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Research Article

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Study of Stress Distribution Characteristics of Borehole Before and After reaming based on FLAC3D

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Abstract Borehole formation technology for coal seams has been a difficult problem to be solved for coal mine gas extraction. This paper takes the underground borehole of Xinjing Mine as the research object. Using FLAC3D technology to simulate and analyze the stress distribution characteristics around the borehole before and after the borehole reaming. The regulation of stress distribution before and after reaming of drilling along and through the seam and the influence range of effective pressure relief of boreholes were analyzed. The results show that with the construction of the borehole, the stresses around the borehole are released and an obvious stress zone is formed. After the borehole reaming, the effective pressure relief range of the down-hole can be expanded from 0.8m to 4m, and the effective pressure relief range of the through borehole can be expanded from 0.6m to 3.8m, which effectively improves the extraction effect of the coal seam.

Keywords pressure relief radius; numerical simulation; surrounding rock stress distribution; FLAC3D

1. Introduction

As one of the important means to guarantee the gas management in coal mines, he drilling hole formation technology has great significance to the safe production underground and the safety of life and property of personnel. For the stress distribution of the borehole before and after the underground borehole formation, related scholars have conducted a lot of researches and achieved certain effectiveness. Wu Xiaohua [1] studied the stress distribution around the borehole before and after the hydraulic cuttings, and considered that the hydraulic cuttings destroyed the stress distribution state of the coal body around the borehole, increased the secondary development of fractures around the borehole, and improved the gas extraction effect. Zheng Chunshan [2] et al. carried out experiments on stress and displacement changes around the borehole before and after the construction of the down-seam borehole, and the experimental results showed that the coal body around the borehole went through four stages, namely, original stress, stress increase to peak, stress decrease, and residual stress, in order during the construction of the borehole. Han Lei [3] et al. measured the on-site borehole stress of coal pillar mining stress in the working face guard lane, and established numerical calculation models based on Moore-Coulomb (MC) and strain-softening (SS) intrinsic model, respectively, to finely study the spatial distribution and evolution law of coal pillar mining stress in the comprehensive working face. Ruimin Wei [4] believes that the factors determining the deformation of the borehole are the stress and strength to which the borehole is subjected, and when the coal seam strength is certain, the deformation of the borehole is only related to the stress to which it is subjected. A lot of research has been conducted by previous authors on the stress distribution before and after borehole construction, but there is less research on the secondary distribution of stress around the borehole and the effective pressure relief range before and after borehole reaming. In this paper, we use FLAC3D numerical simulation software to simulate the stress changes around unexpanded and expanded down-hole and through-hole boreholes, and analyze the secondary distribution of stress and effective pressure relief range around boreholes before and after cavitation. 15124 low and 15124 back-hole boreholes are constructed, and the stress distribution around boreholes before and after expansion is investigated, based on which, the effective pressure relief range of boreholes is obtained. Thus, providing some help to on-site gas extraction.

