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◆Research Paper◆

Simplify the Structure of The Surface Mining and Analytic Calculation

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Abstract: Based on the NATM, established the mechanical model of the mining surface structures, researched the forming of the non-hinged arch during the coal seam mining. Using elasticity center method calculated the internal forces of the non-hinged arch, got the strength, rigidity and stability of the surrounding rock and supporting structure. With analytic calculation, Analyzed the rock stress evolution of the adjacent coal seam mining and the stress distribution of the stope roof rock evolution. Based on the stress field evolution of the stope, analyzed the force and the crack development in different regions of the rock mass, studied the distribution of the strain and shear stress in the rock mass and the impaction of mining velocity on rock stress distribution. Verified the rationality of the surface structure of the model adopted in this paper.

Keywords: mining face structure; mechanical model; no hinged arch; adjacent coal seam; elasticity center method

In the traditional surrounding rock of roadway control theory, the surrounding rock of roadway is a loading, should use the thick concrete to support the loosen rock mass. New Austrian Tunneling Method (NATM) considered rock is a carrier mechanism, build a supporting structure that is thin-walled, flexible and closed to the rock mass, to bear the pressure and maintain maximum stability of the rock mass without loosen or damage. NATM was introduced to China in 60's; it was developed rapidly in late 70's and early 80's. Now NATM is used in all major and difficult underground works, it almost became a basic method in soft crushing rock location to build tunnel.

Based on the NATM, the paper established the mechanical structure model of the roadway mining face structures in the mining process. For the statically indeterminate structure using the force method, the matrix displacement method and moment distribution method to calculate the internal forces, got the strength, rigidity and stability of the surrounding rock and the support structure.

1 Mechanical model

During the coal mining, the advancing of working face keep the internal stress of coal rock continuously self-adjustment, resulting the internal stresses uneven in coal rock, automatically formed an arch structure in rock. The rock in the arch structure located in a region of high stress concentration, the rock on the inside of the pressure arch and near the side of the mined-out area, due to the unloading, the stress is reduced, be in the unloading state. The rock stress near the coal mining gathered to the goaf and gradually increasing. When coal mining to a certain distance, the stress is greater than the ultimate strength of the rock, the coal seam roof will have the first fracture, collapse and caving, also known as the first weighting. The rock mass structure can be simplified show as figure 1. The structure in first weighting bearing the concentration stress q_1 caused by the coal mining, upper strata and their own gravity q_2, the caving rock inside the structure generated extrusion pressure q_3 and q_4, along with unloading the lower strata produced the buoyancy q_5 and concentrated stress q_6, extrusion pressure q_7 and q_8 of the surrounding rock . Along with coal mining continue, the stress arch continue adjustment, when the elasticity modulus of top slab strata is larger, the situation shown in figure 2 will appear, that plus a box structure by an arch structure. Because the top roof has a high ultimate strength, it can bear the additional stress generated by gravity and stress concentration came from the surrounding rock. The arch internal caving rock will provide some support to the arch structure, and will form one pillar at the junction of arch and box interface. Due to the loose structure of the caving rock, with more flexibility and lower compression modulus, can not be simplified into a hinge support, but it can be simplified into the spring holder.

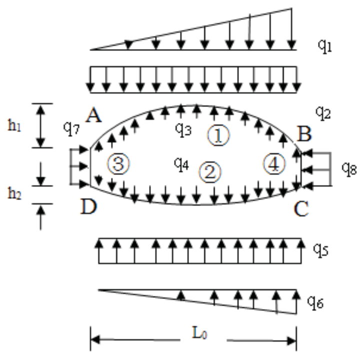

Fig.1 The stress arch and load distribution of first weighting

With the increasing of advance distance, when the structure internal forces is greater than the ultimate strength of the hard layer, the coal layer will collapse again, formed the structure shown in figure 3. Two small arches are connected, and he connection point is connected to the base plate used a spring holder. In this stress arch adjust process, there will be consolidation phenomenon. When the mining to a certain distance, two small arches will merge into a large arch, shown as figure 4. Later keeping repeated the above process to produce small arches, and finally merged into a larger arch structure. In this process, the arch structure forces continue to make adjustment, but the kind of force suffered has not changed, shown as figure 5-6.

