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Fluid-solid Coupling Analysis the Hydrogeological Parameters under the Influence of Confined Water Pressure and Mining Disturbance

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Abstract In order to analyze the variation of rock permeability under the influence of mining disturbances, water pressure and in-situ stress, a multi-physics coupling model were created by COMSOL V.4.2 a in this paper. By establishing the coupling relationship between permeability k and porosity φ, the model simulated rock stress, deformation and hydrogeological parameters characteristics. Results showed that: the porosity and permeability increase significantly in the roof and floor where there is plastic damage zone and decrease in both sides of the pillar where there is stress concentration zone; Permeability changes significantly when the permeability dramatic changes were considered.
Keywords fluid-solid coupling, porosity, permeability, plastic damage, COMSOL

Introduction

In recent years, mining activities were affected by the high underground stress, high hydraulic pressure and mining disturbances under the condition of deep mining. In fact, mutual restraint and mutual influence between these three factors, and groundwater seepage field and the deformation of the rock stress result in groundwater-solid coupling effect (Xu 1995). According to statistics, more than 90% rock slope failure were caused by groundwater penetration, and 60% mine accidents were caused by groundwater role (Li 2008). Generally, in order to prevent pressurized water inrush into the mine space, mining activities pre-leaving a certain thickness of the coal seam based on empirical formula. This empirical formula was summarized from the experience which only takes into account of the aquifer water pressure and rock tensile strength (Yin 2004). The rock deformation or the variation of penetration capability caused by actual mining disturbance was not considered. Thus, there are some defects in the specific mining activities. many underground engineering study and practice showed that fluid-solid coupling analysis is closer to the actual situation and is a more effective method in analysis.

In this paper, the flow-solid coupling was introduced in the tunnel excavation analysis for the underground rock stress field and groundwater seepage field, combination of rock elastic-plastic mechanics and fluid dynamics theory, the multi-physics coupling software COMSOL V.4.2 a which is based on the finite element numerical simulation method was applied. By defining the coupling relationship between permeability k and porosity φ, in the form of a custom function to handle fluid-structure interaction parameters which including permeability k, porosity φ and rock mass plastic damage criterion. Finally, a steady-state model was established to simulate rock stress, deformation and hydrogeological parameters variation characteristics in process of mining activities.

Mathematical model of the fluid-solid coupling

Mathematical model of mass rock flow-solid coupling should include the percolation model of the fluid and solid stress model.
Groundwater seepage field equation: Rock mass displacement equation:

$$\nabla\left[\frac{\rho k}{\mu}\nabla p\right]=0 \tag{1}$$

$$G\nabla^2\mu+\frac{G}{1-2v}\nabla\cdot(\nabla u)-\alpha\nabla p=0 \tag{2}$$

The formula: "K"is the absolute permeability of porous media (m^2); μ is the flud viscosity (Pa.s); and ρ is the fluid density(g/cm^3), "p" is the groundwater pressure (Pa); "G" is the shear modulus; "v" is the Poisson ratio of the medium, "α" is the Biot coefficient, its value depends on the compression performance of the material.and,"G=2E(1+v)","E"is the elastic modulus, u is the displacement in x-axis, the y-axis and z-axis direction.

There is a relationship between permeability k and porosity φ of the rock (Yang 2004, Gu 2005):

$$k=k_0(\frac{\phi}{\phi_0})^3 \tag{3}$$

k_0 and φ_0 are values of permeability and porosity when stress conditions is 0.In fact, the permeability coefficient value will increases abruptly after rock plastic damage occurs. Then, the relationship between permeability and porosity changes. Φ is the equivalent plastic strain(a sudden jump coefficient for the penetration. According to references(YUAN 2001)，General value φ=50. ie:

$$k=\xi k_0(\frac{\phi}{\phi_0})^3,(\varepsilon>0) \tag{4}$$

Simultaneously, the mathematical relationship between the stress state and rock porosity can be expressed as:

$$\phi=(\phi_0-\phi_r)\exp(\alpha_\phi\cdot\sigma_v)+\phi_r \tag{5}$$

φ_r is the minimum porosity value under high pressure stress state, α_φ is the coefficient for the stress factor. According to references (Yuan 2001),General value α_φ=50×10^{-8}Pa^{-1}, σ_v is the mean effective stress, σ_v=(σ_1+σ_2+σ_3)/3+αp.

The rock mass plastic damage criterion adopted amendments to the CM (mohr-coulomb) guidelines.These formulas are based on the expression of the Biot classical percolation theory, According to the study of practical problems, and definitions specific to the conditions for determining solution, Then it can computer simulation for the problem.

Case model analysis

Model description

According to fjg. 1, the physical problem defines the hydraulic conductivity thrust fault width is 20 m. The seam thickness is 5 m, the sandstone thickness is 320 m (ie z-axis direction) which above in the coal seam, Impermeable layer thickness is 30 m which under the coal seam, model thickness in the Y-axis direction is 500 m, the mining space width is 300 m.

