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Trans. Nonferrous Met. Soc. China 21(2011) s556−s561

Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Numerical simulation analysis of covering rock strata as mining steep-inclined coal seam under fault movement

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Received 19 June 2011; accepted 10 November 2011

Abstract: The fault is one important factor for the stability of overburden strata caused by steeply inclined coal seam. The stress and displacement change of overburden strata caused by steeply-inclined coal seam mining activity under faulting was simulated by FLAC2D finite differential program on the basis of Zhaogezhuang mining example belonging to Kailuan Mining Group. From the results, the stress and displacement clouding image after mining became complex because of the fault, that is, a kind of weak structural plane. The stress concentration region concentrated around the goaf, and also around the fault plane. As the mining depth increases, the stress and displacement within the fault zone change significantly. This movement and deformation characteristic of overburden strata can provide theoretical basis for the similar mining condition.

Key words: fault; steep-inclined coal seam; numerical simulation; overburden distortion

1 Introduction

In the underground mining process, the deformation of overburden strata caused by mining activity and surface subsidence is the most important. The occurrence conditions of steeply inclined coal seam are very complex, and the dip is very large, because of the well developed joint and the highly metamorphosed in the coal seam undergoing kind of intense geological tectonic movement in the process before or after its forming [1−2]. Many researchers have discovered the pattern of the deformation of overburden strata caused by mining activity under general geological conditions in domestic and overseas at the present [3−6], but under the faulting factor, there are rarely correlational researches.

The fault, as a kind of weak structural plane, is an important influence factor for the stability of overburden strata caused by steeply inclined coal seam. The wide existence of faults impact the normal arrangement of mining area seriously and also destroy the regular displacements pattern of overburden strata, leading to much more complex pattern [7−8]. The strength of fault zone is much lower than that of the rock zone around it, so when the faults move, shear slip along the fault plane emerges easily, that is fault activation [9−11]. The deformation of the rock near the fault plane and the ground at the outcrop of the fault will focus, resulting in widespread destruction of buildings, railway and tunnel spanning over these faults. As a result, understanding the deformation patterns of overburden strata caused by steeply inclined coal seam mining activity under the faulting exactly is crucial in theoretical and practical field.

Because of the complexity of mining conditions in coal seam and the variation of boundary mode, it is very difficult to figure up the analytic solutions to the complex rock mass problem, even impossible. Hence, the numerical simulation method was adopted to solve the deformation pattern of the rock mass in the mining analysis. The complex medium characteristics, geological and ground stress conditions and mining technology evaluated the deformation and stress distribution of overburden strata, ground surface movement, which became an important approach for finding out the deformation mechanism of the overburden strata [12−15]. Until now, the numerical simulation methods for analyzing geotechnical mining engineering problems included finite difference, finite element, discrete element and boundary element. The FLAC2D finite differential program was chosen to simulate and find out the deformation pattern of overburden strata.

Foundation item: Project (20092142) supported by the Natural Science Foundation of Liaoning Province, China
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2 Engineering examples

Zhaogezhuang Coal Mine is an important production mines of Kailuan Mining Group. It is located in the northeast edge of the Kaiping syncline, coal is roughly east-west direction, tilt to the south, the exploitation is divided into east part and west part. The east part is gently inclined coal seams and inclined coal seam, most west part is steep-inclined coal seam. In steep areas, dip angle is started by 45°, dip angle is gradually increasing toward west, and the largest is more than 70°. The shallow part of the east well field is next to Tangjiazhuang mining, and the deep part is next to Linxi mining, and making the Kaiping syncline axis as boundary, the deep border is 1 200 m below surface. The west part ends at the number 37 profile lines, and it is adjacent to Weishan wells. The mine is 9 050 m long along the strike line, acreage is 15.96 km^2, and exploitative area is 31.55 km^2.

