

The study on the movement law of overlying strata in fully mechanized caving face under alluvium with huge thickness in deep mine

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Abstract. Xin ju-long Mine has characteristics of deep buried depth and large alluvium's thickness, and the ground pressure is obvious. In order to realize the effective control of the overlying strata in the fully mechanized caving face under alluvium with huge thickness in deep mine, the movement law of overlying strata is studied. The relationship between the key stratum's fracture and the movement of overlying strata is analyzed based on 'the key stratum' theory, and the movement law is obtained by numerical simulation. The results show that:1)after the bedrock is completely broken, the strength of the overlying alluvium becomes low, and its supporting capacity is gradually lost and it will gradually sink with the breaking of the bedrock;2)with the increase of the alluvium's thickness, the roof subsidence is gradually increasing, and with the continuous advancement of the working face, the influence range of the support pressure and the amount of roof subsidence also show a trend of increasing; 3)the study on the movement law of overlying strata under this condition provides a reliable and theoretical guide for the selection of the support and the control of ground pressure.

1.Introduction

The depth of Xin ju-long mine is more than 800 meters, the bedrock is relatively thin, and the alluvium's thickness is huge,so the mine is faced with strong pressure appearance in the process of mining.Safe and efficient mining under alluvium with huge thickness in deep mine has become an important research topic in recent years. In combination with the production practice of coal mine and the observation of overlying strata movement, 'the voussoir beam' theory is put forward by Qian Ming-gao(Qian et al.,1989; Qian et al.,2010). Academician Qian Ming-gao and Professor Miao Xie-Xing put forward the 'key stratum' theory based on 'the voussoir beam' theory, who believe that the key stratum plays a major role in the activities of rock mass, and the fracture of the key stratum will make the overlying strata have obvious movement and lead to the strata behaviours (Qian et al.,1996). Based on a large number of field measurements and theoretical analysis, Academician Song Zhen-qi put forward 'the transferring rock beam' theory,which is centered on the overlying strata movement(Tan et al.,2007). Professor Jiang Fu-xing put forward 'the



spatial structure of overlying strata' theory, which is a systematic analysis on the mechanical mechanism of mine dynamic disasters such as rock burst(Jiang et al.,2006).On the basis of previous studies(Xu et al.,2008; Xu et al.,2009; Ma et al.,2010; Liu et al.,2011; Ju et al.,2011; Ma et al.,2013), using the methods of theoretical analysis and numerical simulation, the movement law of overlying strata is studied and the law of the support pressure's distribution and the amount of roof subsidence is analyzed.

2. Calculation of the Key Stratum's Thickness

There is a great relationship between the movement of overlying strata and the fracture of the basic roof. Once the fracture of the basic roof occurs, the subsidence of the overlying strata will occur, which will lead to the subsidence of the ground surface. So the experts gives the concept of the key stratum which plays a major role in the activities of rock mass. The key stratum's thickness is usually determined by the method of field measurement. In addition, it can be obtained according to the weighting average of the first weighting interval and the period weighting interval.

The thickness of the key stratum obtained from the first weighting interval is as follows.

$$m_{E0} = \frac{C_0^2 \gamma_E}{2 \times 1000 \sigma_t} \quad (1)$$

Where: C_0 - the key stratum of the first weighting interval, m; γ_E - the key stratum of the average bulk density, 25kN/m³; σ_t - the tensile strength of the key stratum, kN/m².

The key stratum's thickness of the first and the second periodic weighting is obtained according to the periodic weighting interval.

$$m_{E1} = \frac{3\gamma_E \left[\left(C_1 + \frac{C_0}{4} \right)^2 - \left(\frac{C_0}{4} \right)^2 \right]}{1000 \sigma_t} \quad (2)$$

$$m_{E1} = \frac{3\gamma_E \left[\left(C_2 + \frac{C_1}{4} \right)^2 - \left(\frac{C_1}{4} \right)^2 \right]}{1000 \sigma_t} \quad (3)$$

Where: C_1 -the first period of weighting interval,m; C_2 - the second period of weighting interval, m.

According to the weighted average of the periodic weighting interval, the key stratum's thickness is obtained.

$$m_E = \frac{m_{E0}C_0 + m_{E1}C_1 + m_{E2}C_2}{C_0 + C_1 + C_2} \quad (4)$$

3.Mechanical Analysis on Movement Law of Overlying Strata

3.1 Shear Stress Analysis of the Composite Strata

The combined action of the composite strata results in the compounded effect of the overlying strata. Suppose that the cross section of the composite strata is rectangular, the middle is soft rock, the upper and the lower strata are hard rock.The bending elastic modulus is smaller if the middle strata is thinner and it is greater if the upper and the lower strata are thicker.

