

Yu Xueyi, Huang Senlin**

INFLUENCE OF SHALLOW MINE-WORKINGS ON CRACK FAILURE OF OVERBURDEN STRATA

1. Introduction

The exploitation of Shendong coalfield causes a series of environment protection problems that have to be confronted, as they may restrict the continuous development of the mining area. The overburden strata failure and surface subsidence caused by mining constitute the main problems in exploitation, since they result in the surface vegetation damage, the environmental deterioration and the desertification. Under the condition of the thick aeolian sands and the thin base rock, mining damage has its specificity. What is even more important, its research in the field of the controlled mining theory is nearly non-existent. Therefore, researching the above-mentioned problems has an essential scientific value to the environmental protection. Furthermore, it has an extremely important strategic meaning to the continuable development in Shendong mining area.

2. General situation

What is specific for Shendong mining area is that the Jurassic Yan'an group (J_{xy}) constitutes the main coaly stratum with the thickness varying from 270 m to 310 m. The seams are steady and their geologic structure is simple. The main aquifers are Salawusu group and Shaobian rock. The surface of the mining area can be characterised as a sandy, droughty area, having little vegetation due to the shortage of rain. The seam of the mining area, which has the characteristics of shallow imbedding, thick mining, thin base rock and thick loose sand, is a typical shallow seam.

The 1203 longwall face, which is the first mining face of Daliuta mine in Shendong mining area, has been exploited since March 1993. The parameters of the seam as well as

* Xi'an University of Science and Technology, China

the overburden strata are specified in Table 1 [1]. When the face advanced to a distance of 20,12 m (March 24, 2004), the roof pressure increased sharply, which resulted in the rock waste falling from the coal rib and the roof drenching water. As the effect of the above, the roof of the middle face cut off along the coal rib, the water flooded along the rib (the amount of water reached to 408 m³ per hour), which forced the mine authorities to stop production immediately. Furthermore, cave-in pits and numerous cracks appeared on the ground [2]. On April 3 the production was resumed, the cracks increased alongside with the gob area enlargement, which took a shape of an oval whose major axis was parallel to the face (the major axis was 53 m, the stub axle was 22 m). The discrepancy of rupture was 0,27 m and a 24-meter-deep sand funnel appeared in the south. With the face advancing, the subsidence extension is expanding constantly. The maximal width of the cracks reaches up to 70 cm. The maximal subsidence is 2335 mm with the maximal speed of 131.38 mm per second, and its factor being 0.599.

TABLE 1

Basic parameters of seam and overburden strata in 1203 longwall face of Daliuta mine

Serial numbers	Rock properties	Thickness, m	Density, kg/m ³	Elastic modulus E , GPa	Compressive strength σ_c , MPa
1	Aeolian sand and dinas	27.0	1700		
2	Weathering sandstone	3.0	2330		
3	Part weathering siltstone	2.0	2330	18.0	
4	Sandstone	2.4	2520	43.4	30.3
5	Interbedding sandstone	3.9	2520	30.7	30.3
6	Mudstone	2.9	2410	18.0	15.3
7	Siltstone	2.0	2380	40.0	48.3
8	Siltstone	2.2	2380	40.0	48.3
9	Carbonaceous mudstone	2.0	2430	18.0	15.3
10	Sandy mudstone	2.6	2430	18.0	38.3
11	1 ⁻² coal seam	6.3	1300	13.5	14.8
12	Packsand and siltstone	4.0	2430	38.0	37.5

The deformation on the ground surface is serious over the gob area in Daliuta mine, and there are numerous cracks whose maximal width exceeds 2 m and maximal depth exceeds 10 m on the ground surface. The maximal depth of the cave-in pits is 6.5 m. As all kinds of collieries are mined in two sides of the Kuye river, its branches (e.g. Muhegou, Wangqu, Sanbulagou etc.) have been drying up discontinuously since 1997, which has led

to the situation that the Kuye river (the first branch of the Yellow River) stopped flowing for 75 days in 2000 and was drying for 106 days in 2001. The water level of the largest landlocked lake in the Eerduosi plateau has dropped by more than 2 m for the past 5 years, and the groundwater level has dropped 1,81 m within the range of 50 km around the lake area.

3. Overburden rock breaking rule

The cave-in pits and the falling cracks failure result from the slide and the sudden subsidence of the key stratum that normally plays the role of controlling the falling cracks. Therefore, analysing the slide condition of the key stratum structure is an essential technology to be applied in order to carry out the protecting water mining.

