

# Explore the Impact of Coal Mining on the Safety of the Upper Reservoir Based on FLAC<sup>3D</sup>

Xinya Li<sup>1,\*</sup>, Jiangfeng Wang<sup>2</sup>

<sup>1</sup>College of North China University of Water Resources and Electric Power, Zhengzhou, China

<sup>2</sup>College of North China University of Water Resources and Electric Power, Zhengzhou, China

\*Corresponding Author: Xinya Li

**Abstract:** With the increasing scarcity of land resources, the rational utilization of coal mine goaf areas has become particularly important. To study the impact of coal mining on the safety of the upper reservoir and dam, numerical simulation software FLAC<sup>3D</sup> was used to model existing and future goaf areas created by coal mining. By analyzing the maximum and minimum principal stress clouds, vertical displacement clouds, and the distribution of surface plastic zones for two selected profiles, it was found that under current conditions, coal mining causes a maximum surface subsidence of nearly 2.0m, with the dam area located at the edge of the subsidence basin. The southern area is closest to the goaf, with a maximum subsidence of about 0.5m, and obvious tensile and shear plastic zones are produced; in the future, after the planned mining workforce is completed, the reservoir dam area will experience cumulative subsidence of 2800mm, tilt of 5mm/m, curvature of  $5 \times 10^{-3}/m$ , horizontal movement of 800mm, and horizontal deformation of 6mm/m, which could potentially cause severe deformation and damage to the reservoir dam.

**Keywords:** Numerical Simulation; Coal Mine Goaf; Reservoir Dam; Safety Assessment.

## 1. Introduction

With the continuous advancement of urbanization in China, the rational utilization of mining land is increasingly mentioned. Under the load of the upper structures, the stress of the overlying rock strata of the goaf is redistributed, the rock strata collapse, move, and gradually affect the surface, causing ground subsidence and other disasters, thereby causing immeasurable losses to the nation and the people's lives and property. Currently, a coal mine working face extends under the surface reservoir, and its goaf may undergo severe deformation or even instability collapse under the action of the reservoir dam site and water pressure, with the deformation characteristics of the near-surface goaf being more pronounced, affecting the safe and stable operation of the surface dam site area. Therefore, based on the current mining situation of the coal mine, future mining plans, and the engineering geological characteristics within the research scope, this paper uses FLAC<sup>3D</sup> technology to simulate the impact of coal mine daily production activities on the safety of the upper reservoir, guiding scientific mining activities and ensuring the safe operation of the reservoir.

FLAC<sup>3D</sup> can assess the stability of the goaf by simulating the stress redistribution, displacement changes, and development of plastic zones during the mining process. At the same time, based on FLAC<sup>3D</sup> simulation, the concept of goaf failure probability can be introduced to quantitatively assess the overall stability of the goaf. By statistically analyzing the calculation results of FLAC<sup>3D</sup> grid cells, probability statistical methods (such as Excel's risk analysis add-in @Risk) can be used to calculate the failure probability of the goaf, thus achieving a quantitative evaluation of the stability of the goaf.<sup>[1]</sup>

FLAC<sup>3D</sup> can adopt various methods when dealing with goaf areas, such as direct excavation method and stope softening method. The direct excavation method forms the goaf by directly excavating the coal seam part of the model and

simulating it; the stope softening method simulates the collapse and destruction process of the rock strata after coal mining through softening treatment.<sup>[2]</sup>

Existing research on goaf areas mainly focuses on two aspects: the surface stability of the goaf and the impact of surface engineering construction on the stability of the goaf. There are also many methods for evaluating the stability of goaf areas. Mainly based on the characteristics of the engineering construction object, the impact of the additional load brought by the engineering construction on the stability of the goaf is assessed, and finally, a comprehensive evaluation of the suitability of engineering construction on the goaf is made.<sup>[3-10]</sup>

## 2. Overview of the Study Area

The study area reservoir (a certain coal mine) belongs to the north temperate continental monsoon climate zone, characterized by spring drought and windy, summer heat and rainy, autumn cool and humid, winter cold and less snow; belonging to the Yellow River basin's Yi Luo River water system, the water storage source is mainly composed of atmospheric precipitation, and the water storage volume varies greatly with the seasons; the majority of the landform belongs to the loess tableland landform, only the eastern boundary of the mining area is in the bedrock mountainous area. The overall terrain is lower in the south and higher in the north, lower in the east and higher in the west. The northern mountains, extending in the east-west direction, are mainly composed of loess, with relatively flat ridge surfaces, gentle northern slopes, and steep southern slopes, with many gullies cutting through. The southern part is composed of middle and low mountains formed by the Cambrian and Precambrian strata, with its front being the hilly area formed by the Carboniferous and Permian coal-bearing strata, with ground elevations ranging from 200 to 500m. The central part is a plain area formed by the accumulation of the Neogene and Quaternary, with ground elevations ranging from 100 to

200m. The western part has locally exposed Permian bedrock, with relatively large terrain undulations and gullies developed, which is conducive to the runoff and discharge of atmospheric precipitation, with gullies generally being "V" shaped and deeply cut. The eastern half is basically covered with loess, with relatively small terrain undulations. The surface is covered with the upper Pleistocene loess layer. The reservoir area is about 300 to 500m wide, about 500m long, with a ground elevation of about 320m, and the river valley at the dam site is about 30m wide, with a riverbed elevation of about 285m.

The coal mine is located in the central-eastern part of the Yanlong coalfield, in the Songji area of the southern margin of the North China stratigraphic region. The regional strata include the Archean Dengfeng Group (Ar<sub>dn</sub>), the Mesoproterozoic Jixian System (Pt<sub>3j</sub>), the Upper Proterozoic

Sinian System (Pt<sub>3z</sub>), the Lower Paleozoic Cambrian System (Є) and the Middle Ordovician (O<sub>2</sub>), the Upper Paleozoic Carboniferous Upper Series (C<sub>2</sub>) and Permian (P), the Mesozoic Triassic (T), and the Cenozoic Paleogene (E), Neogene (N), and Quaternary (Q). The Quaternary strata mainly consist of low-liquid-limit clay (Q<sup>3<sub>al</sub></sup>, Q<sup>4<sub>al</sub></sup>) and poorly graded gravel (Q<sup>4<sub>al</sub></sup>); the coal-bearing strata include the Upper Carboniferous Taiyuan Formation, the Lower Permian Shanxi Formation and Lower Shihezi Formation, and the Upper Shihezi Formation, with a total thickness of the coal-bearing strata of 602.54m, divided into eight coal sections from bottom to top. The fully mined area is the II<sub>1</sub> coal seam, with the roof lithology mainly being mudstone and sandy mudstone; the floor lithology mainly being siltstone and mudstone.

