Field and simulation study of the rational retracement channel position and control strategy in close-distance coal seams

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Funding information
Yue Qi Distinguished Scholar Project, Grant/Award Number: 800015Z1138; China Scholarship Council, Grant/Award Number: 202106430048; National Natural Science Foundation of China, Grant/Award Number: 51974317; China University of Mining and Technology, Beijing, and the Fundamental Research Funds for the Central Universities, Grant/Award Number: 800015J6

Abstract
Different from single coal seam mining, the stress evolution in the end mining stage of close-distance coal seams is extremely complex. The unreasonable position and support of the lower retracement channel will cause serious deformation and damage to the surrounding rock. Taking the Yanzishan coal mine as the engineering background, the deformation and failure characteristics of the retracement channel under different overlay environments and the key influencing factors of position design were discussed by numerical simulation, theoretical analysis, and field investigation. The results show that the coupling superposition of upper coal pillar high stress and mining dynamic pressure will form a dangerous area with severe ground pressure behavior. The retracement channel should be preferentially designed in zone A (overlying mining roadways), followed by zone B (overlying end-mining coal pillar), and finally, zone C (overlying section coal pillar). In addition, the rational horizontal distance between the lower retracement channel and the upper end-mining coal pillar should make the channel in a good stress environment. The safety distance between the retracement channel and the nearest main roadway (end-mining coal pillar width) should be greater than the severe range of advance abutment pressure. Finally, the design principle and control strategy for the lower retracement channel is proposed. The feasibility and rationality of the study are verified by industrial applications.

Keywords
close-distance coal seams, deformation, end mining stage, mining dynamic pressure, partition control, residual coal pillar, retracement channel

1 | INTRODUCTION

In recent years, with the expansion of mining intensity, the Jurassic coal resources in Datong coalfield are being increasingly depleted, and the deep Carboniferous-Permian coal seams are highly valued.1,2 Carboniferous-Permian minable coal seams are characterized by large buried depth, multiple layers, small spacing, and great thickness, so the close-distance coal seams are abundant in the Datong mining area.3

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Longwall comprehensive mechanized top coal caving mining (LCMTCCM) is widely used in thick and extra-thick coal seams in China. In the LCMTCCM system, a large cross-section channel parallel to the working face is used to turn and retrace equipment during the final mining period. The large cross-section channel is called the retracement channel, and the virgin coal between the retracement channel and main roadways is called the end-mining coal pillar. There are two types of retracement channels during the end mining of fully mechanized top coal caving face: pre-excavation retracement channel and using coal cutter to excavate retracement channel. The pre-excavation retracement channel technology has advantages in improving the recovery speed of equipment of old working faces. However, when the working face is close to the retracement channel, the channel will suffer serious dynamic load. Therefore, the pre-excavation retracement channel technology is suitable for coal mines with simple and good geological production conditions. The 4# and 3# coal seams of the Yanzishan (YZS) coal mine are close-distance thick coal seams with complex geological conditions. Moreover, repeated mining destroys the integrity of surrounding rock. Therefore, the technology of excavating retracement channel by coal cutter is used in the YZS coal mine.

In the past decades, numerous beneficial studies have been carried out on the surrounding rock control of retracement channels. According to the spatial relationship between retracement channel and main roof fracture line, Wang et al. divided the main roof fracture into four categories and concluded that the roof fracture above the gob is most conducive to the stability of surrounding rock. By establishing the roof cantilever beam model, Ma et al. used hydraulic roof cutting technology to shorten the suspension length of the roof and realize the control of the retracement channel. Feng et al. studied the relationship between end-mining coal pillar width and main roadways stability by numerical simulation. Obviously, the above achievements mainly focus on single coal seam mining, and pay little attention to the relationship between retracement channel and main roadways. However, in the mining of close-distance coal seams, a large number of coal pillars and gobs were left in the upper coal seam, leaving the lower coal seam completely stressed. When the working face advances to the area affected by the coal pillars, the mining pressure increases the stress concentration of residual coal pillars, and then the instability of the coal pillars may cause rockburst and threaten the safety of the working face. Specifically, the high stress of the upper coal pillar and the mining pressure of the lower working face are coupled and superimposed, resulting in serious deformation and damage of the retracement channel. In addition, the position of the retracement channel determines the stress environment of itself and main roadways, so it is one-sided to study the stability of the retracement channel or main roadways alone. Therefore, the design principle of the lower retracement channel and its control strategy has become an urgent problem to be solved.

