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Research on the Numerical Simulation of Overlying Strata Movement Law in Top Coal Caving Working Face Mining Through Syncline Structural Zone

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Abstract

As deep coal mining advances, mine disasters induced by complex geological conditions, such as syncline structural zones, are becoming increasingly severe. Taking the 9401 working face of a certain mine as the engineering background, this study utilizes FLAC3D three-dimensional numerical simulation software to investigate the evolution laws of overlying strata stress and displacement during the dynamic process of a top coal caving working face mining through a syncline structure (downward dipping-syncline axis-upward dipping). The results demonstrate that during the entire process of mining through the syncline, the syncline axis area acts as the core hazard zone, exhibiting the most intense stress concentration, floor deformation, and plastic failure. Notably, the maximum floor heave near the geometric center of the syncline reaches an extreme value of 1023 mm for the entire process. This study reveals the significant controlling effect of the syncline structure on strata behavior, providing an important theoretical basis for surrounding rock control and disaster prevention under similar complex geological conditions.

Keywords

Syncline Structure; Top Coal Caving Mining; Vertical Stress; Overlying Strata Movement.

1. Introduction

With the continuous increase in coal mining depth and intensity, safety risks induced by complex geological structures have become increasingly prominent. Particularly during top coal caving mining in fold structures (especially syncline structures), the strong tectonic stress and asymmetric rock strata morphology are highly prone to inducing severe dynamic disasters, such as roof caving, coal wall spalling, and floor heave [1, 2]. At present, domestic and foreign scholars have conducted extensive and beneficial research on strata behavior laws and overlying strata movement characteristics under various geological conditions [3, 4, 5, 6, 7]. However, existing research is mostly limited to single horizontal or inclined strata, with little systematic analysis focusing on the whole-process dynamic evolution in syncline structural zones. Therefore, taking the 9401 working face with a syncline structure as the engineering background, this paper establishes a three-dimensional numerical model to systematically reveal the dynamic evolution laws and disaster-causing mechanisms of the overlying strata in the stope of the syncline zone, aiming to provide an important theoretical basis for safe mining under similar complex geological conditions.

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2. Engineering Background and Numerical Model Establishment

The 9401 working face of a certain mine is taken as the research object. This working face mainly extracts the No. 9+10 coal seam, with an average coal seam thickness of 6.1 m and an average dip angle of 7°. The mining process of the working face is primarily controlled by the Liujiazhuang syncline structure, which obliquely crosses the entire working face. In the axis area, structural stress is concentrated, and fractures are well-developed.

To accurately reconstruct the syncline structure, a 3D geometric model was built in Rhinoceros and imported into FLAC3D for mechanical parameter assignment. The model measures 1000 m along the strike (advance direction) and 340 m along the dip (including a 240 m working face and 50 m protective pillars on each side). The excavation step is set to 20 m (Fig. 1).

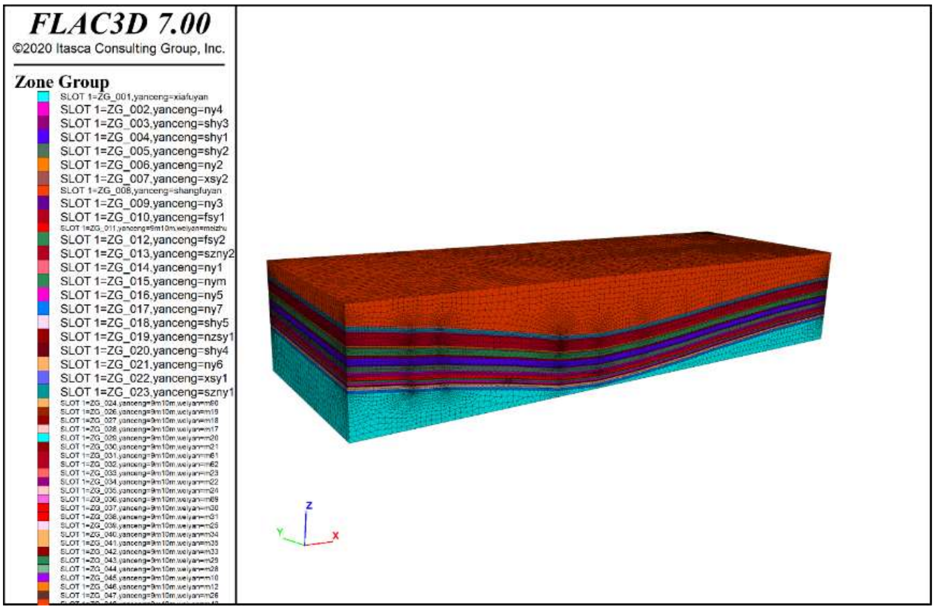

Fig. 1 Numerical calculation model of the 9401 working face

3. Simulation and Analysis of Syncline Mining

The simulation fully captured the mechanical behaviors of the working face within an advance distance of 900 m from the open-off cut, corresponding to the downward dipping mining stage (0–360 m), the near-horizontal mining stage at the syncline axis (360–540 m), and the upward dipping mining stage (540–900 m).