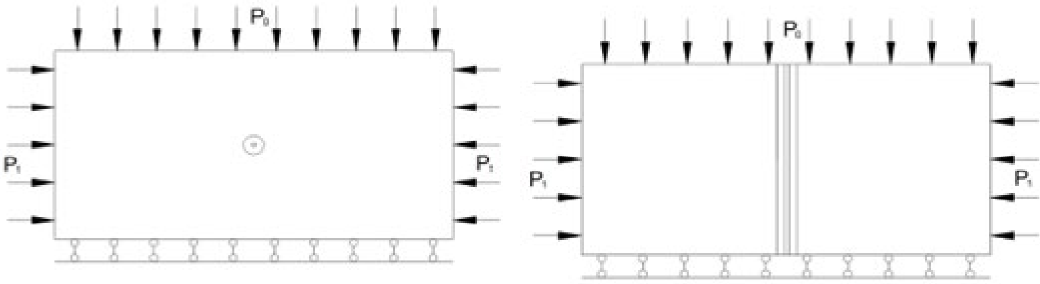
2. Geological overview

Numerical simulation examines the coal seam as No. 15 coal seam of Xinjing Group. No. 15 coal seam is mainly located in the lower section of Taiyuan Group, under K2 limestone. In the southwest of the well field, the thickening of the No.15 coal seam gangue layer appears as a bifurcation phenomenon, and is divided into No.15 coal seam and No.15 lower coal seam. No.15 lower coal seam is a more stable and mostly recoverable coal seam, except for individual point tip extinction, and merged with No.15 coal seam into one layer, thickness 0.60~3.85m, average 2.04m; No.15 coal seam (including the merged layer) is a stable and recoverable coal seam in the whole well field, thickness 3.80~8.85m, average 6.29m. The direct top and bottom plates of the coal seam are gray-black mudstone with small porosity and good sealing ability, and the top and bottom plates of the coal seam are dense and complete, with poor gas escape conditions, which is conducive to gas storage.

3 Numerical modeling

3.1 Borehole mechanics model division

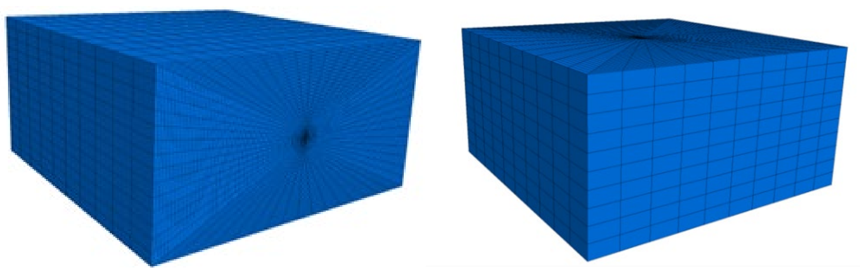
In the process of numerical modeling using FLAC3D, it is assumed that the coal body is an isotropic homogeneous medium conforming to the Moore-Coulomb elastic plastic model, and the borehole section of the coal seam is used as the study object, and the time-dependent physical quantities are not considered in the calculation. On this basis, a coal body model with dimensions of 10m*10m*5m is established, and the boundary deformation in the positive and negative directions of X-axis, positive and negative directions of Y-axis, and negative direction of Z-axis is set to 0, i.e., it is set as a fixed boundary, and the positive direction of Z-axis is set as a free boundary. Because the coal rock layer in the actual working condition is in the gravitational environment, the gravitational acceleration g in the negative direction of Z-axis is taken as 10m/s2 . The load along the negative direction of Z-axis is applied to the upper part of the model as P0 = 17.5MPa, and the upper load is determined according to the formula P =0ρ gh, where P0 is the load,ρ is the density of the rock layer in the upper part of the model as 2500 kg/m3 , g is the gravitational acceleration as 10m/s2 , and h is the burial depth as 700m. A lateral pressure coefficient of 1.2 is applied to the left and right sides of the model, i.e., P1 = 21 MPa lateral pressure is used to simulate the lateral stress of the coal body around the model. The simulated borehole diameter is 100mm to expand the range of stress distribution and decompression damage around the 500mm borehole, and the excavation is carried out in the mode of down-seam borehole and through-seam borehole respectively, and the mechanical models of the two modes are shown in Figure 1, and the mesh division is shown in Figure 2.



(a) Mechanical model of down-layer borehole (b) Mechanical model of through-layer

Figure 1: Mechanical model

The details of the model meshing are shown in Figure 2.



(a) Mesh delineation of down-layer borehole model (b) Mesh delineation of through layer borehole model

Figure 2: Model meshing

3.2 Model parameters Settings

Generally speaking, most of the rock seams can be regarded as elastic-plastic medium, which behaves as linear elastic at certain stress level and plastic beyond this limit. For materials like rocks, they have obvious volume deformation during plastic deformation, so the effect of volume stress must be taken into account, so the calculation of coal seams adopts the elastic-plastic intrinsic model, and the yield criterion adopts the Mohr-Coulomb criterion. The rock mechanical parameters involved in the calculation of the Mohr-Coulomb plasticity model include: density, bulk modulus, shear modulus, cohesion, internal friction angle, etc. The physical and mechanical parameters of the modeled coal seam are shown in Table **1.**

Table 1: Physical parameters of model materials

Name	Density (kg/m^3)	Bulk modulus (GPa)	Shear modulus (GPa)	Cohesive force (MPa)	Angle of internal friction (°)	Thickness (m)
Coal seam	1280	10.5	6.2	1	20	5

4. Analysis of numerical simulation results before and after drilling and reaming

4.1 Analysis of numerical simulation results

The initial stress state distribution of the coal rock layer before the excavation borehole by step-by-step successive excavation of the model is shown in Figure 3.