The diagram of composite strata is shown in Figure 1.

h^1, E^1 - the thickness, elastic modulus of the upper strata; h^2, E^2 - the thickness, elastic modulus of the lower strata; h^3, E^3 - the thickness , elastic modulus of the middle strata;

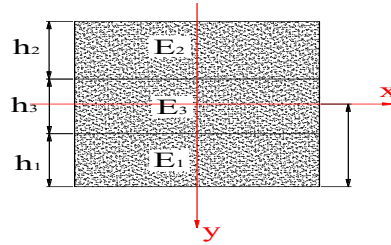


Fig.1 Cross section of the composite strata

The following equations are obtained from the knowledge of the mechanics of materials.

$$\left. \begin{aligned} \sigma_1 &= \frac{E_1 y}{\rho} \\ \sigma_2 &= \frac{E_2 y}{\rho} \\ \sigma_3 &= \frac{E_3 y}{\rho} \end{aligned} \right\} \quad (5)$$

Where: ρ -The curvature radius of the rock beam's neutral layer.

In order to facilitate the calculation, we take the width of the rock beam as one, then the inertia moment of each cross section is as follows.

$$\left. \begin{aligned} I_1 &= \frac{h_1^3}{12} + h_1(a - h_1)^2 \\ I_2 &= \frac{h_2^3}{12} + h_2\left(h_1 + \frac{h_2}{2} + h_3 - a\right)^2 \\ I_3 &= \frac{h_3^3}{12} + h_3\left(h_1 + \frac{h_3}{2} - a\right)^2 \end{aligned} \right\} \quad (6)$$

Where: a -The distance from the neutral axis to the lower cross section.

The dislocation of the rock beam is caused by Q (the shear force). According to the knowledge of the mechanics of materials, the maximum shear failure occurs at the neutral plane. Based on the above analysis, τ_{13} (the shear stress between the upper and middle strata), τ_{23} (the shear stress between the middle and lower strata) and τ_3 (the maximum shear stress on the neutral plane) are obtained as follows.

$$\left. \begin{aligned} \tau_{23} &= \frac{QE_1(2h_2 + h_1 + 2h_3 - 2a)h_1}{2(E_1I_1 + E_2I_2 + E_3I_3)} \\ \tau_{13} &= \frac{QE_2(2a - h_2)h_2}{2(E_1I_1 + E_2I_2 + E_3I_3)} \\ \tau_3 &= \frac{Q[E_2(2a - h_2)h_2 + E_3(a - h_2)^2]}{2(E_1I_1 + E_2I_2 + E_3I_3)} \end{aligned} \right\} \quad (7)$$

3.2 Discrimination of the Composite Strata

Suppose that the composite fracture of the overlying strata occurs , then:

$$\left. \begin{aligned} \tau_{13\max} &\leq \tau_{13e} \\ \tau_{23\max} &\leq \tau_{23e} \\ \tau_{3\max} &\leq \tau_{3e} \end{aligned} \right\} \quad (8)$$

Where: $\tau_{13\max}$, τ_{13e} -the maximum shear stress, the shear strength between the middle and upper strata;
 $\tau_{23\max}$, τ_{23e} - the maximum shear stress, the shear strength between the lower and middle strata is;
 $\tau_{3\max}$, τ_{3e} - the maximum shear stress, the shear strength on the neutral plane.

Once the strata is in accordance with the formula (8), it will form the composite strata which become the main key stratum. The lower part of the strata and the relatively soft strata will be damaged and the separation of the overlying strata will occur. With the advancement of the working face the exposed area of the lower strata is increasing continuously. When the formula ' $\tau_{13\max} \leq \tau_{13e}$ ' is satisfied, the shear failure will occur in the lower strata. The broken strata acts on the soft strata and then acts on the supports, the working face shows a state of pressure at this time.

4 Numerical Simulation of Overlying Strata movement

4.1 Establishment of FLAC3D Numerical Model

According to the geological column of No.2301 fully mechanized caving face, the FLAC^{3D} numerical model is founded. The length in the direction of inclination is 200 m, and the strike length is 250 m, and the height respectively are 200 m, 400 m and 600 m. The transition area on the left is set to 20 m, and the transition area on the right is set to 40 m. The thickness of coal seam is 9 m. The above values are conducive to the calculation and analysis.