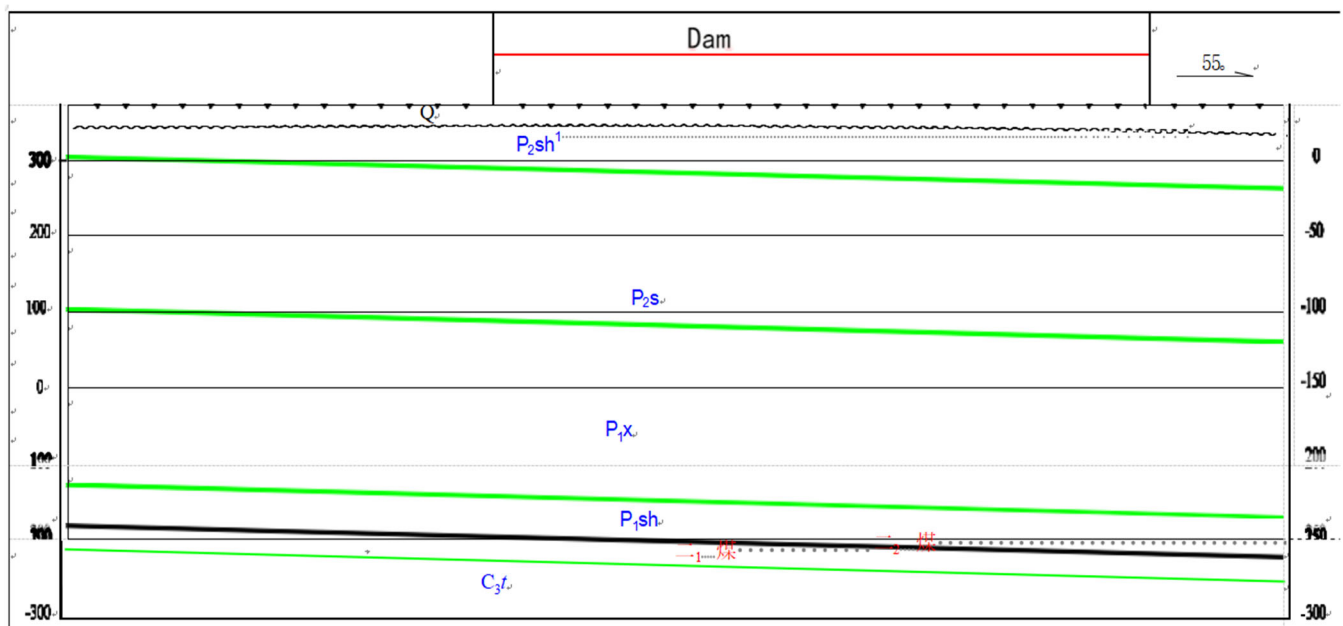


Figure 1. Geological Profile Map

### 3. Numerical Simulation Analysis

#### 3.1. Division of Rock Groups and Model Establishment

This study takes the goaf area under the coal mine in the study area as the research object. According to the topographic map of the study area, a numerical simulation surface model is established. Referencing the comprehensive stratigraphic column of the mining area, the stratigraphic column near the dam, and the stratigraphic structure, the overlying rock mass is divided into 13 model materials based on the similarity of engineering geological characteristics, from bottom to top, they are: limestone of the first coal section, floor sandstone, coal seam, roof sandstone of the second coal section, mudstone of the third coal section, sandstone of the fourth coal section, sandy mudstone of the fifth coal section, mudstone and sandstone interbedded of the sixth coal section,

interbedded sandstone and mudstone of the seventh coal section, mudstone of the eighth coal section, sandstone of the Shi Qianfeng Formation, Quaternary soil layer, and dam concrete panel.

Combining the actual situation of the coal seams 001 and 002 mined in the study area, the average thickness of the coal seam is taken as 4m, the strike length of the calculation model is 1900m, the dip width is 1200m, the height is 700m, the bottom elevation is set at -380m, the vertical X-axis, vertical Y-axis, and Z-axis bottom interfaces are set as fixed displacement boundaries, the top interface is set as a free boundary, and the vertical interface and bottom interface are set as rolling interfaces. A three-dimensional numerical model is used for stress field numerical simulation calculation and Mohr-Coulomb yield criterion to determine rock mass failure, and plastic flow is not considered. The simulation plane schematic diagram and model diagram are shown in Figure 2 and Figure 3.