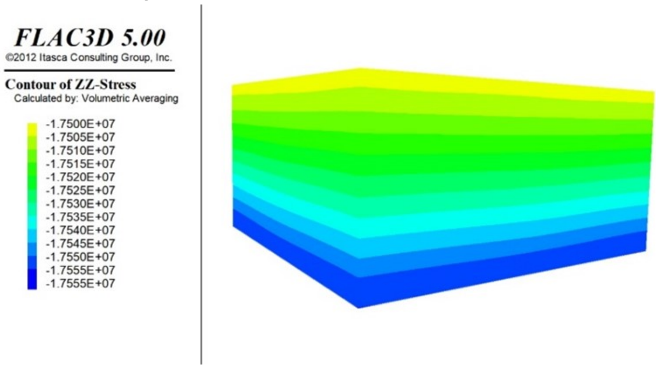
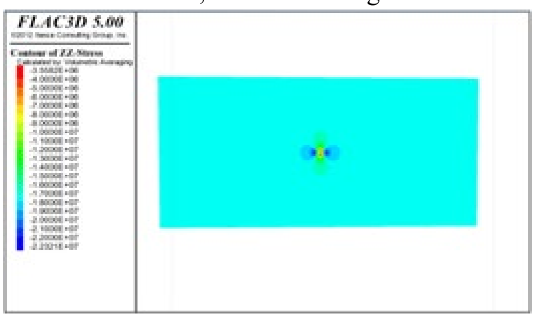


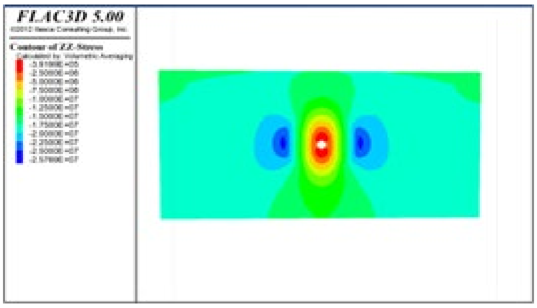
Figure 3 Initial ground stress distribution cloud map

4.2 Analysis of simulation results of cis-layer borehole

By simulating the reaming process of the cis-layer borehole, the stress distribution clouds for a borehole diameter of 100 mm and reaming to 500 mm were obtained, as shown in Figure 4.



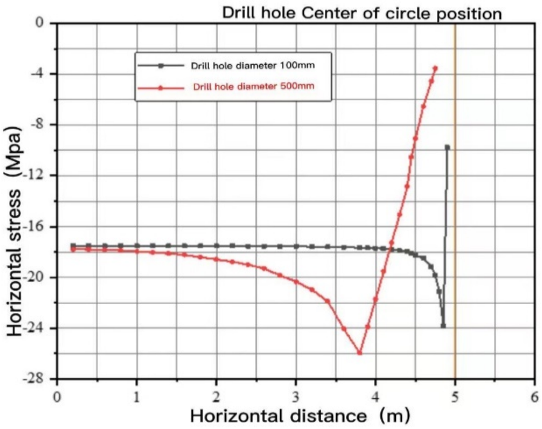
(a)Stress distribution cloud at 100mm borehole diameter



