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Study on the Width of Small Coal Pillar Reserved in the Working Face of Closely Spaced Coal Seams

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Abstract

In the mining operations of adjacent coal seams in close proximity, the extraction of upper coal seams can exert significant mining-induced effects on the roof, floor, and coal mass of neighboring seams. This dynamic process often leads to stress accumulation in the roadways of the lower coal seam working face, resulting in substantial roadway deformation. Taking the 12409 working face of the closely spaced coal seam in Selian No. 2 Coal Mine as the engineering case study, this paper employs numerical simulation techniques to analyze the stability of coal pillar design for the 12409 working face. Through systematic analysis, the study determines that an 8 m coal pillar dimension provides optimal structural support under these geological conditions.

Keywords

Closely Spaced Coal Seams; Small Coal Pillar; Numerical Simulation.

1. Introduction

In adjacent coal seam groups with narrow interlayer spacing, the extraction activities of upper coal seams impose substantial dynamic impacts on underlying coal seams. Specifically in scenarios characterized by minimal seam separation, complex geological conditions, gob-side entry driving, and protective coal pillar arrangements, the manifestations of mine pressure behavior become particularly pronounced. During the mining process of overlying working faces, the stress disturbances generated propagate downward through rock strata, altering or even disrupting the original stress equilibrium within the underlying coal-rock mass. This phenomenon inherently leads to significant surrounding rock deformation issues in the roadways of lower coal seams. Therefore, conducting comprehensive investigations into the failure mechanisms of coal pillars, their deformation evolution patterns under repeated mining disturbances, and the stability of pillar configurations in closely spaced seam systems holds critical importance for ensuring safe and efficient coal production.

Regarding the influence of the mining of the upper coal seam on the mining roadway of the lower coal seam in closely spaced coal seams, Songfeng Li [1] and others used the methods of theoretical analysis, numerical simulation, and on-site monitoring to study the stress distribution law of the surrounding rock of the roadway in the floor during the mining of closely spaced coal seams, and obtained the reasonable planar distance between the roadway of the lower coal seam and the edge of the upper coal pillar. Fang Guo [2] employed numerical modeling approaches to analyze stress distribution patterns during fully mechanized mining operations conducted beneath residual coal pillars and goaf areas from previously mined upper seams. Lixing Cheng [3] developed a gob-side entry driving support technology centered on "high-prestress active reinforcement, grouting modification, and robust rib-roof protection" to address challenges of severe deformation and high support difficulty in high-stress soft rock roadways of deep mines. Pengfei Wang [4] systematically

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investigated the optimal roadway alignment along the goaf roof of negative coal pillar entries and proposed active surrounding rock control principles, aiming to improve support efficiency in gob-side drivages affected by arc-shaped goaf floors in negative coal pillar working faces. These contributions provide theoretical foundations for optimizing gob-side entry drivage stability in negative coal pillar mining systems.

This study systematically investigates the stress distribution patterns and influence zones of residual coal pillars in the 3-1 coal seam working face of Selian No. 2 Coal Mine. Specifically, it examines the plastic deformation behavior of surrounding rock, roof subsidence characteristics, floor heave magnitudes, and rib convergence rates in gob-side entries with varying small coal pillar widths during 4-1 coal seam mining. Based on comprehensive geological and mining data from the mine, a three-dimensional numerical simulation model for closely spaced coal seams was constructed using FLAC3D software. Through systematic analysis of mine pressure behaviors associated with different pillar configurations, this research identifies the optimal dimension of small coal pillars required to maintain stable gob-side entry drivage in this complex mining system.

2. Project Overview

The currently exploited coal seam in Selian No. 2 Coal Mine is the 4-1 coal seam, which represents a typical case of closely spaced seam mining under legacy goafs. The mining operation employs the longwall retreat mining technique with full-seam height extraction and hydraulic roof caving support systems. As illustrated in Fig. 1, the 12409 working face maintains an average vertical interval of 43.3m from the overlying 12310 panel and 44.8m from the 12309 panel in the 3-1 coal seam. The interburden strata between these seams consist primarily of semi-hard lithologies including fine-grained sandstone and sandy mudstone. Previous mining activities in the 12309 and 12310 panels may induce significant mining-induced stress disturbances in the floor strata, potentially compromising the structural integrity of the 12409 working face roof in the underlying seam. At the same time, the 30m coal pillar left by the upper coal seam may form a stress concentration phenomenon around the coal mass. The stress concentration is transmitted to the roof of the lower coal seam through the coal and rock mass, which may seriously affect the stability of the coal pillar setting in the working face of the lower coal seam.