In view of the above problems, the YZS coal mine was chosen as the engineering background. We systematically discussed the deformation and failure characteristics of the N0381 retracement channel, the load transfer law of the residual coal pillar, and the severe range of advanced abutment pressure. Finally, the design principle and control strategy for the lower retracement channel was proposed, and a successful practice was carried out in N0381 working face.

2 ENGINEERING BACKGROUND

2.1 Geological and mining conditions

YZS coal mine is in Datong City, Shanxi Province, China. The 3# coal seam is being mined at present; its average thickness, dip angle, and buried depth are 5.3 m, 2°, and 430 m, respectively. Twenty-five meter above the 3# coal seam is the mined 4# coal seam. The 4# coal seam has an average thickness of 7.5 m and an average dip angle of 3°. The working face layout of 3# and 4# coal seams is shown in Figure 1.

As shown in Figure 1, various types and sizes of protective coal pillars were left in the 4# coal seam. An unreasonable retracement channel position will cause the following risks: On the one hand, under the double disturbance of upper coal pillar high stress and mining pressure, the lower coal seam will suffer serious dynamic load. Therefore, the pre-excavation retracement channel technology is suitable for coal mines with simple and good geological production conditions.
pressure, lower retracement channel has serious deformation and damage, such as roof falling, coal rib spalling, and supporting structure damage. On the other hand, when the distance between the retracement channel and main roadways is too short (end-mining coal pillar width is too small), the severe advance abutment pressure is not conducive to the long-term stability of main roadways. In addition, restricted by the layout of the 3# coal seam, it is inevitable that there will be retracement channels under the coal pillar. Therefore, the control strategy of lower retracement channels with different stress environments becomes another key problem to be resolved.

2.2 Typical case

N0381 working face of 3# coal seam was chosen as a case to determine the reasonable position and control strategy of the retracement channel. N0381 working face adopts LCMTCCM technology, with a mining height of 3.2 m and a caving height of 2.1 m. Its tendency and strike lengths are 180 and 2517 m. Limited by the mining technology, various sizes of coal pillars, gobs, and roadways were left in 4# coal seam (Figure 2). Specifically, a 38 m-wide section coal pillar was left between N0481 and N0482 gobs, and the horizontal distance
between the coal pillar and N0381 tailgate is 30 m. In addition, the width of N0481 and N0482 end-mining coal pillars are 261 and 164 m, respectively. The vertical distance between 3# and 4# coal seam is 25 m, and there is a key layer dominated by medium-fine sandstone. The stratigraphic column of the N0381 working face is shown in Figure 3.

As shown in Figure 2, the position of the N0381 retracement channel is divided into zone A, zone B, and zone C. For zone A, the overlay environment of the N0381 retracement channel is mostly solid coal, and there are only two mining roadways (the width and height are 4 and 3.3 m). For zone B, there are 150 m wide coal pillar, 30 m wide gob, and N0481 tailgate above N0381 retracement channel. For zone C, there are 112 m wide N0481 gob, 38 m wide coal pillar, and 30 m wide N0482 gob above N0381 retracement channel.

3 | NUMERICAL SIMULATION ANALYSIS ON DEFORMATION AND FAILURE MECHANISM

3.1 | Numerical model setup

A numerical model was established to simulate the deformation and failure of the N0381 retracement channel under different overlay environments. As shown in Figure 4, the model size was 400 m × 280 m × 72 m. The grids near the 38 m coal pillar are refined (1 m/grid), and the other grids are 5 m/grid. The model consisted of 3,066,720 zones and 3,149,208 grid points in total. The horizontal and vertical displacements of the bottom boundary were fixed and the horizontal displacement of the model sides was fixed. The vertical stress of 9.25 MPa was applied to the model top to simulate the overburden pressure. The lateral pressure coefficient was set as 1.2. In addition, 9.80 N/kg gravity acceleration was applied. A large deformation option was turned on in the simulation. The double-yield constitutive was used for gob gangue. The strain-softening and the Mohr-Coulomb models were used for coal seams and other strata, respectively.