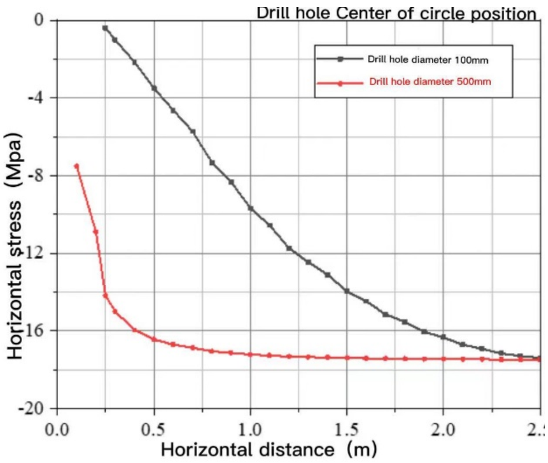
(b) Stress distribution cloud at 500mm borehole diameter

Figure 4: Cloud map of the stress distribution of the coal body on both sides of the drill hole

As can be seen from Figure 4, the vertical stress distribution cloud shows a butterfly-shaped symmetric distribution, and the stress distribution area can be divided into two categories, i.e., stress concentration area and stress reduction area. After the borehole is excavated, the stress relief area appears around the borehole, and the stress concentration area appears on both sides of the borehole due to the concentration of the ground stress generated by the overlying coal rock body. When the diameter of the borehole is 100mm, the stress relief area is small and the stress concentration area is close to both sides of the borehole, but when the diameter of the expanded borehole reaches 500mm, the stress relief area expands significantly and the stress concentration area moves to both sides. In order to more intuitively reflect the stress distribution on both sides of the cis-layer borehole, the vertical stress data of the measurement points in the horizontal line on the left side of the borehole center and the upper half of the vertical line on the center of the borehole were retrieved through the built-in measurement point monitoring command in FLAC3D model, because the stress distribution showed symmetric distribution, and the vertical stress distribution curve on the left side of the borehole and the vertical stress curve on the upper part of the borehole were plotted, as shown in Figure 5.



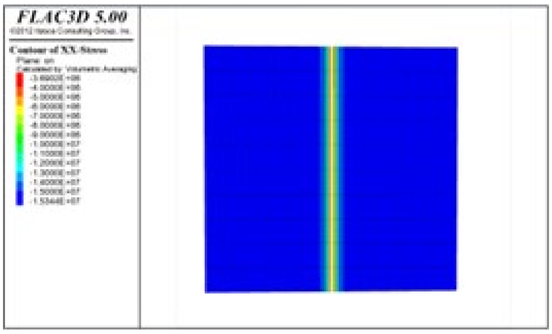
(a) Vertical stress of the horizontal monitoring line



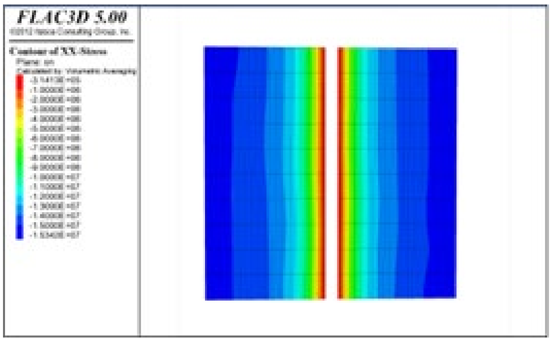
(b) Vertical stress of the vertical monitoring line

Figure 5: Vertical stress curve of the coal body on the left side of the down-seam drill hole

From Figure 5(a), it can be seen that because the original stress balance of the coal body around the borehole is broken, the original structure of the coal body is damaged, and there are side stresses on the left and right sides of the borehole, so there is a certain area of stress reduction area on the left and right sides of the borehole, and due to the existence of ground stress, the stress concentration area acts on the outside of the stress reduction area, and from the analysis of the data in the figure, it can be seen that when the diameter of the borehole is 100mm, the stress relief The maximum stress concentration point is 0.15m to the left of the drill hole center, and the coal body in the area of 0.15m-3.8m to the left of the drill hole center is gradually increasing due to the influence of ground stress, and the maximum stress concentration factor is 1.36. When the diameter of the drill hole is expanded to 500mm, the stress relief area to the left of the drill hole center increases to 1.2 Therefore, after the borehole is enlarged, the pressure relief range increases 2.4 times and the stress concentration factor increases 1.08 times. From Fig. 5(b), it can be seen that in the vertical direction of the borehole, the unloading state appears at the top of the borehole. When the diameter of the borehole is 100mm, the minimum vertical stress is 7.52MPa and the maximum unloading range is 0.8m; when the diameter of the borehole is reamed to 500mm, the minimum vertical stress is 0.4MPa and the maximum unloading range is 2.4m. Compared with the stress of the coal body before reaming, the unloading range Compared with the stress of the coal body before reaming, the pressure relief range is increased by 3 times, and the pressure is completely relieved in the upper part of the hole.



