Impact Factors of Overburden Movement in Longwall Mining over Thin Overlying Strata

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ABSTRACT

For the study of overburden movement in longwall mining of shallow coal seams, most scholars merely consider the thickness of bedrock and top soils. In this paper, the overburden movement in longwall mining of shallow coal seams with thin top soils and key strata group was studied. By using numerical simulation, the development of fractures in the overburden were analyzed for different ratios of panel width to depth (W/D)and depth to mining height. The results show that the overburden movement changed with the variation of mining height, panel width and depth under the specific geological conditions. It also explain how different overburden disturbance structures, such as "three zones"(caved, fractured, and continuous deformation zones)，"two zones"(caved and fractured zones) or “steps-likecollapse” are formed under different mining conditions. The results broaden the vision for research on overburden movement in longwall mining of shallow coal seams.

KEYWORDS: shallow coal seam; overburden movement; panel width; depth; mining height

INTRODUCTION

Stowing slurry is made up of coal gangue, the fly ash, cement and water in a certain proportion. When a longwall panel of sufficient width and length is excavated, the overburden roof strata are disturbed in order of severity from the immediate roof toward the surface, or even the aquifers, which can lead to serious mine-flooding accidents and increased damages of the ecological environments [1, 2]. Thus it is absolutely essential to determine the overburden strata movement for the prevention of water inrush and protection for groundwater resources [3].

The movement characteristics of overburden strata in shallow coal seams are not just confined to the total collapse of the whole overburden and step subsidence [4]. In fact, different geological conditions such as different overburden strata and bedrock thickness produce different subsidence characteristics [5].

MODEL ESTABLISHMENT

The longwall panel studied in this paper is located in the Appalachia Coalfield, United States, where most coal seams are shallow. With a depth of 575ft (175m), the overburden strata are mostly bedrock, and the panel width can reach up to 1,430ft (435m), which is common in the United States, but rarely seen in China. Thus in this case, the practical experience and the theories developed provide the basis for further research on wider panels of shallow coal seam mining in western China[6].

In the numerical model selected for this research, under the thick alluvium in the overburden, there is an aquiclude group composed of gray shale, sandy shale, and limy shale. Underneath the overburden, there are sandstone key strata groups. The overburden stratigraphic sequence is shown in Figure 1.

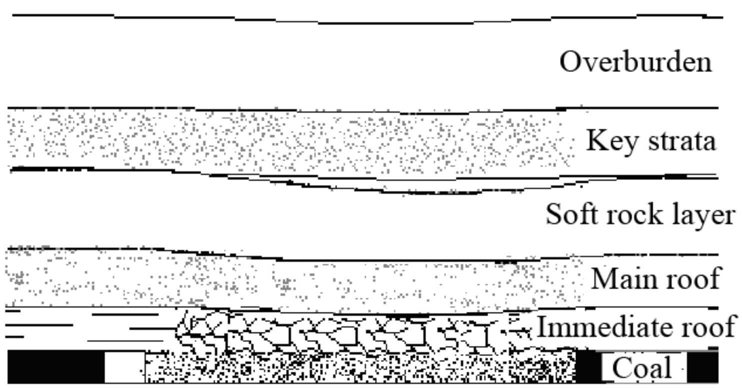


Figure 1: Stratigraphic sequence used in the model

Simulation purposes

(1) Obtain, through numerical analysis of shallow longwall mining, the relationship between the characteristics of overburden movement and panel width; analyze the stress distributions in the surrounding rocks under different panel widths, but similar geological conditions.

(2) Obtain, through numerical analysis of shallow longwall mining, the relationship between the characteristics of overburden movement and mining height; analyze the stress distributions in the surrounding rocks under different mining height, but similar mining depth [8].

(3) Analyze, through numerical analysis of shallow longwall mining of different mining heights, surface subsidence and ground movement under different ratios of panel width to mining depth (W/D)[9].

(4) Analyze the impact of mining on groundwater under different ratios of panel width to mining depth (W/D)by comparing the overburden strata movement and the range of fracture development in different mining height[10].