According to the key stratum theory [3], if Q_1 and M_1 stand for the shearing force and the bending moment respectively, the expressions will be:

$$\begin{aligned} Q_1 &= EIy''' \\ M_1 &= EIy'' \end{aligned} \quad (1)$$

In the case of $x = -l$, namely, in the middle of the beam, its bending moment is

$$M_a = EIy''_{-l} = \alpha q_1 l^2 \quad (2)$$

When y''' is equal to zero, the bending moment (M_β) is M_{\max} , and the place lies in x_β , then

$$x_\beta = \frac{\sqrt{2}}{\omega} \arctan \frac{\sqrt{2}}{\sqrt{2} + \omega l - 2\alpha\omega l} \quad (3)$$

The bending moment is

$$M_\beta = -q_1 l^2 e^{-\frac{\omega}{\sqrt{2}} x_\beta} \left[\left(\frac{\sqrt{2}}{\omega l} + \frac{1}{2} - \alpha \right) \sin \frac{\omega}{\sqrt{2}} x_\beta + \left(\frac{1}{2} - \alpha \right) \cos \frac{\omega}{\sqrt{2}} x_\beta \right] = -\beta q_1 l^2 \quad (4)$$

where:

- k — Winkler groundsill coefficient;
- E_0 — elastic modulus of groundsill, MPa;
- h_0 — thickness of the underlay, m;

α — the bending moment coefficient in the middle of the beam

$$\alpha = \frac{\sqrt{2}\omega^2 l^2 + 6\omega l + 6\sqrt{2}}{6\omega l(2 + \sqrt{2}\omega l)};$$

β — the bending moment coefficient in the front of coal wall

$$\beta = e^{-\frac{\omega}{\sqrt{2}}x_{\beta}} \left[\left(\frac{\sqrt{2}}{\omega l} + \frac{1}{2} - \alpha \right) \sin \frac{\omega}{\sqrt{2}} x_{\beta} + \left(\frac{1}{2} - \alpha \right) \cos \frac{\omega}{\sqrt{2}} x_{\beta} \right];$$

$$\omega = \sqrt[4]{\frac{k}{E_1 I_1}}.$$

In order to analyse the impact of the weak underlay on the maximal bending moment and the position of the key stratum, the parameters of elastic modulus of the hard rock stratum ($E_1 = 30$ GPa) under the general condition, the thickness (4 m) and elastic modulus of the weak underlay ($E_0 = 3$ GPa) can be applied to process the simple numerical simulation. Therefore, the relationship between ω , α , β , x_{β} and the length of the gob area (L) and thickness of the underlay (h_0) can be figured out.

Considering the effect of the underlay, the first limited break distance of the key stratum can be obtained by means of the following method: firstly, differentiate the size of α and β , and try to calculate the maximal bending moment; if α is greater than β ,

$$M_{\max} = \alpha q_1 l^2 \quad (5)$$

Afterwards, providing the tensile strength of the key stratum (σ_t) is equal to $\frac{1}{10}\sigma_c$, and the section modulus of the resistance bend (W_c) is equal to $\frac{1}{6}h_1^2$, in terms of the strength theory, the expression is

$$\sigma_{\max} = \frac{M_{\max}}{W_c} = \frac{6\alpha q_1 l^2}{h_1^2} = \frac{1}{10}\sigma_c \quad (6)$$

Put the expression of α into Eq.(6), then

$$10\sqrt{2}\omega^2 q_1 l^3 + 60\omega q_1 l^2 + (60\sqrt{2}q_1 - \sqrt{2}h_1^2 \sigma_c \omega^2)l - 2h_1^2 \sigma_c \omega = 0 \quad (7)$$

From Eq.(7), l can be gained, then the limited break distance (L_c) is $L_c = 2l + 2x_\beta$. If α is less than β , using analogical way of analysis, an expression about l can be obtained as follows

$$15q_1l^2 e^{-\frac{\omega}{\sqrt{2}}x_\beta} \left[\left(\frac{\sqrt{2}}{\omega l} + \frac{1}{2} - \alpha \right) \sin \frac{\omega}{\sqrt{2}} x_\beta + \left(\alpha - \frac{1}{2} \right) \cos \frac{\omega}{\sqrt{2}} x_\beta \right] - h^2 \sigma_c = 0 \quad (8)$$

Put l into $L_c = 2l + 2x_\beta$, then the limit break distance can be obtained.

