Numerical Research on Goaf Coal Pillar Damaged by Working Face Mining

Guo Xinyao[1,2,4], SONG Yinghua[1,2,3], Lv Wei[1,2,3], Guo Hui[1,2,4] Yang Ang[5]

(1.China Research Center for Emergency Management,Wuhan University of Technology,Wuhan 430070,China;
2.Hubei Collaborative Innovation Center for Early Warning and Emergency Response Technology,Wuhan 430070,China;
3.School of Management,Wuhan University of Technology,Wuhan 430070,China;
4.School of Resource and Environmental Engineering,Wuhan University of Technology,Wuhan 430070,China
5.Chongqing fire corps of Chinese people's armed police force, NO.77 North of YuBei district,Chongqing,China)
Corresponding author:Song Yinghua, Professor of engineering and management;18674051377; Email:sggxy@126.com

Abstract
In order to prevent goaf gas swarm into adjacent tunnel because of goaf coal pillar break when working face excavating,this article used FLAC3D numerical simulation software simulate overlying rock and coal pillar stress, plastic zone distribution when the working face excavating,the simulate results shown that,when working face excavated 32m,coal pillar began to break under the effect of excavation,until excavated 48m,almost whole of the coal pillar damaged ,so the problem of air leak in coal pillar was serious,it needed strengthening measures to solve that problem.In order to prevent of gas accident and ensure the safety production of coalmine.
Keywords: NUMERICAL SIMULATION, COAL PILLAR, PLASTIC ZONE,GOAF,COALMINE SAFETY

1 Introduction

With the development of modern computer science, numerical simulation research has found wide applications in many engineering fields. Watanabe, H. and Otaka. M.studied coal gasification in entrained flow coal gasifier by numerical simulation technology[1]. Xu T. and Tang C. A. Using numerical simulation technology for research on coal and gas outburst mechanism[2]. Jaiswal.A and Shrivastva.B.K, studied on the strength of coal pillar based on numerical simulation technology[3]. Xie.YS and Zhao.YS researched the mechanism in top coal caving process using the discrete element method on Numerical simulation[4]. Skotniczny.P. studied three-dimensional numerical simulation of the mass exchange between longwall headings and goafs in the presence of methane drainage in a U-type ventilated longwall[5]. Coggan.J and Gao Fuqiang et al. used numerical simulation studied the effects of weak immediate roof lithology on the coal mine roadway stability[6]. Badr S.A, et al. researched yielding chain pillars in longwall mines based on Numerical modelling[7]. Li ZX and Sun GY. et al. conducted a research of the flow law of the air leakage within the partition coal pillars in the goaf's fully mechanized top coal caving face and the consumption and variation of the oxygen concentration with the help of numerical simulation[8]. Based on the fluid-solid coupling theory, Wang R. and Meng ZP. et al. simulated the deformation and failure law of the overlying strata in the process of exploiting Donghuantuo coal mine, and revealed the distribution law of the caving zone, water flowing fractured zone and curve subsidence zone of the coal seam roof with the help of FLAC3D numerical simulation calculation software[9]. Mohan, Sheorey PR and Kushwaha used FLAC3D in the strain-softening mode shown that estimation of pillar strength is possible using numerical modelling[10]. Based on the single seam mining and upper and lower seam mining conditions, Yin HY and Wei JC conducted a simulation with the help of FLAC numerical simulation calculation software under their different mining sequence[11]. Si XY and Wang WQ conducted a simulation research of the surrounding rock stress and the distribution law of deformation and plastic zones in the roadway along goaf when the coal pillar width is 2, 4, 6, 8, 12, 20 meters respectively with the help of FLAC3D numerical simulation calculation software[12]. Yang F and Wang LG conducted a simulation research of the abutment pressure distribution in the up and down dip deviation of the Sanjiaohe coal mining area, and the deformation of the roadway rock of driving along goaf of the coal pillar with different heights with the help of FLAC numerical simulation calculation software[13]. Li WF and Peng syd et al. used numerical model analyze the principle for yield pillar design and optimized the yield pillar design for bump control[14]. The scholars mentioned conducted their simulations successfully with the help of numerical simulation technology, and achieved some good results. FLAC3D, a short term of three dimensional fast Lagrangian analysis of continuum, can effectively simulate the failure or plastic flow mechanical characteristics of the geological materials when they reach their strength limits or yield limits. It is especially applicable for the analysis of progressive failure and deformation simulation[15-17]. Therefore, this paper conducted a simulation research of exploiting the working face's influence on the deformation and failure of the upper coal pillars on the condition that goaf exists with the help of FLAC3D.

