Geomechanics and Geotechnical Engineering

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Study on Subsidence Calculation Model Based on Allometric Growth of Separated Strata in Mining Overburden

Abstract: In the sedimentary coal stratum, rock stratum exhibits layered feature and has a obvious level, after the underground coal mining, overlying rock often produces separation strata along the level. However, due to the difference in the layers of rocks, the change of the mining process, the difference height in the level and such factors, the rule of separated strata is extremely complex. Therefore, in this paper, by means of experiment and simulation study found that allometric phenomenon, features and rule of separated strata in mining overburden, the research reveals the mechanical mechanism of allometric development of overburden separated strata, to establish its development formula based on the theory of beam in the mechanics, analyzing the space-time law of mining subsidence and overburden separated strata, to find the relationship between surface subsidence and allometric growth of separated strata in mining overburden, to establish the subsidence model based on allometric growth of separated strata in mining overburden.

Key words: separated strata in mining overburden, allometric growth, surface subsidence, calculation model.

Introduction

Study on mining subsidence damage control and prevention, is conducive to the development of coal industry in China and the stability of the ecological environment and. Separated strata is the key factor about the theory of mining subsidence [1], studying the allometric phenomenon of separated strata in mining overburden, to reveal the mechanical mechanism of allometric development of overburden separated strata, can better analysis the space-time law of mining subsidence and overburden separated strata, to establish the stra-

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** Rely on Qingdao Technological University (Cooperative Innovation Center of Engineering Construction and Safety in Shandong Blue Economic Zone), project supported by National Natural Science Foundation of China (Nos. 51374135、51179080), Qingdao Science and Technology Projec t (SDSITC-0108310), the paper funded by the National Scholarship Fund.

tum subsidence model based on allometric growth of separated strata in mining overburden, can be able to provide a new analytical method for the mining subsidence damage control and prevention.

The mechanical model of separated strata in mining overburden

With the coal mining, the pressure balance arch is emerged in the overburden strata above the mined-out area, in a certain mining area, the distribution of relief and supercharging zone in the overlying rock of mine can be regarded as the stress balance arch structure. Due to the effect of the pressure balance arch, the weight of the overburden above the mined-out area distribute to the arch foot through the pressure balance arch axis, the rock formation inside arch does not bear the load of the overburden, which produces a layered curved sink under the effect of its own gravity stress and horizontal stress, since the rock properties, thickness and rock height are different so that the subsidence of upper and lower strata occurs asynchronous, when the deflection of the upper strata is smaller than the lower strata, the catastrophic instability will occur between the upper and lower strata, and then produce separated strata, form separation space.

The establishment of mechanics model of strata combination. The tope roof is a number of different strata combination that composed by the rock formation with different properties and intensity in a certain order [2], each rock is a plate-like structure, since the length of advancing direction of the coal seam is much longer than the suspension length of basic roof strata trend, so the composed plate model of roof strata can be further simplified to the composed beam model. The mechanical model of composed rock beam is shown in Fig. 1.

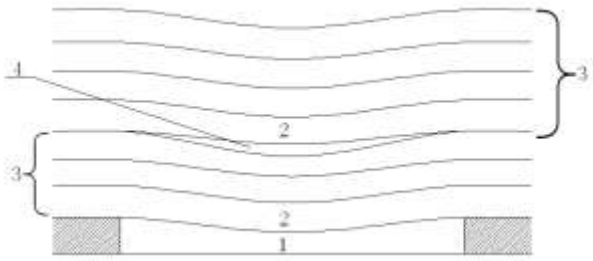

Fig. 1. The mechanical model of composed rock beam. 1 – the mined-out area; 2 – key stratum; 3 – formation combination; 4 – separated strata.

Regard the rock beam as a statically indeterminate structure which fixed at each end, analyze the stress of a rock formation in the composed rock beam and any point on the rock beam, the stress analysis is shown in Fig. 2.