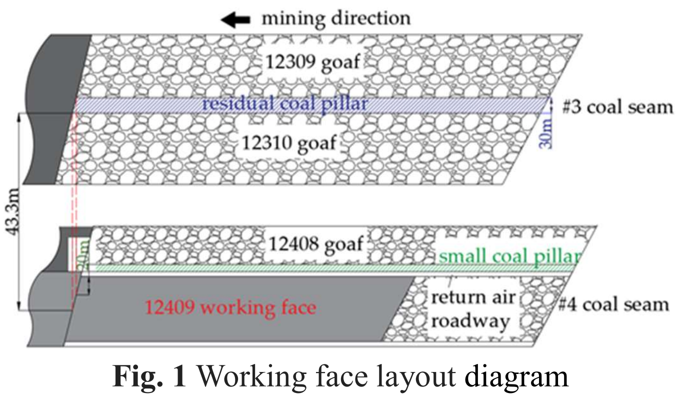

Fig. 1 Working face layout diagram

3. Numerical Simulation of the Width of Small Coal Pillar Setting and the Law of Stress Evolution

To systematically evaluate the stress distribution characteristics and stability of small coal pillars in the lower seam, this study employs a combined analysis of stress field distribution and plastic failure zones. Specifically, the stability of small coal pillars under dynamic mining conditions is assessed through comprehensive characterization of stress concentration patterns and plastic deformation zones. The research findings provide practical guidance for optimizing subsequent mining operations in Selian No. 2 Coal Mine.

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3.1 Establishment of the Numerical Simulation Model

Considering the specific geological conditions of Selian No. 2 Coal Mine and the dynamic mining interactions within the closely spaced coal seam system, a numerical model with dimensions of 400m×320m×160m was constructed. The 4-1 and 3-1 coal seams were meshed with refined grids to ensure accurate stress analysis. The discretized model comprises 1,041,000 elements and 1,121,807 nodes, as shown in Fig. 2. The initial stress equilibrium state is characterized by vertical stress distributions presented in the same figure.

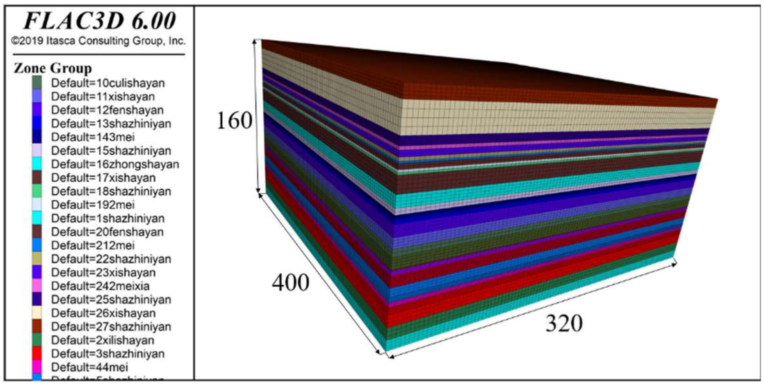

Fig. 2 Numerical simulator model

The numerical model employs the Mohr-Coulomb failure criterion with mining progression along the Y-axis direction. Fixed boundary conditions with zero displacement constraints were applied to the bottom, front, rear, left, and right faces of the model. The top boundary was defined as a stress-free surface with a vertically applied load of 9.9 MPa, equivalent to the overburden self-weight. A lateral pressure coefficient of 0.8 was incorporated to account for in-situ stress conditions. Geomechanical parameters of coal and rock formations are tabulated in Table 1.

