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Effect of combined mining with steeply dipping seam on stability of surrounding rock of inclined shaft in weakly cemented stratum

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Abstract. The combined mining with steeply dipping seam in weakly cemented stratum causes the original stress in the upper strata to be nonlinearly superimposed on the mining disturbance stress. Although the surrounding rock of the main inclined shaft is outside the designed " displacement angle ", with the extension of the depth of the wellbore and the increase of the volume of the mining, the regional deformation still has an important impact on the stability of the surrounding rock of the wellbore. In view of this, this study established a three-dimensional geological model of the mining area and numerically analyzed the influence of the combined mining of No. 3 coal and No. 9 coal with steeply dipping seam on the surrounding rock stress and deformation of the main inclined shaft. The research shows that the No. 3 coal mining has little influence on the surrounding rock of the main inclined shaft. The distribution of the stress distribution in the main inclined shaft after the No. 3 coal and No. 9 coal mining is redistributed. The stratum stress of the stratum elevation +800~+900m is significantly affected by the mining disturbance, but it has little effect on the stress distribution of the surrounding rock of the main inclined shaft arching stage strata. No. 3 coal seam mining and No. 9 coal seam mining have a greater impact on the position of the main inclined shaft surrounding rock elevation of +950 m, but the overall settlement is still small (maximum 8 mm). Therefore, the influence of underground combined mining disturbance has little effect on the arching stage strata of the main inclined shaft, and the surrounding rock of the main inclined shaft arching stage strata is safe and stable.

1. Introduction

Mine wellbore is the key to deep mining and is a safe passage into deep mining. As the wellbore developed by the mines become deeper and deeper, the construction becomes more and more difficult. For the deep mineral resources mining, the strata rock mass is in the complex geological environment of "three high and one disturbance" (high ground stress, high ground temperature, high karst water and strong mining disturbance) [1, 2]. Due to the differences in the distribution characteristics of the rock formations and multi-phase geologic bodies and the complex service environment, the service wellbore is characterized by multiple layers, nonlinearity and irreversibility, which seriously affects the safe operation of the mine [3]. Therefore, with the increase of mining depth, the increase of energy extraction and the demand of national strategy, the stability of the borehole wall is an important issue that needs to be studied in depth and needs in-depth study. At the same time, it is also one of the important basic research works to ensure mine construction and normal production [4].

The Ordos coalfield stratum is dominated by the less mature cretaceous system and the Jurassic system, with weak cementation, low strength, water-rich, and disturbance sensitivity [5-8]. In the weakly cemented stratum, combined mining with steeply dipping seam is carried out, and the influence of underground mining disturbance stress on the occurrence of wellbore strata is more significant. According to the existing research results, the ground stress is the fundamental force that causes the deformation and failure of the surrounding rock, and plays an important role in controlling the deformation and damage of the surrounding rock [9]. Among them, tectonic stress, rock mass temperature stress, vertical additional stress of the borehole wall and regional disturbance stress caused by underground mining will cause deformation and damage of the surrounding rock of the wellbore; the magnitude and direction of tectonic stress have an important impact on the formation and stability of the movable block of the surrounding rock [10-12]; The additional force of the borehole wall is mainly due to the large-scale settlement of the stratum caused by the mining, and the relative slip resistance between the surrounding rock of the wellbore and the borehole wall. When an internal force generated by the additional force is greater than the structural strength, the elastic shearing force and the plastic shearing force may cause local damage to the well wall. And with the extension of the service life of the wellbore and the expansion of the scale of underground mining, the regional horizontal movement deformation range will be expanded, and the deformation of the surrounding rock of the wellbore will be further increased [13,14]; underground mining and mining drainage, and the roof falling and sinking in the mining area cause not only vertical settlement of the surrounding rock of the wellbore, but a small amount of horizontal movement. Specifically, the well wall will bend toward the mining area, and the well wall will be subjected to bending and bending [15]. Therefore, under the condition of combined mining with steeply dipping seam in weakly cemented stratum, the complex stress field, nonlinear large deformation, strong rheological behavior and dynamic response of the surrounding rock of the wellbore make it difficult to ensure the stability of the surrounding rock of the wellbore.