2 General Situation of the Survey Region

The production capacity of a certain coal mine is 2 million t/a. Its current horizontal mining depth is about 500-700m, its coal thickness is 8m on average, and its inclination angle is 16°on average.The coal thickness of the working face is 2-6m, and the average thickness is 4m. The length of the seam strike is 1000-1200m, and the average length is 1100m. The average inclination width is 150m. The occurrence of the coal seam is steady, and the coals are mainly blocks. The streaks are black and dark brown with greasy luster, and the coal bed texture is rather simple. It has one overlying goaf whose average height is 6m, and the width of the coal pillars between goafs is 30m. The spacing between the working face and the overlying goaf is 10-17m, and the average spacing is 14m. The mining method is retreating longwall mining along the strike with comprehensive mechanization and full-seam mining. The fully caving coal mining method is applied to the management of the roof, and the hydraulic support is descended to the roof support and top-collapsing. The working face is equipped with hydraulic support, and full-anchor support is used to manage the roof of the working face.

3 Constitutive Relation of Numerical Simulation

The non-linearity of the rock strain-stress curve is caused by the micro-crack initiation and propagation derived from the damage, rather than by the plastic deformation. Therefore, it is applicable to describe micro-mechanical property of the rock with the constitutive relation of elastic damage mechanics[18-19]. Seen from the rock's micro-structure, rock is not a continuous medium for the existence of abundant joints and fractures; and the rock is also not a discrete medium for it belongs to crystalline material, which illustrate that rock is a nonlinear material from the structural essence of the rock. The nonlinear essence of the rock is also manifested in the rock deformation, evolution, the complexity and high degree of disorder of the spatial distribution of the fractures and pores within the rock and so on.

In the initial stage of the rock breaking, the micro unit is elastic, and its mechanical property can be fully presented by elastic modulus and Poisson's ratio. With the improvement of the element stress, the element begins to suffer damage when the stress state or strained state of the element meets the given damage threshold. The rock breaking is manifested in shearing and stretching when the rock is under different stress combination conditions. Generally speaking, Coulomb criterion can be used as a judgment of compression failure, and the maximum tensile-stress criterion can be used a judgment of tensile failure. The feature of taking the micro unit's damage under compression and shearing stress into consideration and taking the modified Mohr-Coulomb criterion(the tensile damage can also be considered) as the judgment of the elementary breaking is tensile breaking or shearing breaking can be considered at the same time, and its formula[20]is:

$$\sigma_1 - \frac{1+\sin\varphi}{1-\sin\varphi} \ge \sigma_c, (\sigma_3 \ge 0) \quad (1)$$

$$\sigma_3 \le -\sigma_t, (\sigma_3 < 0) \quad (2)$$

In this formula, σ_1, σ_3 is the maximum and minimum stress respectively, and the unit is Mpa; φ is internal friction angle, and the unit is °; σ_c represents the uni-axial compressive strength, and the unit Mpa; and σ_t represents the uni-axial tensile strength, and the unit is Mpa. When the shearing stress meets the Mohr-Coulomb damage threshold, the damage constitutive relation of the element under the stress state of uni-axial pull is

$$D = 0, \quad \varepsilon \ge \varepsilon_{t0} \quad (3)$$

$$D = 1 - \frac{f_{tr}}{E_0 \varepsilon}, (\varepsilon_{t0} > \varepsilon \ge \varepsilon_{tu}) \quad (4)$$

