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◆Research Paper◆

The Numerical Simulation of a Coal Mining Based on the 3D Geologic Model

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Abstract: According to the geological drilling data of a mine area, established the 3D geological model of the mine area. Drawn the sectional view from the model and compared with the actual mining exploration line sectional view, verify the reliability of the model. Based on the multi-layer DEM 3D geological model, proceed simulation in the excavation of the tunnel using the method of advanced excavation. Got the initial gravity field, the calculate results of deferent work layer advance distance. The results showed: When the work layer advanced 200-975m, fault had no effect on mining. When advanced to 990m (from the fault F3 25m), the damage area caused by the mining has been through to the fault, if the working layer keep advance to the fault, it's highly probable to happen roof fall, sudden water accidents. It can be inferred, to NO.9 coalbed first mining face, it should reserve 25 ~ 10m coal pillars at the F3 fault to prevent accidents.

Keywords: 3D geological model; fault; coal mining; numerical simulation

In the coal mining process, because of the faults, and other special construction collapse column, it may appear suddenly water, gas outburst, roof collapse and other dangerous. In order to avoid these dangerous, the exploration and mining are at the same time, or exploration prior to mining. Called "exploration" refers to various methods of physical exploration, such as drilling hole method, electric measurement and acoustic measurement method. However, the physical exploration can measured the range of anomaly zone only, the mining often need to find ways to circumvent the abnormal area to avoid danger, so the coal pillar must be reserved. But the reserved coal pillars are too many will cause waste of resources, and the too little reserved coal pillar will cause a series of danger such as tunnel fall and water inrush[1-2]. How to solve this problem effectively, may both to improve mining amount and avoid the occurrence of the roadway.

In this paper, using drilling information provided by Xiandewang Mine build multi-layer DEM model of the mine area. Build 3D finite element calculation model by obtaining sectional data in different locations, And with a combination of rock mechanics, elastic-plastic mechanics, fracture mechanics, NO.9 coalbed first mining face was carried out a numerical analysis.

1. Build 3D geological model based on drilling information of Xiandewang mine

3D geological modeling is one important part of digital mine. In recent years, some scholars have proposed a method of multi-layer digital elevation modeling DEM (Digital Elevation Model) modeling method[3-4].

1.1 Process original data

Original geological exploration data is generally based on drilling information unit, the drilling information includes the drilling hole number, the plane coordinates, and the corresponding histogram. Generate a 3D geological model need to deal with different geological layers information, so the original data structure based on the drill information only suitable as construction statistics, it can not as the data structure works to generate a 3D geological model. Processing original data is crucial to generate 3D geological model.

During processing original data, the data structure of drilling information units converted into the data structure of the geological layer units. The original data structure based on the drilling number, drilling 2D coordinates, and the corresponding histogram, reflected the geological information of each drilling. The processed data structure is based on drilling hole in each geological layer , reflected the geological information of various geological layers. Represents the plane coordinates of drilling k with $k(x_k,y_k)$, z_{ik}, represents the elevation of k drilling belongs to the i soil layer. Proceed data is (x_k,y_k,z_{ik},i), means location and elevation of all drilling in the i soil layer. The processed data structure reflected the plane information base on geological layer, according it the elevation models can be created for each geological layers.

1.2 Create single layer contour line

After the above processing of borehole data, on a separate layer is a group of discrete data points including the elevation. Apply these data points can be generated independent of level contours. These level contour line will be important data-source to generate DEM by the Kriging difference.

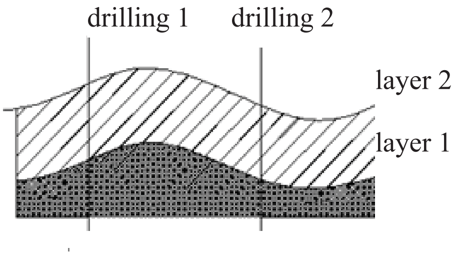
This paper used linear interpolation method to draw contour lines, this method is fast, Low data requirements, The accuracy is slightly lower. However, due to more intensive drilling in mining, the data more adequate, can make up for the manual error caused by the interpolation, so using the linear interpolation method can get same better results, the latter examples verified it too.

1.3 Divided stratum

Due to the spatial distribution of underground mudstone layer may be unevenly and discontinuous, between different strata may be cross or strata missing, it is the key to deal with these special cases to build models.

