Study and Test on Development Regularity of Mining Speed of Coal Seam Separated from Overburden Strata

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***Abstract*—In the sedimentary coal stratum, rock stratum exhibits layered feature and has an obvious level. Overlying rock often produces separation along the level after the underground coal mining. But, due to the difference in the layers of rocks, the change of the mining process, the difference height in the level and other factors, the rule of separation is extremely complex. Therefore, in this paper, the allometric phenomenon, feature and laws of mining overburden separated strata are found by means of experiment and numerical simulation. The paper reveals the mechanical mechanism of allometric development of overburden separated strata, establishes its development formula based on the theory of beam in the mechanics, analyzing the space-time law of mining subsidence and overburden separation, and finally finds the relationship between surface subsidence and allometric growth of mining overburden separated strata, establishing the subsidence model based on allometric growth of mining overburden separated strata.**

***Index Terms*—mining overburden separated strata, allometric growth, surface subsidence, calculation model**

I. Raise of the Question

After the underground coal seam is mined, the overlying strata of the mining has been collapse, break, separate, move and deform from bottle to top of the coal seam. Development of rock mass deformation to the surface, make the surface produces a wide range of subsidence basin subsidence, caused the surface buildings, water bodies, cultivated land, railways, bridge damage and other severe consequences, these consequences become the bottleneck of restricting the mining production and environmental protection. In the study of the basic law of mining subsidence, there is an important feature of overburden separation, which is an important factor influencing the amount of mining subsidence value and an important engineering basis for the separation grouting to reduce the surface subsidence.

Therefore, in this paper, on the basic theory of mining subsidence and slow down the surface subsidence for many years based on the study of the control measures and put forward the basic principle of mining overburden strata crack - abscission layer, the mining strata are studied by experiment from the spallation to the basic rule of abscission layer, as well as the allometric growth rules of overlying strata.

II. Mechanical Mechanism and Dynamic Process of Formation and Development of Overburden Strata Separated by Mining

When the coal seam is cut out, the direction of the maximum principal stress σ_1 of each point is changed from the vertical direction before mining to the deviation from the goaf side. Due to a part of the original rock above the roof, the vertical stress is transferred to the two sides of the goaf, so that the load on both sides of the rock (coal) body is higher than before mining, forming the supporting pressure belt on both sides of the goaf. The abutment pressure zone is arch shaped in overlying rock, referred to as the abutment pressure arch, two foot arch were respectively located behind the working face and the front section of the region, and with the advance of working face and move forward; While the bearing pressure arch at the bottom of the strata, due to its the upper strata pressure is guided to the abutment area of goaf on both sides of the rock, the vertical stress lower than prior to mining, in unloading condition, called the unloading arch. In the unloading arch within the rock itself, due to the elastic recovery and self-gravity, it moves to the face of the mining area in the direction of the air, resulting in bending deformation. Because of the strata lithology, thickness and height of each stratum are different, the subsidence of the upper and lower strata is not synchronous. When the deflection of the upper strata

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is less than the deflection of the lower strata, the upper and lower strata have a sudden change of delamination and instability, resulting in the separation of strata, as shown in Fig. 1.

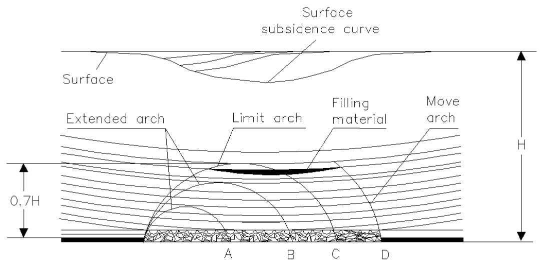


Figure 1. The distribution of support pressure arch and unloading arch expansion, movement and separation development.

From the above analysis we can see that the separation from the interlayer tensile incubation layer crack, first by the gradual change to mutation spallation, produce separation, and then with the working face advancing and expanding, closed, and separation domain is from small to big, from the bottom, the forward distribution development, internal separation space occupy space is from less to more, by changing from more to less again [1].