Establishment of the Three-dimensional Model

(1) Numerical simulation model of long wall Panel

On the basis of the modeling principle of FLAC3D, the panel model was established with the geological conditions of a longwall panel in the Pittsburgh coal seam. The model length, width, and height are 1,930ft (588m), 40ft (12m), and 682ft (208m), respectively. To simulate more closer to the actual situation, the model was established by using the geologic column located in the panel of interest, with a total of 27layers, from the floor up to the surface. According to the drillhole information, the Pittsburgh seam in the panel is 575ft (175m) deep, and the thickness of unconsolidated layer on the surface is only 20ft (6m).

The model is divided into 75,626 grid cells, and the number of grid nodes is 103,212. The density of grid cells is adjusted in order to ensure the speed and accuracy of the calculation.

(2) Numerical simulation models with different W/D

According to the results of borehole extensometer measurements and numerical simulation of overburden movement, when mining height is 7ft (2m) high and seam depth is 575ft（175m）, three zones are formed in the overburden strata, instead of a “steps-like”collapse or whole piece overburden collapse. Thus more factors such as overburden structure, ratio of thickness of surface soil layer to rockbed, panel width, and mining height should be considered in the research on over burden strata movement in shallow coal seams. In order to describe the overburden strata movement in shallow coal seams with different panel widths, the model is simulated with different W/D of 2. 5, 1. 7, 1. 2 and 0. 87.

(3) Numerical simulation models with different mining height

In order to determine the impact of different mining height on the overburden strata movement and ground pressure, four different mining heights, i. e. , 7ft (2m), 10ft (3m),13ft (4m), and16ft (5m)are simulated to observe the overburden strata movement, surface subsidence and stress change.

(4) Numerical simulation models of overburden fracture development with different W/D, and different mining height

The development of fractures on the surface and in the overburden during mining process is one of the key factors affecting groundwater system. The simulation of fracture development with different W/D and different mining heights can help observe the range of fractured zone development and fracture trend of main aquifuge.

Figure 2 shows the three-dimensional numerical simulation model.

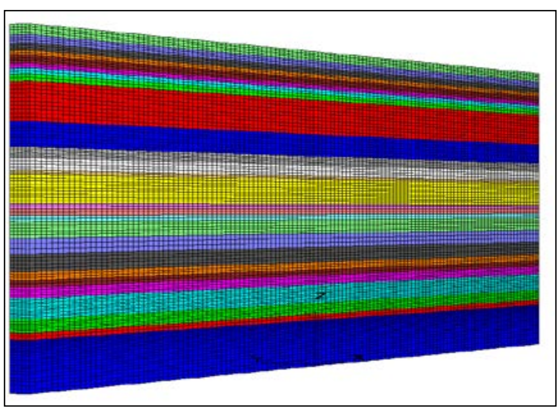


Figure 2: Three-dimensional numerical model

Physical and Mechanical Parameters of Overburden Stratain the Model

Rock property is one of the important parameters affecting the overburden strata movement. Therefore it is also an essential parameter in computer modeling of groundwater flow. In this study, rock samples were collected from the boreholes that were located near the gate roads of the panel of interest.