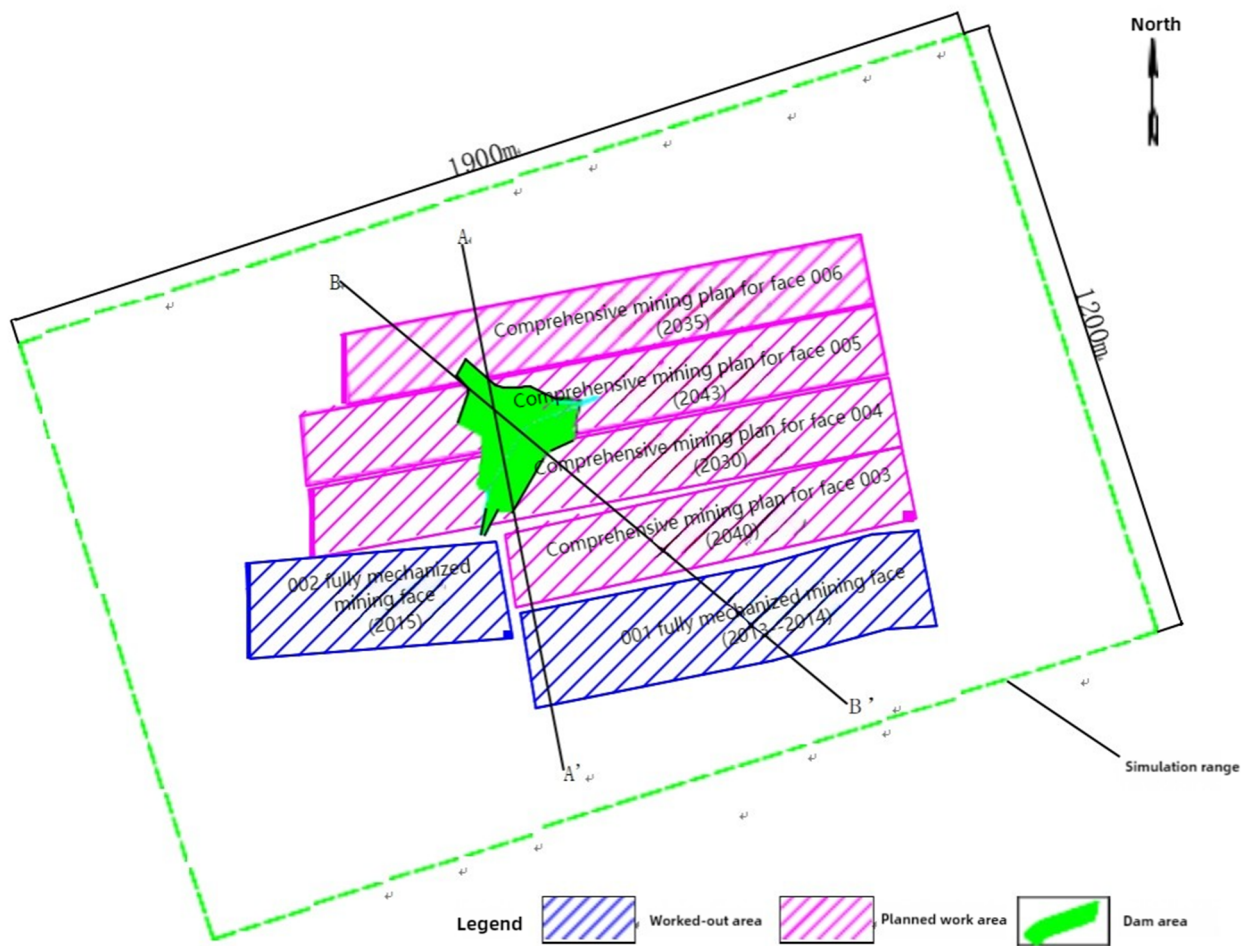


Figure 2. Simulation Plane Schematic Diagram

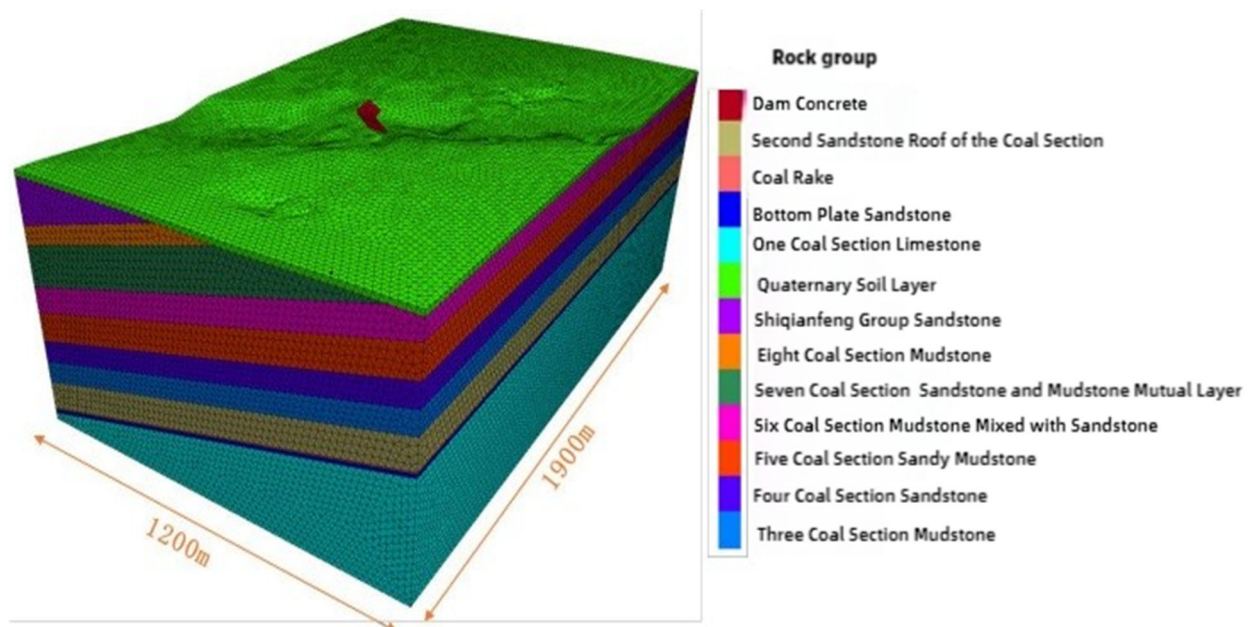


Figure 3. Grid Model Diagram

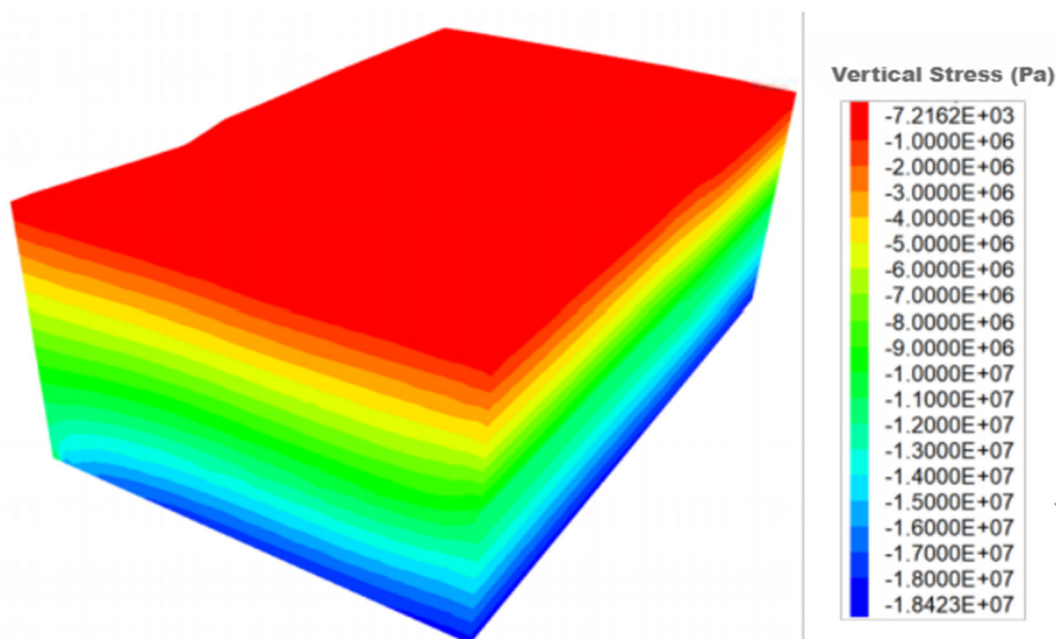
### 3.2. Parameter Selection and Simulation Scheme

According to the production geological report and reserve

verification report provided by the mine, as well as the corresponding calculation results, the parameters used for this simulation are determined as shown in Table 1.

**Table 1.** Geological Model Material Parameters

Rock Group	Unit-Weight (kN/m <sup>3</sup> )	Bulk Modulus (MPa)	Shear Modulus (MPa)	Cohesion (MPa)	Internal Friction Angle (°)	Tensile Strength (MPa)
Dam Concrete	25	18840.58	10236.22	2000	35	2
Quaternary Soil Layer	18	7.65	2.93	0	18	0.01
Shiqianfeng Group Sandstone	26	1415.87	691.47	2000	32	1.5
Eight Coal Section Mudstone	26	938.46	590.32	1154	30	1.3
Seven Coal Section Sandstone and Mudstone Mutual Layer	26.5	925.64	582.26	1740	35	1.2
Six Coal Section Mudstone Mixed with Sandstone	26.5	925.64	582.26	1740	35	1.2
Five Coal Section Sandy Mudstone	26.5	925.64	582.26	1740	35	1.2
Four Coal Section Sandstone	26	1415.87	691.47	3200	32	1.5
Three Coal Section Mudstone	27	938.46	590.32	1154	30	1.3
Second Sandstone Roof of the Coal Section	26	1415.87	691.47	2000	32	1.5
Coal Rake	13	910.00	470.00	1000	25	0.25
Bottom Plate Sandstone	26	1415.87	691.47	2000	32	1.5
One Coal Section Limestone	28	16000.00	9600.00	3000	38	2

**Figure 4.** Vertical stress cloud map of the initial stress field

This simulation is mainly conducted in the self-weight stress field. The impact of underground coal seam excavation on the surface dam is divided into current and future parts. Under the current situation, the simulation has been carried out for the 001 and 002 working faces, where the 001 working face is only simulated to the area that may affect the dam. According to the future mining plan provided by the mining company, four working faces are planned below and near the reservoir dam. This simulation is carried out in four stages according to the future mining time. The simulation results are evaluated for the impact of each stage of working face

mining on the dam by analyzing the stress, deformation, and plastic zone distribution.