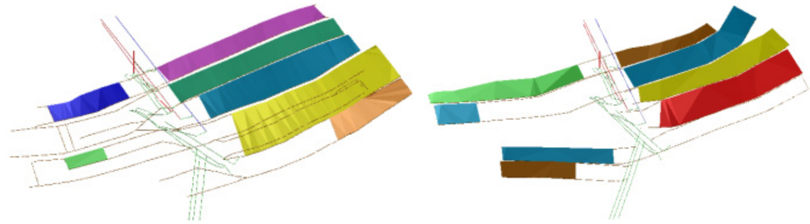
In order to study the effect of composite mining with steeply dipping seam on the stability of surrounding rock in the weakly cemented stratum, this paper establishes a three-dimensional geological model of the mining area by analyzing the geological data of the mining area and collating and generalizing the mining historical data. Meanwhile, the finite element software is imported to perform three-dimensional nonlinear numerical inversion calculation. According to the inversion calculation results, the influence degree of No. 3 coal mining and the combined mining of No. 3 coal and No. 9 coal on the stress and deformation of the surrounding rock in the main inclined shaft is analyzed. In addition, the state and evolution characteristics of the stress field and displacement field of the stratum of the main inclined shaft arching stage strata are analyzed.

2. The establishment and scheme of numerical analysis model

This paper takes the stratum of the main inclined shaft of No. 1 mine of Shanghai Temple in Ordos as the basic geological conditions. From the top to the bottom, the strata are the main strata such as the Quaternary system, Neogene system, Cretaceous system, Jurassic system and Triassic system. The overall structure of the mine field is a single slope inclined to the east, and the inclination angle of the formation is 5° to 40°; the dip angle of No. 3 coal seam is 37.47~44.56°, and the average thickness is 5.09m; No. 9 coal seam dip angle is 24.91 ~ 39.50 °, the average thickness is 4.83m. The main inclined shaft has a dip angle of 22°, an oblique length of 1040 m, a net width of the wellbore of 3.5 m and a net sectional area of 10.41 m2. The main inclined shaft has a slope length of about 300m and is supported by concrete arching. The bedrock section is supported by anchor spray.

2.1. The establishment of 3D geological model

According to the well field data, geological section map, the contour line of No. 3 coal and No. 9 coal seam floor, the comparison map of the upper and lower wells and the mining plan, etc.，a three-dimensional geological model corresponding to the mine shaft wellbore, inclined wellbore, part of the tunnel at the bottom of the well and the extracted area was established by Digital mining Surpac software. The main process of model establishment: the surface model of the lower surface is made according to the floor contour of the coal seam; then the contour line of the coal seam roof is obtained according to the thick line diagram of the coal seam, and the model of the upper surface is formed; the triangulation is connected according to the boundary, and finally a solid model of the coal seam is formed. Figure 1 is a spatial position diagram of the wellbore, roadway and mining face. Figure 2 shows the overall 3D geological model of the coal mine.



a）NO.3 coal mining face b）NO.9 coal mining face

Figure 1. Position map of shaft, roadway and mining face

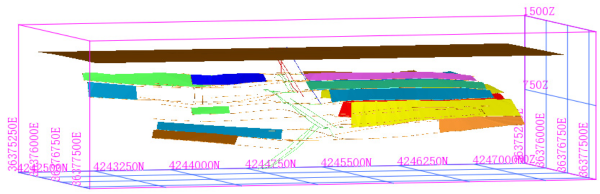


Figure 2. Coal mine overall 3D geological model

2.2. The establishment of 3D numerical calculation model

According to the design data of coal mines, the time-space sequence of mining area mining and the scope of mining impact, a three-dimensional numerical calculation model of the whole mine is established. Figure 3 is the computational model diagrams of the three-dimensional numerical values of the overall mine.

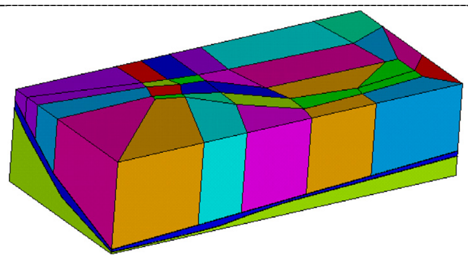


Figure 3. Three-dimensional numerical calculation model diagram of the whole mine

The model has a width of 2,072.79 m in the x direction, 4,634.56 m in the y direction, and 1,240 m in the z direction. A total of 1631012 units and 283485 nodes are divided. The side of the model is limited to horizontal movement, the bottom surface is limited to vertical movement, and the upper part is free surface. The Moor Coulomb model is used to solve the problem, and the stress gradual release method is used to simulate the No. 3 coal mining and No. 9 coal mining process.