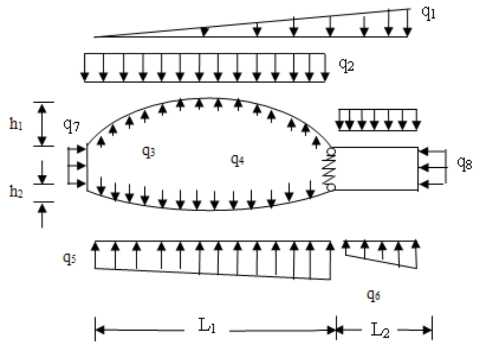

Fig.2 The stress arch and load distribution before second weighting

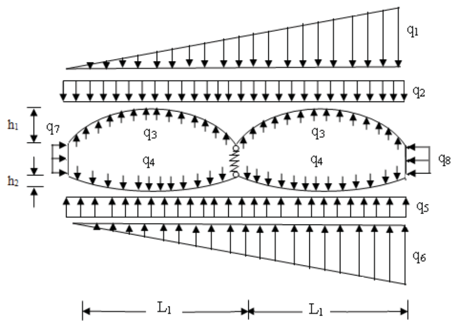

Fig.3 The critical stress arch and load distribution before second weighting

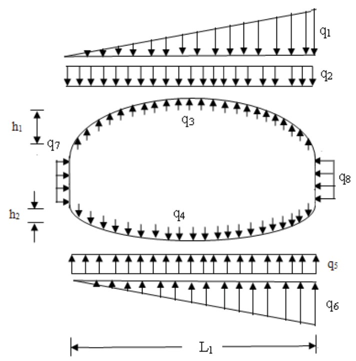

Fig.4 Small arch mergers and loading distribution map

After completed to advance the mining work face, there is a long time to form stable large arch as shown in figure 7. But because after a long period standing, the surround structure no longer bear the concentration stress. The evolution of these arch structures also reflected the transfer direction of the rock stress indirectly. It should be noted that the arch of the pressure arch structure within roof and floor of the coal seam is asymmetric. Mainly due to the own weight of the top slab, the range of rock caving and arch high are both large, the caved rock layer will compact the bottom slab, it will suppress stretching downward of the arch structure in the bottom slab, the arch height smaller.

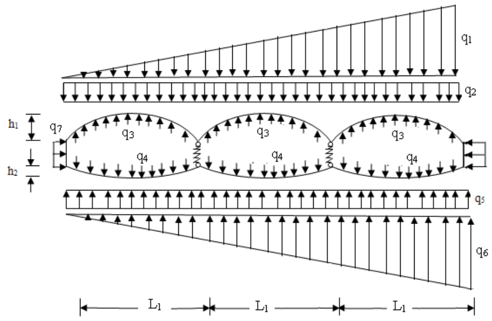

Fig.5 Multi-arch and loading distribution map

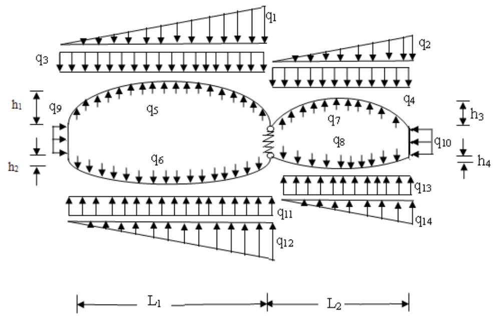

Fig.6 Stress arch merge gradually loading distribution map

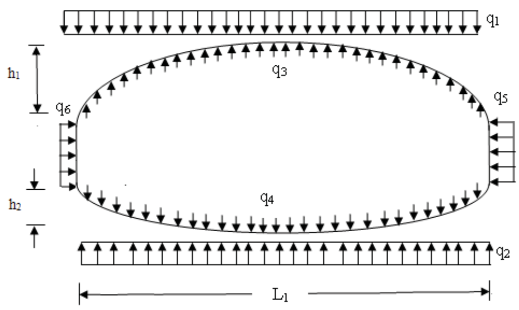

Fig.7 Final stable arch and loading distribution map

2 Engineering Applications

2.1 Project Overview

The working face 22201 is the first face of North 2 mining area 2# Coal of a mine, using leaving road along the goaf and Y-type ventilation. The geological structure is relatively simple, the overall structure is monoclinic, the average inclination 4 °, the average coal thickness 2m, the face is mainly coking coal and high gas content, gas pressure 2MPa. Its northern formed 22202 face, the remaining 2 #

coal was not explored. In the nether 3+4# Coal face, only the mining 24208 Face in southern, other position both no working, and 3+4# coal average thickness 4m. The 5# coal is under the 2# coal, distance 20m, coal thickness 4m. The 22201 Face is the two-roadway plus one borrow roadway layout mode, when the working face stoping, the machines rail combination roadway and assist roadway are inlet air roadway, the 22202 Track way is the main return airway of 22201 mechanized mining face. Rock mechanics parameters calculated as table 1.