First by drilling to split the mining into small area, the drilling data processing of small areas taken sequence from left to right, from shallow to deep. The relationship between these layers in small area may occur the following three situations:

(1) Normal superimposed case (Fig.4), Two strata at neighboring borehole were exposed and in the same order, It can be seen the two strata between the two holes is not cross or no missing. Considering the limited distance between the two bore hole, the following case is extremely rare that the layers cross twice leading the layers vertical order unchanged (Fig. 5)



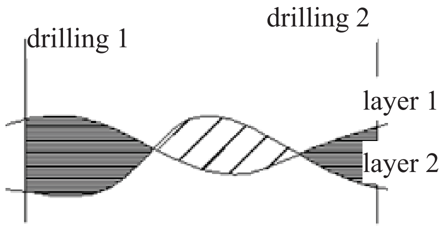
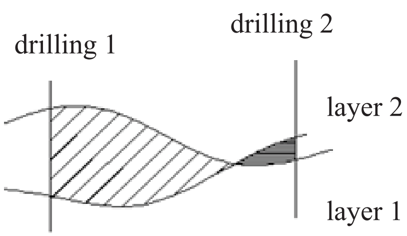


Fig. 4 Normal strata

Fig. 5 Strata appear twice cross

(2) If the order of the expose strata at the two neighbor borehole is changed (fig.6), it is believed that the two soil layers occur cross one time between two bore holes. Generally two curved surface intersect will form one or more intersection line, may use these lines to divide the strata into many. The existence of many curved surfaces does not affect to establish multi-layer DEM. Only in using of multi-layer DEM to create an entity model, should pay attention to the topology relationships between the entity units at intersection.

(3) If two adjacent borehole, one does not expose a stratum drilling (fig.7),it's be considered the no-exposed strata is missed between the two holes. To deal with this case, used to coincide the missing strata with the above or below strata at the drilling didn't expose the strata. Specific to be considered of elevation difference between strata at the previous drilling, choose a small elevation difference strata to coincide with missing strata.



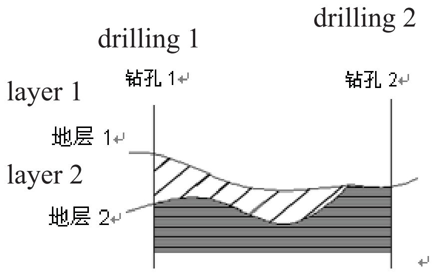


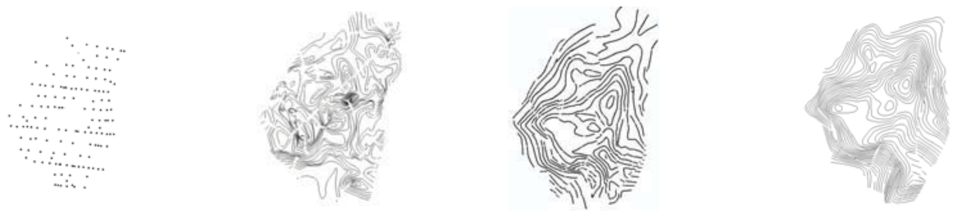
Fig.6 Cross strata

Fig.7 Missing strata

1.4 Establish multilayer DEM model

Using the above method, according to drilling data provided by Xiandewang mine, established multilayer DEM model and verified its reliability. There were 11 lines and 145 exploration drill holes. Distribution of drilling in Figure 8a.

Selected the following layers as three separate layers: the muddy surface, the No. 9 coal and the bottom of the ordovician limestone layer.Because the three layer relative easily to distinguish . Use borehole data processing raw data in accordance with the previous method of data processing. Then use the processed data and general interpolation to generate contour tracing algorithm to generate contour lines. Select layers cenozoic surface, No. 9 coal and ordovician limestone top as an independent three layers,and generate three separate levels of contour lines, fig 8b, c, d

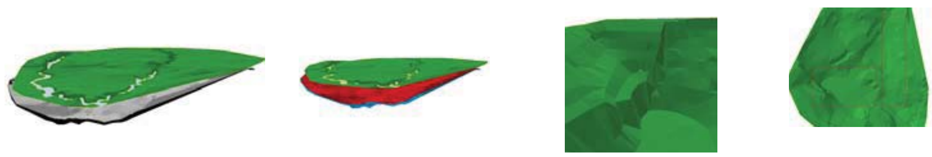


(a) (b) (c) (d)