2.3. The determination of numerical calculation parameters

According to the on-site drilling histogram, the initial data, the mechanical properties of the stratum rock and the indoor physical and mechanical tests, the physical and mechanical parameters of the numerical simulation are determined, as shown in Table 1.

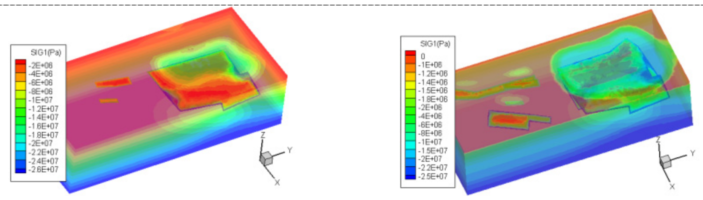
Table 1 Mechanical parameters of rock

Lithology	**E/GPa**	**ρ(kg・m^{-3})**	**C/MPa**	**ϕ /°**	**σ t/MPa**
Quaternary sand layer	1.18	2260	1.13	34.1	0.56
Quaternary gravel layer	1.09	2320	1.32	36.3	0.9
Neogene sand layer	1.23	2230	1.03	34.3	0.75
Neogene clay layer	0.84	2330	1.07	33.7	0.53
Cretaceous fine sandstone	8.51	2430	2.8	37.3	1.52
Cretaceous argillaceous sandstone	5.43	2410	2.21	35.3	1.49
Jurassic coarse sandstone	7.67	2620	2.5	37.2	1.24
Jurassic medium sandstone	11.2	2520	2.60	37.1	1.25

3. Analysis of numerical results

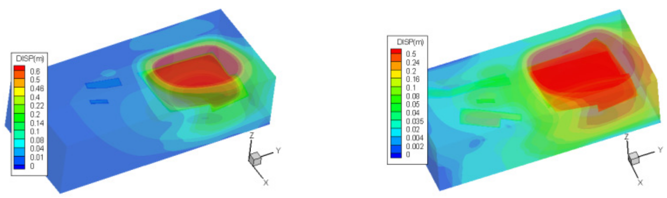
3.1. Influence of underground mining on stress and deformation characteristics of upper strata

Figure 4 is the maximum principal stress distribution cloud map of the strata in the area after coal seam mining. Figure 5 is the total displacement distribution cloud map of the stratum in the area after coal seam mining.



a）NO.3 coal mining b）NO.3 and NO.9 coal mining

Figure 4.Maximum principal stress cloud map of the stratum after coal seam mining



a）NO.3 coal mining b）NO.3 and NO.9 coal mining

Figure 5.Total displacement cloud map of the stratum after coal seam mining

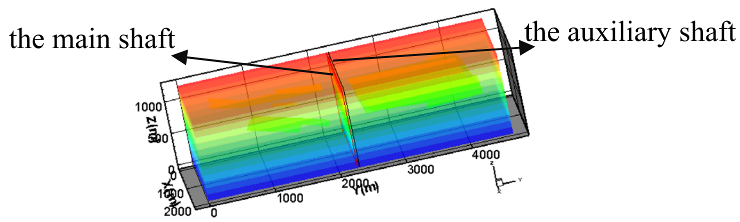


Figure 6. Location map of the existing strata of the main and auxiliary shafts

It can be seen from Fig. 4 that the stratum stresses of the No. 3 coal and No. 9 coal are nonlinearly superimposed, and the maximum principal stress in the stratum is redistributed, which appears in the stress concentration area of the surrounding rock in the mining face. At the same time, sedimentation deformation occurs in the rock formation layer in the mining area. After the mining of No. 3 coal face

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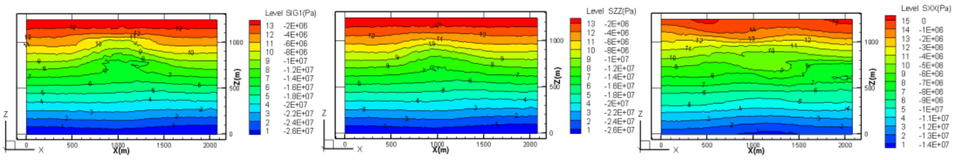
is completed, No. 9 coal mining is carried out. After combined mining, the deformation range and extent of the formation are significantly increased, as shown in Figure 5.

