Available online at www.sciencedirect.com
ScienceDirect
Trans. Nonferrous Met. Soc. China 21(2011) s599−s603
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Numerical simulation of surface movement laws under different unconsolidated layers thickness

DAI Hua-yang[1], LI Wen-chang[2], LIU Yi-xin[1,3], JIANG Yao-dong[3]

1. College of Geosicence and Surveying Engineering, China University of Mining and Technology, Beijing 100083, China;
2. College of Resources and Safety Engineering, China University of Mining and Technology, Beijing 100083, China;
3. College of Mechanics and Civil Engineering, China University of Mining and Technology, Beijing 100083, China

Received 19 June 2011; accepted 10 November 2011

Abstract: Based on specific geology and mining conditions of certain coal working face in China, a series of numerical models under different unconsolidated layers thickness were respectively established by employing FLAC^{3D}. The relationship between the unconsolidated layers thickness and surface movement laws was studied. Maximum surface subsidence, Maximum horizontal displacement and surface subsidence degree were obtained. Contours of surface subsidence/horizontal displacement and curves were drawn. Some laws of surface subsidence/horizontal displacement were analyzed. The role of the unconsolidated layers in surface subsidence was revealed. It is significant to predict surface subsidence of thick unconsolidated layers for coal mine and take effective measures to control surface subsidence.

Key words: unconsolidated layers; surface movement; numerical simulation; deep mining; FLAC^{3D}

1 Introduction

In China, there are considerable amount of coal mines with the thick unconsolidated layers. However, the phenomenon of mining damage and geological damage reduced by underground mining is widely universal and rather severe. It's been highly attracted by many researchers in home and abroad [1−7]. As a part of overburden strata, the unconsolidated layers is one of the most important factors controlling mine subsidence laws [8], and it causes surface subsidence laws to appear specific characteristics. YIN [9] described the role of unconsolidated layers as follows. As a loose medium/mass between the bedrock and surface, the unconsolidated layers transform the displacement and deformation of bedrock, and transmit mining hazard to the surface according to its specific characteristics. Thus, the unconsolidated layers are regarded as the rock softening layer, and the buffering layer of surface deformation. It can be said that the unconsolidated layers is a double-edged sword, with double-sided nature, that is intensifying the strata damage and reducing the surface deformation. Moreover, the existence of the unconsolidated layers affects the evaluation of surface mining degree [10]. Therefore, in order to reasonably predict surface subsidence and take effective measures to control surface subsidence, then to make sure underground mining safely, it is very necessary to know the relationship between the thickness of the unconsolidated layers and surface displacement. So far, few studies concerned to the relationship are reported [11−16]. For a more profound understanding of the relationship, three-dimensional (3D) numerical simulations were carried out and a series of important conclusions are obtained in this work.

2 Establishment of numerical model

Based on specific geology and mining conditions of No.11118 working face in Huainan coal mining district, China, the simulated strata in the model, in ascending order, are as follows: the floor is sandy mudstone, 20 m thick; coal seam is 3.0 m thick; the immediate roof is mudstone, 5 m thick; the main roof is sandstone, 10 m thick; the interbeded sandstone and mudstone, 85 m

Foundation item: Project (2007BAK28B03) supported by the National Eleventh-Five Year Research Program of China; Project (2010YD05) supported by the Fundamental Research Funds for the Central Universities; Project (200911036) supported by the Ministry of Land and Resources Research Special

Corresponding author: DAI Hua-yang, Tel: +86-10-62339133, E-mail: dhy@cumtb.edu.cn

thick; and finally the unconsolidated layers, 400 m thick. The coal seam is 3.0 m thick and 500 m deep. So the mining depth for this model is 500 m. The properties of the coal seam and rocks used in this numerical model are shown in Table 1.

The *x*-axis of the model was along the coal seam strike, *y*-axis along coal seam dip, and *z*-axis along gravity direction. The design of working face was as follows. The strike length of working face was 600 m, while the dip width was 180 m. The numerical model size was 2 400 m×2 400 m×600 m. Coal seam dip was supposed to be horizontal. The finite elements, 28 800, and grid points 31 939, in total, were laid out based on the geometrical dimension of the model, as shown in Fig. 1. Model boundary conditions are set as follows: the horizontal displacement of the front-back and right-left side faces, fixed; the bottom boundary fixed; the top surface, free. According to the mechanical characteristics of overburden strata, the constitutive relation of coal and rock mass were both Mohr-coulomb criterions.