(a)Drilling distribution(b)Cenozoic surface elevation contour map, (c)Nine coal elevation contour map(d)Ordovician limestone top elevation contour map

Fig.8 Contour maps generated by drilling data

Using the above three different levels contours, applied Kriging interpolation method, obtained different levels of digital elevation model (DEM), as shown in figure 9. Seasonal river flowing through the mine in Figure 9 (a), (b) is expressed as a light portion, Its formation process is sketched on the boundary surface model, covering the replacement, mainly to enhance the realism of the model.



(a) (b) (c) (d)

(a)Separate strata superimposed renderings (b) Mine layered geological model, (c)An enlarged view of the fault (d)Two positions syncline

Fig.9 Different levels of digital elevation models

1.5 Get the data of any cross-sectional position

In the multilayer-DEM model，take a line coincident with the exploration of line as the section line, sectional view any profile can be obtained. Sectional view of the DEM model obtained in the two exploration lines shown in Figure 10

1.6 Use profile data to build three-dimensional finite element model

1.6.1 Determine the fault location

The section line is a continuous line. Fault location must have certain criteria to judge. According to common sense, the fault occurs at the stratigraphic dramatic rise or fall, therefore could be considered $dy/dx \geq 0$ to dtermine,that is to say if the slope is greater than Section line at a certain value, the Department considers that a fault. With the above criteria, the approximate location of the fault can be obtained, as shown in Figure 10

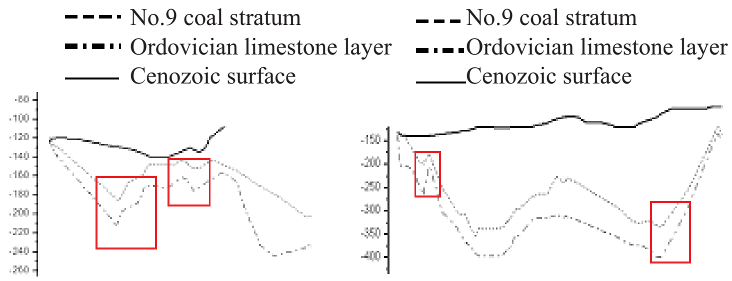


Fig.10 Two exploration line cross-sectional view and location schematic

1.6.2 Dimensional finite element model of the geological

With cross-sectional data and the location of faults, build three-dimensional geological model using finite element modeling of the bottom-up approach. The three-dimensional finite element model can not only calculate the impact of various tectonic movements produced, but also simulate the destruction caused by the mining area and its extension given by the evolution of the relevant external loads and boundary conditions, and gives reasonable security pillar reserved distance.

Three-dimensional geological model is shown in Figure 11:

(a) (b)

(a)Surrounding stratum chart of NO.9 coalbed first mining face, (b)Surrounding stratigraphic units graph partitioning NO.9 coalbed first mining face

Fig.10 Three-dimensional geological model diagram

2. Establishment of a two-dimensional plane strain finite element model

2.1 Model building

The actual mining working face is a three-dimensional. However, considering the length and width of the mining face far greater than the thickness of coal seam, the tendency of coal seam can be ignored, only consider the coal seam towards, then the plane strain model can be used to simulate.

According to the established model of multilayer DEM and extracting section methods, combined with the surrounding stratum chart of NO.9 coalbed first mining face, its cross-sectional can be established, and use this can build a two-dimensional cross-sectional plane strain finite element model to simulate the two-dimensional plane strain mining, shown in Figure 12

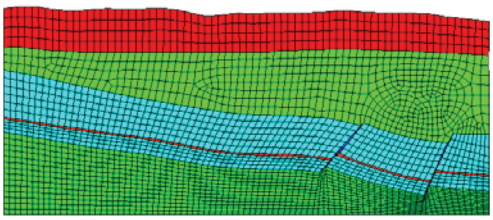
Based on the engineering geological data, there are six stratigraphic model of NO.9 coalbed first mining face. From top to bottom were the cover soil, a mixed layer of mudstone sandstone, shale, sandstone mixed layer, coal, shale, sandstone mixed layer, limestone. For the mixed layer, such as the second, third, fifth layer of the material parameters obtained by averaging. Using bilinear strengthen elastic-plastic model, parameters of each formation are shown in Table 1.

