to 2 m, reaches or exceeds the reinforcement limit of the anchor support, which suggests the failure of support of anchor spry.

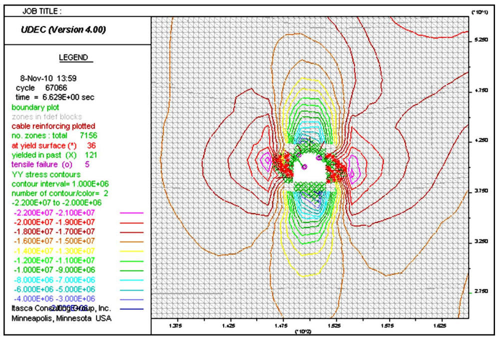

Fig. 9 Rock stress distribution in working face 20 m from district raise

The deformation mechanism of district raise surrounding rock in recovery goes as below.

1) When the distance between the recovery working face and the floor district raise overshadows the overhead mining pre-influence distance, that is when X>100 m, the floor district raise is basically not subjected to upper coal seam recovery.

2) As the recovery working face advances forward gradually, i.e. 100 m>X>0 m, the pre-abutment pressure exerts greater influence on the floor. The combination of abutment pressure and original tunnel stress contribute to relatively great stress concentration on both sides of the tunnel. Under this context, rock failure occurs on the

right side of the overhead mining working face, which is followed by rock failure on both sides of the tunnel, leading to rock destruction or even rib scaling. As deformation on the right side takes the upper hand, support strength of the right side should overshadow that of the left side. Therefore, it is believed that failure and deformation of both sides are the major players in tunnel surrounding rock deformation.

3) Within certain specific area where the overhead mining working face crosses the floor district raise, i.e. -40 m<X<0 m, as the floor goes deeper in the pressure-released area of the gob, district raise surrounding rock stress in the floor substantially declines. While as stress releases due to upper coal seam recovery, tunnel surrounding rock, as a whole, moves toward the gob, and in this context, the horizontal stress is the major contributor to the failure and destruction of surrounding rock in the tunnel. As a result, the elastic failure occurs within a large area of both the celling and the floor. Therefore, failure and destruction of both the celling and the floor are believed to be the major players in tunnel surrounding rock deformation [14−15].

4) Within a certain specific area where the recovery working face crosses the floor district raise, i.e. X<−40 m, as the displacement of floor district surrounding rock towards the gob becomes stable, the surrounding rock stress, lower than that of the original rock, scatters in a relatively small area. Hence, the conclusion that the floor district is basically not subjected to overhead mining and the tunnel gradually stabilizes.

4 Conclusions

1) In light of the influence of mining height and coal embedding depths, by virtue of numerical simulation analysis, the maximum vertical distance in the third and eighth coal seam is 40, 40 and 30 m, respectively.

2) The recovery of 8# is rather than the second or third coal seam, that mainly contributes to district raise deformation and destruction. The abutment stress exerts a dynamic influence on the floor in overhead mining. The factors determining the abutment stress include the mining depth, height, rock quality, residual gob space, adjacent working face recovery and short spacing coal seam recovery.

3) Based on the deformation mechanism of surrounding rock in the tunnel in overhead mining, it can be concluded that efforts should be made to recycle supportive coal pillar and tunnel pillar in the upper overhead mining tunnel so as to improve the stability of the tunnel.

References

[1] JIANG J Q, FENG Z Q, HAN J S. Classification of structural stability of surrounding rocks of roadway affected by overhead mining and decision making of support parameters [J]. Chinese Journal of Rock Mechanics and Engineering, 1999, 18(1): 81−85. (in Chinese)

[2] MENG X R, XU C H, GAO Z N, WANG X Q. Stress distribution and damage mechanism of mining floor [J]. Journal of China Coal Society, 2010, 35(11): 1832−1836. (in Chinese)

[3] GUO W B, LIU M J, LI H M, SHI X L. The optics-elastic simulation study on the stress of the surrounding rock of the coal face in multi-coal seam mining [J]. Journal of China Coal Society, 2001, 26(1): 8−12. (in Chinese)

[4] ZHAO Q F. Study on the stress field and movement laws of overlying strata in gently inclined multi coal seams mining [D]. Huainan: Anhui University of Science and Technology, 2008: 6. (in Chinese)

[5] XIE W B, SHI Z F, YING S Z. Stability analysis of surrounding rock masses of roadway under overhead mining [J]. Chinese Journal of Rock Mechanics and Engineering, 2004, 23(12): 1986−1991. (in Chinese)

[6] ZHANG X C, LI D Y, CHEN S H, LI D, FAN D W. Stability prediction and control of surrounding rocks for roadway affected by overhead mining [J]. Journal of Mining & Safety Engineering, 2008, 25(3): 361−365. (in Chinese)

[7] ZHU Q H. Mechanics analysis of surrounding rock deformation of roadway affected by deep riding mining and its stability control [D]. Xuzhou: China University of Mining and Technology, 2010: 4. (in Chinese)

[8] QIAN Mi G, SHI W P. Mining pressure and strata control [M]. Xuzhou: China University of Mining and Technology Press, 2003. (in Chinese)

[9] LIN D G, SONG K Z. Research on support of bolt-grouting of roadway in cross-mined and soft rock [J]. Rock and Soil Mechanics, 2002, 23(2): 238−241. (in Chinese)

[10] LI S M, QU X X, LIU Z. Deformation forecasting for the surrounding rock of floor roadway when over-the-roadway extraction [J]. Ground Pressure and Strata Control, 2005, 22(4): 56−57. (in Chinese)

[11] MA W D, ZHAO H Y, HAN L J. Experimental study on bolting-routing techniques for reinforcing soft rock roadways in upper coal seam over-the-roadway extraction [J]. Journal of China University of Mining & Technology, 2001, 30(2): 191−194. (in Chinese)

[12] TAO Z Y. Research on rational width of entry protection coal-pillar [J]. Zhong zhou Coal, 2008, (5): 23−27. (in Chinese)

[13] LI X H,YAO Q L, ZHANG N. Numerical simulation of stability of surrounding rock in high horizontal stress roadway under overhead mining [J]. Journal of Mining & Safety Engineering, 2008, 25(4): 420−425. (in Chinese)

[14] JIANG Y D, LIU W G, ZHAO Y X, YIN Z R, LI M, DENG Z Y,HONG Y Q. Study on surrounding rock stability of deep mining in Kailuan mining group [J]. Chinese Journal of Rock Mechanics and Engineering, 2005, 24(11): 1857−1862. (in Chinese)

[15] ZHOU C B, GUO L W, YAO Yi K, YIN X P, JIANG S J. Numerical simulation of wall rock deformation mechanism of mining tunnel [J]. Rock and Soil Mechanics, 2009, 30(3): 654−658. (in Chinese)

(Edited by LI Yan-hong)