

Relationship between surface subsidence factor and mining depth of strip pillar mining

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Abstract: Strip pillar mining is one of the most important technical measures to control mining subsidence in China. Mining depth is one of the most important factors that can affect the mining subsidence in strip pillar mining. Six numerical simulation models were set up to simulate the surface subsidence of strip pillar mining in different mining depths. The mining depth in these six models ranges from 300 to 800 m. The simulated results were compared and analyzed. The formula was established based on the simulated results. It demonstrated that the subsidence of strip pillar mining method is related to mining depth. While the other conditions are the same, the subsidence of strip pillar mining increases with the increase of mining depth by logarithmic relationship.

Key words: subsidence factor; strip pillar mining; mining depth; numerical simulation

1 Introduction

Because the coal resources under shallow overburden strata are depleted gradually, the depth of underground mining becomes deeper and deeper [1]. Also, due to the increase of coal seam depth, the protective coal pillar sizes of the surface structures become quickly large. Therefore, the coal reserves under “three body” (structure, railway and water body) increase quickly in deep mining. In strip pillar mining, coal reserve is divided into regular strips that are mined one in every other strip. The strips left behind, called strip pillars, are designed to support the overburden, prevent surface subsidence and protect the surface structures and ecological environment. So it is widely used in China coal mines [2–5]. This is one of the important methods in “Green Mining Technology” and has become an effective method to mine those coal reserves left under “three body” [6].

The surface subsidence factor is the key parameter for the prediction of surface movement and deformation [7–8]. Its accuracy can directly affect the predicted results of surface movement and deformation and the mining design. So, many scholars have paid a lot of attention to the study of surface subsidence factor of strip

pillar mining. Many ground surface movement stations of strip pillar mining were established to do the research. The observed data and theoretical research demonstrated that the subsidence of strip pillar mining is related with the following factors: mining width (b), strip pillar width (a), mining depth (H), mining thickness (M), recovery ratio (ρ), mining method and roof management method, physical mechanical properties and structure of overburden strata, the mechanical properties of the surrounding rock of coal pillar, roof and floor, the mined-out area, repeated mining, the angle of coal seam and etc [9].

Mining depth is one of the important factors that can affect the surface subsidence of strip pillar mining. Some scholars think that the surface subsidence becomes small with the increase of mining depth. The main reason is that the permanent separation and void in the overburden strata increase and surface subsidence decreases with mining depth increasing. While the other scholars think that the surface subsidence becomes large with the increase of mining depth. The reason is that the load of the overburden strata increases, so the cracked rocks in the caving zone are compressed adequately and surface subsidence increases with mining depth increasing. The study of the relationship between mining subsidence and mining depth in strip pillar mining was

not enough. So the finite element numerical simulation software package (ABAQUS) was used to study the relationship between surface subsidence and mining depth [10].

2 Numerical simulation model

2.1 Model and its boundary conditions

The aim of this numerical simulation is to research the changing laws of surface subsidence with different mining depths, so two-dimensional plane strain model was set up. The overburden strata were considered as continuous medium in these models. And displacement boundary conditions were applied in the models: the horizontal displacements were limited in the two sides of the models. The vertical displacements were fixed on the bottom of the models and the top of the model is free. The models were in the stress state caused by the loads of rock mass in the process of simulation. The tectonic stress was ignored in the models. The initial stress condition in the overburden strata was decided by the properties and gravity of the overburden strata. Six models were set up in this paper and their boundary conditions were the same.

2.2 Mechanical properties of models

The strata of the borehole column in a coalmine are simplified as the simulated strata in the models. In descending order, the simulation strata are: alluvium, the inter-bedded strata of mudstone and sandy mudstone, the inter-bedded strata of medium-grained sandstone and siltstone, the main roof of sandstone, the immediate roof of mudstone, coal seam, and the floor of the coal seam. The mechanical properties of the above strata used in this model are shown in Table 1 [11].

The physical and mechanical parameters of the overburden strata change due to the interruption of coal mining. So, the elastic modulus of the cracked rock mass in the middle of the models is evaluated the 1/4 of its

intact strata based on the back analysis of displacement. In order to compare the simulated results of each model, the physical and mechanic parameters of the strata in each model are all the same.