Table 1: Rock properties of overburden strata used in the model

Lithology	Tensile strength (Pa)	Density (kg/m^3)	Friction angle (0)	Elastic modulus (Pa)	Poisson ratio	Cohesion(Pa)	Bulk modulus (Pa)	Shear modulus (Pa)
27topsoil	1.38×10^{6}	2274	25	1.16×10^{9}	0. 35	1.45×10^{6}	1.85×10^{11}	0.62×10^{11}
26sandstone shale	7.76×10^{6}	2691	35	4.74×10^{9}	0. 22	5.39×10^{6}	4.06×10^{11}	2.80×10^{11}
25gray shale	5.29×10^{6}	2691	34	4.62×10^{9}	0. 27	3.85×10^{6}	4.82×10^{11}	2.62×10^{11}
24limestone shale	1.44×10^{6}	2691	32	11.5×10^{9}	0. 27	3.85×10^{6}	12.0×10^{11}	6.54×10^{11}
23 sandstone shale	7.76×10^{6}	2691	34	4.74×10^{9}	0. 22	5.39×10^{6}	4.06×10^{11}	2.80×10^{11}
22gray shale	5.29×10^{6}	2691	34	4.62×10^{9}	0. 27	2.76×10^{6}	4.82×10^{11}	2.62×10^{11}
21 sandstone shale	7.76×10^{6}	2691	34	4.74×10^{9}	0. 22	5.39×10^{6}	4.06×10^{11}	2.80×10^{11}
20sandstone	6.01×10^{6}	2531	43	1.26×10^{9}	0. 22	4.64×10^{6}	10.8×10^{11}	7.42×10^{11}
19limestone shale	5.40×10^{6}	2675	34	4.62×10^{9}	0. 27	4.38×10^{6}	4.82×10^{11}	2.62×10^{11}
18WB sandstone group	6.28×10^{6}	2643	43	12.6×10^{9}	0. 22	$6.89\times10^{6.}$	10.8×10^{11}	7.42×10^{11}
17gray shale	3.34×10^{6}	2675	34	4.62×10^{9}	0. 27	4.38×10^{6}	4.82×10^{11}	2.62×10^{11}
15sandstone	6.66×10^{6}	2563	44	12.6×10^{9}	0. 22	9.16×10^{6}	10.8×10^{11}	7.42×10^{11}
15gray shale	6.63×10^{6}	2723	34	4.62×10^{9}	0. 27	4.38×10^{6}	4.82×10^{11}	2.62×10^{11}
14UN sandstone group	6.28×10^{6}	2515	43	12.6×10^{9}	0. 22	9.16×10^{6}	10.8×10^{11}	7.42×10^{11}
13gray shale	6.63×10^{6}	2723	33	4.69×10^{9}	0. 27	4.38×10^{6}	4.89×10^{11}	2.66×10^{11}
12 limestone	5.03×10^{6}	2739	45	18.0×10^{9}	0. 3	12.5×10^{6}	21.6×10^{11}	9.99×10^{11}
11gray shale	6.63×10^{6}	2723	34	4.69×10^{9}	0. 27	4.38×10^{6}	4.89×10^{11}	2.66×10^{11}
10 limestone	5.03×10^{-6}	2643	45	18.0×10^{9}	0. 3	12.5×10^{6}	21.6×10^{11}	9.99×10^{11}
9gray shale	6.07×10^{-6}	2739	34	4.69×10^{9}	0. 27	3.42×10^{6}	4.89×10^{11}	2.66×10^{11}
8limestone	5.03×10^{-6}	2643	45	12.0×10^{9}	0. 3	12.5×10^{6}	14.4×10^{11}	6.67×10^{11}
7gray shale	6.07×10^{-6}	2739	34	4.62×10^{9}	0. 27	3.42×10^{6}	4.82×10^{11}	2.62×10^{11}
6sand shale	7.76×10^{-6}	2691	35	4.74×10^{9}	0. 22	5.39×10^{6}	4.06×10^{11}	2.80×10^{11}
5gray shale	6.29×10^{-6}	2739	34	4.62×10^{9}	0. 27	3.42×10^{6}	4.82×10^{11}	2.62×10^{11}
4limestone	5.03×10^{-6}	2723	45	12.0×10^{9}	0. 3	12.5×10^{6}	14.4×10^{11}	6.67×10^{11}
3gray shale	6.63×10^{-6}	2739	30	4.62×10^{9}	0. 27	3.42×10^{6}	4.82×10^{11}	2.62×10^{11}
2coal	0.69×10^{-6}	1409	28	2.48×10^{9}	0. 34	0.71×10^{6}	3.72×10^{11}	1.33×10^{11}
1gray shale	6.07×10^{-6}	2739	39	4.62×10^{9}	0. 27	3.42×10^{6}	4.82×10^{11}	2.62×10^{11}

ANALYSIS OF THE SIMULATION RESULTS

Simulation Results with Different W/D

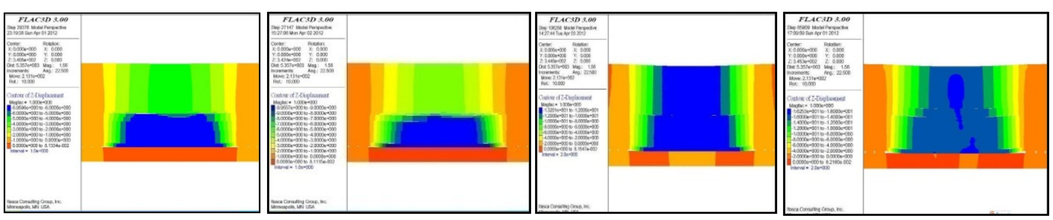
(1) Overburden strata movement under different W/D

As coal mining proceeds, the overburden strata above the gob will subside, separate and fracture. The vertical displacement in the simulation reflects well the subsidence of overburden strata in the mining process. Figures 3-6 show the overburden strata vertical movement with different W/D and mining height. Figures 7 and 8 show the surface subsidence subjected to different W/D's and mining heights.