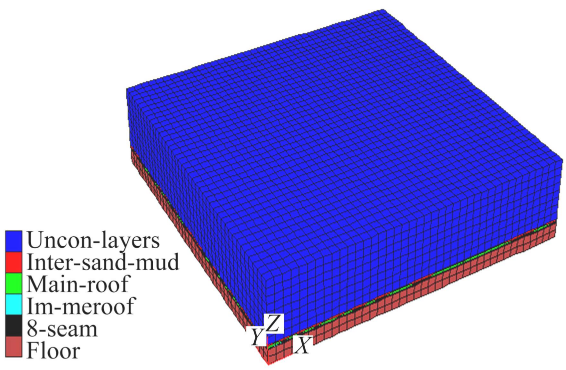

Fig. 1 FLAC^{3D} numerical simulation model

3 Methods of simulation and results

In order to study the effect of the unconsolidated layer on surface subsidence, 15 different numerical models were established by using FLAC^{3D}. The unconsolidated layers thicknesses (*h*) were respectively assigned to 0, 30, 50, 100, 200, 250, 325, 450, 500, 600, 700, 800, 900 and 1 000 m. In process of numerical simulation, other simulation conditions were unchanged. A number of results were obtained from the numerical studies, such as surface subsidence contours, surface horizontal displacement contours along *x*-axis and *y*-axis, maximum surface subsidence and maximum surface displacement values, etc. When the unconsolidated layers thickness is 400 m, surface subsidence and displacement contours are shown in Figs. 2−4.

According to the numerical simulation results under different unconsolidated layers thickness (*h*), maximum Surface subsidence value (W_0), maximum surface horizontal

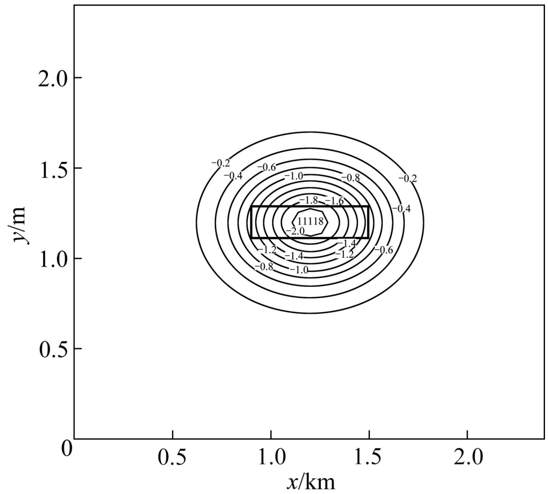

Fig. 2 Surface subsidence contours (*h*=400 m)

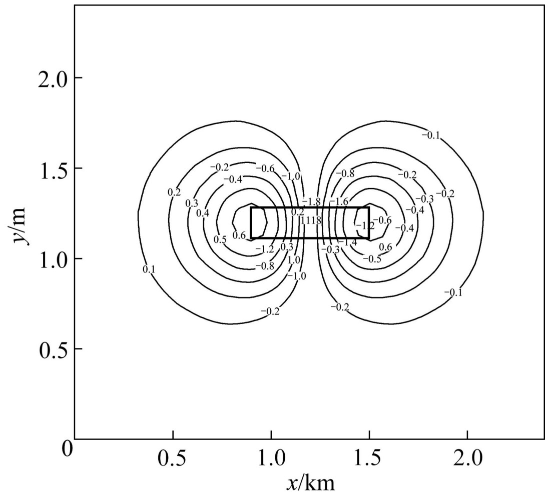

Fig. 3 *x* horizontal displacement contours (*h*=400 m)