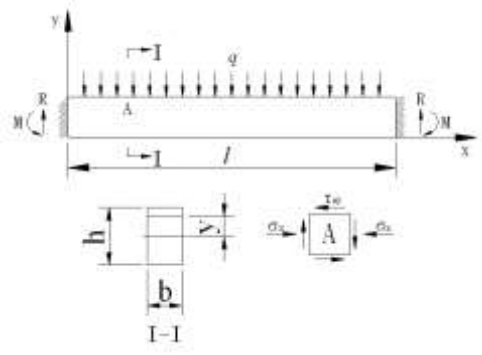

Fig. 2. Stress analysis of the rock beam.

The mechanical criteria of allometric development of overburden separated strata

According to the mechanics structure model of composed rock beam, due to the differences of subsidence deflection between two strata in the stratum, will lead to a processes of initiation, development and closing of separated strata [3]. Take one of the separated strata in the stratum for analysis, in the range of the boundary influence line, the lower strata where includes separated strata is supported by the bottom of rock mass, it can be seen as a beam on elastic foundation, key stratum above the separated strata can be seen as a statically indeterminate beam which fixed at each end, based on the mechanical model of composed beam in the Fig. 3, to establish the mechanics analysis model of separated strata as shown in the figure below.

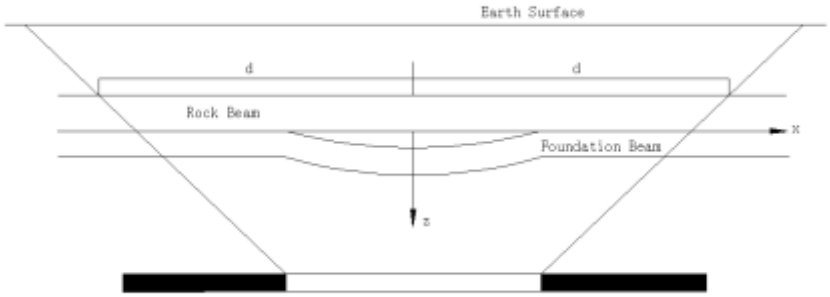

Fig. 3. The mechanics model of the development of separated strata.

Under the action of uniformly distributed load q (including the self-weight of rock stratum and the load passed down from overburden), set the vertical displacement of foundation beam to *z(x)*, pressure between the beam and foundation to *p(x)*, by Winkle assumption can be got, the relation between the foundation subsidence *z* and ground pressure *p* is: $p = kz$, where *k* is the resistance coefficient of foundation beam, *z* is the subsidence deflection of foundation beam.

Take the bottom of rock beam as x-axis, the midpoint of separated strata as the origin, the direction of subsidence as z-axis, establish the coordinate system. Calculate the subsidence deflection of foundation beam on the right of origin, the relationship between the subsidence deflection *z*, the load *q* and ground pressure *p* can be written as flow:

$$EI\frac{d^4z}{dx^4} = q - p = q - kz\,. \tag{1}$$

The flexibility characteristic value of beam is $\lambda = \sqrt[4]{\frac{k}{4EI}}$, *EI* is the flexural stiffness of foundation beam, obtain the integral equation is [4]:

$$z = \frac{q}{k} + e^{-\beta x}(C_1 \sin\lambda x + C_2 \cos\lambda x) + e^{\beta x}(C_3 \sin\lambda x + C_4 \cos\lambda x)\,.$$

by qualitative analysis can be know, when x approaches positive infinity, the subsidence deflection *z* approaches $\frac{q}{k}$, only when $C_3 = C_4 = 0$, this condition is met, therefore, the formula can be changed to:

$$z = \frac{q}{k} + e^{-\beta x}(C_1 \sin \lambda x + C_2 \cos \lambda x).$$

According to the reality, subsidence in the infinity of mining boundary is zero, and the calculated value is the deflection of subsidence between load and non-Loaded rock stratum in both cases before and after mining. Therefore, in order to get the actual value of subsidence $\frac{q}{k}$ should be subtracted from the formula, so obtain the subsidence curve equation of beam on elastic foundation as flow:

$$z = e^{-\beta x}(C_1 \sin \lambda x + C_2 \cos \lambda x).$$

According to the boundary conditions: $z/_{x=0} = W_{\max} = m\eta$; $\frac{dz}{dx}/_{x=0} = 0$, can be obtained $C_1 = C_2 = W_{\max}$, in the formula, $W_{\max}$ is the maximum subsidence value of beam on elastic foundation, *m* is the mining thickness of coal seam, is the subsidence coefficient of rock stratum.