The structural type in Zhaogezhuang Coal Mine is fracture primarily. The characteristics and distribution law of the fracture structure is the same as the geological structure of Kaiping syncline region as a whole, that is, Kaiping syncline is one unit of new northeast Huaxia tectonic system, that formed after yanshan movement. Every liner structure has the new Huaxia structure's characteristics, strata strike is north east. The dip angle of northwest part of syncline is steeply, till inversion, and follow with a large amount of squeezed over thrust fault and secondary fold. The fault strike is consistent with syncline axis, it has large gap, playing a controlling role of mine. The faults associated with folds and various types of small faults, the structures is very complicated. The influenced by Qinlongshan anticline, the northeast side of syncline axis deflects to east west. The strata inclination of the southeast part of syncline is gently, to the main wrinkle, but the tensile shear fracture is also very developed, strike is north west-south east, and the pressure-shear fracture orthogonal, transecting direction of strata, fault dip angle is greater than the seam, and the gap is from a few meters to tens of meters.

3 Numerical simulation model

3.1 Computation fundamental assumption

In order to better understand the overburden strata deformation regularity in Zhaogezhuang coal mine, a certain simplification of the complex actual geological conditions.

The main litho logy of calculating profile is sandstone, the mechanical properties of top and bottom rock are different, also the litho logy. The mechanical properties were accounted as main factor in calculation, thus the rock types were simplified, so mechanical parameters will be given as top, bottom and coal seam three types. Its strike is the same as coal seam, the top and bottom of fault does not contact. Coal mining is from top to down, mining depth is from 200 m to 800 m below surface, and mining height is about 200 m in every stage.

Foregoing considerations, a two-dimensional numerical model by FLAC finite differential program was built. Taking 2 000 m as the horizontal dimension of model, and 1 000 m as the vertical dimension, the coal seam's dip angle is 60°, and the fault is 10°. Specific model structure is shown in Fig. 1. The plane strain model is numerically simulated using the contact elements of FLAC program to simulate the fault. The displacement constraints in horizontal direction on both sides of model, and clamped constraint on the bottom are applied. The elastic-plastic materials, adopting the Mohr-Coulomb criterion as yield criterion, are calculated.

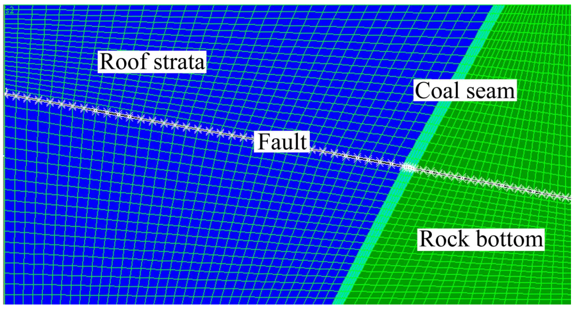


Fig. 1 Numerical calculation model

In the calculation, the average thickness of topsoil is 100 m, and its density is 2×10^3 kg/m^3. Therefore, 2 MPa uniformly distributed load is added on the model calculation. The gravity is used as initial stress field in basic scheme of calculation.

3.2 Layer and material parameters of model

Mechanical parameters of materials are mainly on the basis of indoor and outdoor rock test. The actual monitoring data were used to anti-analysis and rock mechanics calculation providing by relevant literature, finally determine through above factors. Mechanical parameters in the calculation in the final are shown in Tables 1 and 2.

4 Numerical simulation results and analysis

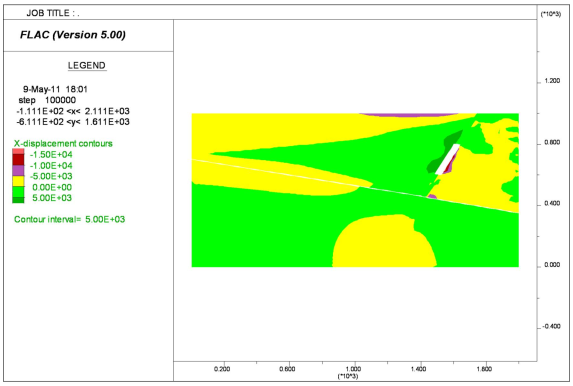
The simulation was used to summarize the rules of covering rock strata as mining steep-inclined coal seam under fault movement, so the x and y direction displacement of convective are obtained, where x and y are the direction stress and shear stress of convective and surface subsidence curve of the strata respectively by three different mining depth (see Figs. 2−7). According

