Numerical Simulation on Failure Rules of Overburden Strata in Shallow Coal Seam

Huang Senlin 1, 2, a

1 State Key Laboratory of the Gas Disaster Detecting, Preventing and Emergency Controlling, Chongqing 400037, China
2 CCTEG Chongqing Research Institute, Chongqing 400037, China
a email: yuanban@cqccteg.com

Abstract. The mining, under the condition of the shallow coal seam, the thick loose beds and the thin base rock in Shendong mining area in Shaanxi province of China, makes the surface subsidence take on the situation of the discontinuous falling crack failure. A great deal of analysis and research indicates that the crack damage is controlled by the key strata in the overburden strata. Therefore, the key for solving the control of mining damage under this condition is to research the rules of the key stratum failure in the shallow seam. Taking 1203 longwall face in Daluta mine of Shendong mining area as the example, the paper studies the relationship between the stability condition of the key stratum structure and the mining damage, supplying the theoretic evidence for the environmental protection and the confirmation of the reasonable and economical controlled mining methods in Shendong mining area.

1. Introduction

With the exploitation of Shendong coalfield that is called the international high-quality coal base, it comes into a new phase. However, at the same time, it brings a series of the ecological environment problems that have been paid attention to. And these problems will restrict the continuable development of the economics in the mining area. The overburden strata failure and surface subsidence caused by mining are main problems in exploitation. The main reason that results in the surface vegetation damage, the environmental deteriorate and the desertification is the failure of the shallow aquifers. Under the condition of the thick aeolian sands and the thin base rock, mining damage has itself speciality in shallow seam and its study is an initial phase. What’s more important, its research in the field of the controlled mining theory is nearly blank. Therefore, researching above-mentioned problems has an important scientific value to the environmental protection; furthermore, it has an important strategic meaning to the continuable development in Shendong mining area.

2. General situation

2.1. General situation of mining area

In Shendong mining area, Jurassic Yan’an group (J3y) is the main coaly stratum. Its thickness varies from 270m to 310m and it generally includes the seams of 5-15 layers. The seams are steady and their geologic structure is simple. The main aquifers are Salawusu group and Shaobian rock. There are more aeolian sands, droughty, short of the rain and little vegetation on the ground surface in the mining area.
Its ecological environment is brittle extremely. The seam of the mining area that has the characteristics of shallow imbedding, thick mining, thin base rock and thick loose beds is a typical shallow seam.

2.2. General situation of mining face

1203 longwall face is the first mining face of Daliuta mine in Shendong mining area. The mining seam is 1-2, its geologic structure is simple, its average angle of dip is 3°, its average thickness is 6m, its imbedded depth is about form 50 to 60m. The thickness of the loose beds that are on the top of the base rock varies from 15 to 30m. The thickness of weathered base rock is about 3m. There are aquifers whose thickness is from 6m to 9m under the loose beds. The groundwater level varies from 18 to 22m deep. The face length is 150m and the mining height is 4m. Parameters of the seam and the overburden strata are listed in Table 1 [1].

Table 1. basic parameters of seam and overburden strata in 1203 longwall face mine

| Serial numbers | Rock properties            | Thickness (m) | Density (kg/m³) | Elastic modulus E (GPa) | Compressive strength σc (MPa) |
|----------------|----------------------------|---------------|-----------------|------------------------|------------------------------|
| 1              | Aeolian sand and dinas     | 27.0          | 1700            |                        |                              |
| 2              | Weathering sandstone      | 3.0           | 2330            |                        |                              |
| 3              | Part weathering siltstone | 2.0           | 2330            | 18                     |                              |
| 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                     | 15.3                         |
| 7              | Siltstone                 | 2.0           | 2380            | 40                     | 48.3                         |
| 8              | Siltstone                 | 2.2           | 2380            | 40                     | 48.3                         |
| 9              | Carbonaceous mudstone     | 2.0           | 2430            | 18                     | 15.3                         |
| 10             | Sandy mudstone            | 2.6           | 2430            | 18                     | 38.3                         |
| 11             | 1^2 coal seam             | 6.3           | 1300            | 13.5                   | 14.8                         |
| 12             | Packsand and siltstone    | 4.0           | 2430            | 38                     | 37.5                         |

2.3. Condition of mining damage

The coal in 1203 longwall face was mined at first On March 5, 1993. And when the face advanced to a distance of 20.12m on March 24 in this year, the roof pressure increased sharply; likewise, the coal rib fell waste rocks and the immediate roof drenched water. At 10 past 16 in this afternoon, the roof of the middle face cut off along the coal rib, the water flooded along the rib, and the amount of water reached to 408m³ per hour, which led to the mine have to stop producing, the cave-in pits and cracks occurred on the ground surface [2]. On April 3 the production was resumed, the cracks increased with the gob area enlarging, and it took on the oval whose major axis is parallel to the face (the major axis is 53m, the stub axle is 22m). The discrepancy of rupture is 0.27m. The 24-meter-deep sand funnel appears in the south. With the face advancing, the subsidence extension is expanding constantly. The maximal width of the cracks reaches to 0.7m. The maximal subsidence is 2335mm. The maximal subsidence speed is 131.38mm per second, and the subsidence factor is 0.599.