Table 1 Parameters of each stratum

stratum	Density(kg/m^3)	Modulus of elasticity(GPa)	Poisson's ratio	Yield stress(MPa)	Strengthening modulus(GPa)
Cover soil	2000	9	0.33	15	1
mud-sandstone	2200	15	0.31	22	3
coal	1800	2	0.35	10	0.2
Sandstone and shale	2400	25	0.295	30	5
Limestone	2700	40	0.23	55	10

2.2 Fault handling

There are two faults F3 and F18 in figure 12. Simplified handling for faults. In general, the fault should be established at the face - face contact. Considering the simulation is face mining, fault could not produce significant slip deformation. Therefore, using a soft elastic material to fill the gap between faults. In fact, due to the geological fault is the fracture zone, often be filled with mud, water, sand, and has a large amount of gaps, so this is a reasonable assumption. Enlargement at fault shown in Figure 13.



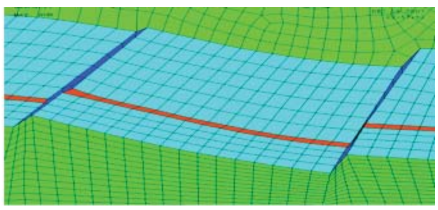


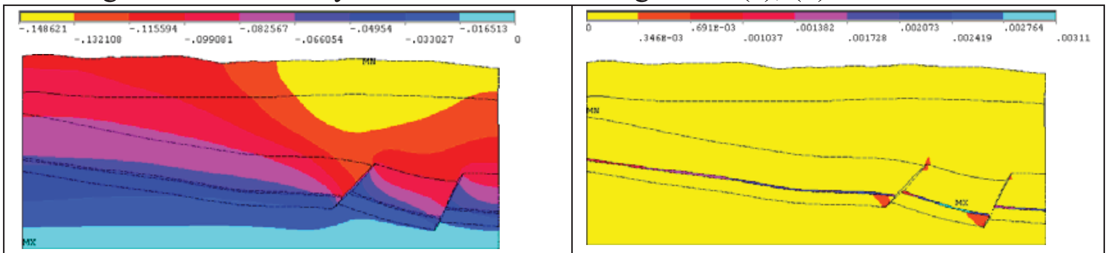
Fig.12 Two-dimensional plane strain finite element model Fig.13An enlarged view of the fault

2.3 Results and analysis

Mainly analysis the NO.9 coalbed first mining face on the left part of fault F3, The length of this part is about 1000m. Using advanced methods that used in tunneling to simulate the excavation. Below given the calculation results of the the initial gravity field, working face go forward 200m, 400m, 700m, 950m, 975m, 990m .

2.3.1 Simulate initial ground stress in gravity field

In order to simulate the mining process, initial ground stress must be simulated, in order to facilitate the release of the follow-up exploration step to simulate the stress. Failure criterion is used to achieve a certain degree plastic strain on behalf of damage. Initial ground stress analysis results shown in Figure 14 (a), (b).



(a)Y-direction displacement cloud under the action of gravity

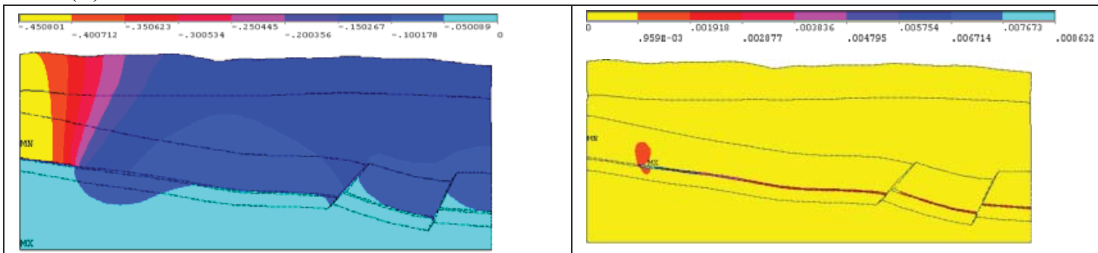
(b)Plastic strain cloud under gravity

Fig.14 Initial ground stress analysis results

It can be seen from Figure 14，under the gravity，there have been some plastic strain upper and lower ends of the softer seams and faults. This is consistent with the actual