The normal displacement and velocity around the model is zero. In the model, and the top of the model is affected by the uniformly distributed load whose size is the weight of the overlying strata. The physical and mechanical parameters in the numerical model are shown in Table 1.

Tab. 1 The physical and mechanical parameters in the numerical model

Lithology	Thickness /m	Density /kg/m ³	Bulk modulus /GPa	Shear modulus /GPa	Cohesion /Pa	Internal friction angle [°]	Tensile strength /MPa
Fine sandstone	2.4	2879	9.81	5.46	4.2e6	42	8
Medium sand	7.2	2851	9.96	6.52	4e6	40	9
Siltstone	3.5	2877	8.13	4.87	3.4e6	41	7
Fine sandstone	5.0	2879	9.81	5.46	4.2e6	42	8
Fine sandstone	12.32	2879	9.81	5.46	4.2e6	42	8
Medium sand	11.6	2851	9.96	6.52	4e6	40	9
Grit stone	27.6	2480	8.24	5.87	6.1e6	38	7
Fine sandstone	4.0	2879	9.81	5.46	4.2e6	42	8

Siltstone	2.63	2876	8.13	4.87	3.4e6	41	7
3#Coal	9.0	1339	5.68	3.42	5.2e6	18	1.2
seam							
Siltstone	22.4	2877	8.13	4.87	3.4e6	41	7

4.2 Simulation Results of Roof Subsidence under Different Alluvium's Thickness

When the alluvium's thickness is 200 m, choose 20m, 40m, 60m, 80m, 100m and 120m respectively as the advancing distance, then the simulation results are shown in figure 2.

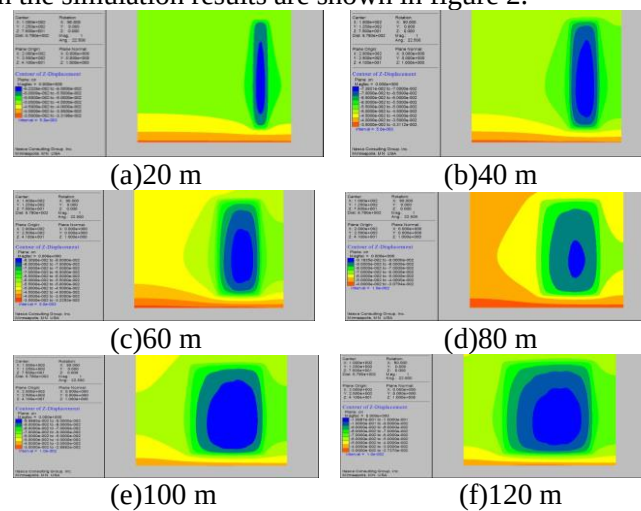


Fig. 2 Roof subsidence of different advancing distance under 200m-alluvium's thickness

When the alluvium's thickness is 400 m, choose 20m, 40m, 60m, 80m, 100m and 120m respectively as the advancing distance, then the simulation results are shown in figure 3.

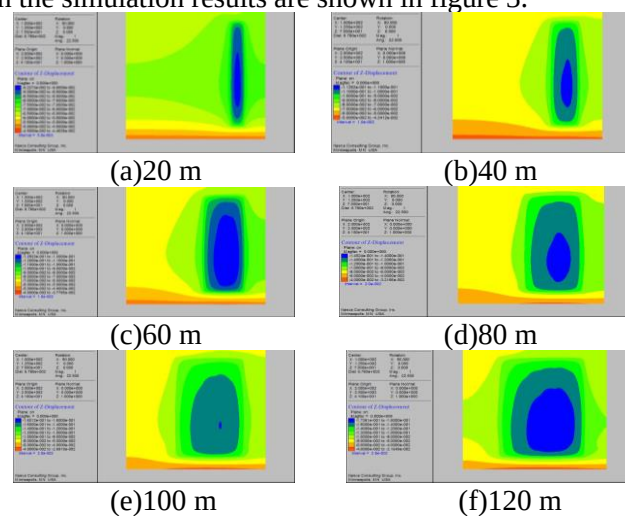


Fig. 3 Roof subsidence of different advancing distance under 400m-alluvium's thickness

When the alluvium's thickness is 600 m, choose 20m, 40m, 60m, 80m, 100m and 120m respectively as the advancing distance, then the simulation results are shown in figure 4.