In the numerical model, three types of retracement channel positions were designed in the lower coal seam, corresponding to zone A, zone B, and zone C. When the gob is about 0.12–0.3 times of the buried depth from the edge of the coal pillar, the gob will restore the original rock stress state. The mining experience of the YZS coal mine shows that the gob gangue reaches an in situ stress state 55 m away from the edge of the coal pillar. The specific parameters are shown in Figure 4.

3.2 | Rock mass parameters and constitutive models

(1) Coal and rock mass parameters

The premise of FLAC3D to successfully simulate coal mine engineering cases is to input reasonable coal and rock mass parameters. To determine the physical and mechanical properties of coal and rock, the on-site samples were processed to form standard specimens, and a series of laboratory tests, such as shear strength and uniaxial compression, were carried out to obtain the intact coal and rock parameters. However, the fractures and joints could reduce the strength of rock mass; the laboratory parameters obtained from intact rock cannot be directly used in numerical simulation. In this paper, the laboratory parameters were revised to coal and rock mass parameters by Roclab. The coal and rock mass parameters are shown in Table 1.
(2) Strain-softening model parameters

The strain-softening constitutive model divides the failure of coal into three phases: elastic phase, plastic phase and residual phase (Figure 5). Compared with the perfect elastic-plastic model, the strain-softening model is more consistent with the progressive failure of coal. Therefore, the strain-softening constitutive was used for 3# and 4# coal seams. The strain-softening parameters were obtained from laboratory tests, as shown in Table 2.

(3) Double-yield model parameters

With the movement of overlying strata, the gap of gob gangue will be gradually compacted, and its mechanical properties will appear. Feng et al. point out that the data obtained by double-yield constitutive are in good agreement with Salamon’s equation, and the results show that the double-yield model can effectively reflect the loading characteristics of gob gangue. Therefore, the double-yield model was used to simulate the mechanical properties of gob gangue. The double-yield parameters were obtained by using trial and error, as shown in Tables 3 and 4.

(4) Numerical model validation

The surrounding rock convergence of N0381 tailgate obtained from field measurement and numerical simulation were compared to verify the correctness of the input parameters. Figure 6 shows that the deformation of the N0381 tailgate obtained by numerical simulation and field measurements has similar trends. Specifically, they increase as the distance from the N0381 working face decreases. As the N0381 tailgate in the numerical model is without a support structure, so the surrounding rock deformations are larger than the field measurement. However, the simulation dates are very close to the field

### Table 1: Coal and rock mass parameters

| Lithology           | $m_i$ | $D$ | GSI  | $\sigma_i$ (MPa) | $E_m$ (GPa) | $K$ (GPa) | $G$ (GPa) | $\Phi$ (°) | $c$ (MPa) | $\nu$ |
|---------------------|-------|-----|------|------------------|-------------|-----------|-----------|------------|-----------|------|
| Coarse sandstone    | 16    | 0.8 | 72   | 0.50             | 21.29       | 11.83     | 8.87      | 48.6       | 2.70      | 0.20 |
| Fine sandstone      | 10    | 0.8 | 62   | 0.17             | 8.91        | 5.12      | 3.68      | 35.2       | 1.27      | 0.21 |
| Siltstone           | 11    | 0.8 | 64   | 0.17             | 9.47        | 5.85      | 3.85      | 36.1       | 1.32      | 0.23 |
| 4# coal seam        | 5     | 0.8 | 40   | 0.03             | 1.90        | 1.22      | 0.77      | 16.3       | 0.42      | 0.24 |
| Medium-fine sandstone| 12   | 0.8 | 66   | 0.28             | 13.08       | 7.78      | 5.36      | 41.0       | 1.74      | 0.22 |
| Kaolinite rock      | 7     | 0.8 | 53   | 0.07             | 4.42        | 2.73      | 1.80      | 25.3       | 0.75      | 0.23 |
| Conglomerate        | 14    | 0.8 | 68   | 0.22             | 12.86       | 7.39      | 5.31      | 41.2       | 1.68      | 0.21 |
| Fine sandstone      | 10    | 0.8 | 62   | 0.15             | 8.51        | 5.06      | 3.49      | 34.5       | 1.22      | 0.22 |
| Carbonaceous mudstone| 7    | 0.8 | 47   | 0.05             | 3.30        | 2.03      | 1.34      | 23.3       | 0.66      | 0.23 |
| 3# Coal seam        | 5     | 0.8 | 33   | 0.01             | 1.20        | 0.77      | 0.49      | 13.2       | 0.31      | 0.24 |
| Carbonaceous mudstone| 7    | 0.8 | 47   | 0.05             | 3.29        | 2.03      | 1.34      | 23.3       | 0.66      | 0.23 |
| Kaolinite rock      | 7     | 0.8 | 53   | 0.07             | 4.42        | 2.83      | 1.78      | 25.3       | 0.75      | 0.24 |
| Medium-fine sandstone| 12   | 0.8 | 66   | 0.28             | 13.10       | 7.53      | 5.41      | 41.0       | 1.75      | 0.21 |