According to the theory of the key stratum [3], in the case of $x = -l$, that is, in the middle of the beam, its bending moment (M_a) is zero. Then the continuous beam model turns into the cantilever beam model. Suppose x is equals zero, the shearing force will be Q_0 and the bending moment will be M_0 , then the curve of the cantilever beam deflection on the elastic ground sill is

$$y_1 = e^{-\frac{\omega}{\sqrt{2}}x} \left[\frac{\sqrt{2}Q_0 + \omega M_0}{E_1 I_1 \omega^3} \cos \frac{\omega}{\sqrt{2}} x - \frac{M_0}{E_1 I_1 \omega^2} \sin \frac{\omega}{\sqrt{2}} x \right] \quad (9)$$

In order to work out the periodic break distance, the position of the maximal bending moment (x_1) must be figured out. From Eq.(9),

$$y_1''' = \frac{1}{\sqrt{2}} e^{-\frac{\omega}{\sqrt{2}}x} \left[\frac{\sqrt{2}Q_0 + \omega M_0}{E_1 I_1} \left(\cos \frac{\omega}{\sqrt{2}} x - \sin \frac{\omega}{\sqrt{2}} x \right) - \frac{\omega M_0}{E_1 I_1} \left(\cos \frac{\omega}{\sqrt{2}} x + \sin \frac{\omega}{\sqrt{2}} x \right) \right] = 0 \quad (10)$$

When y_1''' is equal to zero, x_1 can be expressed as

$$x_1 = \frac{\sqrt{2}}{\omega} \arctan \frac{Q_0}{Q_0 + \sqrt{2}\omega M_0} \quad (11)$$

where:

Q_0 — the shearing force

$$Q_0 = q_1 l;$$

M_0 — the bending moment

$$M_0 = \frac{1}{2} q_1 l^2.$$

According to the strength theory of the beam, the expression is

$$\sigma = \frac{M_z}{W_c} = \frac{\sigma_c}{10} \quad (12)$$

An expression about l_1 can be obtained as follows

$$3q_1 l e^{-\frac{\omega}{\sqrt{2}}x_1} \left[\frac{2\sqrt{2} + \omega l_1}{\omega} \sin \frac{\omega}{\sqrt{2}} x_1 + l \cos \frac{\omega}{\sqrt{2}} x \right] - h_1^2 \sigma_c = 0 \quad (13)$$

Then the periodic break distance (L_z) can be worked out from $L_z = l_1 + x_1$.

If the effect of the underlay is considered, the formula of the break distance of the key stratum will be complicated. In order to make the engineering application more convenient, the applied formula should be reduced. The formula of the first break distance and the periodic break distance can be expressed as follows:

$$L_c = 2l_c + 2x_{\beta}, \quad (14)$$

$$L_z = l_z + 0.5x_1 \quad (15)$$

According to above the two formulas, the first break distance and the periodic break distance of the key strata are 25.6 m and 9.7 m respectively in 1203 face.

The break rule of the key stratum was studied using the numerical simulation software (FLAC2D) in shallow seam. The strike length of the design model was 100 m, its mining height was 2 m and 4 m respectively, its simulated vertical height was the same as the thickness of the base rock. The loose beds on top of the base rock were represented on the top border of the model in the form of uniformly distributed load, and the magnitude of the load was equal to the weight of the loose beds. According to differentiating key stratum program, the serial number of the key stratum (as Fig. 1 indicates) was 8 in 1203 face of Daliuta mine. The rock property was siltstone, and its thickness was 2.2 m. The model adopts Mohr – Coulomb plasticity model, and the key stratum break is on the basis of the tensile failure.



Fig. 1. Stress distribution in the first breakage of the key stratum with the mining height of 4 m

On the basis of the analysis of the numerical simulation results it may be concluded that with the mining height of 4m and with the face advancing, the tensile stress of the key stratum among overburden expands significantly. Furthermore, the cracks develop fully near the open-off cut, and the overall failure area is shown as the asymmetry. With the face advancing up to a distance of 30 m, the maximal tensile stress (2.0 MPa) that reaches the value of its tensile strength (2.0 MPa) appears in the key stratum, which proves the key stratum breaks for the first time and its length is 30 m (Fig. 1).

With the mining height of 4 m and with the constant advancement of the face, the overburden strata stress in the front of the wall translates into the tensile stress from the compressive stress; besides, the advanced tensile cracks emerge in overburden. With the face advancing up to a distance of 12 m, the key stratum in overburden has no obvious high tensile stress area, since the tensile stress of the key stratum exceeds its tensile strength and the periodic break occurs in the key stratum (the break length is 12 m). The tensile stress is zero. The shearing failure area of the key stratum communicates directly with the coal wall of the face. It is verified that the cracks extend alongside with the advance of the face, and the cracks communicate with the face, which induces the fall of the roof in the face, welling up of water and bursting into sands calamity if the face is advanced below the cracks.