Table 1 Physical and mechanic parameters of model

Rock type	Thickness/m	Density/(kg·m^{-3})	Friction angle/	Cohesion/MPa	Elastic modulus/GPa	Poisson ratio	Tensile strength/MPa
Unconsolidated layers	400	1 800	15	0.01	0.01	0.40	0.001
Interbeded sandstone and mudstone	85	2 480	33	8.0	3	0.26	6.0
Main roof	10	2 560	37	6.0	2.8	0.22	2.0
Immediate roof	5	2 540	32	9.0	3.5	0.35	3.0
Coal seam	3	1 400	25	3.0	2.2	0.42	2.4
Floor	197	2 590	38	1.0	1.0	0.2	2.0

displacement value (U_0) and surface subsidence ratio (q') were obtained (as shown in Table 2). Surface subsidence and surface horizontal displacement curves along the strike section are shown in Figs. 5−6. Figures 7 and 8 clearly show the relation curves between W_0/q' and h. Finally, the relation curves between the ratio of the unconsolidated layers thickness to mining deep (h/H_0) and W_0/q' are also shown in Figs.9−10.

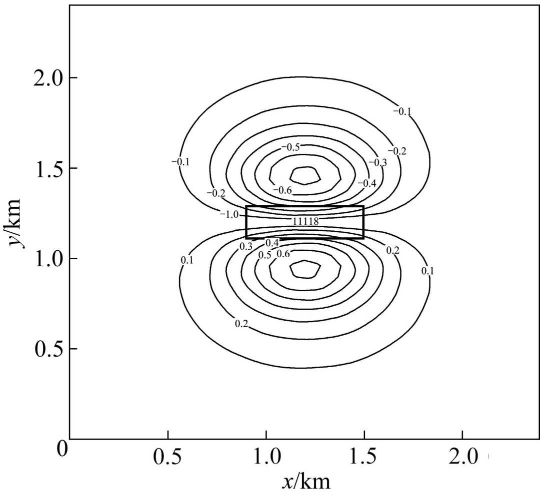

Fig. 4 *y* horizontal displacement contours (h=400 m)

Table 2 Numerical simulation results in different unconsolidated layer thickness

Model	h/m	h/H_0	W_0/mm	U_0/mm	q'
1	0	0.00	2 227	619	0.74
2	30	0.23	2 243	935	0.75
3	50	0.33	2 294	953	0.76
4	100	0.50	2 308	936	0.77
5	200	0.67	2 331	886	0.78
6	250	0.71	2 252	820	0.75
7	325	0.76	2 189	763	0.73
8	400	0.80	2 138	728	0.71
9	450	0.82	2 096	697	0.70
10	500	0.83	2 100	687	0.70
11	600	0.86	2 117	671	0.71
12	700	0.88	2 099	663	0.70
13	800	0.89	2 037	626	0.68
14	900	0.90	1 962	585	0.65
15	1 000	0.91	1 856	537	0.62