When W/D= 2. 5 and mining height is less than 10ft (3m), the overburden strata forma stable structure of "three zones". The subsidence factor is around 0. 5. When mining height is larger than 10ft (3m), the overburden strata forma stable structure by itself and collapse in a whole unit or in step subsidence. The subsidence factor is around 1, which means the whole overburden drops down as a unit.

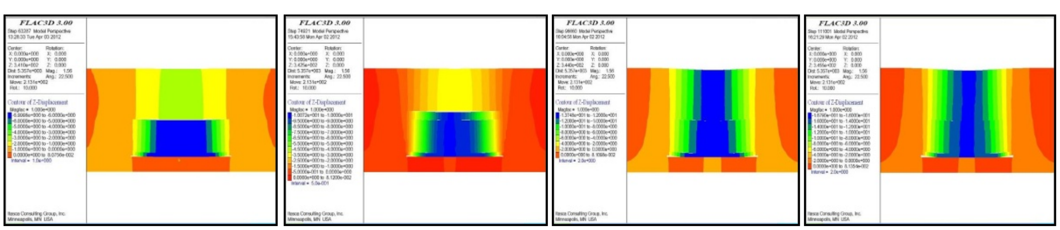
When W/D = 1. 7 or 1. 2, the overburden collapse is similar to that of when W/D = 2. 5. The overburden strata forma stable structure of "three zones" just as the case when mining height is less than 10ft (3m). When mining height is larger than 10ft (3m), the overburden strata form a stable structure by itself and collapse in a whole unit or in step subsidence. The subsidence factor is around 1.

When W/D = 0. 87, the overburden strata form a stable support structure itself as well. Surface subsidence is reduced significantly, with the subsidence factor less than 0. 15. When mining height is larger than 10ft (3m), failure of overburden continues until it reaches the surface in "two zones",i. e. , the fractured and caving zones. When mining height is less than 10ft (3m), the overburden strata form a stable structure of "three zones".



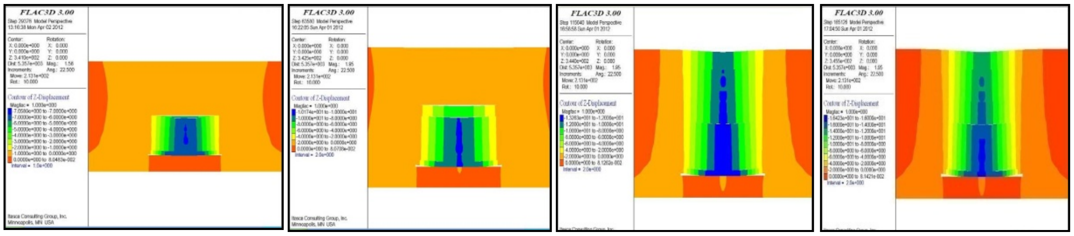
(a) mining height 7ft(2m) (b) mining height 10ft(3m) (c) mining height 13ft(4m) (d) mining height 16ft (5m)

Figure 3: Overburden strata movement under different mining height when W/D = 2. 5



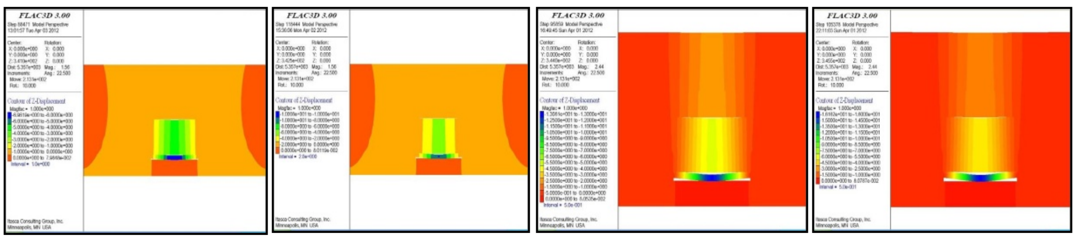
(a) mining height 7ft(2m) (b) mining height 10ft(3m) (c) mining height 13ft(4m) (d) mining height 16ft (5m)