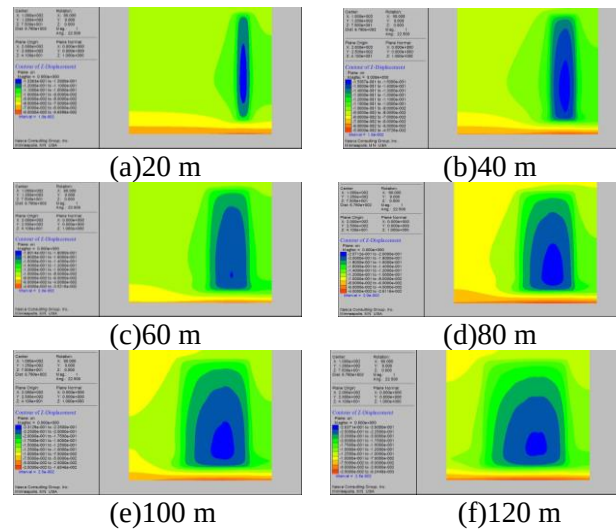


Fig. 4 Roof subsidence of different advancing distance under 600m-alluvium's thickness
 According to the amount of roof subsidence at 23 metres from the top of roof, the law of roof subsidence with different advancing distance under different alluvium's thickness is existed as follows.

- (1) Under a certain alluvium's thickness, the amount of subsidence at the open-off cut and the coal wall is minimum in early stage of caving mining and the amount is maximum at the middle of the working face. The vertical displacement of the roof gradually decreases from the middle of the working face to the open-off cut and the coal wall.
- (2) Under a certain thickness of the alluvium, with the advancement of the working face the amount of roof subsidence gradually increases and the influence range gradually enlarges. The influence range is the rectangular area centered on the middle part of the stope.
- (3) Because the 3# coal seam is nearly horizontal, the roof strata are in the same direction. With the advancement of the working face, the amount of roof subsidence gradually decreases.
- (4) Compared with the general conditions, the roof of the working face under alluvium with huge thickness is more active, and the strata behaviour is more obvious, and the supporting work is more difficult.

4.3 Change of the Roof's Vertical Displacement under 600m-alluvium's Thickness

When the alluvium thickness is 600 m and the advancement distance is 120 m, the fracture and evolution of overlying strata at different locations above the roof is shown in Figure 5.

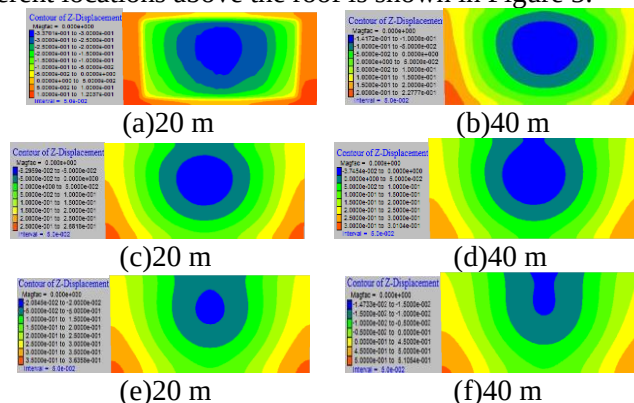


Fig. 5 Change of roof's vertical displacement at different locations above the roof
 Figure 5 reveals the following law.

- (1) The farther away from the roof of the working face, the more the roof subsidence is not obvious;

- (2) The amount of roof subsidence gradually decreases from the middle part of working face to both sides.
- (3) The amount of roof subsidence at the upper and the lower end shows asymmetrical distribution, and the amount at upper end is obviously smaller than that at the lower end.

5 Conclusions

- (1) There is a close connection between the key stratum and the movement of overlying strata, the fracture of the key stratum plays an important role in the movement of the overlying strata., especially under the condition of large depth and huge thickness of the alluvium. After the bedrock are all broken, the strength of the overlying alluvium became lower and the supporting capacity was lost, then the overlying alluvium gradually subsides. Because the alluvium's thickness is very large, the bench convergence does not occur on the ground surface.
- (2) With the increase of the alluvium's thickness, the amount of roof subsidence in fully mechanized caving face increases gradually. With the continuous advancement of the working face, the influence range of bearing pressure and the amount of roof subsidence also increase gradually.
- (3) To find out the movement law of overlying strata in fully mechanized caving face under alluvium with huge thickness in deep mine can achieve effective control of the overlying strata, and further provide theoretical guidance for strata control and support selection of working face.

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