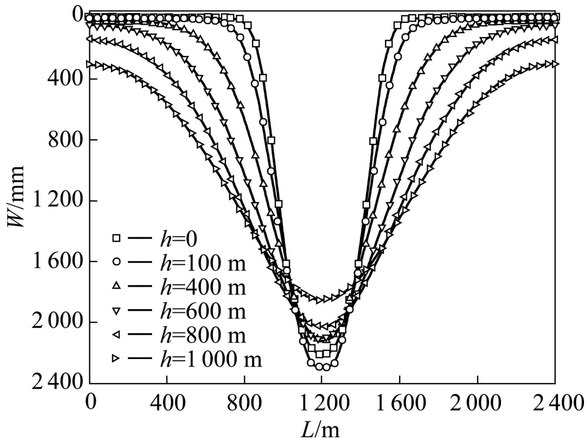

Fig. 5 Surface subsidence curves of different unconsolidated layers thickness

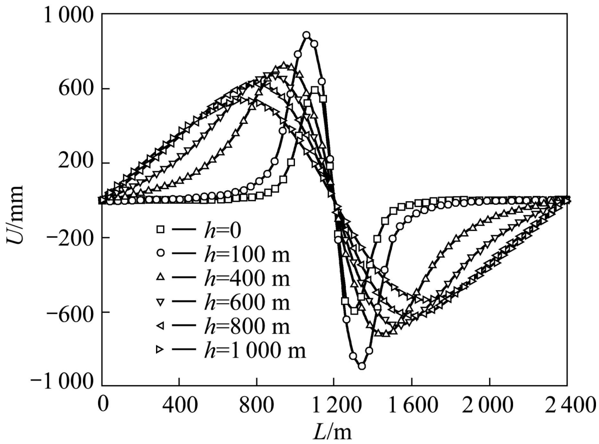

Fig. 6 Surface displacement curves of different unconsolidated layers thickness

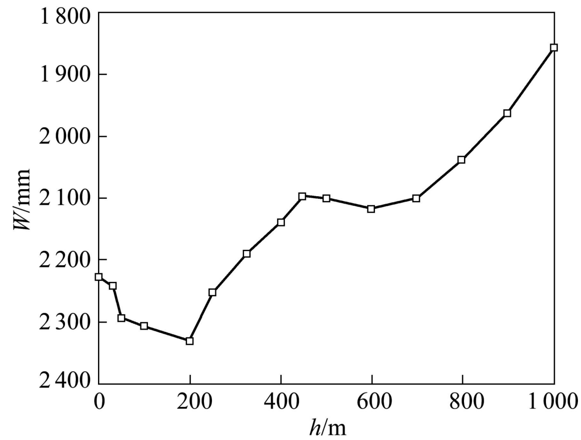

Fig. 7 Maximum surface subsidence value vs h

4 Results and discussion

In general, the distribution law of surface displacement curves due to mining under the unconsolidated layers is similar with the law of mining under general geological conditions. Surface subsidence curves are symmetrical about the point of maximum subsidence, and the point of maximum subsidence is located at the above surface of the center of opening. Surface horizontal curves are antisymmetric about the point of maximum subsidence, being 2 peaks (1 positive, 1 negative). Where being location of maximum

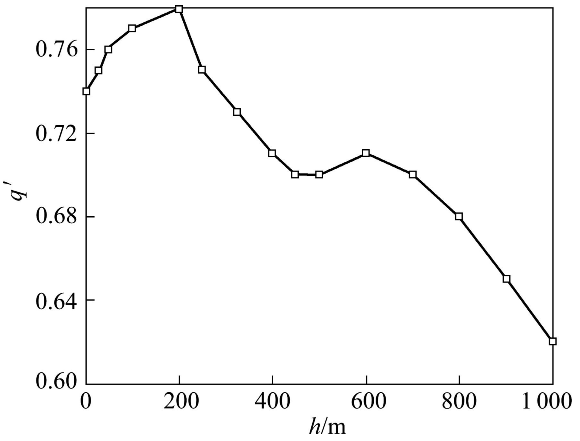

Fig. 8 Unconsolidated layers thickness vs q'

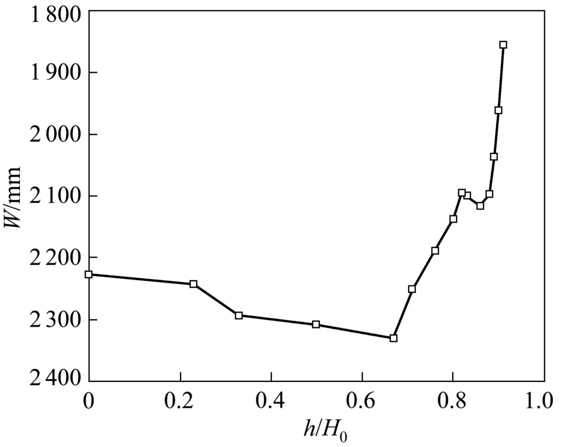

Fig. 9 Maximum surface subsidence value vs h/H_0

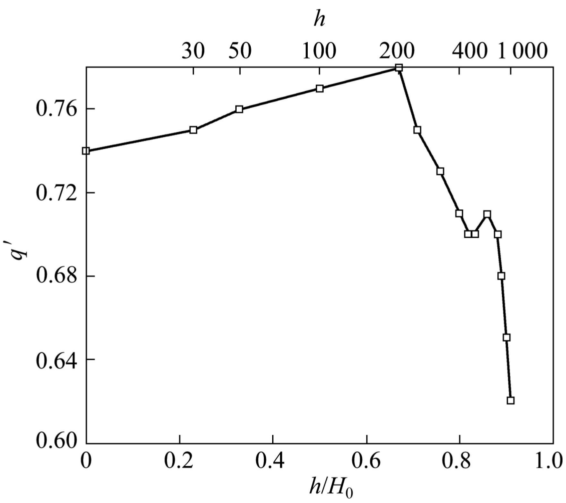

Fig. 10 h/H_0 vs q'

subsidence, the surface horizontal displacement value is equal to zero.