Tab.1 Calculation rock mechanics parameters

Lithology	Thickness m	The bulk modulus GPa	The shear modulus GPa	Density kg/cm^3	Friction angle°	Internal Cohesion MPa	Tensile strength MPa
Quartz sand	25	35.5	25	2650	40	12.8	7.5
Mudstone	13	23.3	10.8	2400	30	2.8	2.8
Sandy mudstone	7	24.2	12.5	2500	41	6.8	4.1
2$^{\#}$coal	2.8	14.8	6.06	1400	35	2.1	1.8
Fine-sandstone	4	37.4	26.9	2700	34	18.4	7.8
Sandy Mudstone	2	24.2	12.5	2500	44	6.8	4.2
Mid -sandstone	4	34	21.4	2450	36	18.4	6.5
Sandy mudstone	4	24.2	12.5	2550	44	6.8	4.1
3+4$^{\#}$ coal	4	14.8	6.06	1400	38	2.1	1.8
Sandy mudstone	4	24.2	12.5	2600	46	6.9	4.1
5$^{\#}$coal	4	14.8	6.06	1400	40	2.1	1.8
Sandy	8	24.2	12.5	2650	48	6.9	4.2

mudstone							
Limestone	9	30.4	16.5	2450	46	14.6	7.2

2.2 Results and analysis

2.2.1 The vertical stress analysis of the coal rock along the roadway

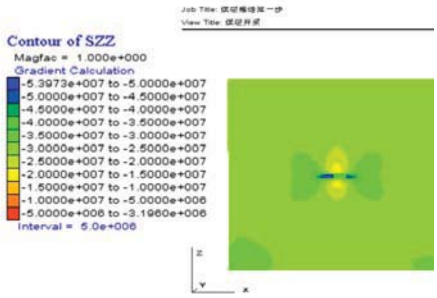

Fig.8 10m excavation stress cloud

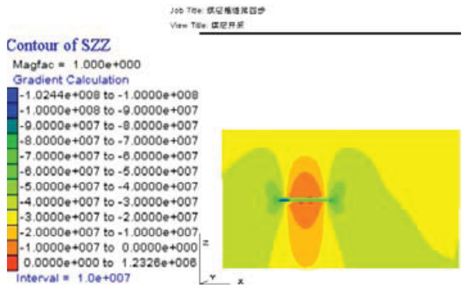

Fig.9 40m excavation stress cloud

Figure 8-9 respectively reflected the stress distribution rule when neighbor coal mining advanced to 10m, 40m. Disturbed by coal mining, the original stress equilibrium state inside the coal rock was broken, the stress will find a new equilibrium state, and this process is called stress redistribution. During the mining advancement, the additional stress generated by the rock under the impact of coal mining resulting in that the coal rock showed obvious regional characteristics, shown as figure 9, that are the stress increasing zone (compression of front of the working face, as blue area in the clouds figure), stress reducing area (This area rock stress is less than the initial stress, in unloading state, as red area in the clouds figure, the coal rock occurred expansion deformation). However, due to the limitations of numerical calculation, cloud no stress recovery area (cause by the caving of coal roof), these areas constantly adjusted and repeated with the coal mining, the specific features are as follows.

Rock mass stress increased area: The area is located near the border of the coal mining face, Stress level of coal rock was significantly increased. Under the centralized stress, the rock exposed in the goaf was affected by the tension effects parallel to the rock surface, and born a large horizontal compressive stress within a certain distance of the the goaf, leading to the coal rock produced a large number of joints and cracks, and with the increasing of centralized stress, the cracks may be closed.

Rock mass stress reduced area: After coal mining, in order to resist the uneven deformation caused by the unloading, the rock shifted the stress direction through adjust itself, formed a dynamic arch structure. It passed outside mine pressure to the surrounding rock, its supporting point located in the area of stress concentration. The stress reduced area distributed in the inner side of the structure and located near the goaf and all in the unloading state, there is a lot of tension cracks. The rock located in the stress reduced area will not be affected by the pressure of the arch outside of the mine, its own weight will not affect the strata outside of the arch.

Rock mass stress recovery area: In this area the rock additional stress will gradually increase, there is a trend to recover to the initial stress. The reason is that with the coal advance, the top roof will be cyclical broken, the rock continue caving, so the coal floor seam suffered the re-compaction of gangue.