$$D = 1, \quad \varepsilon < \varepsilon_{tu} \quad (5)$$

In this formula, D represents the damage variable, D=0 corresponds with no damage state, D=1 corresponds with complete damage state, 0< D <1 corresponds with damages of different levels; f_{tr} represents the element residual strength, and its unit is Mpa; ε_{t0} represents the tensile strain corresponded with the elastic limit; E_0 represents the initial elastic modulus, and its unit is Mpa. When the shearing stress meets the Mohr-Coulomb damage threshold, the damage constitutive relation of the element under the compressive stress state of uni-axial pull is

$$D = 0, \quad \varepsilon < \varepsilon_{c0} \quad (6)$$

$$D = 1 - \frac{\lambda \varepsilon_{c0}}{\varepsilon}, (\varepsilon_{c0} \le \varepsilon) \quad (7)$$

In the above formula, ε_{c0} represents the maximum principal strain corresponded with the strain when the maximum principal stress reaches the uni-axial compressive strength; λ represents the elementary residual strength coefficient

4 Numeric Simulation Scheme

Coincident with the development of modern computer technology has been the application of numeric simulation in engineering practice. The numeric simulation software FLAC3D, a widely used software in geotechnical engineering, can conduct large strain simulation. Thanks to the fully dynamic motion equation, FLAC3D can simulate the physical unstable process without numerical obstacles. What's more, it is rapid in linear solution. Based on the above advantages, this paper simulated close distance coal seam mining's influence on coal pillars in goaf with the help of FLAC3D.

Based on the real geological condition of the research area, the numeric model is divided into 27 coal and rock seams, the coal thickness is 4 meters, the immediate roof is a 6 meter thick siltstone, the main roof is a 5 meter fine sandstone, and the immediate bottom is a 2 meter shale. The coal column is shown in Figure I.

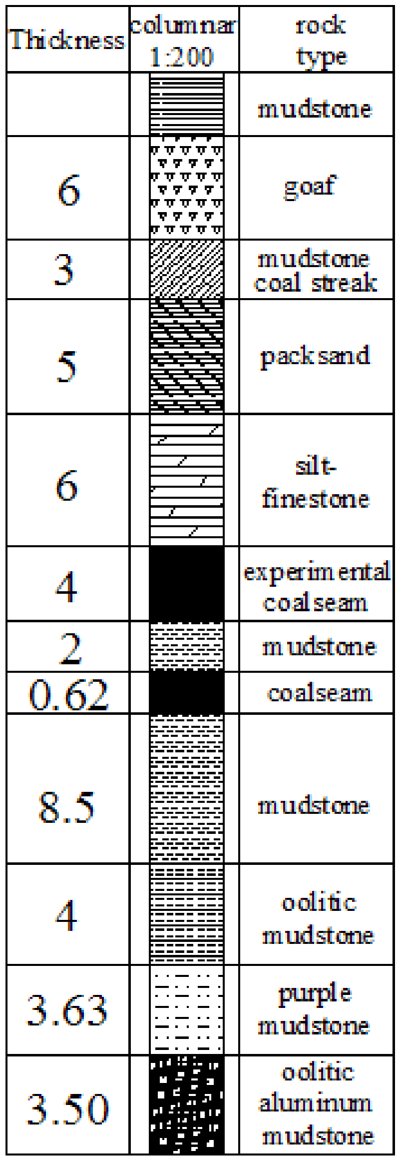


Figure 1. The experimental area working face coal rock of integrated histogram

4.1 Rock Breaking Criterion and the Selection of Physical and Mechanics Parameters

Coal is a elastoplastic material with high plasticity, which can be seen as a approximate ideal elastoplastic model. Therefore, based on the real condition, the breaking criterion chooses the Mohr-Coulomb criterion, namely $f_t = \sigma_3 - \sigma_t$, $f_s = (\sigma_1 - \sigma_3) - 2c\cos\varphi - (\sigma_1 + \sigma_3)\sin\varphi$. In the above formula, σ_1, σ_3 is the maximum and minimum stress respectively, and c, φ, σ_t represents the cohesion, internal friction angle and tensile strength of the coal-rock mass material respectively. When fs< 0, the coal will suffer shearing failure, and when ft> 0, the coal will suffer tensile failure. Gangue falling from the goaf can be seen as a loose medium. With the propelling of the working face, the spacing between the caving gangues are compressed gradually, and its strength is also improved gradually. Therefore, it can be approximately demonstrated as elastic support. The density ρ, elastic modulus E, and Poisson's ration v of the gangue also increase with time (t), which can be expressed with