Table 1 Strata thickness and computational mechanical parameters

Strata name	Strata thickness/m	Elastic modulus/GPa	Poisson ratio, υ	Density/ (10^3kg·m^{-3})	Cohesion/ MPa	Internal friction angle, Φ/(°)
Roof	1 560	9.5	0.23	2.68	14.1	40
Floor	700	4.9	0.28	2.67	1.99	44.6
Coal	40	0.83	0.36	1.34	1.91	40.2

Table 2 Mechanical parameters of fault

Elastic modulus/ GPa	Cohesion/ MPa	Internal friction angle/(°)	Normal stiffness/ MPa	Shear stiffness/ MPa
0.2	0.15	24	2	2



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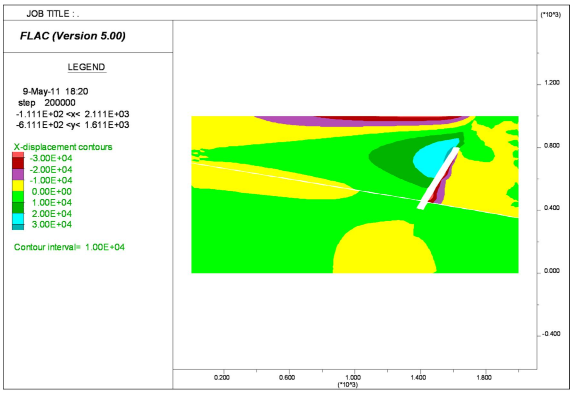

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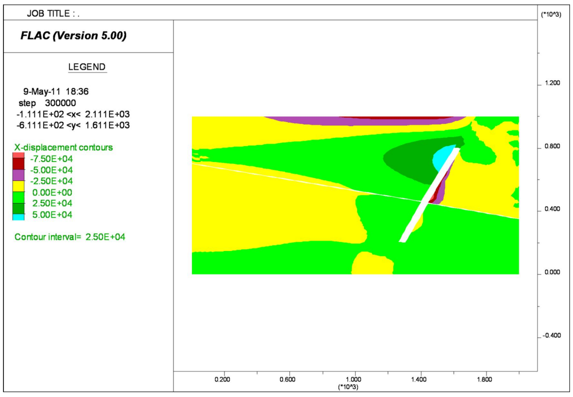


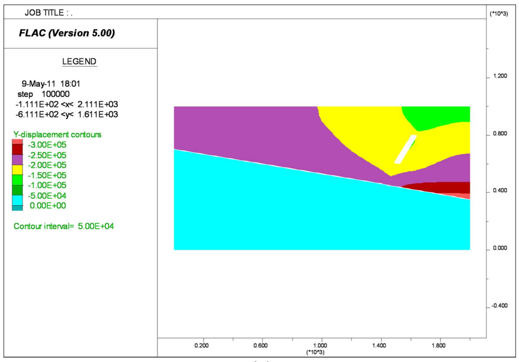
(c)

Fig. 2 Coal bed mining horizontal displacement of convective overburden strata at different stope heights: (a) 200 m; (b) 400 m; (c) 600 m

to the simulation results, the deformation law of overburden strata was analyzed from the following three aspects, displacement, stress and the surface subsidence curves.

4.1 Displacement

Horizontal displacement of overburden in the mined area and near the fault is changed greatly, gob area's



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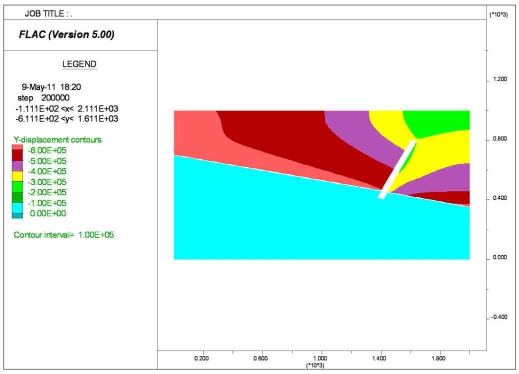