2.2.2 The coal rock mass displacement analysis

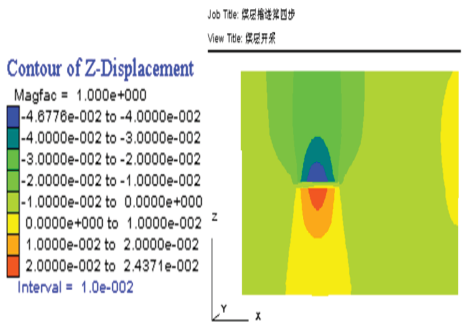

Fig.10 Displacement contour plot clouds as excavation 40m

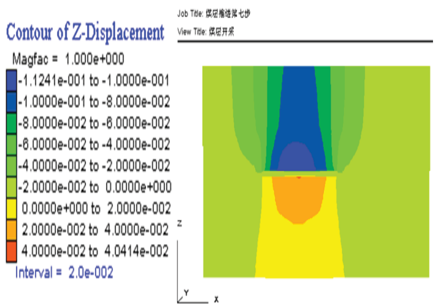

Fig.11 Displacement contour plot clouds as excavation 70m

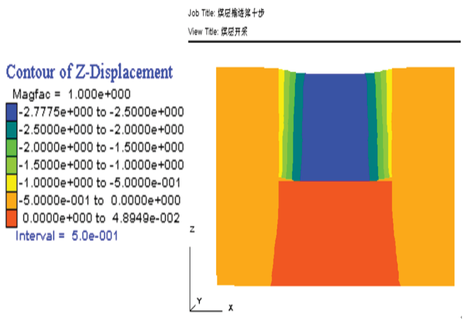

Fig.12 Displacement contour plot clouds as excavation 100m

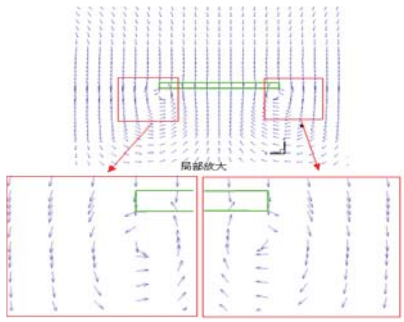

Fig.13 Displacement vector that the direction along the roadway as excavation 70m

The Fig.10-13 shown the longitudinal displacement distribution law of the coal along the roadway respectively when the working face advanced to 40m, 70m and 100m. When the coal excavated to 40m, the mining disturbance is less impact on the rock mass, the unloading range and the displacement range are small. But with the working face forward, the overburden on top of the goaf due to the increasing range of the unloading, the rock withstand loading and displacement were gradually increased, displacement values can be up to 2.78m. During this period the uneven subsidence and dislocation in the horizontal direction of the rock strata will produce lot of vertical cracks and fissures delamination may increase coal seam permeability significantly. In FLAC-3D calculation and analysis, the longitudinal displacement reflected the delamination fractured development caused by the coal rock subsidence. The bottom slab appeared the phenomenon of floor heave, increased the permeability of bottom slab, and also increased the gas storage and transport channels.

It is evident that the moving trends at different locations strata in figure 16, due to stress concentration caused a partial compression in the goaf corner, both ends of the rock are under pressure to produce displacement away from the the goaf. The rock below the goaf has a trend to whole movement upward, in the transition region of compression and expansion zone there are unsynchronized displacement in each strata, based on the original fissure will produce many secondary cracks, became a gas adsorption, migration favorable channel, but also offered the possibility for the realization of gas extraction.

