

Study on Optimization of Shallow Section Coal Pillar Width of Gently Inclined Medium-Thickness Coal Seam

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Abstract. This paper takes a coal mine gently inclined medium-thickness coal seam as the object. Firstly, the principal stress characteristics and displacement characteristics of roadway surrounding rocks after roadway driving along goaf under section columns with different breadths were analyzed by simulation method, and the roadway stability was evaluated to determine the reasonable breadth. The results show that when the breadth of column is 4 m, the Mohr stress circle of the pillar intersects the strength envelope and the roof and side displacement of roadway are significant; when the breadth is 6 m, the Mohr stress circle on both flanks of the pillar intersects at the strength envelope and the roof and side displacement of roadway are significant; when the breadth is 8-12 m, the Mohr stress circle of surrounding rock is separated from the strength envelope and the surrounding rock displacement meets the production needs. Therefore, it is in a stable state. 8-12 m is the reasonable width range of coal pillar. Secondly, through the actual project verification, the 8 m wide coal pillar is the most reasonable for the shallow part of the gently inclined medium-thickness coal seam.

Keywords. Medium-thickness coal seam, section coal pillar, principal stress, displacement of surrounding rock.

1. Introduction
Firstly, the optimized section pillar improves the roadway safety by changing the stress of roadway. Moreover, the coal pillar with traditional experience can be avoided and the coal recovery rate is improved. The world has rich coal resources and large coal output in the shallow and medium-thickness seam with gentle dip. Therefore, the discussion on the breadth of shallow section column in the medium-thickness seam with gentle dip is of great significance for guaranteeing people’s life safety and preventing property loss.

Extensive studies of coal pillars have been carried out. Prassetyo, Simon Heru et al. [1] put forward a reckoning method of coal pillar strength. Das, Arka Jyoti et al. [2] obtained a generalized strength formula for predicting inclined coal pillars. Fuxing Jiang et al. [3] ascertained the reasonable width of the section pillar of superhigh seam under deep mine. van der Merwe, J. N. [4] proposed the coal pillar strength equation including time. Hegang Qi et al. [5] obtained the influence of section coal pillars under concentrated load on the stability of roadway surrounding rocks in deep regions. Mo, S. et al. [6] obtained the relationship between the force characteristics of the pillar under the viscous and non-viscous backfill and the ratio of the pillar width to the mining height. Zhujun Yang [7] reduced the additional load of key blocks of overlying strata on the section coal pillar. Frith, Russell et al. [8] proposed a coal pillar design method to reinforce the overlying rock in the goaf. Jie Zhang et al. [9]
analyzed and evaluated the column stabilities with different breadths. Ruifu Yuan et al. [10] obtained the distortion and wreck traits of overlying rocks and coal pillar sections in goaf after mining in inclined coal seam. Mark, Christopher et al. [11] invented design software for coal pillar size. Jingkai Li et al. [12] made a comparative analysis on the stability of unilateral and bilateral mining of working faces under different pillar widths. Kexue Zhang et al. [13] obtained the calculation method for the breadth of small columns when mining large columns. Kumar, Ashok et al. [14] obtained the performance parameters of deep coal pillars in deep mines in the Czech Republic. Xueliang Zhang [15] carried out optimization of section coal pillar in xinyao upper coal mine to improve coal production rate. Jawed, Mohammad et al. [16] obtained the feasibility study of deployment of Side Discharge Loader when using diamond pillars in goafs of steep coal seams. Xihua Hou et al. [17] evaluated the rationality of section coal pillar size. Seryakov, V. M. et al. [18] analyzed the stress state of newly assembled rooms on coal face. Chong Shi et al. [19] ascertained the dimension of section column under coal face mining, so as to improve the coal extraction rate. Ghosh, Nilabjendu et al. [20] optimized the chain column array in the longwall mining of multiple coal seams.

Abundant achievements have been made in the research of section coal pillar, but there are few researches on the optimization of the width of section pillar in the shallow part of gently inclined medium-thickness seam. In the analysis of rock stress, the combined influence of the maximum and small principal stresses in Mohr Coulomb criterion is ignored, which makes the analysis of rock stress inaccurate. The medium-thick coal seam of a coal mine as the object, this paper USES simulation software to simulate the initial field, roadway excavation and support, working face mining, and excavation and support of adjacent working face transport roadway, analyzes the main stress and displacement characteristics of wall rock, and determines the optimal breadth of section column. Finally, the conclusion is verified by practical engineering. The research conclusion provides reference for similar coal pillar retention in shallow section of gently inclined medium-thickness coal seam.