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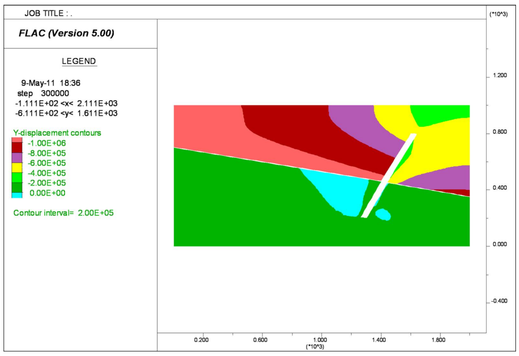

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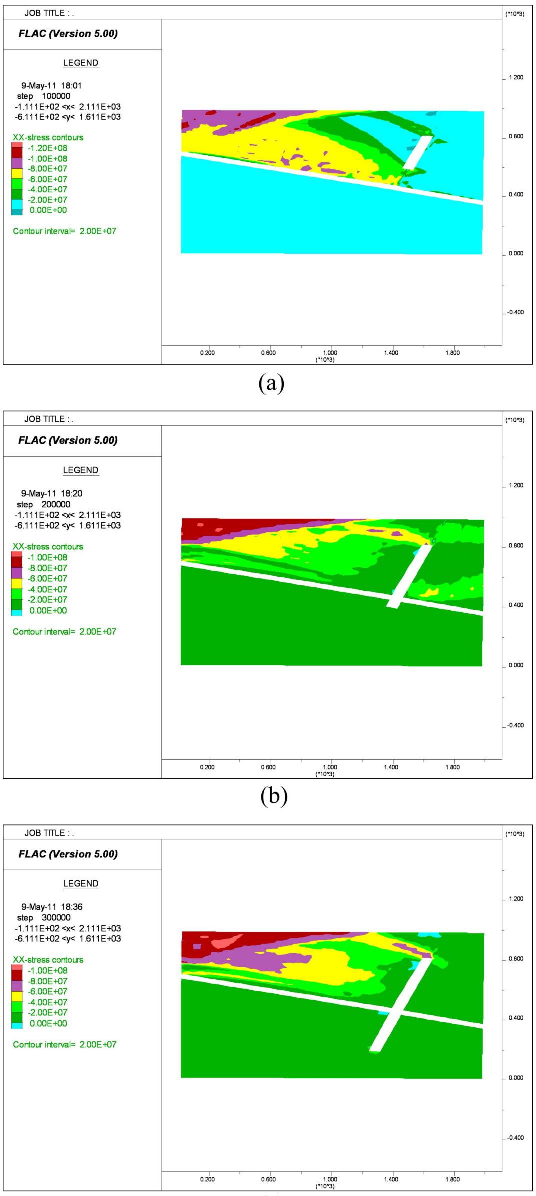
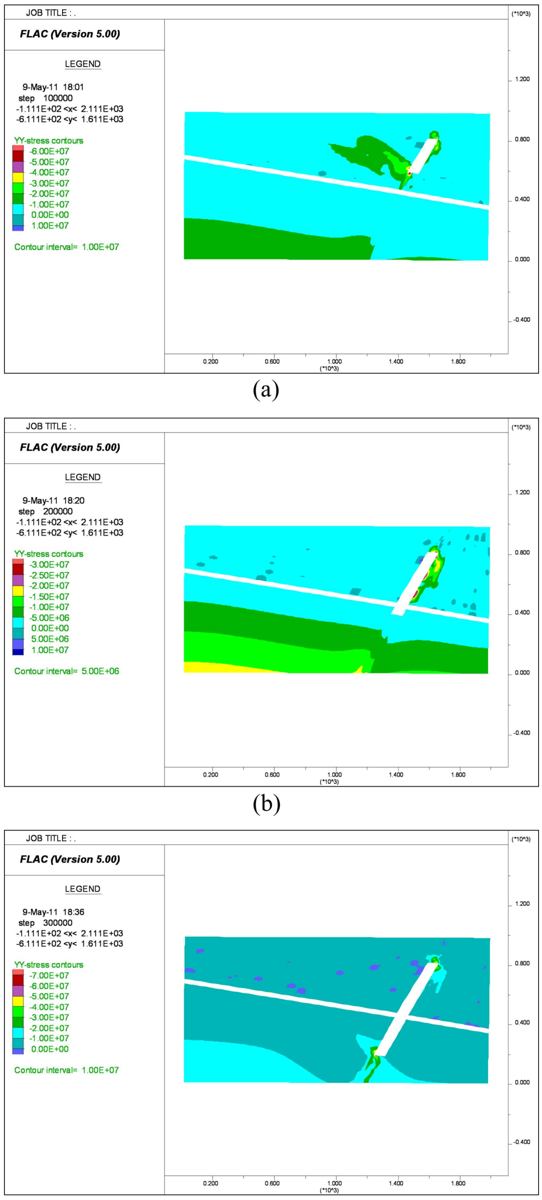
Fig. 3 Coal bed mining vertical displacement of convective overburden strata at different stope heights: (a) 200 m; (b) 400 m; (c) 600 m