### Table 2: Strain-softening parameters

| Properties | $\varepsilon_p$ | $\varepsilon_f$ | $C_r$ (MPa) | $\Phi_r$ (°) |
|------------|-----------------|-----------------|-------------|-------------|
| Value      | 0.007           | 0.013           | 0.23        | 11.4        |

### Table 3: Material parameters

| Parameter | $\gamma$ (kg/m³) | $G$ (GPa) | $K$ (GPa) | $\varphi$ (°) | $\sigma_i$ (MPa) |
|-----------|------------------|-----------|-----------|---------------|-----------------|
| Value     | 1340             | 1.15      | 3.74      | 27            | 0               |
measurement results, and the error is less than 6.5%. This error meets the requirements of the engineering applications. In addition, the references show that the tensile strength, cohesion, and elastic modulus of coal and rock mass are about 0.1 – 0.25 times the laboratory test. The modified parameters in this paper agree with this conclusion. Therefore, the modified parameters by Roclab software can effectively reflect the field geological conditions.

3.3 | Analysis of simulation results

(1) Principal stress difference of surrounding rocks

The strain increment of coal and rock mass in the plastic state can be regarded as pure shear deformation, and the maximum shear stress plays a major role in the generation and development of plastic failure. By reflecting the distribution of shear stress, the principal stress difference can characterize the failure degree of the surrounding rocks. Therefore, the principal stress difference \((\sigma_1 - \sigma_3)\) is used to compare and study the relationship between N0381 retracement channel position (zone A, zone B, and zone C) and the surrounding rock stability.

Figure 7A shows the deformation and failure characteristics of the N0381 retracement channel under section coal pillar (zone C). The X-axis represents the mining direction of the working face, and Z-axis represents the vertical direction. It can be seen that the principal stress difference under the section coal pillar is approximately symmetrical. Four typical Sections I-1–I-4 correspond to coal pillar central, coal pillar edge, N0481 headgate, and gob, respectively. It can be seen that the roof principal stress difference in Section I-2 is the largest, followed by Section I-1 and Section I-3, and the minimum in Section I-4. The law of principal stress difference of coal rib is similar to the roof, but there is no obvious change in the floor. In summary, the superposition of high stress of upper coal pillar and mining dynamic pressure will aggravate surrounding rock damage. A trapezoidal dangerous area with a prominent principal stress difference is formed, and the bottom angles of the dangerous area are 73° and 60°, respectively.

The principal stress difference of the N0381 retracement channel under the end-mining coal pillar (zone B) is shown in Figure 7B. It can be seen that the principal stress difference law of the retracement channel in zone B is consistent with that in zone C (Figure 7A), that is, Section II-2 is the largest, followed by Section II-1 and Section II-3, and Section II-4 is the smallest. However, the peak range of principal stress difference in Section II-1–II-4 is reduced compared to Sections I-1–I-4. There are two reasons for this phenomenon: (a) The abutment stress on the end-mining coal pillar is less than that of the section coal pillar and (b) the Sections II-1–II-4 are far away from the middle of the retracement channel. In summary, there is also a dangerous area under the end-mining coal pillar, but its scope is about half of that under section coal pillar.