According to the geological conditions of the mine and the scale of the numerical model, in order to better use the numerical calculation results to analyze the formation stress and deformation characteristics of the main inclined shaft, we select the location profile of the main inclined shaft to analyze the formation stress and deformation characteristics. The specific section position is shown in Figure 6. Since the main and auxiliary inclined shafts are close to each other, the formation characteristics are almost the same. Therefore, this paper focuses on the analysis of the stress and deformation characteristics of occurrence strata in the main inclined shaft.

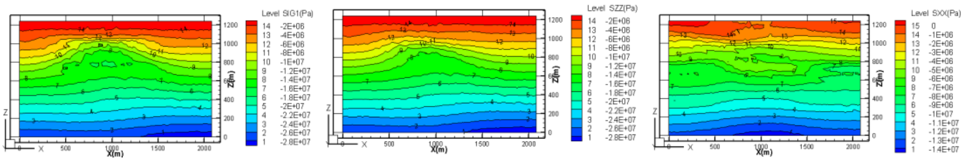
3.2. Influence of combined mining on stress distribution in the occurrence strata of main inclined shaft

Figure 7 is a stress distribution diagram of the occurrence strata of the main shaft after the No. 3 coal mining. It can be seen from Figure 7 that the formation stress is basically horizontally distributed after the No. 3 coal mining. The No. 3 coal mining has little influence on the stratum in the main inclined shaft section, and has little effect on the surrounding rock of the main inclined shaft arching stage strata. Figure 8 is a stress distribution diagram of the occurrence strata of the main shaft after mining of No. 3 coal and No. 9 coal. It can be seen from 8 that after the mining of No. 3 coal and No. 9 coal, the stratum stress distribution of the main well section is affected to some extent. The stratum stress of the elevation +900m~+1050m changes, but it has little effect on the stress distribution of the surrounding rock of the main inclined shaft arching stage strata.



a) b) c)

Figure 7. Stress distribution diagram of the stratigraphic section of the main well after NO.3 coal mining. a) maximum principal stress distribution diagram b) vertical stress distribution diagram c) horizontal stress distribution diagram



a) b) c)

Figure 8. Stress distribution diagram of the stratigraphic section of the main well after NO.3 coal and NO9 coal mining. a) maximum principal stress distribution diagram b) vertical stress distribution diagram c) horizontal stress distribution diagram

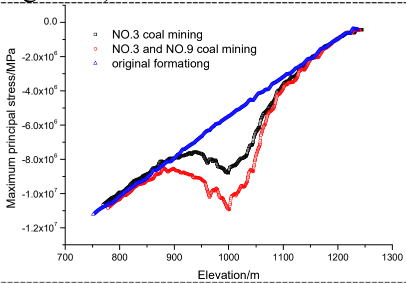
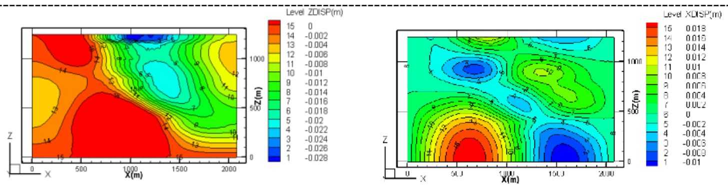


Figure 9. Variation of the maximum principal stress distribution in the stratum of the main inclined shaft after coal seam mining

Figure 9 shows the variation of the maximum principal stress distribution in the occurrence strata of main inclined shaft after coal seam mining. It can be seen from Fig. 9 that the underground No. 3 coal seam mining and the No. 9 coal seam mining both have the greatest influence on the position where the wellbore is located at a height of +1000 m in the occurrence strata, but the maximum principal stress change value is much smaller than the compressive strength of the well wall structure. Therefore, the surrounding rock of the shaft wall structure is in a safe and stable state.