(a) (b) (c)

Fig. 4 Coal bed mining horizontal stress of cloud overburden strata at different stope heights: (a) 200 m; (b) 400 m; (c) 600 m



(a) (b) (c)

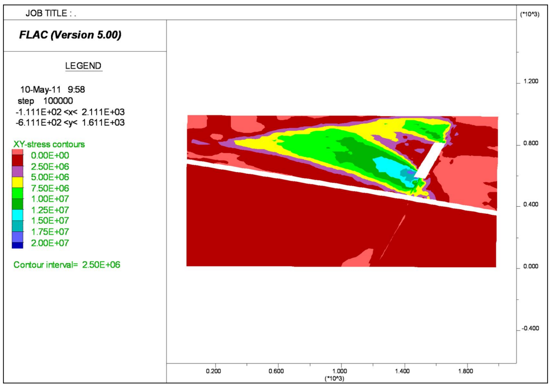
Fig. 5 Coal bed mining vertical stress of cloud overburden strata at different stope heights: (a) 200 m; (b) 400 m; (c) 600 m

displacement with the increase of mining depth, the value and influenced range are all increased. The change of displacement of upper wall and the top part of the overburden has little effect by the excavation depth, this shows that the change of displacement value mainly by the fellow fault effect. There appear positive displacement in mined-out top place, it declare that the roof rock has the trend to collapse, and the collapse range increases gradually with the increase of mining depth (see Fig.2).

The maximum vertical displacement of overburden rock is located at both ends of the upper wall, especially the area contacted with lower wall followed by the top part of the gob. At the upper wall, the variation scope of vertical displacement makes the mined-out area as the center, showing a class ring to spread outside the mined-out area. With the increase of mining depth, the vertical displacement of the value and scope increases (see Fig. 3).

4.2 Stress

The maximum horizontal stress appears at upper wall. At the ends of top rock, horizontal stress decreases gradually toward coal seam, but above mined-out areas and roof tensile stress appears in the small scope. With the increase of mining depth, the whole horizontal stress of coal increases and the maximum stress range has gradually expanded (see Fig. 4).



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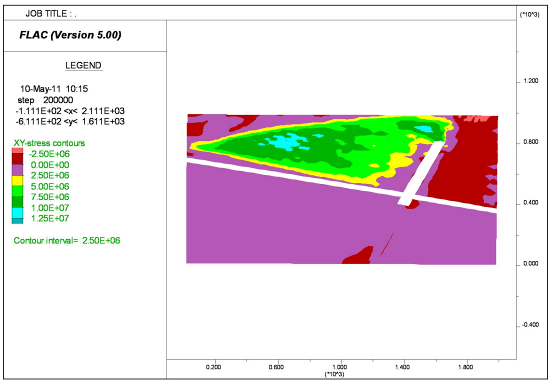

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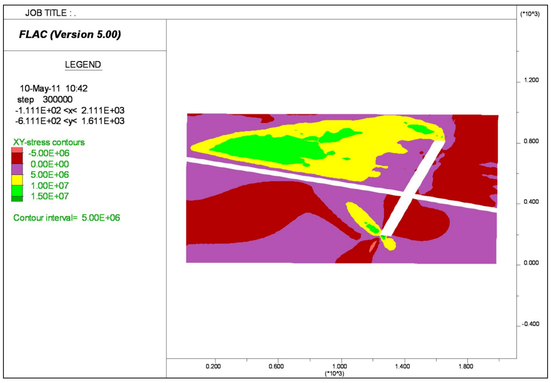