### 3.3. Simulation of Current Coal Seam Mining

Under the current situation, the working faces affecting the dam area are 001 and 002. This time, the two working faces are simulated in the order of mining time, and the impact of coal seam mining on the dam is analyzed through the A-A' section and B-B' working face. The simulation results are shown in Figures 5-14.

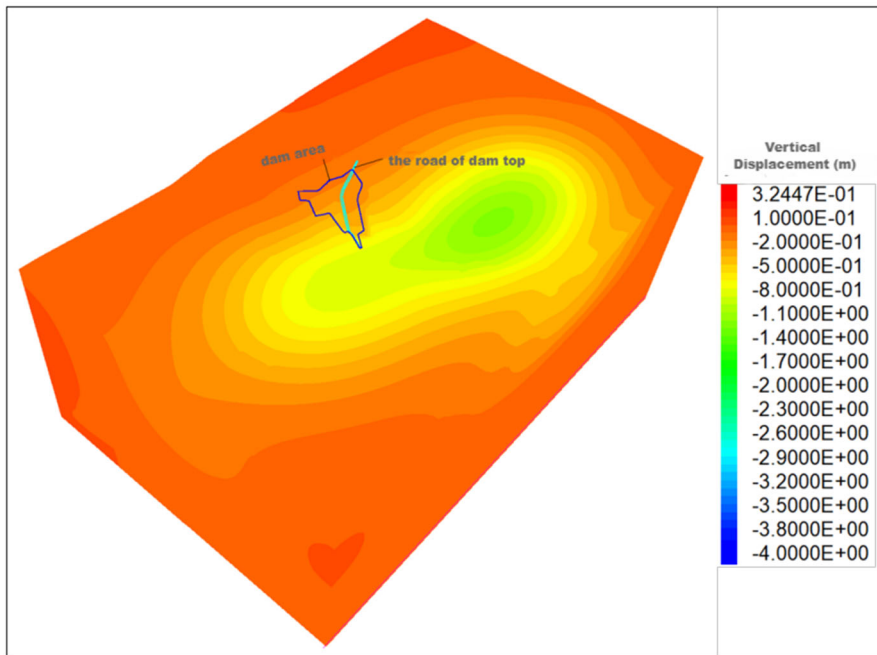


Figure 5. Cloud map of the surface settlement contour line under the current situation

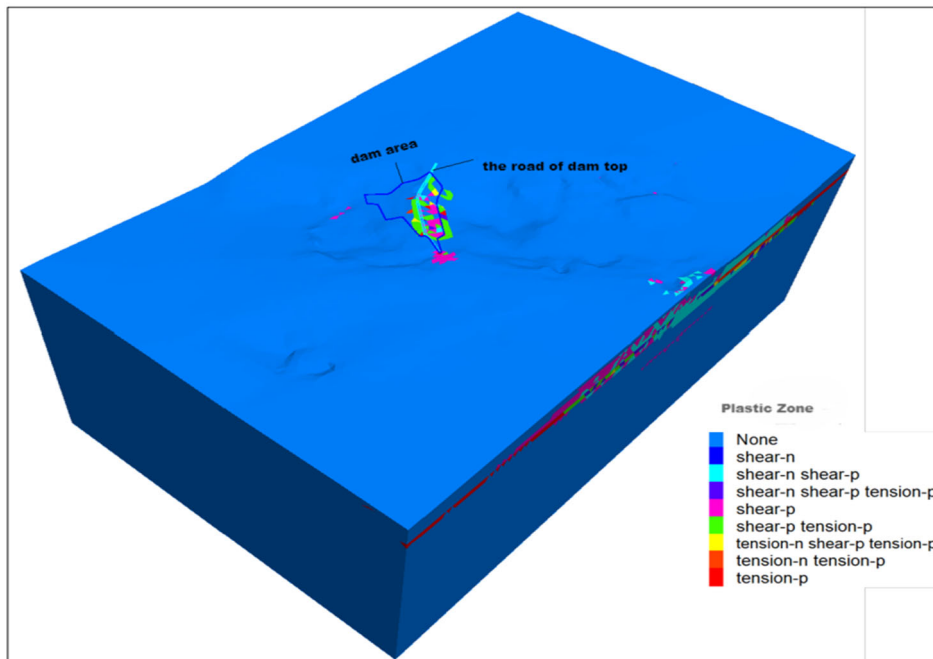


Figure 6. Cloud map of surface plastic area distribution

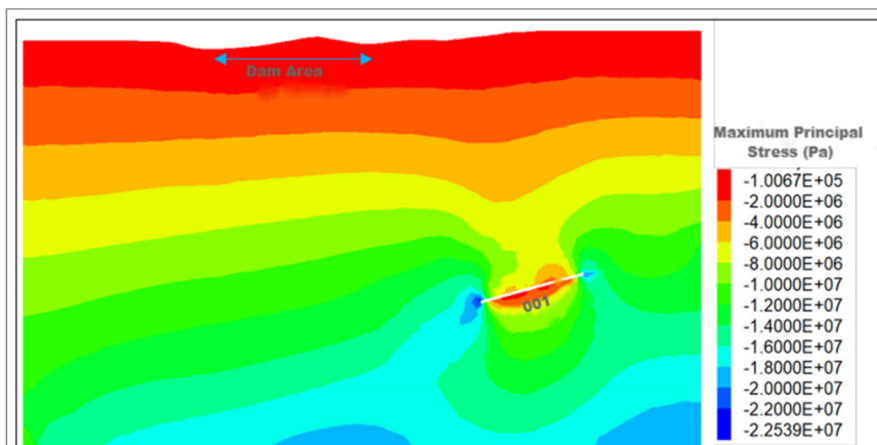


Figure 7. Maximum principal stress cloud map of A-A' section under current conditions

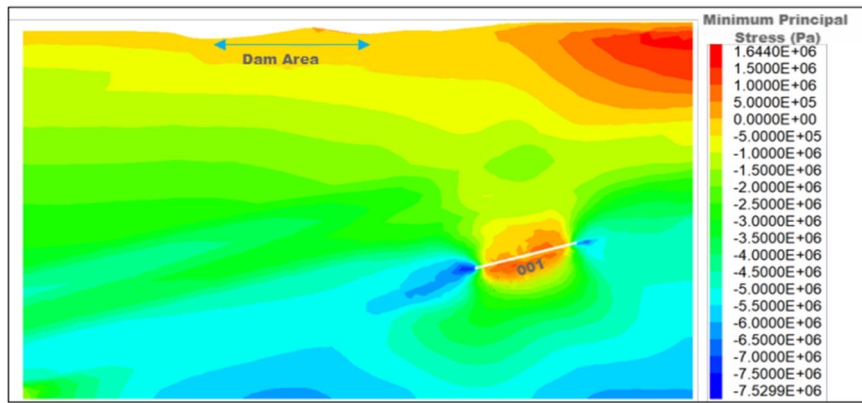


Figure 8. Minimum principal stress cloud map of A-A' section under current conditions