In addition, because the mining area is so large that the caving of mined-out area is sufficient. Therefore, the volume of rock mass expands and the gangue in the gob will touch the roof and floor. In the end the gangue is solidly re-compressed, and then it can support the overburden strata to some degree. So the physical and mechanical properties of the gob gangue can affect on the overburden strata and the surface movement and deformation to some degree. In order to make the simulated results have good agreement with the actual value, the supporting of the gob material in mined-out area has been considered in this research. Some scholars have studied on the material properties of gob material. In general, the gob material has the properties of strain-hardening; the elastic modulus increase with the increase of compressive strain. MORSY et al [12] give the stress-strain relationship of gob material based on his study and introduces it into the finite element numerical simulation. The actual examples can prove that the following constitutive equations can describe compressive properties of gob material well.

$$\sigma = \frac{R_0 E_i}{a} (e^{a\varepsilon} - 1) \quad (1)$$

where σ and ε are normal stress and strain, respectively; R_0 and a are constant; E_i is elastic modulus of the intact rock mass.

3 Analysis of numerical simulation results

3.1 Modeling and results

In order to obtain the surface subsidence laws of different mining depths in strip pillar mining method, six models were established. The mining depths in these models are 300, 400, 500, 600, 700 and 800 m, respectively.

Table 1 Physical and mechanic properties of overburden strata

No.	Rock type	Elastic modulus/ GPa	Poisson ratio	Density/ (kg·m ⁻³)	Remarks
1	Alluvium	0.85	0.40	1 750	
2	Inter-bedded strata of mudstone and sandy mudstone	6.80	0.36	2 600	
3	Inter-bedded strata of medium-grained sandstone and siltstone	16.90	0.22	2 650	Elastic modulus of cracked rock mass due to coal mining is the one fourth of the intact rock mass.
4	Main roof	17.20	0.20	2 700	
5	Immediate roof	4.50	0.35	2 450	
6	Coal seam	2.60	0.38	1 480	
7	Floor	16.50	0.20	2 660	

The average mining height in these models is 4.0 m, the mining width and strip pillar width are both 60 m. the design recovery ratio in the strip pillar mining is 50% and the coal seam is horizontal. There are 6 mining strips and 5 strip pillars in each model. Because the mining depth of these models is different, the two side pillars widths of the model are also different. In order to reduce the influence of boundary effect, the two side pillars widths range from 1 100 to 2 300 m. The height of models increases with the increase of mining depth. And the mining depths in these models are changed through variation of the overburden strata thickness.

Based on the simulated calculation of these models, the surface subsidence curve and the maximum surface subsidence value of each model were obtained. The surface subsidence curves (the mining depths range from 300 m to 800 m) are shown in Figs. 1–6, respectively. And the maximum surface subsidence value of each model is shown in Table 2.

3.2 Analysis of results

Based on the numerical simulation results (shown in Fig. 1 and Fig. 2), the laws of surface subsidence of strip pillar mining are similar to full extraction. The point of

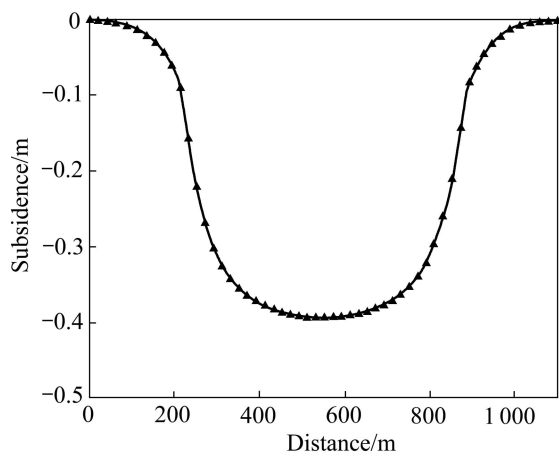


Fig. 1 Subsidence curve of model No.1 (mining depth is 300 m)

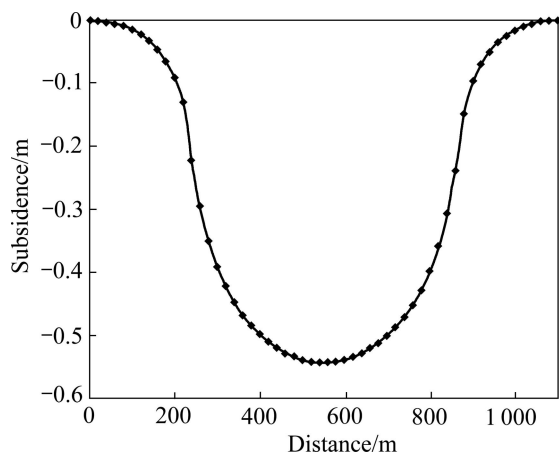


Fig. 2 Subsidence curve of model No. 2 (mining depth is 400 m)