Table 1. Multi-element analysis of ore

Lithology	Density/ ($kg·m^{-3}$)	Bulk modulus/ (GPa)	Shear modulus/ (GPa)	Cohesion/ (MPa)	Internal friction angle/ (°)	Tensile strength / (MPa)
Coal	1390	1.1	0.8	1.5	28	0.5
Fine sandstone	2670	2.46	2.26	2.4	33	3.5
Siltstone	2690	2.56	2.51	2.4	33	3.5
Fine-grained sandstone	2670	2.71	2.49	2.1	26	3.45
Medium-grained sandstone	2590	2.84	2.71	2.3	36	3.56
Coarse-grained sandstone	2752	2.87	2.79	2.5	30	3.5
Sandy mudstone	2570	1.79	2.43	2.9	34	3.04

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A 30m coal pillar was installed between adjacent panels in the 3-1 coal seam. In the numerical model, following initial stress equilibration, the 3-1 coal seam goaf was sequentially excavated in 20m increments. Each mining step was followed by stress re-equilibration calculations before proceeding to subsequent excavations. The mining sequence configuration is presented in Fig. 3.

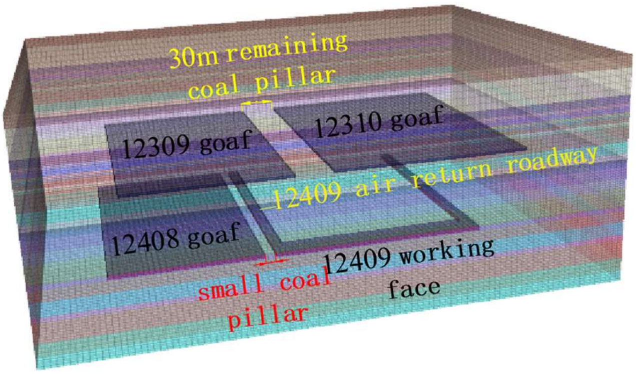


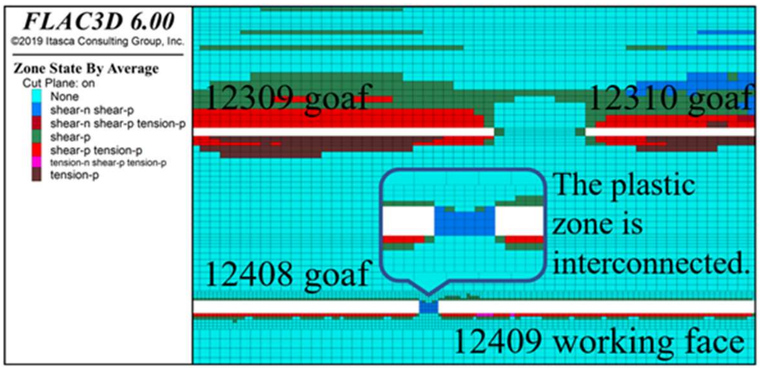
Fig. 3 Working face layout diagram

3.2 Evolution Law of the Stress of Coal Pillars with Different widths During the Mining Period

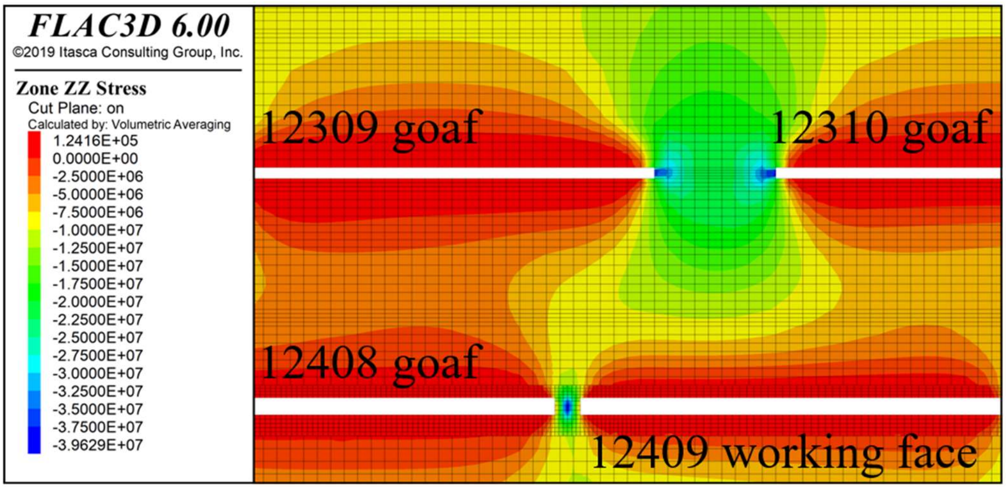
To systematically assess the stability of varying-width coal pillars under dynamic mining conditions, a transverse section perpendicular to the Y-axis was established 60m from the 12409 working face return airway opening. This observation plane enabled continuous monitoring of plastic failure zone distributions within the small coal pillar and stress propagation patterns during the mining progression.