2.3.2 Numerical simulation and analysis when working face moving forwards

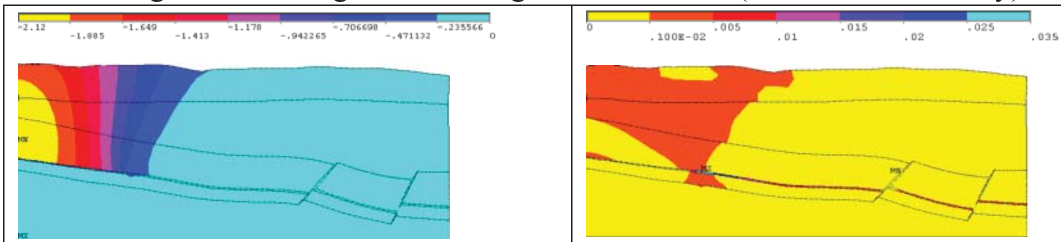
(1)Numerical simulation



(a) (b)

(a)y-direction displacement cloud (b)plastic strain cloud

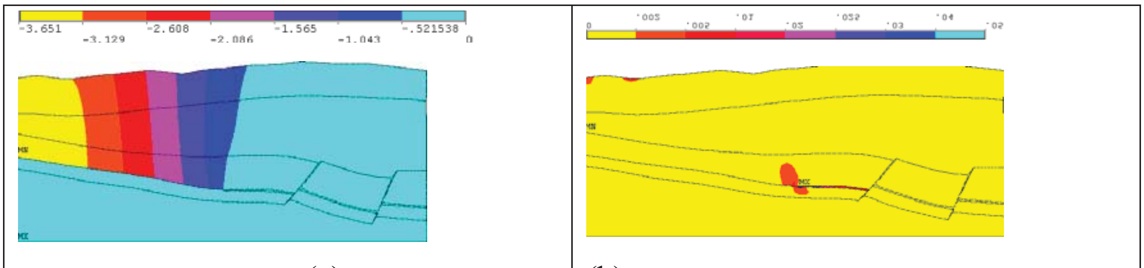
Fig.15 Working Face Moving Forwards 200m(Fault F3 800m away)



(a) (b)

(a)y-direction displacement cloud (b)plastic strain cloud

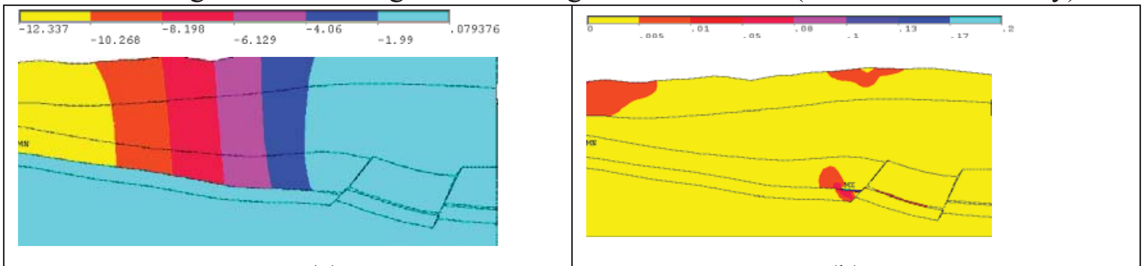
Fig.16 Working Face Moving Forwards 400m(Fault F3 600m away)



(a) (b)

(a)y-direction displacement cloud (b)plastic strain cloud

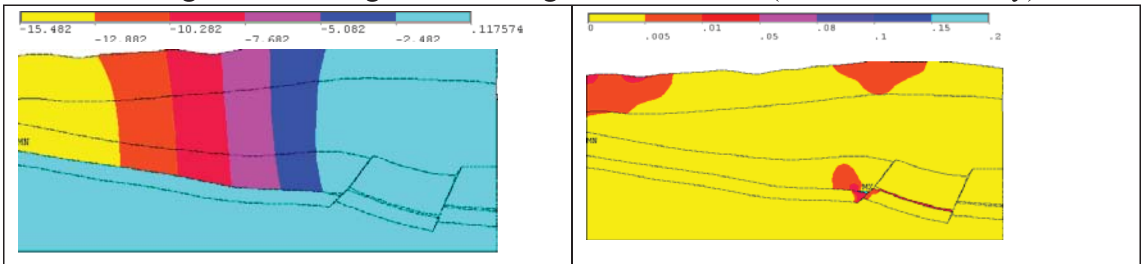
Fig.17 Working Face Moving Forwards 700m(Fault F3 300m away)