There are only two mining roadways (N0481 headgate and N0482 tailgate) above the retracement channel, as shown in Figure 7C. It can be seen that the stress concentration occurs around the mining roadways, but the influence range is only three to four times of roadway height. From the simulation results of finite element software FALC3D, the distribution of principal stress difference in Sections III-1–III-4 has no obvious change.

To visually compare the principal stress difference characteristics of surrounding rock in different stress environments, 10 roof survey lines were arranged at Sections I-2, II-2, and III-2. The peak stress and its position at different heights of the roof were counted.

| Strain | 0.00 | 0.01 | 0.03 | 0.05 | 0.07 | 0.09 | 0.11 | 0.13 | 0.15 | 0.17 |
|--------|------|------|------|------|------|------|------|------|------|------|
| Stress (MPa) | 0.00 | 0.53 | 1.78 | 3.37 | 5.44 | 8.26 | 12.34 | 18.76 | 30.30 | 57.23 |

FIGURE 6  Comparison between numerical simulation and field measurement
FIGURE 7  Principal stress difference of retracement channel with different overburden environments: (A) overlying section coal pillar (zone C), (B) overlying end-mining coal pillar (zone B), and (C) overlying mining roadways (zone A).
in Figure 8. Figures 8A,C, E show that the principal stress difference of roof in the three sections has similar distribution characteristics. Specifically, the principal stress difference of shallow roof (0–10 m) increases exponentially. With the increase of roof depth, the peak position shifts from coal rib to retraction channel. However, the peak value and peak position of principal stress difference in the three sections are different. The roof peak stress in Section I–2 is much greater than that in Section II–2 and Section III–2, and its position is closer to coal rib. The peak stress of the shallow roof (0–10 m) of
Section II-2 is roughly equal to that of Section III-2, but the deep roof is significantly larger than Section III-2 (Figure 8B,D,F).

Based on the above comparative study, the distribution law of principal stress difference of surrounding rock is mainly determined by the mining pressure of the working face, but the high stress of the upper coal pillar will aggravate the principal stress difference and make the peak position closer to coal rib.

(2) Vertical displacement of surrounding rock

Figure 9 shows the vertical displacement characteristics of the roof in typical sections (Sections I-2, II-2, and III-2). The displacement evolution of the roof is as follows:

(a) The vertical displacement distribution in the three sections is similar. From the gob side to the coal rib side, the roof deformation decreases approximately linearly, and the deformation tends to be stable above the coal rib.

(b) The roof subsidence of Section I-2 is the most serious, followed by Section II-2 and finally Section III-2. The maximum vertical displacement of the roof is 1061, 875, and 734 mm, respectively.

(c) Sections I-2 and II-2 show that the survey lines above retracement channel are almost overlapped, indicating that the deep roof is seriously damaged; in section III-2, the stability of deep roof is good.

4 | DESIGN PRINCIPLE AND CONTROL STRATEGY FOR LOWER RETRACEMENT CHANNEL

4.1 | Determine the reasonable position of the retracement channel

(1) Influence factors of retracement channel position

Based on the geological and mining conditions of the YZS coal mine, the position design of the lower
retracement channel should include the following aspects: (a) The priority of lower retracement channel position (zone A, zone B, and zone C). (b) The distance between the retracement channel and main roadways (end-mining coal pillar width) should not only improve the recovery rate of coal resources but also ensure the stability of the main roadways. (c) The reasonable staggered distance between lower retracement channel and upper end-mining coal pillar edge.

2) Advance abutment pressure of N0381 working face

Taking the working face under solid coal (zone A) as an example, the distribution law of advance abutment pressure is analyzed.