With the increase of the unconsolidated layers thickness, the range of surface subsidence basin has the trend of gradually spreading, and the trend is obvious. Within the range of model, the surface subsidence basins appear slow convergence. The distribution form of curve is gradually slow from the steep condition above the goaf. It is thus clear that the range of surface subsidence extend widely and the surface deformations are mitigated with the increase of the unconsolidated layer thickness, to the benefit of protecting buildings or other objects.

When the bedrock thickness is constant (100 m), with the increase of the unconsolidated layers thickness (h), surface maximum subsidence value (W_0) and surface subsidence ratio (q') appear the linear relation of phase change. In detail, firstly, when the unconsolidated layers thickness is 0 m up to 200 m (corresponding mining depth range from 100 m to 300 m), W_0 appears increasing trend, from 2 227 mm to 2 331 mm; secondly, when h varies from 200 m to 450 m (mining depth from 300 m to 450 m), W_0 trends to decrease, from 2 331 mm to 2 096 mm; thirdly, when h varies from 450 m to 700 m (mining depth from 550 m to 800 m), W_0 occurs with less fluctuation, but overall be stable condition, equals to 2 100 mm; finally, when h varies from 700 m to 1 000 m (mining depth from 800 m to 1 100 m), W_0 presents decreasing trend again, from 2 099 mm to 1 856 mm.

In conclusion, the relationship between surface maximum subsidence value and the unconsolidated layers thickness is not a fixed function to increase or decrease, but appears different trends. It is obtained that the contribution or the effect of the unconsolidated layers on surface subsidence is different when the unconsolidated layers thickness is different. It is different to the role of unconsolidated layers on surface subsidence, as a load or a mitigation of the surface deformation, or even has no effect. So-called “double-edged sword” effect of the unconsolidated layers on surface subsidence be emphasized, cannot take all into account or make generalizations, but should be respectively considered depending on different situations, as well as taking into account the impact of mining depth.

With the increase of the ratio of the unconsolidated layers thickness to mining deep (h/H_0), surface maximum subsidence value (W_0) and surface subsidence ratio (q') also appear the linear relation of phase change. When the thickness of unconsolidated layers is 0 m to 200 m, h/H_0 from 0% to 67%, q' gradually increases. Instead, when the unconsolidated layers thickness is more than 200 m, h/H_0 also more than 67%, q' gradually decreases. It is concluded that as loose medium of low flexural capacity, the unconsolidated layers can not only be simplified the load uniformly distributed in the bedrock surface, but also fill the bedrock subsidence sink in the form of slow rheology to cause surface subsidence. The large range of surface subsidence basin depends on the rheological property of the unconsolidated layers, and has the increasing trend with the increase of the unconsolidated layers thickness.

5 Conclusions

1) The distribution law of surface movement due to mining under the unconsolidated layers is similar with the general geological conditions. With the increase of the unconsolidated layers thickness, the surface subsidence and displacement curves both have the trend of gradually extending the subsidence basin range and the trend is very obvious. Surface basins near the boundary present slow convergence. The surface subsidence and displacement above the goaf have characters of centralized distribution. In conclusion, with the increase of the unconsolidated layer thickness, the range of surface subsidence/displacement extends widely and the surface deformations are mitigated, to the benefit of protecting buildings or other objects.

2) When the bedrock thickness is constant (100 m), with the increase of the unconsolidated layers thickness, the ratio of the unconsolidated layers thickness to mining deep (h/H_0) also increases, so, surface maximum subsidence value (W_0) and surface subsidence ratio (q') also appear the linear relation of phase change. When mining depth is smaller (shallow mine, mining depth < 300 m), W_0 and q' gradually increase along with h/H_0 increases. When mining depth varies from 300 m to 550 m (medium-deep mine), W_0 and q' trends to decrease with the increase of h/H_0. When mining depth varies from 550 m to 800 m (deep mine), W_0 and q' both trend to be stable condition. When mining depth varies from 800 m to 1100 m (super-deep mine), W_0 and q' also trend to decrease. In conclusion, with different thickness of the unconsolidated layer, the surface subsidence is not with a fixed function to increase or decrease, but showed different trend with change of the unconsolidated layers thickness.