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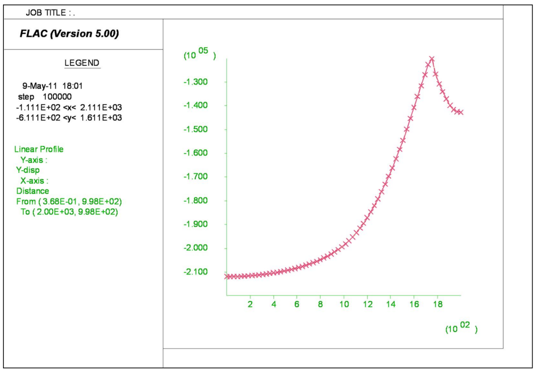
Fig. 6 Coal bed mining shear stress of cloud overburden strata at different stope heights: (a) 200 m; (b) 400 m; (c) 600 m



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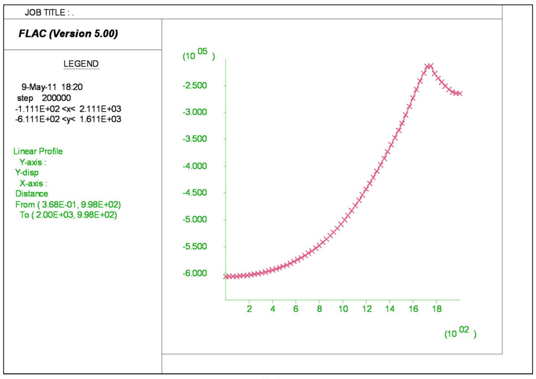

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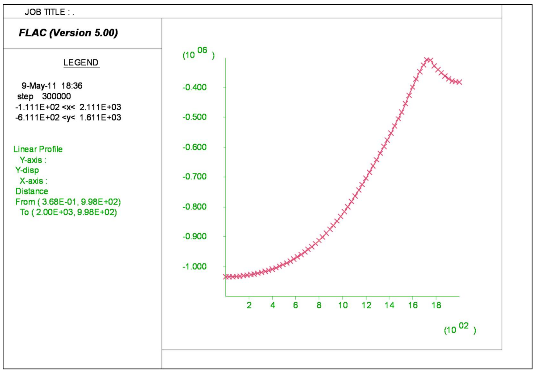

(c)

Fig. 7 Coal mining surface subsidence curve at different stope heights: (a) 200 m; (b) 400 m; (c) 600 m

At the end of gob, the vertical stress of overburden occurs stress concentration, and gob roof parts of the stress are high. The higher vertical stress area is located at the footwall of fault, which is different from the horizontal stress. The stress changing area is parallel to the fault plane. With the increase of mining depth, the stress value and its range increase gradually (see Fig. 5).

The maximum shear stress of overburden appears at the bottom of the gob, close to that at the roof. With the increase of mining depth, the stress zone expands toward upper wall. At the end of roof, and its scope and stress values are getting higher. The stress zone is also presented as narrow ring shape, parallel to the fault plane (see Fig. 6).

4.3 Subsidence curve

With the increase of the mining depth, the trend of subsidence curve is roughly the same, however, the value increases gradually. The roof part of the overburden subsidence is much greater than that of the floor, since the position behind gob and the subsidence significantly reduce (Fig. 7).

5 Conclusions

1) In the absence of fault, the changing zone of displacement and stress of the overburden rock are mainly around the gob. If the fault exists, the change of displacement and stress is influenced significantly by the

fault, and the changing zone extends to the surrounding area of fault.

2) Because of the large mining depth, it may make the fault active to a certain extent, so the stability of overburden becomes worse.

3) The existence of fault makes the asymmetry of pressure distribution and the displacement variation more apparent, after steep-inclined coal mining.

4) The existence of faults seriously affects the deformation and movement of overburden strata, thus affects the layout of working face and the roadway.

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(Edited by LI Yan-hong)