$$\rho = 1600 + 800\left(1 - e^{-1.25t}\right)$$

$$E = 15 + 175\left(1 - e^{-12.5t}\right) \qquad [21]$$

$$\nu = 0.05 + 0.2\left(1 - e^{-1.25t}\right)$$

Table 1. Coal rock mechanical parameters

Name	Bulk modulus (GPa)	Shear modulus (GPa)	Cohesion (MPa)	Internal friction angle (°)	Tensile strength (MPa)	Density (kg/m3)
Coal	1.199	0.368	2	25	0.03	1400
Mud rock	1.613	1.26	3.5	34	0.8	2100
Pack sand	2.02	1.709	4.1	33	0.86	2400
Silt stone	5.914	4.622	5	38	1.03	2660

Of all the rock mass physical mechanical parameters needed in the numeric simulation in this paper, the main task of parameter modification is to modify the elasticity modulus of the coal-rock mass[22].The rock mass physical mechanical parameters are modified with the reference of the neighboring mines of the research area. Figure 1 listed the main physical mechanical parameters of the coal and rock strata.

4.2 The Determination of Model Boundary Condition

Based on the results of the above stress measurement report of neighboring mines, the vertical maximum principal stress of this area is far smaller than horizontal maximum principal stress, indicating that the horizontal crustal stress is consist of tectonic stress produced by tectonic action. Therefore, in order to simulate the initial geostress field which is more close to the reality, stress boundaries are exerted on both x-direction(vertical bearing) and y-direction(horizontal bearing) of the model. The counting stress and actual stress of the research area are made to have a fine fitting effect after many inverse calculations of the boundary stress. It is finally decided that the upper part of the model should be loaded with 12·25Mpa uniform load by means of equivalent load. The horizontal stress of x-direction and y-direction is approximately 21·7Mpa and 7·2MPa respectively. The bottom of the model is constrained by displacement constraint.

The size of the model is 150m×200m×150m with a 16°dip angle. It is divided into 325000 units, and it applies Mohr-Coulomb strength theory model. The boundary conditions of the model are set as follows: The left and right side boundary and the front and back side boundary are limited to displace horizontally; the horizontal displacement of x-direction and y-direction is limited to 0; the bottom is set to be a free boundary; the top is exerted with initial vertical stress and two sides are with horizontal stress. At first, the overlying goaf and coal pillars are formed, and when they reach a balance, the mining work begins by simulating the working face. The mining work goes down 4 meters each time, and the time step is 2000. The width of the working face is 100 meters, and it goes down from y=20m gradually to y=180m. The simulation mining work ends in the 160m.

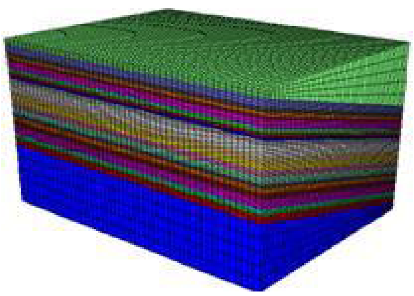


Figure 2. Simulation model

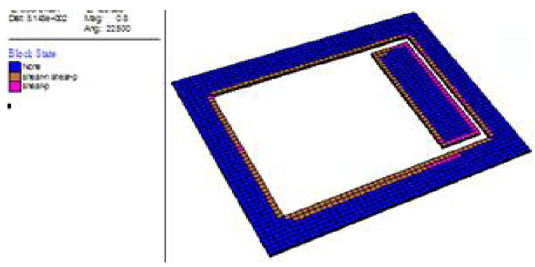
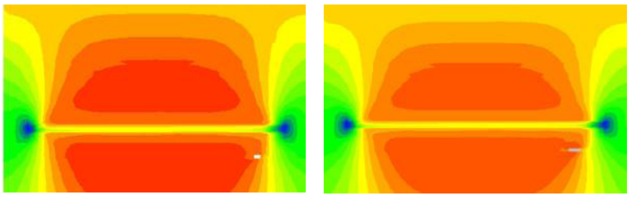