The deformation on the ground surface is serious over the gob area in Daliuta mine, and there are a great number of the cracks whose maximal width exceeds 2m and maximal depth exceeds 10m on the ground surface. The maximal depth of the cave-in pits is 6.5m. As all kinds of collieries are mined in two sides of the Kuye river, its branches such as Muhegou, Wangqu, Sanbulagou and so on have dried up discontinuously since 1997, which lead to the Kuye river, the first branch of the Yellow River stops flowing for 75 days in 2000 and drying for 106 days in 2001. The water level of the largest landlocked lake in the Eerduosi plateau has dropped more 2m during the past 5 years, and the groundwater level drops 1.81m within the range of 50 kilometers around the lake area.
3. Overburden strata breaking rule

The cave-in pits and the falling cracks failure result from the slide and the sudden subsidence of the key stratum that plays the controlling role in the falling cracks. Therefore, analyzing and researching the slide condition of the key stratum structure are the key technology to realize the protecting water mining.

3.1. Length of key stratum caving

According to the key stratum theory [3], if the effect of the underlay is considered, the formula of the break length of the key stratum will be complicated. In order to convenience the engineering application, the applied formula should be educed. The formula of the first break length and the periodic break length can be expressed as follows:

\[ L_c = 2l_c + 2x_p \]  \hspace{1cm} (1)
\[ z_L = z_l + 15.0x \]  \hspace{1cm} (2)

According to above the two formulas, the first break length and the periodic break length of the key stratum are 27.6m and 11.7m respectively in 1203 face.

3.2. Analyzing rules of key stratum break

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

Figure 1. Stress distributing figure of the first breakage of the key stratum when the mining height is 4m

Figure 2. Stress distributing figure of the overburden strata when the mining height is 2m

Analyzing the results of the numerical simulation, when the mining height is 4m, with the face advancing, the tensile stress of the key stratum among overburden expand obviously; what’s more, the cracks develop fully near the open-off cut, and the overall failure area is shown as the asymmetry. When the face advanced to a distance of 30m, the maximal tensile stress (2.0MPa) that reaches to its tensile strength (2.0MPa) appears in the key stratum, which proves the key stratum break for the first time and its length is 30m, as Fig.1 shows.

When the mining height is 4m, with the constant advance 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. When the face advanced to a distance of 12m, the key stratum in overburden has no obvious high tensile stress area, for the tensile stress of the key stratum exceeds its tensile strength, the periodic break occurring in the key stratum (the break length is 12m). The tensile stress is zero. The shearing failure area of the key stratum directly communicates with the coal wall of
the face. It is verified that the cracks extend with the advance of the face, and the cracks communicate with the face, which induce the roof in the face to fall, to well up water and to burst into sands calamity when the face is advanced below the cracks.

When the mining height is 2m, the key stratum stress translates into the tensile stress from the compressive stress with the face advancing. However, when the face advanced to a distance of 60m, the slide doesn’t appear in the key stratum. The stress distributing of the overburden strata is shown as Figure 2. When the mining height reduces, the structure slide doesn’t occur in the key stratum, and the falling crack failure don’t appear among the overburden strata, for the cracked blocks of the immediate roof fills the gob area by mining.

Above-mentioned calculating and analyzing indicates, under the condition of thick eolian sands in Shendong mining area, the break form of the key strata is the tensile failure; the failure near the opening occurs at first, the form of the tensile failure is unsymmetrical at last. In addition, for the shallow seam mining, the mining method of limited mining height can control the key strata slide, avoiding the overburden strata falling and the discontinuous breakage on the ground surface.

4. Mining damage analysis
The condition of the especial geology and mining determines the mining damage in shallow seam has itself particularity. The characteristics of mining damage are mainly shown in the following several aspects:

(1) 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 arouses violent caving and step subsidence (the maximal subsidence is 1m) in the face, but also results in the base rock falling, the surface discontinuous breaking and the graben occurring. The discrepancy of the graben is about 20cm in the first caving.

(2) With the face advancing, the cracks constantly occur on the ground surface, and the maximal width of the cracks reaches to 2m. The rapid subsidence appears on the ground surface, and the maximal subsidence exceeds 10m. The sand funnels appear, the depth of them reaches to 24m; in addition, the cave-in pits are formed, as shown in Figure 3 [4].

Figure 3. The character of cracks, ruptures and cave-in pits in the process of mining in 1203 face

(3) There are aquifers in the mining area; the main aquifers of the mining area are Salawusu group and bumt rock. Though some strata have better watertightness, if the large-scale mining is carried on, they will be destroyed and the cracks make a large number of water in the aquifers pour into the face. Because the aquifers are destroyed, the soil erosion and the desertification are serious in the mining area.

(4) 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 a large number of loose beds pour into the face, forming the routed sand calamity.

5. Controlled mining method
The control mining methods can reduce the extent of mining damage in shallow seam. Analyzing the
present conditions of production and technology and 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].

1) 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 mechanized coal mining of the high height is serious to mining damage in shallow seam. According to the result of the numerical simulation, when the mining height is 4m in 1203 face, with the face advancing, the key stratum breaks and its slide occurs. When the mining height is 2m, 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.

2) Part cut-and-fill mining method in working face: according to the slide condition of the key strata structure, it is necessary to choose 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 suddenly subsidence that leads to the falling cracks on the ground surface.

6. Conclusions
In shallow seam, the surface crack failure that possesses itself particularity is determined by the condition of the special geology and mining. This paper, according to the actuality of the mining damage in shallow seam, analyzes the rules of the overburden stratum failure, as well as the rules and characteristics of mining damage in shallow seam; in addition, it discusses the adaptive controlled methods in Shendong mining area, supplying the theoretical evidence for implementing the mining method to protect the water resource and protecting the ecological environment in Shendong mining area.

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