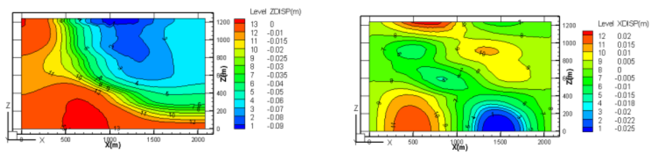
3.3. Influence of combined mining on formation deformation in the occurrence strata of main inclined shaft

Figure 10 is a deformation cloud diagram of the occurrence strata of main inclined shaft after the No. 3 coal mining. It can be seen from Fig. 10 that after the No. 3 coal mining, the main inclined shaft section is subsided, and the overall settlement is small, and the deformation is less than 2 mm. The vertical settlement and horizontal deformation of the stratum of the main inclined shaft arching stage strata are almost zero. Therefore, the influence of No. 3 coal mining has little effect on the deformation of the occurrence strata of main inclined shaft.



a) vertical direction b) horizontal direction

Figure 10. Deformation cloud diagram of the stratigraphic section of the main inclined well after NO.3 coal mining



a) vertical direction b) horizontal direction

Figure 11. Deformation cloud map of the stratigraphic section of the main inclined well after NO.3 coal and NO.9 coal mining

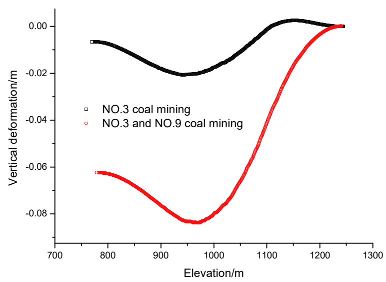


Figure 12. Influence diagram of ground settlement caused by main inclined shaft after coal seam mining

Figure 10 is a deformation cloud diagram of the occurrence strata of main inclined shaft after the No. 3 and No.9 coal mining. It can be seen from Fig. 11 that the stratum settlement of the main inclined shaft section after mining of No. 3 coal and No. 9 coal is larger than that of No. 3 coal after mining, so the disturbance effect of No. 9 coal mining is obvious. However, the overall settlement is still small, the maximum settlement occurs at the surface, the maximum settlement is 9mm, and the vertical settlement and x-direction deformation of the main inclined shaft arching stage strata are less than 1cm. Therefore, the influence of No. 9 coal mining has little effect on the deformation of the occurrence strata of main inclined shaft.

Figure 12 is the settlement diagram of the occurrence strata of main inclined shaft after coal seam mining. It can be seen from Figure 12 that the underground No. 3 coal seam mining and No. 9 coal seam mining have a greater impact on the elevation of +950 m. The overall settlement is still small, with a maximum of 8mm. Therefore, the influence of mining disturbance has little effect on the deformation of the arching stage strata in the main inclined shaft. The surrounding rock of shaft wall section structure is safe and stable.

4. Conclusions

(1) Through the established three-dimensional geological model of the mine, this paper analyzes the spatial position relationship between the main inclined shaft and the mining area, and the complex mining disturbance process with steeply dipping seam and the space-time correspondence of the wellbore deformation area in the weakly cemented stratum.

(2) In the weakly cemented stratum, the different areas of the surrounding rock of the main inclined shaft with steeply dipping seam are disturbed in different disturbance stages, and the disturbance form, stress environment and deformation characteristics are different, so the deformation mechanism has a big difference.

(3) According to the numerical calculation results, the disturbance of No. 3 coal seam mining has little influence on the surrounding rock of the main inclined shaft, and has little effect on the surrounding rock of the main shaft arching stage strata. The No. 3 coal seam and No. 9 coal seam mining have a certain influence on the surrounding rock stress distribution of the main inclined shaft. The stratum stress of elevation +800~+900m is significantly affected by the mining disturbance, but it has little effect on the stress distribution of the surrounding rock of the main inclined shaft arching stage strata.

(4) No. 3 coal seam mining and No. 9 coal seam mining have a greater impact on the position of the main inclined shaft surrounding rock elevation of +950 m, but the overall settlement is still small (maximum 8 mm). Therefore, the influence of mining disturbance has little effect on the deformation of the occurrence strata arching stage strata in the main inclined shaft.

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