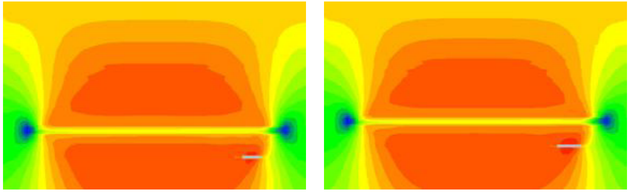
Figure 3. The overlying goaf coal pillar damage before working face excavation

5.Analysis of the Simulation Results

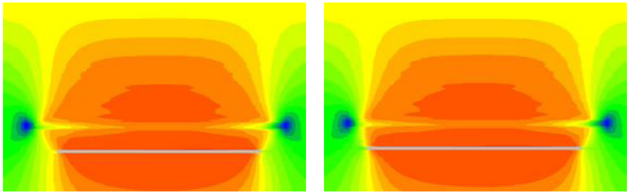
(1) Distribution Law of the Coal Pillar Stress



(a) 4m (b) 8m



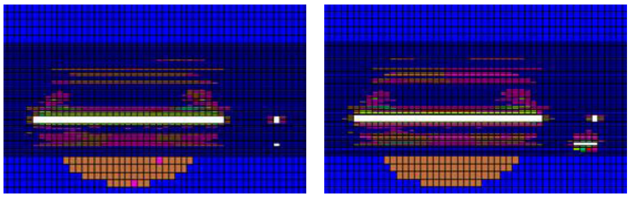
(c) 12m (d) 16m



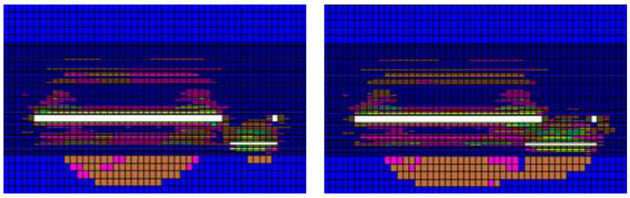
(e) 132m (f) 160m

Figure 4. The vertical stress changes when working face excavating

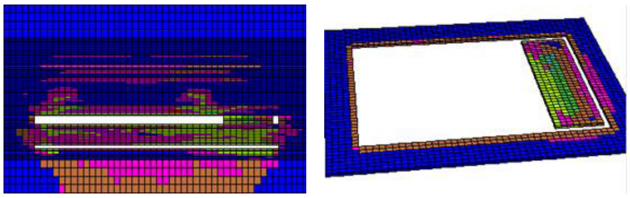
Figure 4 reveals the stress distribution law of the upper coal seam with the mining of the working face. According to the simulation results, with the propelling of the experimental working face, the goaf continues to expand, the hanging roof stays longer, the stress influence moves up gradually, and finally it expands to the coal pillar. During the mining of the working face, there is a short stress lifting accompanied by the propelling of the working face. The stress lifts more clearly when it is close to the working face, and then it goes down rapidly. During this period, the stress condition of the coal and rock mass changes obviously, and the rubbing phenomenon can be seen obviously, which will lead to serious breaking and increase its air permeability. Before the goaf is compacted, the size and the distressing effect of distressed zone of the roof surrounding rock are similar with the base plate. But the distressing effect of the base plate neighboring the extraction zone is better than that of the carrier plate. After the goaf is compacted, the stress of the area which is close to the carrier plate lifts a little quickly at the same time with the rapid improvement of the stress of the base plate distressed zone. The stress of the carrier plate neighboring the working face also lifts a little quickly, but the inner stress of the carrier plate which is distant from the protective layer remains a low stress condition within a period of time. That is to say, the distressing effects of the carrier plate and the base plate are both sufficient, but the stress distressing time of the carrier plate is longer than that of the base plate. Before the mining work, the coal pillars are located at the low stress zone, therefore the range of the vertical stress is between 0.8 and 1.5Mpa. During the propelling of the working face, the stress concentration first appears in the coal pillars, and after the propelling of the working face, stress reduction appears. The change of the stress will lead to coal pillars failure, which will further influence the sealing and supporting effects.