Figure 4: Overburden strata movement under different mining heightwhen W/D = 1. 7



(a) mining height 7ft(2m) (b) mining height 10ft(3m) (c) mining height 13ft(4m) (d) mining height 16ft (5m)

Figure 5: Overburden strata movement under different mining height when W/D = 1. 2



(a) mining height 7ft(2m) (b) mining height 10ft(3m) (c) mining height 13ft(4m) (d) mining height 16ft (5m)

Figure 6: Overburden strata movement under different mining height when W/D = 0. 87

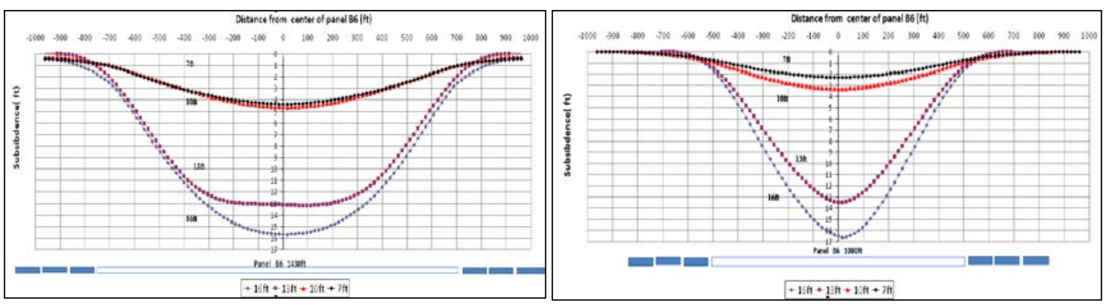


Figure 7: Surface subsidence under different mining height when W/D = 2. 5 and 1. 7

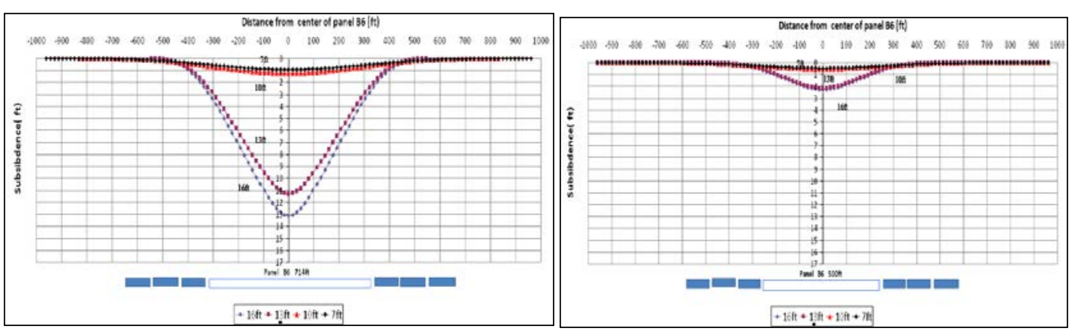


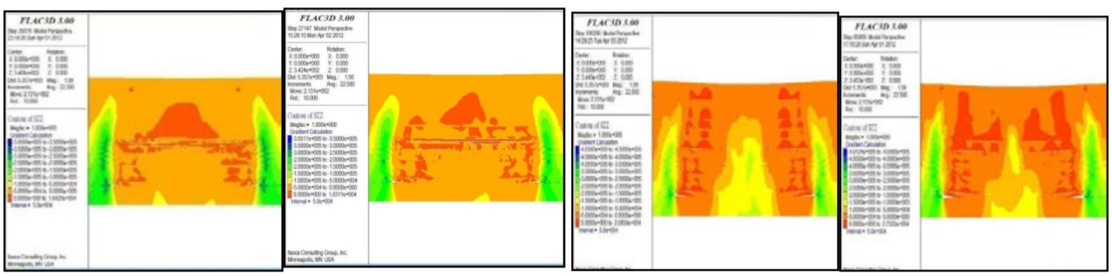
Figure 8: Surface subsidence under different mining height when W/D = 0. 2 and 0. 87