As presented in Fig. 4 (a), which illustrates the plastic failure zone distributions of the 6m narrow coal pillar, intact elastic zones with robust bearing capacity are denoted by blue regions, while other color gradations indicate varying degrees of rock mass damage. For the 6m pillar configuration, continuous plastic failure zones are observed across both pillar sides, indicating the absence of stable load-bearing structures within the coal pillar. This results in a fragmented mechanical state dominated by shear failure mechanisms.

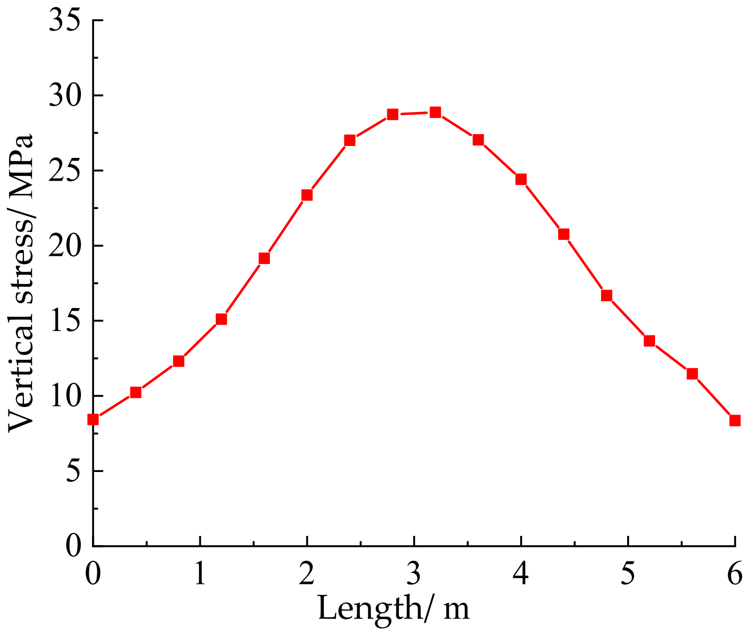
Notably, Fig. 4(b) and (c) show vertical stress profiles through the 6m coal pillar, revealing significant stress concentration phenomena at 2.5~3.5 m intervals. As the pillar width increases, peak stress magnitudes rise to 38.8 MPa, yet the overall stress distribution retains a "single-peak" profile. This indicates that even with increased width, the coal pillar fails to achieve stable load-bearing capacity under these mining conditions.



(a) Distribution of the plastic zone of the 6 m small coal pillar



(b) Vertical stress distribution of the 6 m small coal pillar



(c) Vertical stress distribution curve of the 6 m small coal pillar

Fig.4 6 m small coal pillar plastic zone and stress distribution

As depicted in Fig. 5 (a), which illustrates the plastic failure zone distributions of the 8 m narrow coal pillar, intact elastic zones with robust bearing capacity are denoted by blue regions, while other color gradients represent progressive rock mass degradation. For the 8 m pillar configuration, a continuous elastic core zone measuring approximately 2 m in length (constituting 25% of the total pillar width) is observed. This indicates improved load-bearing potential compared to narrower pillars.

Notably, Figs. 5(b) and (c) show vertical stress profiles through the 8 m coal pillar, revealing localized stress overlaps within the pillar body. Under these conditions, the stress distribution transitions from a "single-peak" to a "saddle-shaped" profile, with a peak abutment pressure magnitude of 30.3 MPa. The incomplete stress superposition on both pillar sides suggests the existence of a stable load-bearing structure. Therefore, the 8 m coal pillar configuration is deemed suitable for maintaining stable mining operations in the 12409 working face.