Therefore, the curve equation of beam on elastic foundation is:

$$z = W_{\max} e^{-\beta x}(\sin \lambda x + \cos \lambda x) \quad (x \geq 0). \tag{2}$$

In the same way, subsidence curve equation of beam on elastic foundation in the left side of origin is:

$$z = W_{\max} e^{\beta x}(\sin \lambda x - \cos \lambda x) \quad (x \leq 0). \tag{3}$$

For the rock beam, the relationship between deflection *z* and the load *p'* is:

$$E'I' \frac{d^4 z'}{dx^4} = p'.$$

According to the boundary conditions: $z/_{x=\pm d} = 0$; $\frac{dz}{dx}/_{x=\pm d} = 0$, so obtain the subsidence curve equation of rock beam as flow:

$$z' = \frac{p'}{24E'I'}(x^2 - d^2)^2. \tag{4}$$

In the formula, *d* is the half length of the rock beam, $E'I'$ is the flexural stiffness of rock beam, p' is the suffered load of rock beam.

By the formula (3) and (4) to calculate the deflection of the upper and lower rock stratum, the width of separated strata can be obtained:

$$Z = z - z^{'} = W_{\max} e^{-\beta x} (\sin \lambda x + \cos \lambda x) - \frac{p^{'}}{24 E^{'} I^{'}} (x^2 - d^2)^2 \ (x \geq 0).$$

$$Z = z - z^{'} = W_{\max} e^{\beta x} (\sin \lambda x - \cos \lambda x) - \frac{p^{'}}{24 E^{'} I^{'}} (x^2 - d^2)^2 \ (x \leq 0). \quad (5)$$

At the point of z=0, that is the half-point of beam, the deflection differences of two rock stratum is the maximum, let Z equal to vt, the equation as flow can be obtained:

$$v = \frac{W_{\max} e^{-\beta x} (\sin \lambda x + \cos \lambda x) - \frac{p^{'}}{24 E^{'} I^{'}} (x^2 - d^2)^2}{t}. \quad (6)$$

Since x is a variable, as can be seen, with the passage of time, speed and time is disproportionate relationship, therefore, the development speed of separated strata is not uniform, it show the feature of allometric growth.

The development characteristic of mining subsidence

The surface subsidence caused by underground coal mining is a process of development gradually with the move of overlying strata, the process of surface subsidence development over time can generally be divided into three stages, and they are the initial stage, development stage and the attenuation stage of the surface subsidence [5].

After the initial mining, the stress balance of overlying rock in coal seam is destroyed, overburden began to collapse, the mined-out area move upward in the form of separation space in the overlying strata, eventually spread to surface, make the surface subsidence and sinking speed grow from 0, surface subsidence come into the initial stages; with the mining working face advancing, after the fully mining of the stratum, a large area of surface subsidence come to appear, surface subsidence basin gradually move forward, sinking speed and the surface subsidence are both developed to a larger value, the surface subsidence come into the accelerated development stage at this time; when the coal seam stop mining, the surface subsidence basin almost no longer move forward, the Surface subsidence come into the rapid attenuation stage, in this stage, with the compaction of the rock and the closure of separated strata and fracture in the strata caving zone, surface subsidence still has some increase, sink to stable eventually.

There are many influence factors of surface subsidence caused by mining, including coal mining width, dip angle of coal seam, strike length of the working face (advancing distance), mining rate, and surrounding rock properties and so on. But when for a particular working face, advancing at a constant speed along the direction of mining, in addition to the advancing distance of working face will change, other factors can be considered as constant [6], the settlement value of any point on the surface subsidence basin in the process of mining, is just change along with the variation of working face advancing distance. The working face advancing distance l is the directly scale of mining degree along strike, also has a direct relationship with time factor. Therefore, in this paper, using working face advancing distance as a scale that reflect the space-time relationship of surface subsidence.