（a）Stress distribution cloud at 100mm borehole diameter



(b) Stress distribution cloud at 500mm borehole diameter

Figure 6: Top view of horizontal stress profile of coal body around the cis-borehole

The horizontal stress unloading indicates that the coal fissures around the borehole are developed, which is favorable for gas extraction, therefore, the horizontal stress top view profile of the model was retrieved, as shown in Figure 6, according to which it can be seen that the coal stress around the borehole starts to unload on the left and right sides of the borehole as the borehole is excavated, and after the borehole is expanded, the coal unloading range around the borehole increases obviously, in order to show the coal unloading range around the borehole more clearly, the In order to show the unloading range of coal around the borehole more clearly, the horizontal stress data of the left part of the borehole in the horizontal direction was retrieved, and Figure 7 was drawn.

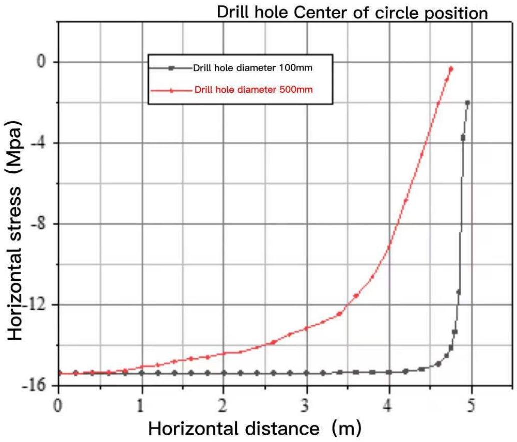
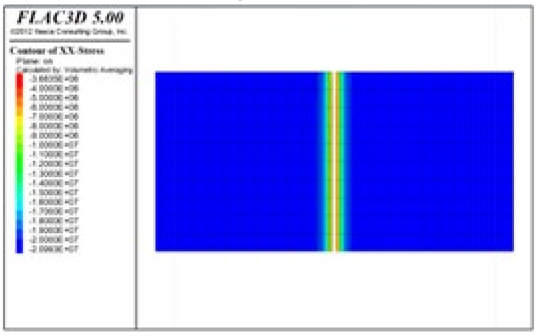


Figure 7: Horizontal stress curve of the coal body on the left side of the down-seam drill hole

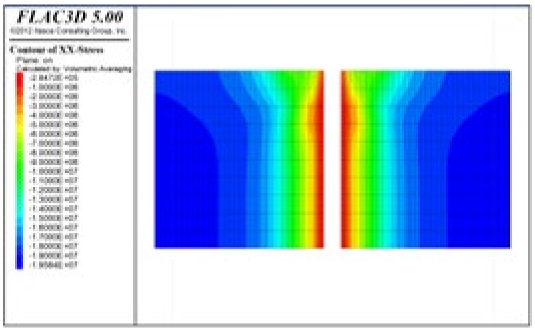
According to Fig. 7, the pressure relief range is 4.2-5m and the radius of pressure relief is 0.8m when the diameter of drill hole is 100mm in horizontal direction, and the pressure relief range is increased to 1m-5m and the radius of pressure relief is 4m after the diameter of drill hole is expanded to 500mm. after the diameter of drill hole is expanded, the pressure relief range is increased by 80%, the pressure relief range in horizontal direction is increased, the fissure around the drill hole is developed, and the gas extraction capacity is improved. The fracture development around the borehole improves the gas extraction capacity. The data analysis shows that after reaming the borehole, according to the vertical stress distribution data of the coal body on the left side of the borehole, the pressure relief range in the horizontal direction is increased by 2.4 times, and the pressure relief range in the vertical direction is increased by 3 times; in the horizontal stress distribution on the left side of the borehole, the pressure relief radius increases from 0.8m to 4m after reaming, and the pressure relief radius increases by 5 times; it shows that after reaming, the coal body around the borehole is well relieved, and through The negative pressure gas extraction of the borehole makes the gas flow better in the fissures generated in the damaged coal body near the borehole, and improves the gas extraction rate.