2.2.3 Volumetric strain increment analysis of the coal rock

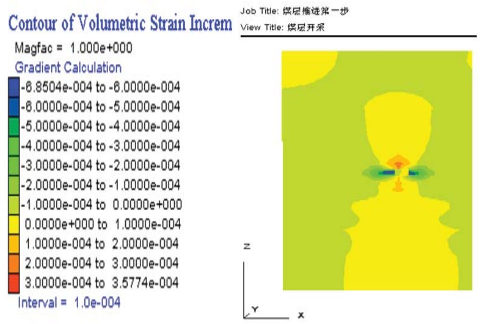

Fig.14 Volumetric strain increment when mined 10m

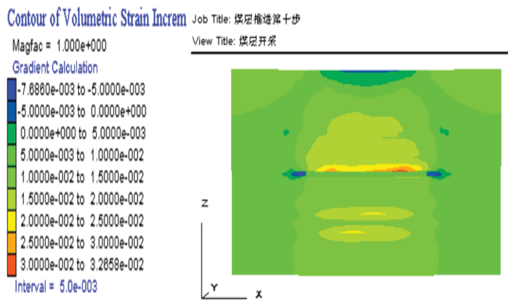

Fig.15 Volumetric strain increment when mined 90m

Show as Fig.14-15, with the coal mining, rock at the top and bottom of the goaf will produce swelling deformation, in the open-cut hole and the support pressure area front of the coal wall will produce compressive deformation, it is consistent with the vertical stress distribution that will produce compressive deformation in the stress concentration area. The volumetric strain cloud of each stage excavation is corresponding to its vertical stress cloud, and the volumetric strain increment is nonlinear increasing in the advance process. After excavated to 90m along the roadway, the volumetric strain increment is up to 3.26e-2, the maximum value is in the red region of the coal roof, and subjected to the full impact of mining, resulting in damage. In addition to the transition zone of the volumetric strain increment that from the compression area to the expansion area, there are dramatic changes in the strain gradient and will exist a large number of through-cracks.

2.2.4 Coal rock shear stress analysis

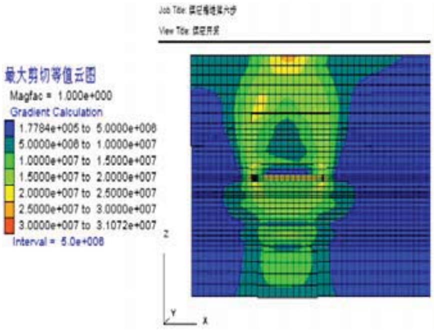

Fig.16 the maximum shear stress cloud when mined to 60m

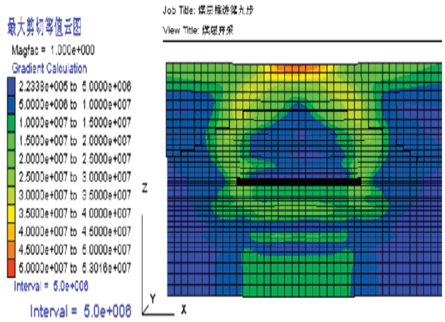

Fig.17 the maximum shear stress cloud when mined to 90m

Show as Fig.16-17, after the coal mining, the second distribution of the coal rock stress will be caused inevitably. When mined to 60m, the front coal wall of the working face will have a great stress concentration, its shape is consistent with the simplified model in chapter 2. When mined to 90m, the arch range of maximum shear stress increased significantly, the maximum shear stress that around the goaf appeared significant concentration phenomenon in the front coal wall and the open-cut hole, it reflected the force transmission mechanism of the coal rock arch structure.

Experiments show that most of rock destruction are shear failure, and comply with Moore- Coulomb criterion. Therefore, in the vicinity of the arch will exist a large number of shear fractures, and when the external force increased to a certain extent, the native fissures and newborn fractures in rock were extended or cut through, will eventually lead to the rock destruction.

The rock on the maximum shear stress arch is the main load-bearing structure of the rock mass, in its inside is densely region of the fractures development, is also the most serious damage area in the rock. With the working face advancement, the pressure arch constantly adjusted its own stress state, once the external loads exceed their carrying capacity, the coal rock will produce caving again, and the outside arch will form a larger arch body to maintain the stability of upper coal rock.

3 Conclusions

(1)Based on the evolution of coal mining into the arch structure, proposed a simplified model of rock mass structures, and gave the loading distribution form of the structure combined with the actual situation, using of the substructure method, the elastic center method and the superposition principle of the structural mechanics to obtain the internal force analytical solution of the structure.

(2)Before the coal is mined, the rock mass is in three-dimensional stress equilibrium state, the distribution of internal stress is uniform and gentle. With the coal mining, the internal stress equilibrium state of the rock mass is broken, the stresses is redistributed. In the process of working face advancement, the rock additional stress generated by the mining resulted to the coal rock mass showed three obvious regions: increased stress area, reduce stress area and recovery stress area. These three areas adjusted constantly and repeat appeared with the working face advancement. With the increase of extraction distance, the rock stress bubble was transited from the Initial arch to a parabolic gradually, finally formed the saddle shape. The variation rules of the mining rock mass displacement field is corresponding with the stress field, the displacement of the roof slab is along with the increases of extraction step, the displacement of the bottom slab will be some floor drum. The roof slab caving will be re-compacted, but not be restored to its original state.

(3)The rock volume strain increment reflected the rock mass deformation in different regions, when the changing amount reaches a certain value the coal rock will produce fissures, resulting in damage, improve permeability. The maximum shear stress cloud reflected the characteristics of coal rock arch structure, verified the reasonableness of the coal rock structure system simplify model that proposed in this paper, and the rock mass inside the arch stress is a enrichment fractures area.

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