The monitoring of the advance abutment pressure is often carried out in headgate or tailgate. It is difficult to directly measure the advance abutment pressure from the middle of working face. However, the latter can better represent the advance abutment pressure of the whole working face. In addition, in the long-term operation of main roadways, the influence of rock creep on the advance abutment pressure cannot be ignored. In view of this, a safety factor \( k_3 \) is given to the measured data of the N0381 tailgate to reflect the advance abutment pressure of the whole working face. Three measuring stations were arranged in N0381 tailgate with an interval of 20 m. Every station includes two monitoring points, and the distance between shallow hole (8 m) and deep hole (14 m) is 5 m. The monitoring scheme and data are shown in Figure 10.

The stress value of the meters show a trend from decline to rise. When the distance between the N0381 working face and the monitoring point was 30 m, the advance abutment pressure increased significantly. According to the previous experience of the YZS coal mine, the safety factor is determined as 1.5. To avoid the hazard of mining pressure on main roadways, the retracement channel should be at least 45 m away from the main roadways.

(3) Load transfer model of upper end-mining coal pillar

The high stress formed in the edge of the upper end-mining coal pillar will be transmitted downward through floor rock. When the N0381 retracement channel is designed within the high-stress range, the double disturbance of coal pillar high stress and mining pressure will aggravate the deformation and failure of surrounding rock. A mechanical model was established to study the load transfer law of the upper end-mining coal pillar, as shown in Figure 11. The virgin coal of segment AB is far from the coal pillar edge, and its load is calculated as in situ stress;

![Figure 10](https://example.com/figure10.png)
the abutment stress range BD is simplified as two linear loads, and the stress of segment DE is simplified as a uniform load to simulate gob gangue.

According to the model, the load distribution function \( q(\eta) \) is obtained:

\[
q(\eta) = \begin{cases} 
\gamma H_2, & -l_0 \leq \eta \leq -l_1, \\
\gamma H_2 \left( \frac{K_1}{l_1 - l_2} \eta - l_1 \right), & -l_1 \leq \eta \leq -l_2, \\
-\frac{K_2 \gamma H_2}{l_2}, & -l_2 \leq \eta \leq 0, \\
K_2 \gamma H_2, & 0 \leq \eta \leq l_3,
\end{cases}
\]  

where \( K_1 \) is the peak stress factor of coal pillar, \( K_2 \) is the stress concentration factor of gob gangue, \( l_2 \) is the horizontal distance between peak position and coal pillar edge, \( l_1 \) is the range of abutment stress, \( l_1 \) and \( l_2 \) can be estimated as follows\(^4\):

\[
l_2 = \frac{m_2}{2f} \ln \left[ \frac{K_1 \gamma H_2 + C \cot \varphi}{C \cot \varphi} \right],
\]  

\[
l_1 = l_2 + \frac{m_2}{2f} \ln K_1,
\]

where \( m_2 \) is the mining height of 4# coal seam, \( H_2 \) is the average burial depth of 4# coal seam, \( \gamma \) is the average density of overburden, \( C \) is the cohesion of coal, \( \varphi \) is the internal friction angle of coal, \( f \) is the friction coefficient, \( \xi \) is the triaxial stress coefficient, which can be calculated by \( \xi = (1 + \sin \varphi)/(1 - \sin \varphi) \), \( \lambda \) is coefficient of horizontal pressure.

The stress at point \( M(x, y) \) in the floor can be expressed as\(^4\):

\[
\sigma_x = -\frac{2}{\pi} \int_{-l_0}^{l_3} \frac{y(x - \eta)^2 q(\eta) \, d\eta}{\left[ y^2 + (x - \eta)^2 \right]^2},
\]

\[
\sigma_y = -\frac{2}{\pi} \int_{-l_0}^{l_3} \frac{y^2 q(\eta) \, d\eta}{\left[ y^2 + (x - \eta)^2 \right]^2},
\]

\[
\tau_{xy} = -\frac{2}{\pi} \int_{-l_0}^{l_3} \frac{y^2 (x - \eta) q(\eta) \, d\eta}{\left[ y^2 + (x - \eta)^2 \right]^2}.
\]

The principal stress difference \( (\sigma_1 - \sigma_3) \) can be calculated by

\[
(\sigma_1 - \sigma_3) = 2 \sqrt{\left( \frac{\sigma_x - \sigma_y}{2} \right)^2 + \tau_{xy}^2}.
\]