III. Mechanical Mechanism of Overburden Layer Separation in Mining Overlying Strata

A. Selection of Mechanical Model of Abscission Layer

Due to the coal strata are sedimentary rocks, so thick hard rock strata in stope overburden thickness is limited [2], [3], it is usually 4~20m, and a large area of mining goaf size is relatively unlimited, it is usually 100~1000m and rock plate as a sheet of geometrical conditions are satisfied.

B. Thin Slab Coordinate System

The coordinate system of the thin slab is shown in Fig. 2. The stress σ_x and σ_y of the two opposite sides of the rectangular rock plate are sometimes equal, sometimes unequal, and the self weight stress q is equal for the horizontal mining area with rectangular mining area. But for the inclined coal seam mining, the edge stress of the rock plate is unequal, and the self weight stress q is equal.

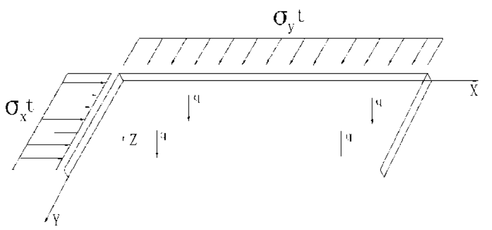


Figure 2. Calculation coordinate system of thin rock slab.

C. Dimension Calculation of Thin Slab with Separated Layers

In the overlying strata of the horizontal coal seam mining area, the calculation of the size of the rock strata with bending separation layer is shown in Fig. 3.

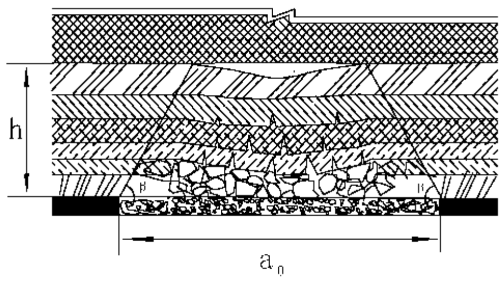


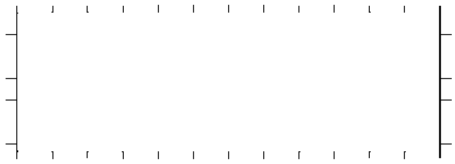
Figure 3. The calculation of thin slab length of separated layer in horizontal coal seam.

According to the caving angle, the strike length of the separated strata is

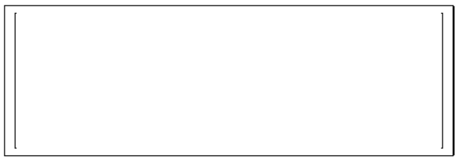
$$a = a_0 - 2hctg\beta \quad (1)$$

D. Boundary Constraint Representation of Thin Rock Slabs

The boundary constraints for the thin slab are shown in Fig. 4.



a. Clamped plate



b. The simply supported plate

Figure 4. Boundary constraint representation of thin rock slabs.

The boundary constraint conditions of rock plate are calculated according to the actual situation. Clamped plate selects 4a and simply supported plate selects 4b representation.

E. Deformation Mechanism and Mechanical Model for Deflection Calculation of Thin Rock Slabs

As the length of the mining space is generally larger than the inclination length, the force of the thin rock plate is shown in Fig. 5. It is assumed that the thin plate forms a deflection surface along the strike direction. Four sides are fixed or simply supported and symmetrical.

In Fig. 5, a long strip is distributed along the plate with a uniformly distributed load. The interception of a unit width (I—I) to study the bending slab. When bending, the section of the plate is kept flat and the neutral axis is at the center of plate thickness. The following assumptions are used to solve flexural load of thin plates:

1) An ideal plate with four edges simply supported.
2) The load acts on the neutral plane of the plate.
3) When a thin plate is transformed from stable equilibrium state of the plane to a slightly curved surface, the cross section keeps a plane.
4) The material is an ideal elastic body.