An analysis is now conducted on the simulation results at advance distances of 300 m, 400 m, 460 m, and 800 m.

As shown in Figs. 2 and 3, the advance abutment pressure exhibits a distinct inverted "V" shaped evolution during the working face advance. At 300 m (downward-dipping stage), the face approaches the syncline axis, and stress concentration remains at normal levels. At 400 m and 460 m, the face enters the syncline axis. Influenced by superimposed tectonic squeezing, the abutment pressure spikes sharply, reaching its maximum at 460 m (geometric center), marking this area as the "core hazard zone." At 800 m (upward-dipping stage), the face moves away from the axis, tectonic stress releases, and the stress distribution stabilizes. This fully verifies the significant "load-increasing effect" of the syncline structure on strata behavior.

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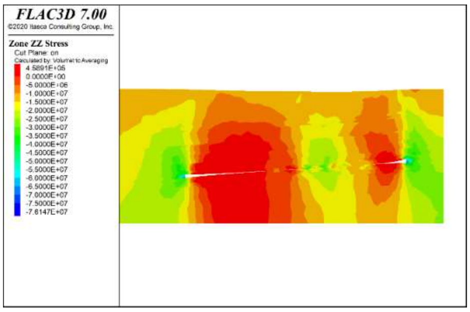
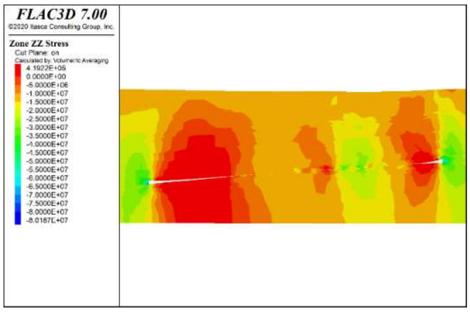
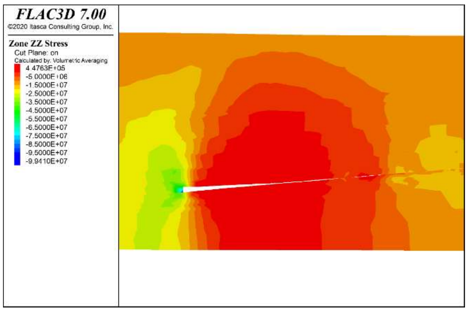


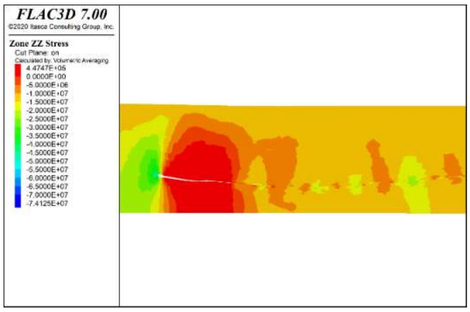
(a)300m



(b)400m



(c)460m



(d)800m

Fig. 2 Vertical stress distribution contours of overlying strata during working face advance