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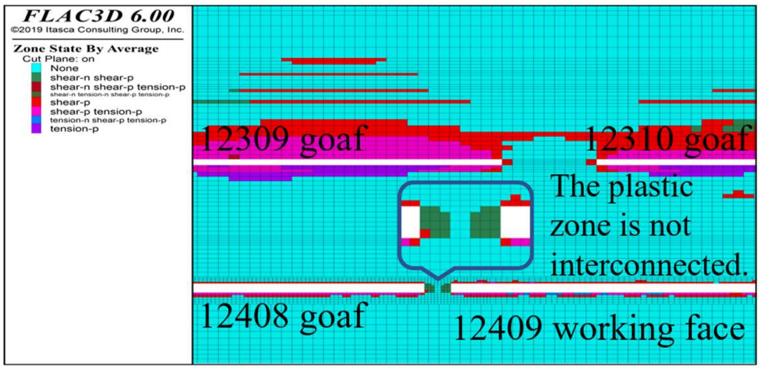
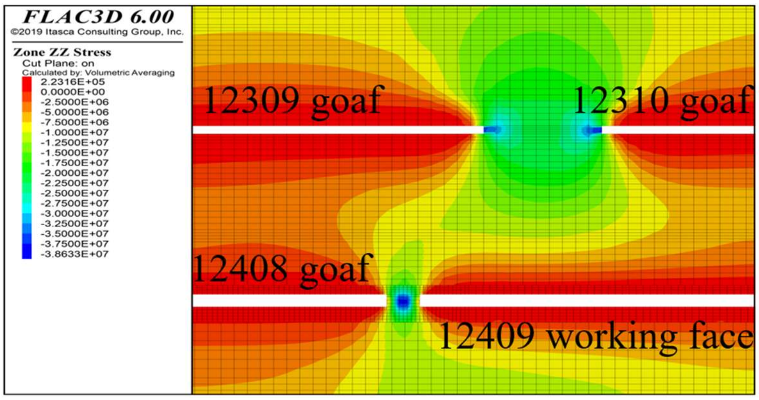
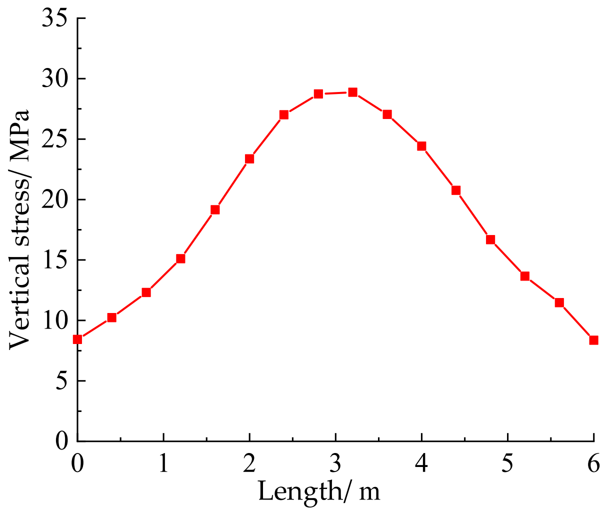


(a) Distribution of the plastic zone of the 8 m small coal pillar



(b) Vertical stress distribution of the 8 m small coal pillar



(c) Vertical stress distribution curve of the 8 m small coal pillar

Fig.5 8 m small coal pillar plastic zone and stress distribution

Analysis of the 6 m and 8 m small coal pillars reveals the following: For the 6 m small coal pillar, the plastic zones on both sides are connected, there is no stable load-bearing structure, and shear failure is the main failure mode. Stress concentration occurs at the 2.5~3.5 m section, with a peak stress of 38.8 MPa. The stress curve shows a single-peak shape, indicating that the coal pillar has lost its stability.

In contrast, the 8m narrow coal pillar exhibits a continuous elastic core zone measuring 2m in length, constituting 25% of the pillar width. This structural characteristic promotes a stress redistribution pattern transitioning from a single-peak to a saddle-shaped profile, with a peak abutment pressure of 30.3 MPa. The incomplete stress superposition on both pillar flanks indicates the formation of a stable load-bearing structure capable of supporting mining operations. Based on comprehensive stress analysis and deformation behavior, the 8m pillar dimension is determined to be the optimal configuration for ensuring safe production in the 12409 working face.

4. Conclusion

This study establishes a numerical simulation framework for optimizing coal pillar design in subsequent mining of closely spaced coal seams. Through systematic comparison of plastic failure zone distributions and vertical stress profiles across varying pillar dimensions, it reveals that the 8m narrow coal pillar maintains a continuous elastic core zone. This structural feature promotes a stress transition from a single-peak to a saddle-shaped profile, ensuring adequate load-bearing capacity for safe mining operations in the 12409 working face.

Acknowledgments

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