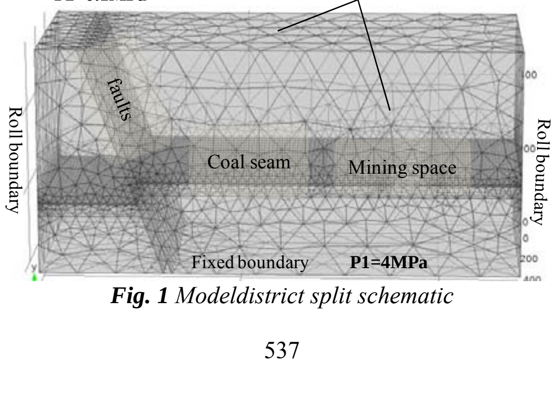

Fig. 1 *Modeldistrict split schematic*

Determine conditions for this problems

The water pressure is 4 MPa in the model of the underside, the underside of the model was set as a fixed boundary which displacement is 0, the model top surspace (including the upper part of the fault and mining space) was defined as the free boundary which directly connected with the atmosphere, the free boundary pressure is atmospheric pressure (= 0.1 MPa), the model on all sides of the surspace is defined as the roller boundary which only in the vertical displacements(z-axis direction),but the horizontal displacement is 0.

Stress and displacement

In this model, stress refers to the first principal stress of the vertical, and displacement was total displacement, define the tensile stress is the "+" and compressive stress is"-", and downward displacement of the "+" or up to"-".

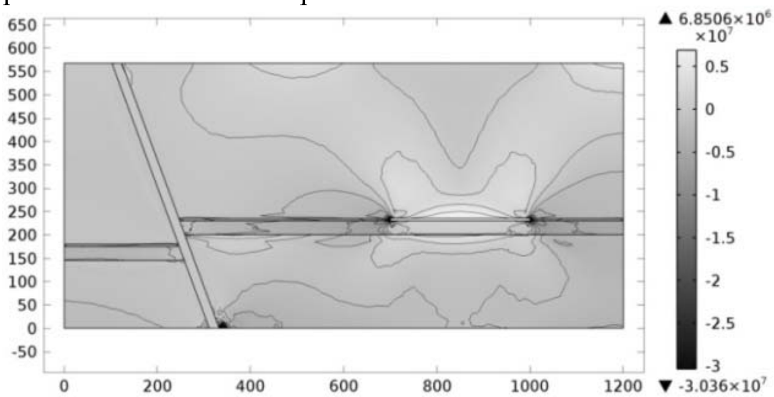

Fig. 2 *Stress contours（Pa）*

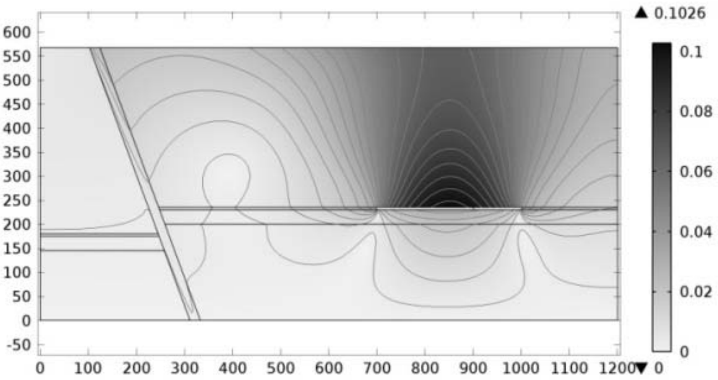

Fig. 3 *Displacement contours（m）*

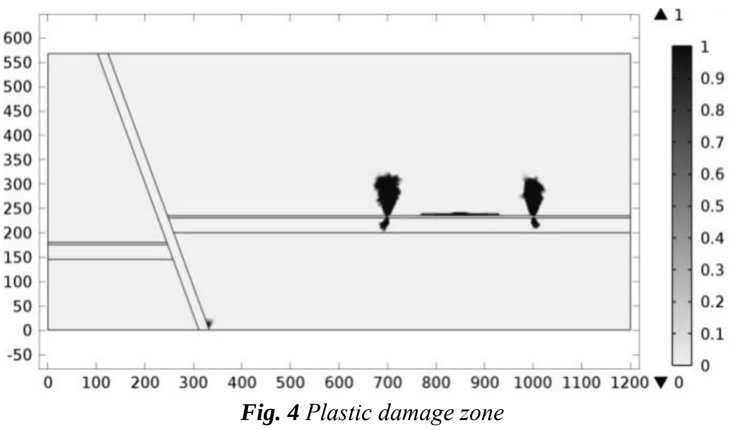

Fig. 4 *Plastic damage zone*

According to fig. 2-4, the stress concentration zone occurred in both sides of the mining space, and the maximum compressive stress is -3.306×10^{7} Pa. The original compressive stress state transfer into tensile stress state within a certain range of the top and bottom of mining space, the maximum tensile stress up to $+6.85\times10^{6}$ Pa; At the same time, the subsidence displacement is +0.1026 m on the top of mining space. the plastic damage occurred within 16 m range outside the coal space where there is stress concentration zone, and the plastic damage zone to bottom depth of about 20 m;

The porosity and permeability parameters variation

In order to easily analysis and comparison the medium porosity and permeability changes in influence of mining disturbance and water pressure, the entire model were given the same initial value, porosity φ_0=0.1, permeability $k_0=1\times10^{-14}$ m^2 .