3) When the unconsolidated layers thickness is different, it is different to the role of unconsolidated layers on surface subsidence, as a load or a mitigation of the surface deformation, or even has no effect. So-called "double-edged sword" effect of the unconsolidated layers on surface subsidence had to be emphasized, cannot take all into account or make generalizations, but should be respectively considered depending on different situations, as well as taking into account the impact of mining depth.

References

[1] LIU Yi-xin. Overburden failure and surface movement laws due to deep mining under thick unconsolidated layer [D]. Beijing: China University of Mining and Technology. College of Geosicence and Surveying Engineering, 2010: 58−64. (in Chinese)

[2] CHEN Xiang-en, LI De-hai, GOU Pan-feng. Mining under thick soil layer and surface movement [M]. Xuzhou: China University of Mining and Technology Press, 2001: 123−125. (in Chinese)

[3] LI De-hai. Strip mining under thick soil layer [M]. Beijing: China Science and Technology Press, 2006: 1. (in Chinese)

[4] LIU Bao-chen, YANG Jun-sheng, ZHANG Jia-sheng. Ground movement and deformation due to dewatering and open pit excavation [J]. Mining Science and Technology, 1996: 41−44.

[5] XIE Wen-bing, DENG Ka-zhong, DA Jian-yuan. The pre-calculation model of ground subsidence under thick water-bearing strata [J]. Mining Science and Technology, 1996: 399−341.

[6] GE Xin-hui, YU Guang-yun. Influence of underground mining on ground surface and railway bridge under thick alluvium [J]. Journal of China University of Mining and Technology, 2006, 16(1): 97−100.

[7] PENG S S. Surface subsidence engineering [M]. Littleton: Soc Min Metall Exploe, 1992: 13.

[8] HE Guo-qing, YANG Lun, LING Geng-di, JIA Feng-cai, HONG Du. Mining subsidence science [M]. Xuzhou: China University of Mining and Technology Press, 1994: 98−99. (in Chinese)

[9] YIN Zuo-ru. On the laws of strata movement and surface subsidence due to coal mining under unconsolidated layer in kailuan [D]. Beijing: China University of Mining and Technology. Faculty of Resources & Safety Engineering, 2007: 41−42. (in Chinese)

[10] WANG Jin-zhuang, CHANG Zhan-qiang, CHEN Yong. Study on mining degree and patterns of ground subsidence in condition of mining under thick unconsolidated layers [J]. Journal of China Coal Society, 2003, 28(3): 230−234. (in Chinese)

[11] LIU Yi-xin, DAI Hua-yang, GUO Wen-bing. Surface movement laws of deep wide strip-pillar mining under thick alluvium [J]. Journal of Mining & Safety Engineering, 2009, 26(3): 336−340. (in Chinese)

[12] LI De-hai, CHEN Xiang-en, LI Dong-sheng. Estimate of surface movement and rock movement parameter analysis under thick soil layer mining [J]. Ground Pressure and Strata Control, 2002, (1): 90−92. (in Chinese)

[13] HU Bing-nan, ZHAO You-xing, ZHANG Hua-xing. Surface movement parameters and practice effect of strip mining under thick alluvium and thin bedrock [J]. Coal Mining Technology, 2006, 11(1): 56−58. (in Chinese)

[14] LI Feng-ming. The research on the laws of surface movement parameters and its changing regularity in the thick alluvium mine field [D]. Beijing: China University of Mining and Technology, Beijing, 1995: 535−537. (in Chinese)

[15] HAO Yan-jin. Strata and surface displacement law due to fully mechanized caving mining under thick unconsolidated layer [D]. Beijing: China University of Mining and Technology. Faculty of Resources & Safety Engineering, 2000: 5−6. (in Chinese)

[16] LIANG Qing-hua. Study of numerical simulation and application on thick-alluvium surface subsidence [D]. Qingdao: Shandong University of Science and Technology. College of Natural Resources and Environmental Engineering, 2006: 4−6. (in Chinese)

(Edited by ZHAO Jun)