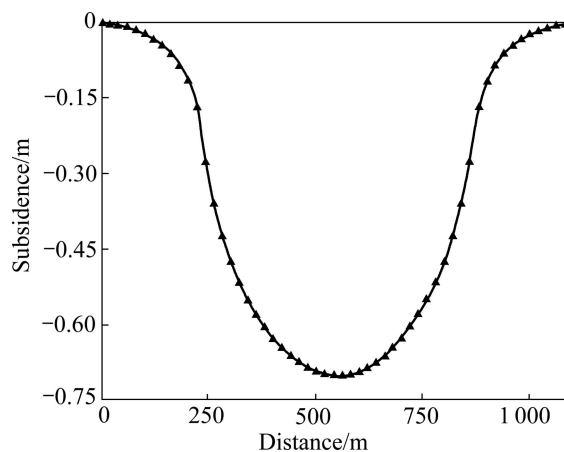


Fig. 3 Subsidence curve of model No. 3 (mining depth is 500 m)

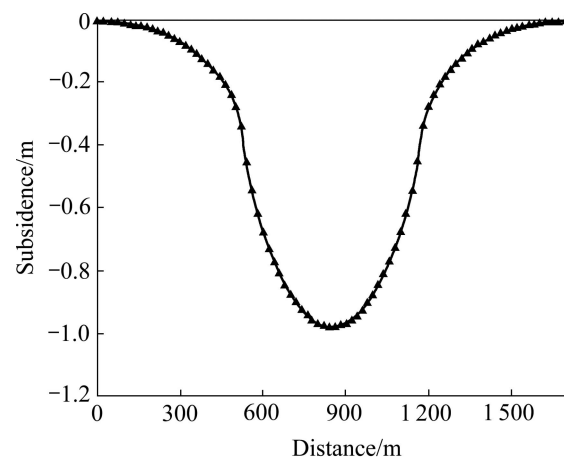


Fig. 4 Subsidence curve of model No. 4 (mining depth is 600 m)

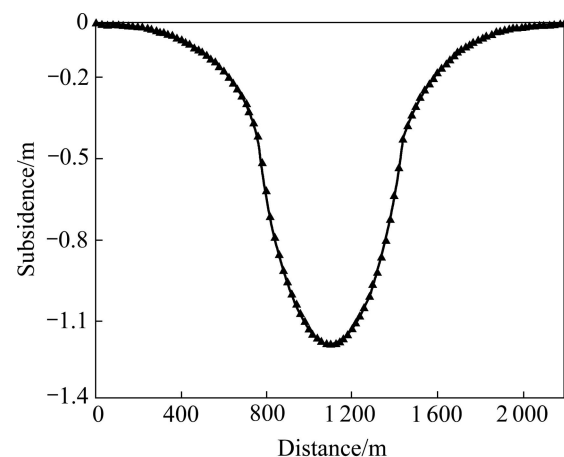


Fig. 5 Subsidence curve of model No. 5 (mining depth is 700 m)

maximum surface subsidence is located in the centre of ground surface above gob. And with the increase of the mining depths of strip pillar mining, the surface subsidence changes from sufficient mining subsidence to in-sufficient mining subsidence. So, it needs to calculate subsidence factor on the condition of sufficiency mining based on the maximum surface subsidence (W_{\max}). The

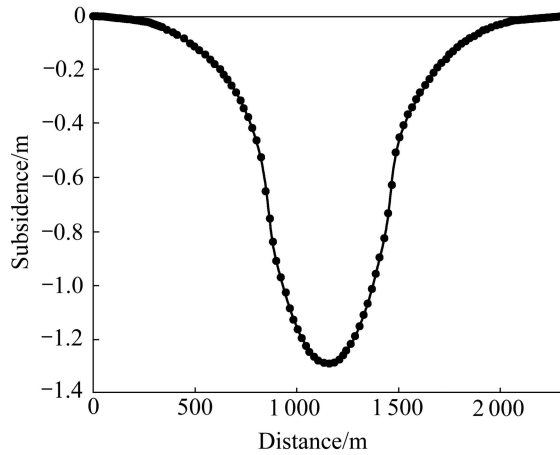


Fig. 6 Subsidence curve of model No. 6 (mining depth is 800 m)