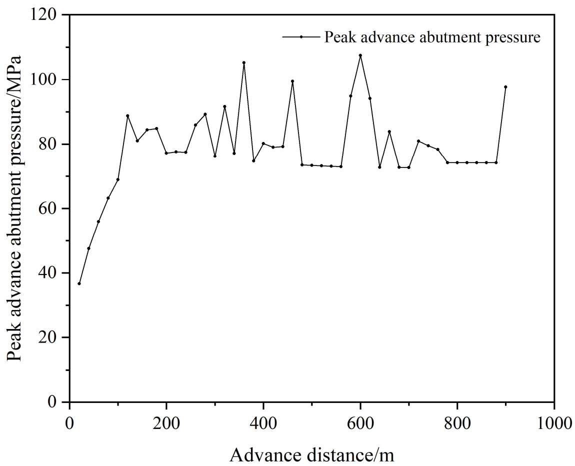


Fig. 3 Evolution of peak advance abutment pressure during working face advance

Combined with the displacement contours (Fig. 4) and evolution curves (Fig. 5), the stope displacement shows a stage-dependent, sharp increase with advance distance. At 300 m, roof and floor deformations are small, following normal settlement laws. Upon entering the syncline axis (400 m and 460 m), driven by high stress concentration and rock fragmentation, displacement surges. Notably, the floor heave increment significantly exceeds roof subsidence, reaching an extreme value of 1023 mm at 460 m, causing large-scale plastic uplift. Beyond 800 m, the deformation rate drops and stabilizes. Overall, this indicates that the high stress in the syncline axis absolutely controls the asymmetric large deformation of the floor.

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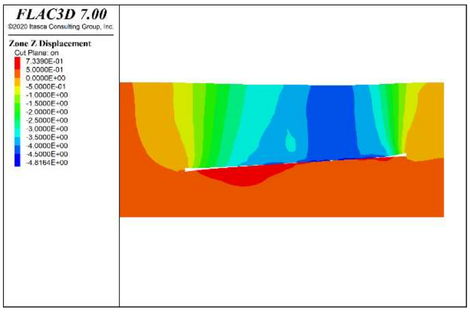
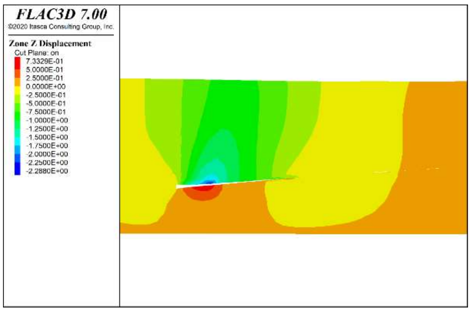
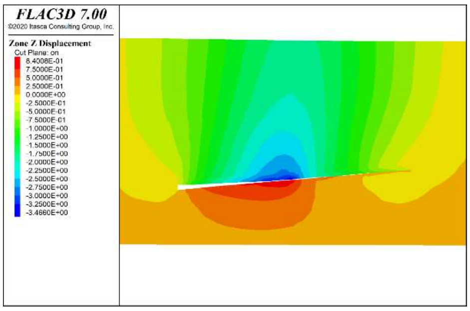


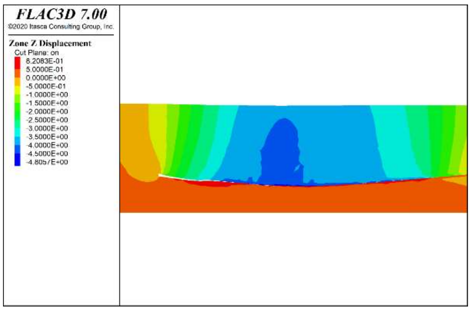
(a)300m



(b)400m



(c)460m



(d)800m

Fig. 4 Displacement distribution contours of the stope during working face advance

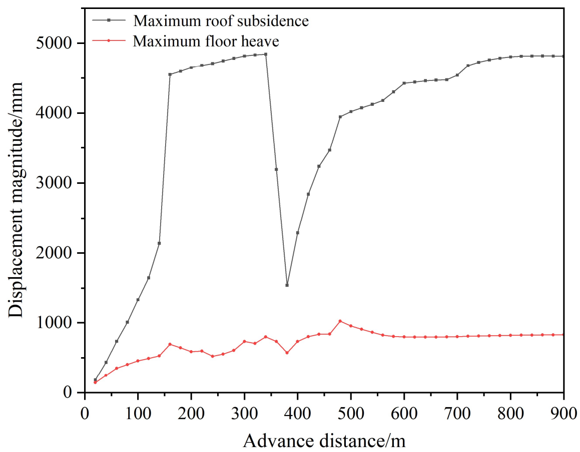


Fig. 5 Evolution curves of maximum roof subsidence and floor heave during working face advance

4. Conclusion

During the mining of the top coal caving working face through the syncline structure, the vertical stress of the overlying strata exhibits a significant nonlinear evolution. The syncline axis acts as the zone with the most severe stress conditions, where the strongly superimposed tectonic stress is highly prone to inducing coal wall spalling or high-intensity dynamic impacts. Due to the extreme squeezing from high-level tectonic stress, the syncline axis is highly susceptible to abnormal floor heave following mining-induced unloading. The maximum floor deformation reaches up to 1023 mm, which verifies that the structural activation of the floor is the key inducing factor for the instability of the surrounding rock in the syncline area.

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