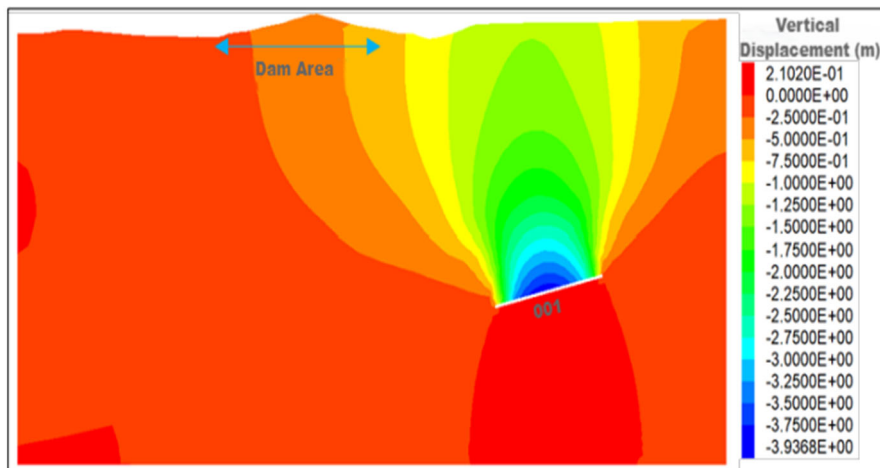


Figure 9. Vertical displacement of A-A' profile in current situation

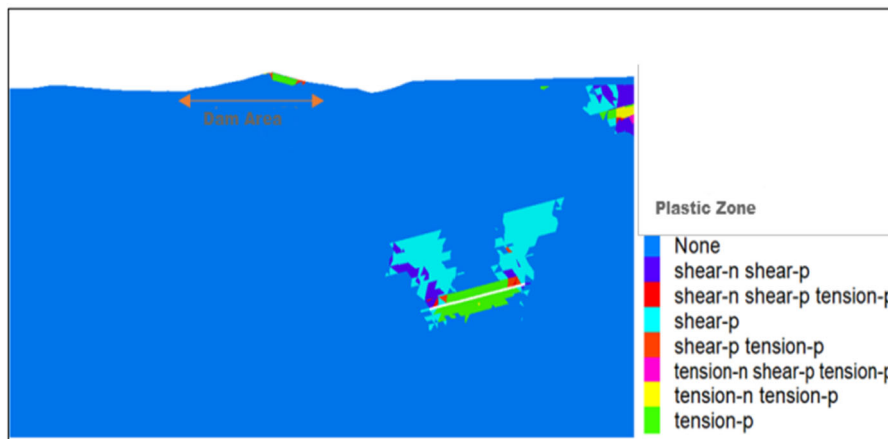


Figure 10. Plastic zone distribution map of A-A' section under current conditions

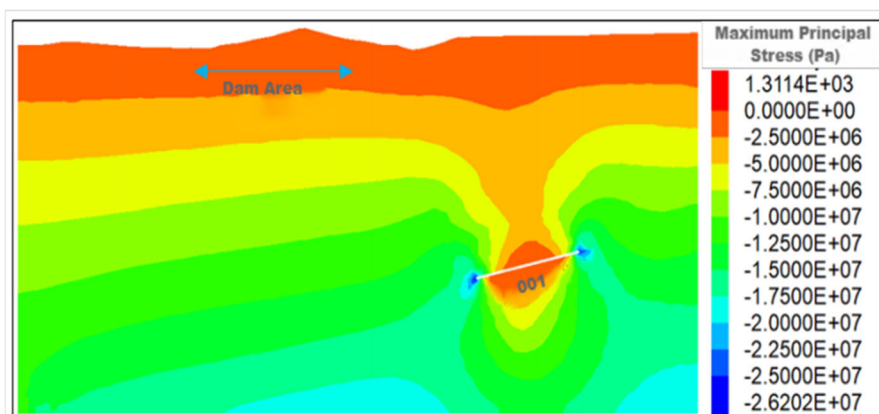


Figure 11. Maximum principal stress cloud map of B-B' section under current conditions

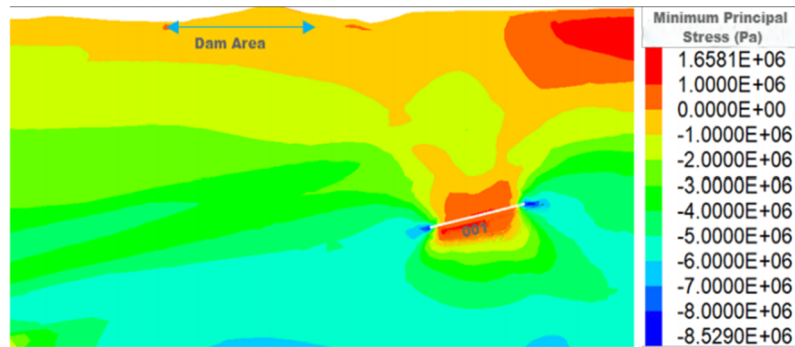


Figure 12. Minimum principal stress cloud map of B-B' section under current conditions

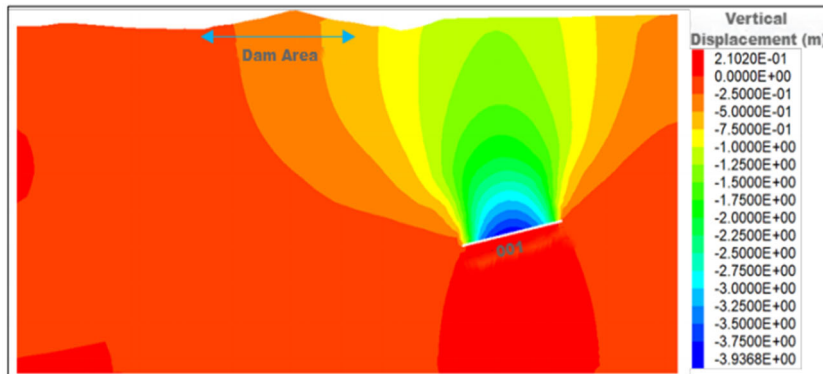


Figure 13. Vertical displacement of B-B' profile in current situation

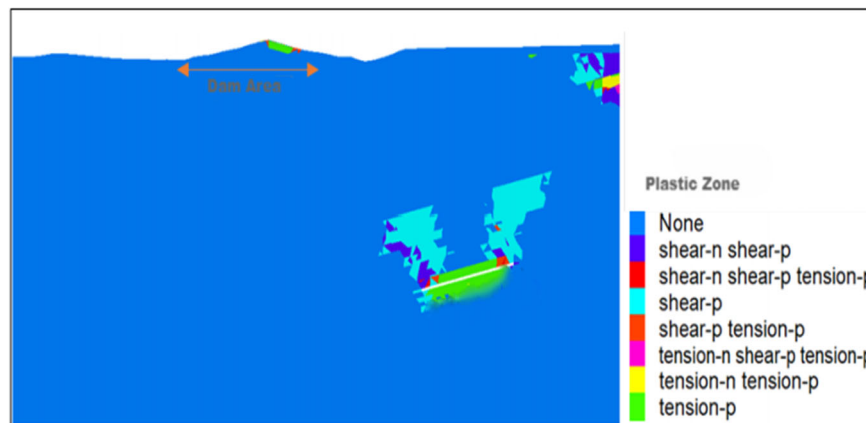


Figure 14. Plastic zone distribution map of B-B' section under current conditions

According to Figure 5, the maximum surface subsidence caused by coal seam mining under the current situation is close to 2.0m. The dam area is located at the edge of the subsidence basin. The southern area of the dam is closest to the goaf, with a maximum subsidence of about 0.5m. Generally, the edge of the subsidence basin is prone to cause tensile and shear cracks. According to Figure 6, there are obvious tensile and shear plastic zones in the dam area, and the southern side is more severe than the northern side. The simulation results are basically consistent with the field investigation.