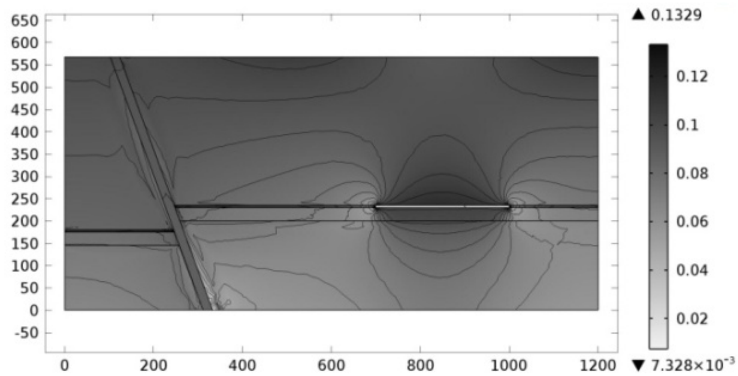

Fig. 5 *Porosity φ contours*

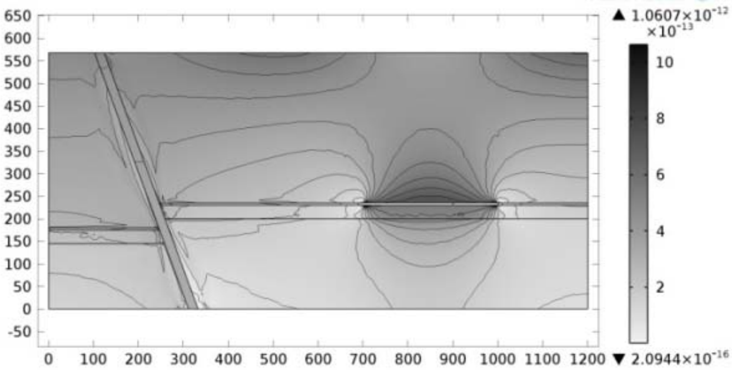

Fig. 6 *Permeability k contours (m^2,not consider plastic damage impact)*

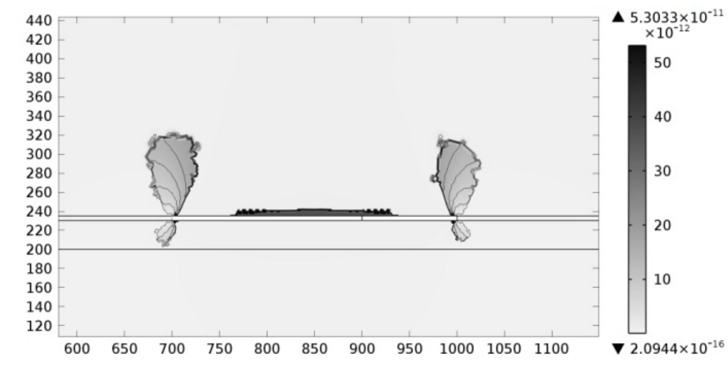

Fig.7 *Permeability k contours (m^2, consider plastic damage impact)*

According to fig.5-6, the plastic damage regional impact was not considered, the porosity φ and permeability k increased significantly in the roof and floor of the mining space under the influence of water pressure and mining disturbance, and the maximum φ, k values respectively increased to 0.133 and 1.06×10^{-12} m^2 .However, the porosity φ and permeability k decreased in both sides of the coal space, the Minimum φ, values were $7.3\times10^{-3}$and 2.09×10^{-16} m^2 According to fig. 7, Perrmeability changes significantly when considering the plastic damage regional impact, the maximum k values increased to 5.3×10^{-11} m^2.

Conclusions

A fluid-solid coupling model was established based on COMSOL V.4.2 a. Model results showed that: under the influence of water pressure and mining disturbance, the plastic damage occurred within 16 m range outside the coal face where there were stress concentration zone and the plastic zone to bottom depth of about 20 m; The porosity and permeability increased significantly in the roof and floor of the mining space where were plastic damage zone and decreased in both sides of the pillar where there was stress concentration zone; Permeability increased significantly when considering the permeability dramatic changes. With expanding the scope of plastic failure, the permeability was significantly increased where is the high possibility of water inrush occurs. This paper provided some reasonable and scientific basis for mining activities safety in situation of high underground stress, high hydraulic pressure and mining disturbances.

Acknowledgements

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