2. Overview of Research Area
The terrain of the study area is relatively flat, belonging to the north temperate territoriality drought climate zone, with small precipitation and large evaporation. The average annual temperature is 5.87°C. From June to August, the average temperature is 21.7°C, the highest temperature is +35.3°C, and the lowest temperature is -27.6°C. From the beginning of November to the end of March of the following year, the average temperature was -12.38°C and the lowest temperature was -32.2°C. The water resources in the study area are mainly supplied by precipitation. The coal-bearing geosphere in the study area are composed of mudstone, sandstone and coal-rock. The working faces of 10 012 and 10 013 are located in the no.3 seam. The medium thickness of the coal bed is 3.1 m. The inclination is in the north and the dip Angle is 9° ~ 13°. The geological structure is relatively simple.

The return air tunnel of working face no. 10 012 is squareness. Its width is 4 300 mm. Its height is 3 100 mm. The transport roadways of working faces no. 10 012 and no. 10 013 are squareness. Their width are 4 100 mm. Their width are 3 100 mm. The anchor cables at the top of the roadway are steel strands. Its diameter is 17.8 mm. Its height is 10 000 mm. The distance between the anchor cables is 800 mm.

3. Numerical Model and Material Parameter
First, the numerical simulation Fast Lagrangian Analysis of Continua 3D software was used to simulate the mining of no. 10 012 forefield. Secondly, the software was used to demonstrate the excavation and support of the transportation roadway of no.10 013 forefield under the column breadth is 4 m, 6 m, 8 m, 10 m and 12 m, the main pressure and shifting analysis of the surrounding rock of the transportation roadway are carried out, so as to provide a numerical analysis basis for determining the pillar breadth. In figure 1, the numerical simulation model of the study area is 150 m long, 110 m wide and 120 m high, with 160 896 nodes and 117 900 elements. In this model, the return air roadway is a rectangular section. Its width and height are 4 700 mm and 3 100 mm. The rectangular section width and height of the transport roadway are 4 300 mm and 3 100 mm respectively. In order to
advance the accuracy of the analysis, grids are generated according to the principle that the closer to
the key research objects, the denser the grids are. The top surface of the mould is free surface, and the
bottom and the periphery are fixed with the consideration of the influence of coal face mining.

![Figure 1](image)

**Figure 1.** Numerical simulation model.

In this numerical simulation, the rock and soil mass adopts Mohr Coulomb constitutive relation and
elastic-plastic model. The density of the rock and soil is 961~2637 kg/m³, the internal friction angle is
15°~33°, the cohesion is 0.7~3.7 MPa, and the poisson's ratio is 0.23~0.36.

4. Analysis of Numerical Model Results
Firstly, the initial stress field equilibrium is calculated by numerical simulation software. Secondly, the
simulation software is used to calculate the backdraft roadway and transportation roadway excavation
and support of no. 10 012 coal seam working face. Then, the mining of no. 10 012 coal seam working
face is simulated by simulation software. Finally, the excavation and support simulation calculation of
no. 10 013 coal face transportation roadway is carried out.

4.1. Principal Stress Analysis
According to Mohr-Coulomb linear strength criterion of rock and soil mass it is found that the
maximum and small principal stresses of rock and soil mass can reflect the shear failure state of rock
mass. When the Mohr pressure circle ensured by the principal stress intersects the strength envelope,
the rock is in shear failure state. When the circle and the envelope is tangent, the rock is safety. When
the circle and the envelope is divided, the rock is safe. The principal stress difference of rock can
reflect the circle size, and the position relationship between the circle and strength envelope can be
determined by combining the minimum principal stress. the stability of transportation roadway can be
analyzed and evaluated.

The software simulated the mining of no. 10 012 forefield and the excavation and support
simulation of transportation roadway of no. 10 013 working face when the section coal pillar width
was 4 m, 6 m, 8 m, 10 m and 12 m, and the main stress difference diagram below diverse pillar widths
is obtained as shown in figure 2.
Figure 2. Principal stress difference with coal pillar of different widths.