3.3 Analysis of simulation results of drilling through layers

By simulating the reaming process of the penetration borehole, the stress profile distribution clouds for a borehole diameter of 100 mm and reaming to 500 mm are obtained, as shown in Figure 8. As can be seen from Figure 8, after the excavation of the borehole through the layer, a pressure relief area is formed around the hole wall, and the pressure relief area shows symmetric distribution. In order to more intuitively show the pressure relief range, a horizontal measuring line is set in the middle of the model to monitor the horizontal stress, and since the stress basically shows symmetric distribution, the horizontal measuring line only retrieves the stress data of the left half of the borehole, and the stress distribution curve in Figure 9 is drawn based on the data.



(a) Stress distribution cloud at 100mm borehole diameter



(b)Stress distribution cloud at 500mm borehole diameter

Figure 8: Horizontal stress distribution profile cloud of coal body in through-seam borehole

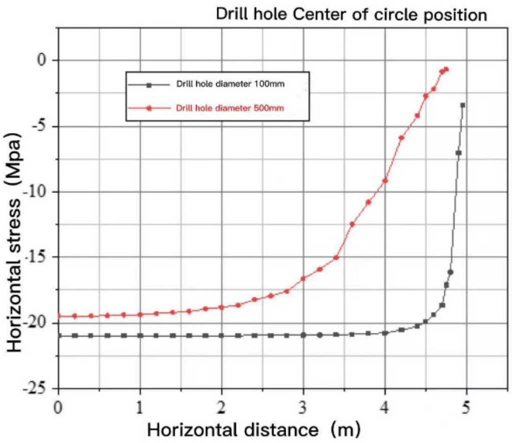


Figure 9: Horizontal stress curve of the coal body on the left side of the penetration hole

As can be seen from Figure 9, after the excavation of the coal seam penetration borehole, the original stress balance of the coal body around the borehole is broken and the structure of the coal body is damaged, and the coal body around the borehole is gradually decompressed, and with the expansion of the borehole diameter, the decompression range of the coal body around the borehole is also increasing. From Figure 2-70, it can be seen that when the diameter of the borehole is 100mm, the unloading state occurs within 0.6m to the left of the borehole center, and the minimum horizontal pressure is 3.33MPa, and the stress factor is 0.16 relative to the horizontal stress of the original rock; when the diameter of the borehole is expanded to 500mm, the unloading range of the coal body around the borehole is expanded to 3.8m to the left of the borehole center, and the minimum horizontal stress is 0.64 After the diameter of the borehole is expanded, the pressure relief area around the borehole is expanded from 0.6m to 3.8m, which is 6.3 times larger, and the minimum horizontal stress is reduced from 3.33MPa to 0.64MPa, which is 80% lower. In summary, after the expansion of the penetration hole, the pressure relief range is increased, the pressure relief state is good, the coal body around the hole is damaged, and a large number of fissures are produced in the process of pressure relief, which makes the gas flow channel be opened, which improves the gas extraction effect and increases the influence range of gas extraction.

5. Conclusion

The numerical simulation results show that after the reaming of the down-seam borehole, the pressure relief range is relatively small on the left side of the borehole, and the pressure relief range is larger on the upper part of the borehole, and the pressure relief range can be extended to the top plate of the coal seam after reaming; on the left side of the borehole, the pressure relief radius is 2.8m after expanding the borehole diameter, and the fissures are more developed. After expanding the hole diameter on the left side of the borehole, the unloading radius is 2.8m, and the fissures are more developed, which can effectively improve the gas extraction efficiency of the borehole.

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