The buried depth of 4# coal seam \( (H_2) \) is 400 m; the mining height of 4# coal seam \( (m_2) \) is 7.5 m; the average density of overburden \( (\gamma) \) is 2500 kg/m\(^3\); the cohesion \( (C) \) is 1.9 MPa; the internal friction angle \( (\varphi) \) is 34°; the friction coefficient \( (f) \) is 0.2; \( l_0 \) and \( l_3 \) are 40 m, and the stress concentration coefficient of coal pillar \( (K_1) \) and gob gangue \( (K_2) \) is 2.1 and 0.6. Substituting the above parameters into Formula (1)–(5), the principal stress difference distribution of 4# coal seam floor can be obtained by visualization software (Figure 12). Six survey lines are extracted from Figure 12, and the principal stress difference and its horizontal change rate are displayed (Figure 13).

![Load transfer model of end-mining coal pillar](image)

It can be seen from Figure 12 that the principal stress difference is highly concentrated under the end-mining coal pillar and transmitted downward at an angle. The principal stress difference decreases with the increase of floor depth, but its diffusion range increases significantly. Figure 13A shows that the principal stress difference presents a single peak within the floor depth of 20–30 m, and the horizontal distance between the peak position and the coal pillar edge is 10 m. Previous studies have shown that the surrounding rock is more prone to deformation and failure in an environment with a
(4) Design principle of lower retracement channel position

According to the analysis above, the principles for determining retracement channel position are summarized as follows: (a) The lower retracement channel should be preferentially designed in zone A (overlying mining roadways), followed by zone B (overlying end-mining coal pillar), and finally, zone C (overlying section coal pillar). (b) The safety distance between the retracement channel and the nearest main roadway should be greater than the range of advance abutment pressure. (c) The rational horizontal distance between the lower retracement channel and the upper end-mining coal pillar should make the channel in a good stress environment.

The safety factors \( (k_1, k_2, \text{and } k_3) \) are introduced, the formula for determining the position of the lower retracement channel can be expressed as follows:

\[
k_2S_2 + k_3S_3 < L_2,
\]

\[
\begin{cases}
k_2S_2 + k_3S_3 > L_2, \\
k_1S_1 + k_2S_2 < L_1 - L_2, \\
k_3S_3 - k_3S_3 < L_2,
\end{cases}
\]
where \( L_1 \) is the width of N0481 end-mining coal pillar, \( L_2 \) is the width of N0482 end-mining coal pillar \((L_1 > L_2)\), \( S_1 \) and \( S_2 \) are the staggered distance between lower retracement channel and the edge of upper end-mining coal pillar, \( S_3 \) is the severe range of advance abutment pressure.

When the engineering parameters meet Formula (6), the lower retracement channel should be designed in zone A (Figure 14). On the premise of ensuring the stability of main roadways, the N0381 end-mining coal pillar should be shortened as far as possible to improve the recovery of coal resources. When the parameters meet Formula (7), the retracement channel could be designed in zone B. In other cases, the retracement channel is designed in zone C.

### 4.2 Surrounding rock control strategy of retracement channel

The numerical models show that the closer the roof is to the gob side, the stronger the mining dynamic pressure is. In addition, the upper coal pillar high stress and the mining dynamic pressure are coupled and superimposed, and the double force sources aggravate the roof damage, forming a dangerous area with severe ground pressure behavior. According to the deformation and failure of the N0381 retracement channel, the mining pressure of the N0381 working face and the high stress of the upper coal pillar should be considered fully.

A partition control idea was put forward, including the following strategies: (a) The high-strength “cable–beam–mesh” is used in the roof. Especially, I-beam is selected to replace W-steel tape for gob side roof. By improving roof surface confining pressure, strengthening the self-supporting ability of rock stratum, and restricting the high-stress transfer to coal ribs. (b) Improve the support strength of the dangerous area. By increasing the anchor cable density, the bearing capacity of the roof is enhanced. (c) Roof grouting and three holes anchor cable group are used to reinforce top coal cracks in a dangerous area, so as to improve the integrity of the weak roof and realize the three-dimensional compression of coal and rock mass.