(2) Stress Change in Overburden Strata under Different W/D

The area of vertical stress concentration is mainly located in the roof around the coal pillar and above the key stratum. Figures 9-12 show the vertical stress distribution with different W/D and mining height. The maximal stress is generally located along the faceline, while the stress on the floor is transferred to the interior of the coal pillar. Dark red in the stress diagram indicates vertical stress, and the magnitude in the stress concentration zone indicates the capacity of the overburden to carry the load.

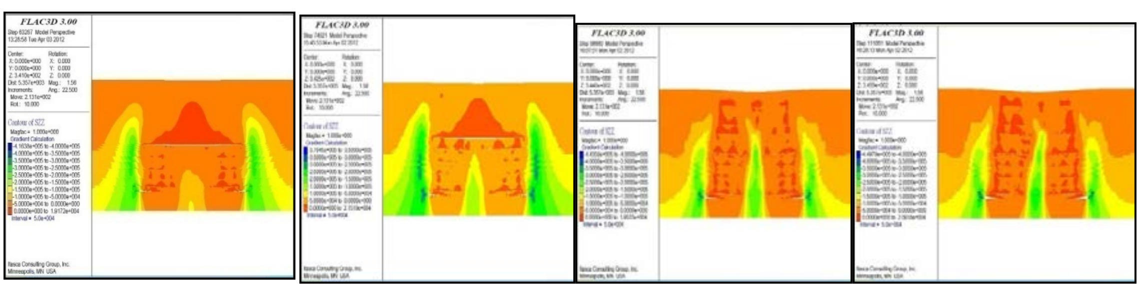
As is shown in these figures, one of the overburden strata is the area of stress concentration indicating that when W/D is larger than 1 and the mining height is less than 10ft (3m), it can carry the load and form a stable structure. When mining height is higher than 10ft (3m), the area of stress concentration decreases or even disappears as the mining height increases further.

When W/D is less than 1, the area of stress concentration would appear in the overburden strata. When mining height is larger than 10ft (3m), the numbers of stress concentration zone is more than 1. In other words, the higher the mining height is, the larger the area of fracture is. But the strata would not collapse because there are certain hard rock strata that support the overburden all the way up to the surface.



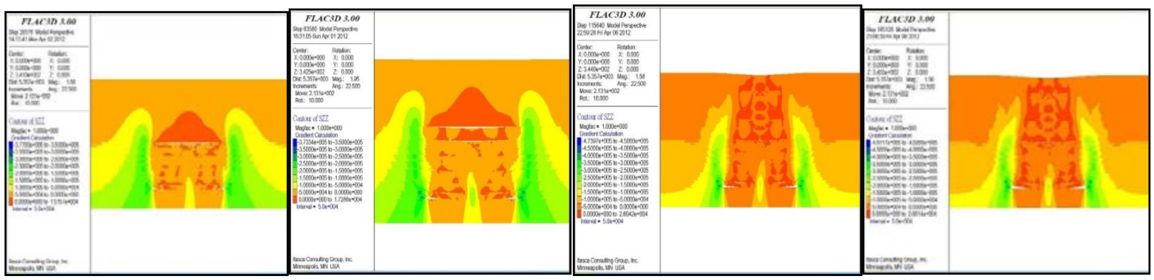
(a) mining height 7ft(2m) (b) mining height 10ft(3m) (c) mining height 13ft(4m) (d) mining height 16ft (5m)

Figure 9: Vertical stress distribution under different mining heightwhen W/D = 2. 5