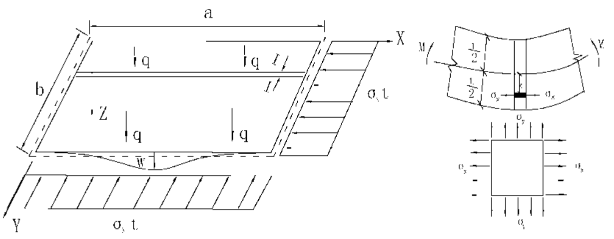


Figure 5. The force of the thin rock plate.

The total deflection of the thin slab is derived from the sum of the deflection between the horizontal stress σ_x, σ_y and the self weight stress q [4], [5].

$$W = a_{mn1} + a_{mn2} + a_{mn3}$$
$$= 4\sqrt{6}\frac{(1-\mu^2)a^2b^2(\sigma_x+\sigma_y)}{Et\pi^2(a^2+b^2)} + \frac{4a^2b^2}{t\pi^2(a^2+b^2)}\sqrt{\frac{3(1-\mu^2)q}{E}} \quad (2)$$

Order $w=vt$, introduce the time factor, and list the speed formula of deflection:

$$v = \frac{W}{t} = \frac{4\sqrt{6}\frac{(1-\mu^2)a^2b^2(\sigma_x+\sigma_y)}{Et\pi^2(a^2+b^2)} + \frac{4a^2b^2}{t\pi^2(a^2+b^2)}\sqrt{\frac{3(1-\mu^2)q}{E}}}{t}$$
$$= 4\sqrt{6}\frac{(1-\mu^2)a^2b^2(\sigma_x+\sigma_y)}{Et^2\pi^2(a^2+b^2)} + \frac{4a^2b^2}{t^2\pi^2(a^2+b^2)}\sqrt{\frac{3(1-\mu^2)q}{E}} \quad (3)$$

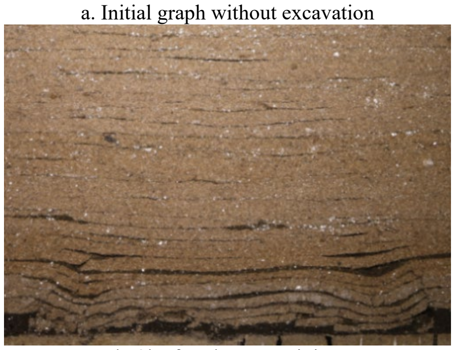
Because of $a = a_0 - 2hctg\beta$, where is a_0 variable, it can be seen that over time, speed and time are not proportional to each other. Therefore, the speed of abscission layer development is not uniform but rather allometric.

IV. Study on Similar Simulated Test of Disturbed Overburden Separation

The process of surface subsidence with time can be divided into 3 stages, namely the surface subsidence in the initial stage, the development stage and the attenuation stage [6]. In the process of surface subsidence, there are many influencing factors, including excavation width, stratum dip angle, strike length of working face (advancing distance), excavation speed, nature of surrounding rock and so on. But when on the specific working face, advancing along the excavation direction is constant, in addition to working face advancing distance will change, other factors can be regarded as a constant [7]. Disturbance degree of working face advancing distance I is along the strike scale directly, also have direct relations with the time factor. Therefore, this paper using working face advancing distance as reflected in the test, the surface settlement of the relationship between time and space scales [8]-[10].