According to Figures 7-8 and Figures 11-12, the stress simulation results of A-A' and B-B' show that coal seam mining causes the overburden stress to redistribute. Stress concentration occurs at both ends of the working face, and the roof forms a tensile stress arch. At the same time, due to the full mining of the working face, the stress effect extends to

the surface, and some areas on the surface form a tensile stress zone. The minimum principal stress in the dam area is tensile stress, and the tensile stress value on the south side of the dam is larger. Under the action of tensile stress, tensile failure is prone to occur.

According to Figures 9-10 and Figures 13-14, the displacement and plastic zone simulation results of A-A' and B-B' also show that the dam area is located at the edge of the basin, and plastic failure has occurred in the dam area.

### 3.4. Simulation of Future Coal Seam Mining

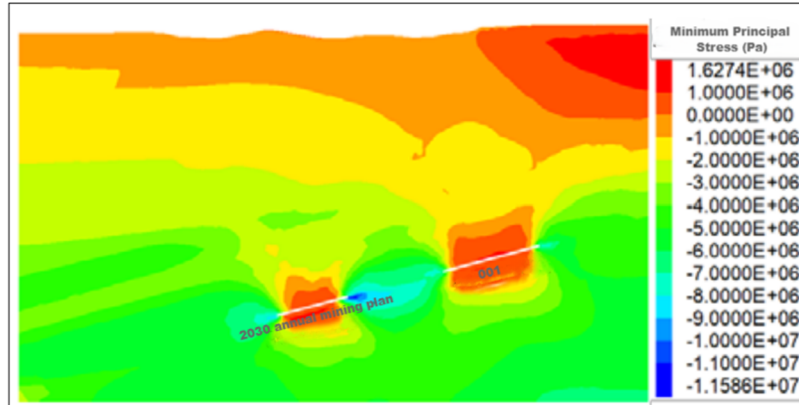
According to the future mining plan provided by the mine, after the mining of 003,004,005 and 006 in the future, multiple working faces may lead to the formation of large goaf, resulting in secondary collapse and the expansion of surface deformation range. See Table 2 for the specific prediction results in surface movement deformation.

**Table 2.** Calculation results of surface movement and deformation in the reservoir dam

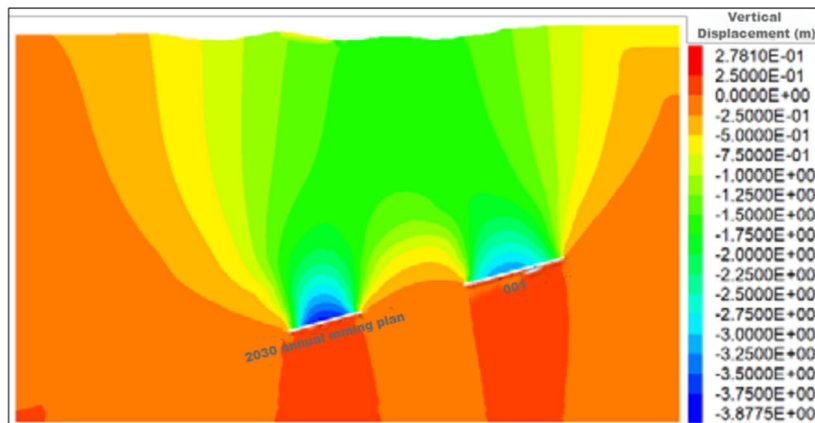
Time	Settlement (mm)	Tilt (mm/m)	Curvature ( $\times 10^{-3}/m$ )	Horizontal Scroll (mm)	Horizontal Distortion (mm/m)
In 2035,	300-2300	1-9	0.01-0.10	10-650	0.1-7
In 2040,	900-2500	0.1-7	0.01-0.10	10-700	0.1-7
In 2043,	1000-2500	0.1-7	0.01-0.09	10-700	0.1-7
In 2047,	2200-2800	0.1-5	0.01-0.07	100-800	0.1-6

According to the calculation results, the future mining of the mining area may cause significant damage to the surface facilities such as the reservoir dam and spillway. This time, based on the mining time of the working face, the results of the minimum principal stress, vertical displacement, and

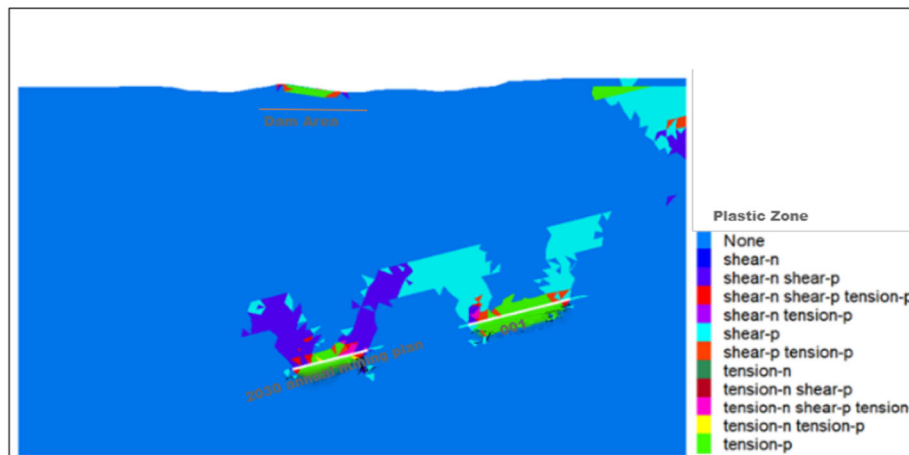
plastic zone of the A-A' section are analyzed for the impact of future mining in 2030, 2035, and 2040. The impact in 2043 is only shown through the range of the entire surface plastic failure area. The simulation results are shown in Figures 15-24.



**Figure 15.** Minimum principal stress cloud map of A-A' section (2030)



**Figure 16.** Vertical displacement cloud map of A-A' section (2030)



**Figure 17.** Plastic zone distribution map of A-A' section (2030)

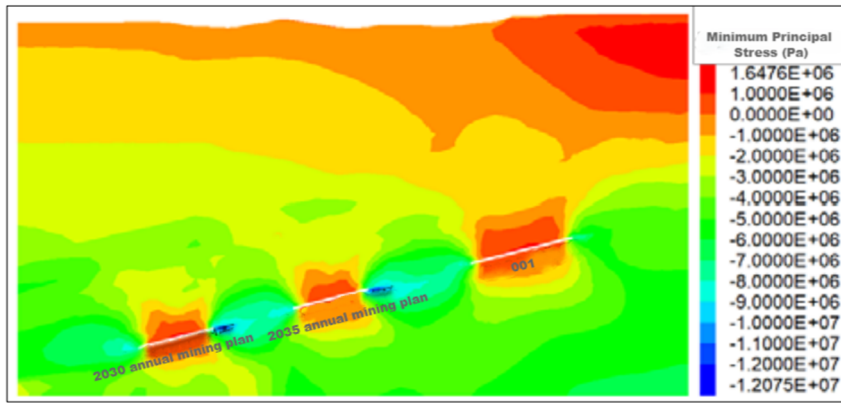


Figure 18. Minimum principal stress cloud map of A-A' section (2035)