With the mining height of 2 m, the key stratum stress translates into the tensile stress from the compressive stress with the face advancing. However, with the face advancing to a distance of 60 m, the slide doesn't appear in the key stratum. The stress distribution in the overburden strata is presetned in Figure 2. With the mining height reduced, the structure slide doesn't occur in the key stratum, and the falling crack failure doesn't appear among the overburden strata, since the cracked blocks of the immediate roof fill the gob area during mining exploitation.



Fig. 2. Stress distribution in the overburden rock with the mining height of 2 m

The above-mentioned calculations and analysis clearly indicate that, under the condition of thick aeolian sands in Shendong mining area, the tensile failure constitutes the break form of the key strata. The failure near the opening occurs at first and at the end the form of the tensile failure is unsymmetrical. In addition, in the case of a shallow seam, the mining method of limited exploitation height can control the key strata slide, avoiding the falling of overburden strata and the occurrence of the discontinuous breakage on the ground surface.

4. Mining damage analysis

The characteristics of mining damage are mainly discussed in the following selected aspects:

- Under the condition of the shallow seam, the thick loose beds and the thin base rock in Shendong mining area, the key stratum break not only causes violent caving and step subsidence (the maximal subsidence is 1 m) in the face, but also results in the base rock falling, the surface discontinuous breaking and the occurrence of the graben. The discrepancey of the graben is about 20 cm in the first caving.
- With the face advancing, the cracks constantly occur on the ground surface, and the maximal width of the cracks reaches up to 2 m. The rapid subsidence appears on the ground surface, and the maximal subsidence exceeds by 10 m. The sand funnels appear, the depth of which reaches up to 24 m; in addition, the cave-in pits are formed, as shown in Figure 3 [4].
- There are aquifers in the mining area; the main aquifers of the mining area are Salawusu group and Shaobian rock. Though some strata have better watertightness, if the large-scale mining is carried on, they will be destroyed and the cracks will allow for pouring large amounts of water into the face from the aquifers. Since the aquifers are destroyed, the soil erosion and the desertification become serious problems in the mining area.

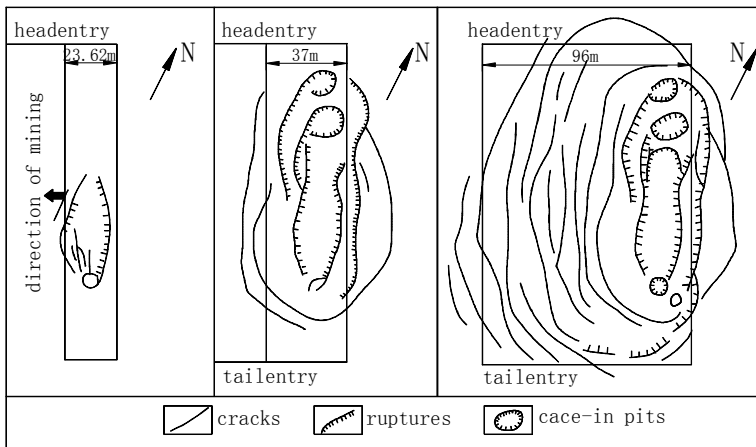


Fig. 3. Cracks, ruptures and cave-in pits in the process of mining in 1203 face

The ground surface is covered by thicker loose beds of Quaternary Period in the mining area. With the face advancing, the key stratum breakage forms the cracks in the coal wall.

The key blocks circumgyrate reversely, making the cracks open, which leads to the situation that a large number of loose beds pour into the face, forming the routed sand calamity.

5. Conclusions

The control mining methods can reduce the extent of mining damage in a shallow seam. Analysing the present conditions of production and technology as well as the characteristic of mining damage in the mining area, the following mining methods can effectively control the extent of mining damage [5, 6, 7, 8]:

- Mining method of limited mining height: implementing the layer mining in the thick seam can decrease the extent of the mining damage. Adopting the fully mechanised coal mining of the significant height brings about a serious risk of mining damage in a shallow seam. According to the result of the numerical simulation, when the mining height is 4 m in 1203 face, with the face advancing, the key stratum breaks and its slide occurs. When the mining height is 2 m, with the face advancing, the key stratum slide doesn't appear. Therefore, the mining method of the limited mining height can effectively control the mining damage in this case.
- Part cut-and-fill mining method in working face: according to the slide condition of the key strata structure, it is necessary to select an appropriate position to fill from the ground surface bore or adopt the part strip to fill with the face advancing. The measure that controls the key strata would make it subside slowly, and avoid sudden subsidence that leads to the occurrence of the falling cracks on the ground surface.

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