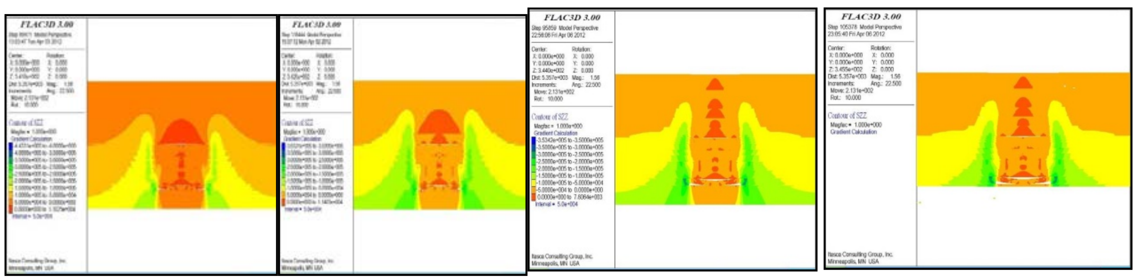
(a) mining height 7ft(2m) (b) mining height 10ft(3m) (c) mining height 13ft(4m) (d) mining height 16ft (5m)

Figure 10: Vertical stress distribution under different mining height when W/D = 1. 7



(a) mining height 7ft(2m) (b) mining height 10ft(3m) (c) mining height 13ft(4m) (d) mining height 16ft (5m)

Figure 11: Vertical stress distribution under different mining height when W/D = 1. 2



(a) mining height 7ft(2m) (b) mining height 10ft(3m) (c) mining height 13ft(4m) (d) mining height 16ft (5m)

Figure 12: Vertical stress distribution under different mining heightwhen W/D = 0. 87

(3) Calculation Steps

Figure 11 shows once the model reaches equilibrium how the calculation steps vary with W/D under different depths of overburden. It can be seen that with the exception of mining height = 7ft (2m), when W/D is less than 1, the required calculation step is the minimum before the model reaches the equilibrium condition. AsW/D increases, the required calculation steps decreases, indicating that when panel width increases, or mining depth decreases, to some extent, the roofwill subside quickly to achieve a stable structure, and the damage would be more severe after mining.

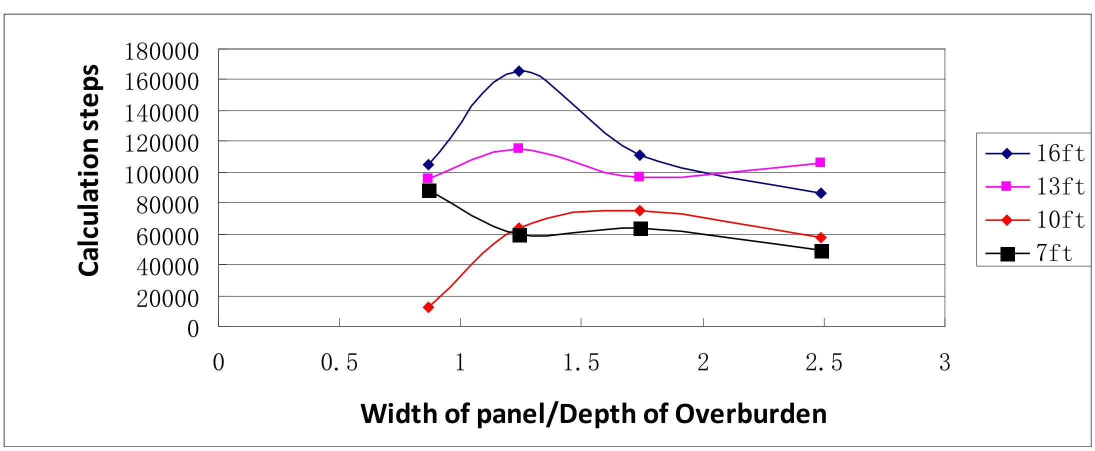


Figure 11: Calculation steps vs W/D

CONCLUSION

(1) When W/D>1 and the mining height is less than 10ft(3m), the overburden strata forma stable structure of “three zones”. When the mining height is larger than 10ft (3m), the overburden strata do not form a stable structure themselves. As a result the overburden strata would collapse in a whole unit or in step subsidence. The subsidence factor is around 1.

(2) When W/D<1, the overburden strata form a stable structure themselves, and surface subsidence is reduced significantly. The subsidence factor is less than 0. 15.

(3)The areas of stress concentration: the area of stress concentration in the hard stratum that supports the overlying strata is larger and appears in a“ horse saddle” pattern. The stress concentration zone is mainly found in the “three zones” structure, especially above the key stratum.

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