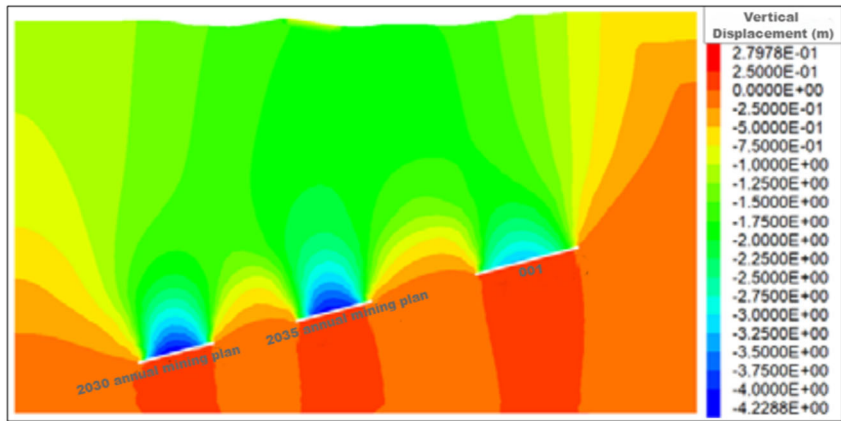


Figure 19. Vertical displacement cloud map of A-A' section (2035)

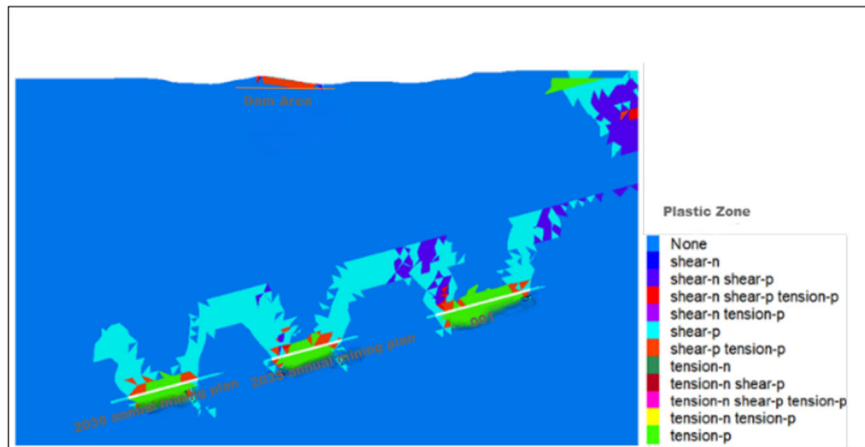


Figure 20. Plastic zone distribution map of A-A' section (2035)

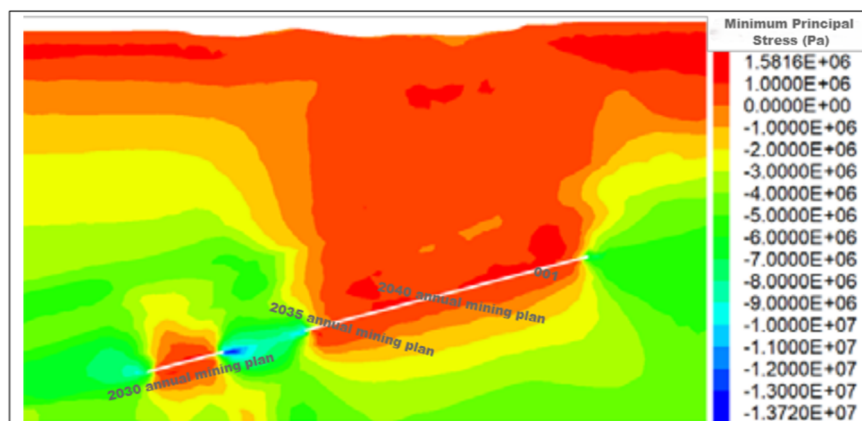


Figure 21. Minimum principal stress cloud map of A-A' section (2040)

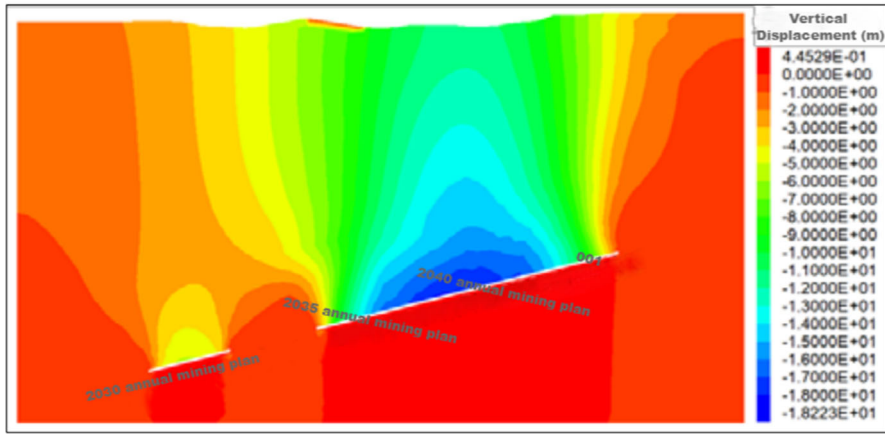


Figure 22. Vertical displacement cloud map of A-A' section (2040)

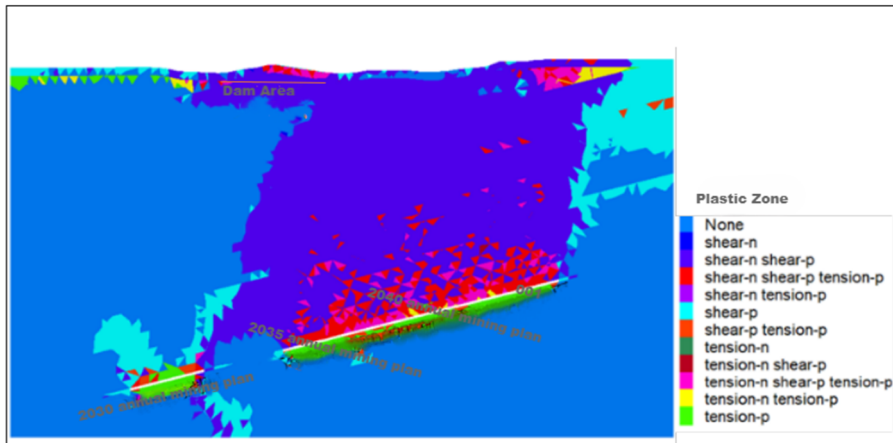


Figure 23. Plastic zone distribution map of A-A' section (2040)