### 5 FIELD TESTS

#### 5.1 Reasonable position and control strategy of N0381 retracement channel

Taking N0381 working face as an example, the range of advance abutment pressure \((S_3)\) is 30 m; the staggered distance between the lower retracement channel and the edge of upper end-mining coal pillar \((S_1 \text{ and } S_2)\) is 30 and 35 m; the width of upper end-mining coal pillars \((L_1 \text{ and } L_2)\) is 231 and 134 m; and the safety factors \((k_1, k_2, \text{ and } k_3)\) are 1.2, 1.2, and 1.5. Since \(k_2 \times S_2 + k_3 \times S_3 < L_2 \) (Formula 1), N0381 retracement channel should be designed in zone A. Finally, considering the coal recovery rate and the long-term stability of main roadways, the N0381 retracement channel is designed in zone A, and the horizontal distance from the nearest main roadway is 56 m.

Based on the control strategy of the retracement channel, the double steel meshes are laid on the roof to improve the integrity of top coal. “I-beam + anchor cable” and “W-steel strip + anchor cable” are drilled at the gob side roof and coal rib side roof, respectively. In addition, the anchor bolts with a length of 1700 mm and a diameter of 18 mm are installed in coal rib, and their spacing is 1000 mm × 1500 mm. As the first mining face of 3# coal seam, the overburden movement of the N0381 working face is uncertain. Therefore, “I-beam + anchor cable” is used in the potential danger area \((60#–110# \text{ hydraulic supports})\) to improve roof strength. The detailed support parameters are presented in Figure 15.
To validate the rationality of the design position and support scheme of the N0381 retracement channel, three monitor stations were set up to continuously monitor the deformation of surrounding rock. Station 1 was arranged at 60# support (in the middle of the working face), Station 2 was arranged at 90# support (under mining roadway), and Station 3 was arranged at 30# support. The monitoring arrangement and results are shown in Figure 16.

Due to the hydraulic supports being transported, the observation days of the three stations were different. The data of Stations 1 and 2 show that the deformation of surrounding rock can be divided into two stages. The data show that the maximum deformation of the roof is

FIGURE 15 Support scheme of N0381 retracement channel

FIGURE 16 Displacement monitoring of retracement channel

5.2 Monitoring analysis of surrounding rock deformation

The data of Stations 1 and 2 show that the deformation of surrounding rock can be divided into two stages. The data show that the maximum deformation of the roof is
Based on the above, the design principle and partition control strategy were put forward for the lower retracement channel. The field tests show that the maximum deformation of the roof and coal rib are 338 and 111 mm, respectively, and safety production is guaranteed.

6 CONCLUSIONS

(1) According to the geological conditions of the YZS coal mine, the position of the lower retracement channel is divided into three categories (zone A, zone B, and zone C), which are respectively located below mining roadways, end-mining coal pillar, and section coal pillar.

(2) The principal stress difference law of the lower retracement channel is mainly determined by the mining pressure of the working face. However, the coupling superposition of coal pillar high stress and mining pressure will form a dangerous area with severe ground pressure behavior. The retracement channel should be preferentially designed in zone A, followed by zone B, and finally, zone C.

(3) When the N0381 retracement channel is located at the gob side or the coal pillar side, its horizontal distance from the edge of the upper end-mining coal pillar shall be greater than 30 and 35 m, respectively. In addition, the distance between the retracement channel and nearest main roadway should be greater than the severe range of advance abutment pressure.

(4) Based on the above, the design principle and partition control strategy were put forward for the lower retracement channel. The field tests show that the maximum deformation of the roof and coal rib are 338 and 111 mm, respectively, and safety production is guaranteed.

ACKNOWLEDGMENTS

This study was supported by the National Natural Science Foundation of China (No. 51974317), the Yue Qi Distinguished Scholar Project (800015Z1138), China University of Mining and Technology, Beijing, and the Fundamental Research Funds for the Central Universities (800015J6), the China Scholarship Council (No. 202106430048).

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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**How to cite this article:** Lv K, He F, Li L, Xu X, Qin B. Field and simulation study of the rational retracement channel position and control strategy in close-distance coal seams. *Energy Sci Eng*. 2022;10:2317-2332. doi:10.1002/ese3.1140