1) Stress concentration occurs in the coping of solid coal side and the bottom of coal column side. The stress concentration degree at the bottom corner of section column side of roadway is more evident than that at the top corner of solid coal side, indicating that the molar stress circle radius at the bottom corner of section column side is larger. The main stress dissimilarity between the roof and floor is significantly smaller than that of surrounding rocks, and the Mohr stress circle radius is small.

2) Stress concentration appears on side of roadway. Follow the breadth decreases, the maximum principal pressure difference at the pillar magnifies, the coal pillar changes from two stress concentration areas to a single stress concentration area, and the proportion of pressure accumulation area in the section pillar increases.

In order to accurately analyze the main stress difference on pillar, the direction of the tunnel width is taken as the direction of the monitoring line. The midpoint of the side wall of the section column of the return air tunnel of no. 10 012 working face was set as the initial monitoring point, and the distance was 1 m. The main stress difference of the monitoring points under different widths is revealed in figure 3.

Figure 3. Principal stress difference curve of monitoring points with coal pillar of different widths.
(3) As the breadth decreases, the main pressure difference curve of the section column changes from a bimodal state to a single peak state, the main stress difference at the peak of the curve increases gradually, and the main stress difference at the valley bottom increases gradually. The proportion of the concentrated area of the main stress difference in the column increases. The Mohr stress circle in the section column increases with the width decrease. The main stress difference of solid column has no significant change with the breadth change.

(4) When the breadth decreases from 12 m to 8 m, the curve emerges a bimodal state and the supreme main pressure dissimilarity increases slightly. When the breadth decreases from 8 m to 4 m, the curve gradually emerges an isolated peak state and the maximum principal pressure dissimilarity increases greatly, indicating that the breadth is 4 m and 6 m, the section column is prone to failure and the roadway is prone to instability.

The simulation software was used to conduct the mining and supporting simulation of the transport roadway of no. 10 012 working face and no. 10 013 working face, and the minimum main stress diagram under coal columns of diverse breadthes is displayed in figure 4. By analyzing the variations of the minimum principal pressure and combining the research results of principal stress difference, the deformation and failure state of circumjacent pena is explicit, and the stability of circumjacent pena is evaluated.

\[ \text{Figure 4. Minimum principal stress with coal pillar of different widths.} \]

(1) The tensile stress and principal stress difference of rocks in the middle of grotto headpiece is small, and the pull pressure of rocks here is concentrated. At the same time, due to the low tensile strength of rocks, the rock in the middle of roadway roof is prone to fracture failure.

(2) On the superjacent of the noumenal coal side and the underside of the section pillar side, the molar stress circle formed intersects with the strength envelope line, indicating that the rock at the corner corner of the roadway has shear fracture phenomenon.

(3) The stress concentration phenomenon occurs at the section pillar of roadway. With the breadth decreases, the concentrated stress and the area of concentrated stress at the section coal pillar gradually decrease, indicating that the average minimum main pressure decreases, while the main pressure dissimilarity increases. Therefore, the shear failure phenomenon occurs easily with the breadth decrease. For the solid coal side of roadway, as the breadth decreases, the concentrated stress and the area of concentrated stress at the solid coal side gradually increase, indicating that the minimum principal stress at the noumenal coal side is large, and the main pressure dissimilarity does not transform significantly. So the coal seam at the solid coal side of roadway is in a stable state.
In order to obtain more accurate stability analysis and evaluation results of roadway surrounding rock, the graph of minimum principal stress at monitoring points with different breadths is drawn in figure 5. The minimum principal stress is analyzed, and the state of circumjacent rock is identified by combining the results of main pressure dissimilarity, and the stability of roadway is evaluated.

![Figure 5](image)

**Figure 5.** Minimum principal stress curve of monitoring points with coal pillar of different widths

(1) For the noumenal coal side of the roadway, when the width is 8 m, 10 m and 12 m, the change of the minimum main pressure and main pressure dissimilarity is not significant, and the molar stress circle is separated from the strength envelope. Therefore, the rock is in a safe state and the surrounding rocks at the solid coal side are stable. When the breadth is 4 m and 6 m, the minimum main pressure of the noumenal coal side does not change significantly, the principal stress difference is concentrated significantly, and the molar stress circle intersects at the strength envelope line. Therefore, the noumenal coal is in a state of instability.