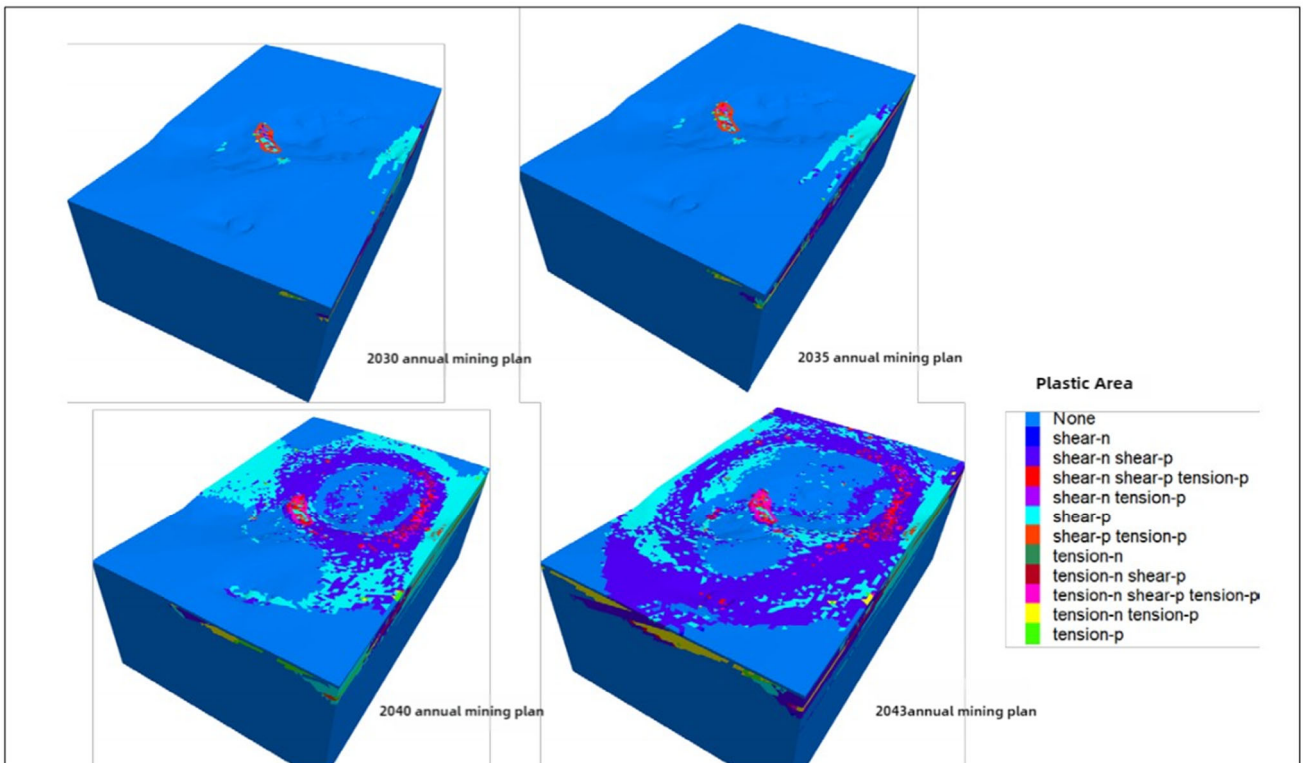


Figure 24. Future mining surface plastic zone distribution change map

Through the analysis of this simulation process, it can be found that when the simulation is excavated to the planned face in 2040, the numerical calculation process becomes non-

convergent, and the overburden and surface have a large area of plastic failure; According to the minimum principal stress cloud map, vertical displacement map, and plastic zone

distribution map of the three stages, due to the interval mining of the future planned face, there is still coal pillar support between the mining faces in 2035, and the tensile stress distribution of the overburden does not extend to the surface. The surface deformation basin further expands, and the plastic failure of the dam area is also further aggravated compared to the current situation. By 2040, all the working faces on the south side of the dam have been mined, and the simulation calculation becomes non-convergent. The tensile stress area of the entire overburden extends to the entire surface, and the dam and the surrounding area of the dam have a large area of plastic failure. Therefore, future mining may cause serious damage to the dam.

#### 4. Conclusions and Suggestions

Through the numerical simulation analysis of the current situation of coal mining, it is believed that the cracking and settlement of some areas of the reservoir dam and spillway are related to the mining of the 001 and 002 working faces; The surface movement and deformation caused by the current mining has entered a slow residual deformation period, and the surface movement and deformation have stabilized. Under the condition that there is no new mining impact, it is suitable to carry out the dam risk mitigation and reinforcement work.

(2) Through the numerical simulation analysis of future coal mining, according to the future mining plan provided by the mining company, it is believed that the surface facilities such as the reservoir and dam, spillway located in the goaf collapse basin may be affected by the future planned working face mining, which may cause serious mining-induced deformation and damage to the reservoir dam and spillway (including the planned risk mitigation and reinforcement project), which may lead to the reservoir unable to operate normally.

(3) It is recommended to carry out special demonstration work before mining the 003, 004, 005, and 006 working faces, fully understand the possible impact on the ground facilities after mining, and minimize economic losses as much as possible.

(4) During the future mining period, the reservoir management should strengthen the patrol and fixed inspection of the reservoir dam structure, continuously carry out the settlement and horizontal monitoring of the dam and the

nearby surface, and the monitoring range should not be less than the reservoir dam. The monitoring frequency should be no less than once every quarter; During the future planned mining period, increase the maintenance and protection measures for the reservoir dam.

#### Reference Documentation

- [1] Shang Zhenhua, Tang Shaohui, Jiao Wenyu, et al. Scale goaf failure probability study based on FLAC ~ (3D) simulation [J]. *Rock-soil mechanics*, 2014,35(10):3000-3006.DOI:10.16285/j.rsm. 2014. 10.028.
- [2] Zhang Lei. Discussion on the treatment method of the goaf in FLAC ~ (3D) [J]. *Shanxi Coking Coal Technology*, 2017,41(11): 26-30.
- [3] Liu Bin. Study on the comprehensive evaluation and treatment scheme of the goaf stability of a copper polymetallic mine [J]. *Mining Technology*, 2023,23(06):88-93.DOI:10.13828/j.cnki.ckjs. 2023.06.032.
- [4] Wang He, Zhang Chi. Refined stability analysis based on 3 D laser scanning empty area [J]. *Non-ferrous metals (mine part)*, 2023,75 (05): 70-75.
- [5] Ma Mingkang, Lu Yongjun, Guo Xu, et al. Study on the slope stability of Maogou open pit mine under the influence of goaf [J]. *Open-pit mining technology*, and 2022,37(01):69-71+75.DOI:10.13235/j.cnki.ltcn. 2022.01.019.
- [6] Xue Guoqiang, Pan Dongming, Yu Jing Estate. Overview of geophysical exploration applications in goaf in coal mines [J]. *Progress in Geophysics*, 2018,33 (05): 2187-2192.
- [7] Li Shu-Mingzhi. Research and application of key technologies of urban construction in coal mining subsidence area [J]. *Coal mining*, 2016,21 (02): 73-77.
- [8] Teng Yonghai, Tang Zhixin. Research and application of ground building technology in the old goaf [J]. *Coal Science and Technology*, 2016,44 (01): 183-186.
- [9] Liu Yixin, Zhang Junying, Jia Xinguo. Assessment of foundation stability in goaf of photovoltaic power station built in coal mining subsidence area [J]. *Coal Science and Technology*, 2016, S2:189-192.
- [10] Guo Keyi, Yi Sihai, Teng Yonghai. Construction and protection technology of wind farm project in mining mining area [J]. *Metal Mines*, 2015, (04): 150-153.