Similar Simulation Study about Mining Overburdens

Data analysis of separated strata on the simulation test. This paper simulates coal-bearing strata of mainly sandstone, study the mechanical mechanism of allometric development of overburden separated strata, study the relationship between surface subsidence and allometric growth of mining Overburdens. The mining depth of simulation is 80 m, thickness of coal seam mining is 4m, mining width is 50 m, the average bulk density of overburden of coal seam is 2.5×10^{-3} kg/cm^3, the uniaxial compressive strength is 40 MPa. The bulk density of coal is 1.4×10^{-3} kg/cm^3, the uniaxial compressive strength is 20 MPa. The geometric similarity constant of the model is 1:100. This test uses all caving mining method, takes the natural collapse of upper strata as one excavation step. It is divided into six steps when mining to 50 cm. The mining advancing distance of corresponding six excavation steps is 12 cm, 18 cm, 23 cm, 31 cm, 39 cm and 50 cm. With the advancing of working face, the situation of internal subsidence damage of stratum is shown in the Fig. 4.

a. Initial graph without excavation

b. Advancing distance 12 cm

c. Advancing distance 18 cm

d. Advancing distance 23 cm

e. Advancing distance 31 cm

f. Advancing distance 39 cm

g. Advancing distance 50 cm

h. 2h after the stop mining

Fig. 4. The internal subsidence process of stratum.

Through the simulation of coal seam excavation process, can be intuitive to observe the caving, fracture of rock and so on when coal was mining. As the working face advancing, above the mined-out area can be observed to produce a lot of separated strata and cracks, the growth of separated strata have to undergo a process of initiation, development and closing. The produce and development of separated strata also have some influence between each other; they have some relationship of time and space.

Now on the basis of simulation test, measure the changes of the length and width of one separated strata in the process of coal mining, study allometric feature in the growing process of separated strata, test data is shown in the following table.

The length and width of separated strata

Time away from initial cracking of separated strata /s	The length of separated strata /cm	The width of separated strata /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

Take the initial cracking time of separated strata as the origin; draw the time-varying curve graph of length and width of separated strata, as shown in the Fig. 5, 6.

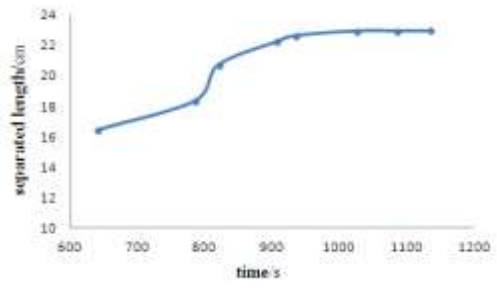

Fig. 5. Time curve of separated length.

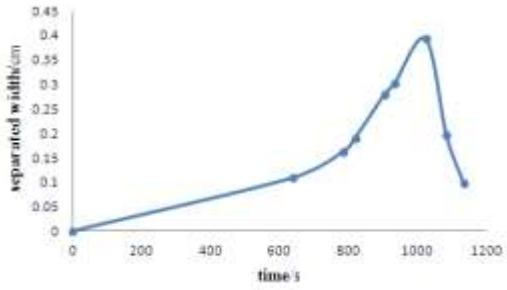

Fig. 6. Time curve of separated width.

By analyzing the data from the test, we can know that the lengths and widths of separated strata increases with time grow when separated strata in the initiation and development stage. In the closing stages, the length of separated strata basic have no significant change, the width of separated strata gradually decreases until it is closed completely. The slope of the curve in every stage is different in the figure, it shows that the morphological change rates of separated strata are different in the stage of initiation, development and closing, present the form of allometric growth.

Date analysis of surface subsidence on the simulation test. When the advancing distance of the working face is 23 cm, 50 cm and 2 hours after the stop mining, the surface subsidence curves measured though the test are shown in the Fig. 7.