(a) (b)

(a)y-direction displacement cloud (b)plastic strain cloud

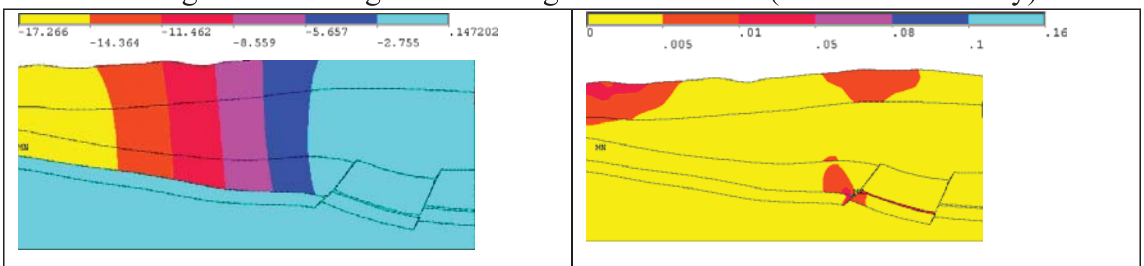
Fig.18 Working Face Moving Forwards 950m(Fault F3 50m away)



(a) (b)

(a)y-direction displacement cloud (b)plastic strain cloud

Fig.19 Working Face Moving Forwards 975m(Fault F3 25m away)



(a) (b)

(a)y-direction displacement cloud (b)plastic strain cloud

Fig.20 Working Face Moving Forwards 990m(Fault F3 10m away)

(2)Analysis

The paper used life and death method of the units to simulate the processing of the mining, kill the been mined coal unit to simulate the advance of working face

When the work face advance 200 meters (Fig.15), the strata above the mined - out area appears to sink, because he node stress of the mined - out area didn't be released , upper part of the mined - out area has not plastic strain. In fact, this state is similar with supporting to counteract the ground stress. However, the soil layer of the mined-out area appeared to sink due to didn't simulate alone support system. Also the top and floor near the working face appeared a certain degree of plastic strain, but it not yet reached the degree of broken damage.

When the working face advanced 400m-950 meters, shown as Fig.16-18, with the advancing of the working face, the plastic strain progressively became larger. The plastic strain is concentrated in front of the working face, the strata on the bottom and top of the working face had a certain degree of plastic strain. Damage region concentrated in the upper and lower rock of working face and the limited distance from the coal seam, it was safe of mining, so the destruction of these areas did not the focus.

When the working face advanced 975 meters (Fault F3 25 meters away), shown as F19, y-direction displacement and plastic strain had increased further, the plastic strain region has been extended to through to the fault, but the plastic strain of the through area was little, did not reach the damage judgment criterion of coal rock. Damage region concentrated in the upper and lower rock of working face and the limited distance from the coal seam. So at this time there was no fault impact on mining yet, the likelihood of accidents was still low.

When the work face advance 990 meters (Fault F3 25 meters away), shown as Fig.20b, can be seen by the plastic strain cloud figure, that the damage area by the mining has through to the fault, and the remaining coal have all over the destroyed limit, at this time the reserved pillar could not resist the stress concentration caused by faults . Due to damage area has through to the fault, the damaged rock will release stress at the fault, if the working face kept continue advance to the fault direction, it was highly likely to occur roof fall and sudden water accidents. So in the case of NO.9 coal-bed first mining face, should reserve 25 ~ 10m of coal pillar at fault F3 to prevent accidents.

3. Summaries

(1)Based on the existing mine borehole data, established multi-layered geological model DEM.According to the borehole data and geological model multilayer DEM, established a finite element model.

(2) Combined with rock mechanics, elastic-plastic mechanics, using fracture mechanics, two-dimensional plane strain elastoplastic damage model, Simulated the actual coal exploitation Xiandewang of NO.9 coalbed first mining face.

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engineering

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