(a) 4m (b) 16m



(c) 32m (d) 48m



(e) 160m (f) 160m General Failure Condition

Figure 5. The plastic failure of coal pillar when working face excavating

During the propelling of the working face, the overlying layer of its goaf will bend, subside, crack or even cave. The distribution law of the plastic deformation of the overlying layer is a significant representation of the rock failure condition. It is also a principal way to research the failure mode of the overlying layer. According to Figure 5, when the mining work of the working face goes down into 8 meters, the vertical failure range of the roof rock layer is 4 meters, indicting the initial caving of the working face. The overlying rock layer suffers obvious dilatancy. When the mining work goes down into 12 meters, the range expands to 5 meters and it expands to 8 meters when the work goes down into 16 meters, and the coal pillars remain intact. When the mining work goes down into 32 meters, the coal pillars begin to be damaged, and it is completely damaged when the work goes down into 48 meters. From the Figure 5(f), we can find that the overall coal pillars have been damaged. Connected crack of the coal pillars will have a negative effect on the sealing effect, leading to the goaf gas's entrance to the neighboring tunnels. The upper and lower goafs are connected, the gas in the upper goaf will flow into the lower working face along with the migration pathway, leading to the over-ranging of the gas in the working face. Therefore, the numeric simulation has provided a reference of governing the gas of this mine.

6 Conclusion

1) Numeric simulation technology can simulate complicated geotechnical engineering problems in accordance with specific engineering conditions.

2) According to the vertical stress nephogram of the overlying layer of the working face, with the propelling of the working face, coal pillars first have stress concentration, and then have stress dropping. Change of the stress will lead to the failure of the coal pillars.

3) According to the distribution nephogram of the plastic zone in the process of mining the working face, when the mining work goes down into 32 meters, the coal pillars begin to be damaged, and it is completely damaged when the work goes down into 48 meters. Besides, the upper and lower working faces are connected, which will leading to the overrunning of the gas. While under the situation the problem needed to be solved.

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Anini iron ore deposit:mineralogy,wet magnetic separation enrichment and metallurgical use

R. Chaabia[*1], M. Bounouala[1], A. Benselhoub[2], M.Kharytonov[2]

[1] Mineral Processing and Environment Laboratory, Mining Department, Earth Sciences Faculty, Badji Mokhtar University, Annaba, 23000, Algeria.
Email: chaabiaraouf@gmail.com
[2] Ecology and Environment ProtectionDepartment, State Agrarian and Economic University, Dnipropetrovsk, Ukraine .
Email:benselhoub@yahoo.fr

Abstract
In recent decades, emphasis was on improvement the Algerian mining industry by creating new smelting complexes such as the metallurgical plant in Bellara (Jijel) with a productive capacity of 5 million tons per year to satisfy the increasing demand in steel. The present study was conducted at Anini's iron ore mine to develop its mineral resources in order to use it in the metallurgical industry (Arcelor-Mittal complex of Annaba Algeria).Representative samples were collected from the iron ore mine of Anini in northwestern of Setif. A series of chemical and mineralogical analysis was performed. However, the analysis by (XRD, SEM and XF) shows that this mineral is hematite iron type clay and siliceous gangue. Moreover the mean levels of Fe_2O_3, SiO_2 and Al_2O_3 are 50.52 %, 24.06% and 7.80%. The results obtained with the magnetic separation in wet process reveals significant content of iron ore with 65.11% of Fe_2O_3, 2.46% SiO_2