(2) For the section coal pillar, the curve is a isolated peak. When the breadth is reduced from 12 m to 8 m, the minimum principal pressure of the section pillar does not change significantly, the radius of pressure circle is small, and the mohr pressure circle and strength envelope are separate. The section pillar is stable state. When the breadth drops from 8 m to 4 m, the minimum principal stress at the single peak decreases significantly. However, the stress circle radius determined by the principal stress difference is large, and mohr stress circle intersects at the strength envelope line. Therefore, the section column is failure state and the circumjacent rock is unstable.

4.2. Analysis of Circumjacent Rock Displacement
In order to more intuitively analyze transport roadways under different coal pillars, the displacement curves of circumjacent rocks under different breadths are displayed in figure 6.
Figure 6. Displacement of roadway surrounding rock with coal pillar of different widths.

1) The surface deviation of circumjacent rock is negatively correlated with the breadth, and the ostensible deviation gradually increases as the breadth decreases. The increment of grotto head is the most slow.

2) The subsidence phenomenon of roadway roof is the most significant. The deflection roadway displacement of surrounding rock at the section column side of roadway is sharper than that at the solid coal side. The floor heave is the smallest.

3) When the breadth of section column is 8-12 m, the displacement of circumjacent rock is within the allowable range. When the breadth is 6 m and 4 m, the deviation of head and flank wall is significant, and the stability of roadway is shameful, so this roadway is difficult to serve the mining work of coal seam face for a long time.

5. Engineering Practice Verification
In order to expatiate the idoneity of optimal width of shallow section coal pillar of gently inclined medium-thickness coal seam in the study area. The transport roadway of no. 10 013 forefield in the study area is proposed as the monitoring object to survey the displacement, and the separation degree of roadway roof at the same time; Floor monitoring is not carried out because the floor of the roadway is frequently treated. The first 30 m in the heading direction was taken as the first measuring station, with an interval of 20 m. Three test stations were set up, with the depth of 1.8 m for shallow monitoring points, 7 m for deep monitoring points and for 80 day mine pressure monitoring.

1) The surface displacement of the roof of the transport roadway was 83 mm, the surface drift of the noumenal coal side was 39 mm, and the surface drift of the sect column side was 72 mm. It shows that the current supporting scheme makes the roadway surface stable.

2) The separation amount of the shallow monitoring point on the roof of the transport roadway was 32mm, and that of the deep monitoring point was 56 mm. It shows that the current supporting scheme can efficaciously prevent the roof from uncoordinated distortion and failure, and prevent the rock from sudden failure.

According to the analysis of the actual monitoring results, when the width is 8 m and the circumjacent rock adopts the existing supporting scheme, the boundary of circumjacent rock is in a stable state and the sudden failure of the roadway roof can be prevented, so the circumjacent rock presents a consummate state and the coal recovery rate is improved.

6. Conclusion
(1) When the breadth of section pillar is 8-12 m, the molar stress circle of circumjacent rock is separated from the strength envelope, so the circumjacent pena is in a stable state. When the width is 6 m, the molar stress circles of both flanks of the grotto are intersected at the strength envelope line. These characteristics are not conducive to the long-term bearing capacity of the section column, so the circumjacent rock has poor stability. When the width is 4 m, the molar stress circle of the section
column intersects at the strength envelope line, the whole shear failure of the column occurs. Therefore, the circumjacent pen is in a state of instability.

(2) When the breadth of section column is 8-12 m, the displacement of surrounding rock is within the allowable range. When the breadth is 6 or 4 m, the head and side displacement of the grotto are significant, and the circumjacent pen is poor, which makes it difficult to serve the mining work of the coal seam face for a long time.

(3) From the stress and displacement analysis of the circumjacent pen, The 8-12 m is the reasonable breadth range of the section column. The application of practical engineering shows that when the breadth is 8 m, the deformation and failure of surrounding rock can be effectively controlled, and the coal productivity and recovery rate can be improved to the maximum extent. 8 m is the optimal width of section coal pillar.

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