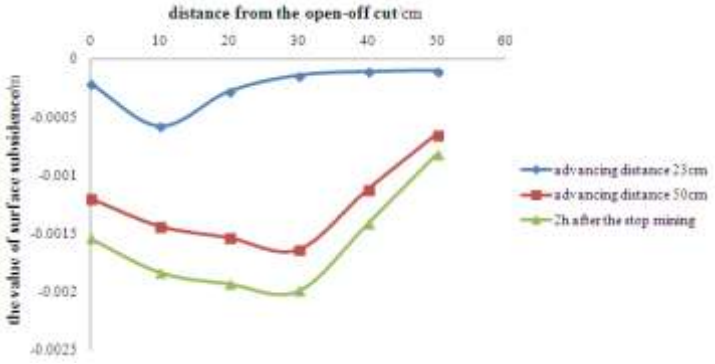

Fig. 7. Surface subsidence curve at different times.

As can be seen, when the advancing distance was 23 cm, the surface began to sink and subsidence increases gradually, surface subsidence was in the initial stage; when the advancing distance was 50 cm, the value of surface subsidence was larger, the surface appeared large area of subsidence, achieved a fully developed state; when 2 hours after the stop mining, the subsidence of surface began to weaken, maximum ground subsidence increase is smaller, surface subsidence entered a decay stage, the change of surface subsidence and the growth of overburden separated strata had a greater relationship in this stage.

Through data analysis shows, when mining width was 23 cm, the maximum surface subsidence measured through the test was 0.0006 m, converted to the actual value was 60mm, the maximum settlement point appeared above the center of mined-out area; when mining width was 50 cm, the maximum surface subsidence measured through the test was 0.0016 m, converted to the actual value was 160 mm, the maximum settlement point moved to above the center of mined-out area along the direction of mining; when 2 hours after the stop mining, surface subsidence will last for a period of time to stop, ultimately measured the maximum surface subsidence was 0.002 m, converted to the actual value was 200 mm, had an increase compared with when the advancing distance was 50 cm, this is due to the collapse of the lower rock, the closure of fracture and separated strata, until the broken rock natural compaction. Because the mining width in the test is small, it fails to form a fully mining surface subsidence basin in the test model; the flat shape doesn't appear in the surface subsidence model.

Conclusions

1. To study the mechanical mechanism of separated strata in mining overburden development, establish the mechanical model of the composed rock beam in the stratum structure, verify the existence mechanism of allometric growth of separated strata based on this model, and verify the allometric feature of separated strata in mining overburden in the growth stage.

2. For the three developmental stage of surface subsidence in coal mining process, using similar simulation test to verify. Take the advancing distance of working face as direct variable, other factors constant, analyze the process of surface subsidence when the working face advancing, conform to the characteristics of each stage which surface subsidence experienced. When the mining stopped, surface subsidence enter a decay stage, at this point there are a lot of separated strata in the stratum gradually enter the closing stage, lead to the maximum surface subsidence increase slowly after stop mining until the subsidence stabilize finally.

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The report was delivered at the *5th Russian-Chinese Scientific Technical Forum Deep Level Rock Mechanics and Engineering*, August, 5-7th, 2015, Weihai, CPR. On its basis, the author has written an article especially for *FEFU: School of Engineering Bulletin*.

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НАУКИ О ЗЕМЛЕ. Геомеханика и строительная геотехнология

УДК 539.3

ЮЙ ГУАНМИН, ХУ СЯОЯН, ЛЮ ШИБАО, СУН ЧУАНЬВАН, ЛИ БИНБИН

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Исследование неравномерного оседания покрывающей толщи при подземной разработке месторождений

Аннотация: Путем экспериментов и моделирования в ходе исследования выявлены закономерности и свойства неравномерного оседания покрывающей толщи при подземной разработке месторождений угля.
Ключевые слова: разделенные слои при вскрышных работах, аллометрический рост, оседание поверхностных грунтов, расчетная модель.