Table 2 Maximum subsidence value and subsidence factor

No.	Mining depth/m	Maximum subsidence/mm	Subsidence factor
1	300	0.417 1	0.104 3
2	400	0.606 1	0.151 5
3	500	0.819 6	0.204 9
4	600	1.028 3	0.274 1
5	700	1.231 7	0.354 5
6	800	1.360 2	0.418 6

formula to calculate the subsidence factor (q) is as follows:

$$q = \frac{W_{\max}}{m \cos \alpha \sqrt{n_1 n_3}} \quad (2)$$

where m is the mining height; α is the angle of coal seam; n_1 and n_3 are factor of mining extent along dip and strike direction, respectively. It can be obtained by the following formulas.

$$n_1 = k_1 \frac{D_1}{H}, \quad n_3 = k_3 \frac{D_3}{H}$$

where if n_1 or n_3 is larger than 1.0, the value of n_1 or n_3 is given 1; k_1 and k_3 are constant, it usually equals to 0.8; H is mining depth.

The surface subsidence factors of these models are shown in Table 2. The relationship curves of mining depths and surface maximum subsidence and subsidence factor are shown in Fig. 7. It is shown in Fig. 7 that with the increase of mining depths, the surface maximum subsidence value and subsidence factor also increase gradually. The relationship between surface maximum subsidence value W_{\max} and mining depths (H) can be expressed by the following formula:

$$W_{\max} = 0.9904 \ln H - 5.2866 \quad (3)$$

The relationship between surface subsidence factor

q of strip pillar mining and mining depths (H) can be expressed by the following formula:

$$q = 0.2936 \ln H - 1.5934 \quad (4)$$

Based on this analysis of the results, it indicates that both the surface subsidence value and surface subsidence factor of strip pillar mining are related to the mining depth. When the other mining and geological conditions are the same, with the increase of mining depth, the surface subsidence value and surface subsidence factor increase by logarithmic relationship. While the theoretical and field observed data have proved that with the increase of mining depth of full extraction, the separation and voids in the overburden strata increase. And then surface subsidence due to full mining becomes smaller, so the surface subsidence factor becomes smaller with the increase of mining depth. In strip pillar mining, with the increase of mining depth, the weight of the overburden strata increases. Then the loads acted on strip coal pillars and gob material become larger. The strip coal pillars are more compressed and gob materials are also densely compressed. Therefore, both the surface subsidence value and the subsidence factor increase in the end. This demonstrates that the surface subsidence mechanism of strip pillar mining is different from the surface subsidence mechanism of full extraction.

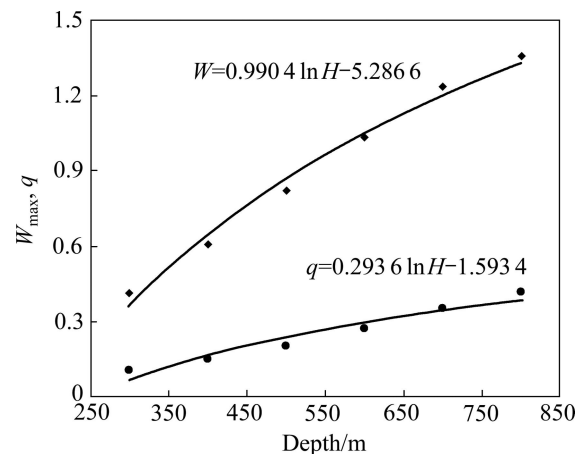


Fig. 7 Relationships between mining depths and maximum surface subsidence (W_{\max}) and subsidence factor (q)

4 Conclusions

1) Because of the differences and diversities of mining and geological conditions, the influencing factors of mining subsidence are very complicated. Mining depth is one of the important factors that can affect the surface subsidence of strip pillar mining. When the other mining and geological conditions are the same, the mining subsidence value and the subsidence factor of strip pillar mining become larger with the increase of mining depth by logarithmic relationship and the

formulae are established based on the simulated results.

2) The surface subsidence law of strip pillar mining is similar to that of full extraction, but the surface subsidence mechanism of strip pillar mining is different from that of full extraction. With the increase of mining depths in strip pillar mining, the weight of the overburden strata also increases. Then the loads acted on strip coal pillars and gob material become larger. The strip coal pillars are more compressed and gob materials are also densely compressed. Therefore, both the surface subsidence value and the subsidence factor become larger.

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