This paper simulates the coal bearing strata dominated by sandstone, studies the heterogeneous development mechanism of overlying strata separation, and the relationship between surface subsidence and abnormal growth of disturbed overburden strata separation. The simulated excavation depth is 80m, the excavation thickness is 4m, the excavation width is 50m, the average density of overlying strata is 2.5 x 10^{-3}kg/cm^3, and the single axial compressive strength is 40Mpa. The geometric similarity constant of the model is 1:100. In this experiment, all caving mining methods are adopted, and the natural caving of overlying rock is taken as a excavation step. When mining to 50cm, it is divided into six mining steps. The excavation distance corresponding to the six excavation steps is 12cm, 18cm, 23cm, 31cm, 39cm and 50cm respectively. With the advancing of the working face, the subsidence and failure in the stratum is shown in Fig. 6.

a. Initial graph without excavation



b. 2h after the stop mining

Figure 6. The internal subsidence process of stratum.

Through the simulation of mining process, the occurrence of rock fall and separation can be observed visually. On the basis of the simulation test, the variation of the length and width of a separation layer during the excavation of the ore body is measured, and the allometric characteristics of the growth process of the separation layer are studied. The test data are shown in Table I.

TABLE I. The Length and Width of Separated Strata

Time of initial cracking (s)	The length of the separation (cm)	The width of the separation (cm)
640	16.42884	0.109447
785	18.3687	0.162586
820	20.7486	0.190419
905	22.2612	0.279347
935	22.6901	0.302816
1025	22.9970	0.393069
1085	22.9971	0.196165
1135	22.9972	0.097599

Based on the time of the initial cracking of the separation, the curves of the length and width of the separation are plotted as shown in Fig. 7 and Fig 8.

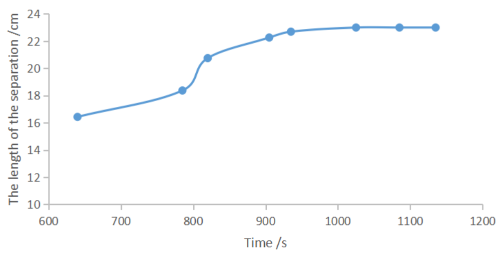


Figure 7. Time curve of separated length.

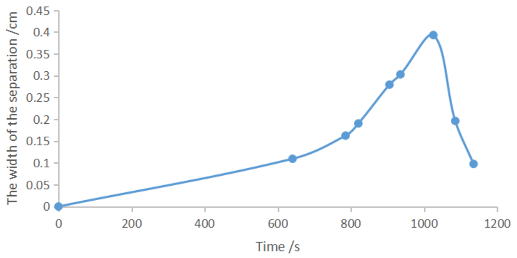


Figure 8. Time curve of separated width.

Through the analysis of experimental data, it can be seen that the length and width of separation layer increase with time in the stage of initiation and development. In the closing stage, the length of separation layer is no longer changed with time, and the width of separation layer decreases until completely closed. The slope of the curves in each stage is different, which indicates that the rate of morphological change of the abscission layer at different stages of initiation, development and closure is different, showing the form of allometric growth.

V. Conclusions

Through this study and test on development regularity of mining speed of coal seam separated from overburden strata, some main conclusions can be drawn:

1) Based on the analysis of the dynamic process of overburden strata separation, the mechanical model of overlying strata is established, and the mechanism of the development of overburden separation is established on the basis of the model.

2) Through the analysis of experimental data, it can be seen that the length and width of separation layer increase with time in the stage of initiation and development; In the closing stage, the length of separation layer is no longer changed with time, and the width of separation layer decreases until completely closed.

3) The curves of the length and width of the separation layer with time are described. It is found that the slopes of each curve are different. It shows that the rate of morphological change of the abscission layer at different stages of initiation, development and closure is different, showing the form of allometric growth.

4) The research shows that the process of surface subsidence has a significant dependence on the development rate of overburden separation layer, which is of great significance for understanding the law of ground subsidence through the development process of overburden separation.

Conflict of Interest

The authors declare no conflict of interest for the paper.

Author Contributions

All the authors made significant contributions to the work. Guangming Yu, Xianzhang Ling, Chuanbo Hao and Kun Wang conceived this study; Guangming Yu and Xiankun Zeng wrote the paper; Guangming Yu reviewed the manuscript for scientific contents; all authors had approved the final version.

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