

Impacts and applications of full-cycle floor drift on excavation and working face

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Abstract: To investigate the impact of full-cycle floor drifts on the production and safety of mining faces, this study aims to clarify the overlapping range of fracture zones between coal roadways and floor gas drainage drifts during excavation, as well as the stability-maintaining parameters and functional mechanisms of full-cycle floor drifts during mining. The time-varying superimposed effects of fracture zones in full-cycle floor drifts and coal roadways were analyzed, leading to the determination of the optimal layout interval between full-cycle floor drifts (with different service lives) and coal roadways. Additionally, the optimal goaf pressure reduction coefficient was identified using the comprehensive mean difference, and the depth and width of fracture development in the mining face floor were quantified. Based on these theoretical results, numerical simulations were performed using FLAC3D software, field tests were conducted to verify the reliability of the theoretical deductions and numerical models. The verification results indicate that when the full-cycle floor drifts in the Xin'an Coalfield is arranged 17 m below the coal seam floor and 10 m inward offset from the coal roadway, it can fully satisfy to the technical requirements of face excavation and mining. Specifically, the height and width deformations of the full-cycle floor drifts are reduced from 800–950 mm and 510–520 mm to 450–550 mm and 250–350 mm, respectively, with deformation reduction rates of 42–43% (height) and 32–50% (width). Meanwhile, temporary boreholes in the full-cycle floor drifts can effectively extract gas from the coal seam (around the open-off cut of the mining face) and goaf, reducing the gas emission rate of the working face by 0.95 m³/min and ensuring that the gas concentration in the return airflow remains stable within 0.22% during mining in thick coal zones.

Keywords: full-cycle floor drift; mining-excavation production needs; comprehensive mean difference; coal floor drift deformation amplitude; gas extraction in goaf

1 Introduction

With the increasingly stringent requirements for mine gas control, per-drainage of coal seam gas via cross-layer boreholes in floor drainage roadways has become one of the primary technical approaches for outburst elimination in working faces and coal roadway strips[1-2]. Production practice demonstrates that the stability of full-cycle floor roadways[3] not only affects the construction, sealing performance and per-drainage efficiency of cross-layer drainage boreholes during working face excavation[4-5], but also restricts safe production and gas control during working face mining[6-7].

Improper design of floor roadway layout parameters tends to cause problems such as floor collapse and subsidence during working face retreat[8-9], and undermines the secondary drainage capacity[10-11] of cross-layer boreholes in floor roadways for the dynamic pressure zone of the mining face[12-13]. For instance, when the open-off cut of a working face in Xin'an Coal Mine advanced to 150 m, a roof fall occurred in the floor roadway, and the resulting

DOI: 10.67762/5pc3gd65

Submission date: June 2, 2026

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Fund Support: Key Scientific Research Project of Colleges and Universities in Henan Province (24A440002).

fractures propagated through to the floor of the working face open-off cut. The emission of gas accumulated in the floor roadway triggered a marked rise in gas concentration at the upper corner and in the return air flow of the working face, jeopardizing safe mining operations.

Chinese scholars have conducted extensive research on the layout parameters of floor roadways. Wang et al.[14] investigated the evolution of long-term drainage performance and rock roadway stability of the No. 21071 floor roadway in Liangbei Coal Mine under the combined influences of stress, gas drainage and floor water inrush. Liu[15] performed numerical simulations and field tests in Xintian Coal Mine to analyze the roof and floor deformation of floor roadways and track roadways during the mining period. Guo et al.[16] took No. 8 Coal Mine of Pingmei Group as a case study to explore the impact of floor roadway horizon arrangement on the support and maintenance of coal roadways. Yang et al.[17] examined the pressure relief zone ahead of the coal mining face and the influence of working face stress migration patterns on roadway stability.

Overall, abundant studies have been carried out on the layout horizon of floor roadways in China[17-19]. However, few have considered the comprehensive impact of full-cycle floor roadways on the entire excavation and mining process of working faces, and there is a research gap in extending floor roadway studies from single-stage (excavation or mining) to full-cycle (excavation and mining) scenarios[21]. Since the stress-bearing objects and research objectives differ significantly between full-cycle and single-stage floor roadway studies, the corresponding conclusions will vary considerably.

Accordingly, taking Xin'an Coalfield as the research background, this paper conducts theoretical research on the determination of goaf pressure relief coefficient and the fracture depth of floor roadways. Numerical simulations are performed based on the theoretical findings, and field tests are guided by the simulation results. The influence and significance of full-cycle floor roadway layout on working face floor stability, gas emission and gas control are systematically analyzed.

2 Study on characteristics of full-cycle floor roadways in Xin'an coalfield

2.1 Lithology of roof and floor strata in Xin'an coalfield

In the Xin'an Coalfield, the coal mass has a firmness coefficient of 0.14 – 0.27, an original gas content of 0.23–16.37 m³/t, a gas pressure of 0.10 – 3.10 MPa, and a coal seam permeability coefficient of 0.0052 – 0.0497 m²/(MPa²·d). The immediate roof is composed of mud-stone, the main roof is sandstone, and the floor strata consist of sandstone and mud-stone. The detailed lithology and mechanical parameters of the roof and floor strata are presented in Table 1.

Table1 Rock physical and mechanical parameters about xinan coalfield

Stratum Horizon	Rock Type	Thickness (m)	Density (kg·m ⁻³)	Cohesion (MPa)	Internal Friction Angle(o)	Tensile Strength (MPa)
Main Roof	Mud-stone	18.2	2 200	4.2	38	2.6
	Coarse-grained Sandstone	3.1	2 460	3.55	29	1.18
Immediate Roof	Sandy Mud-stone	8	2 630	3.5	43	4.4
Coal Seam	No. II ? Coal Seam	5.2	1 650	3	20	1.2
Immediate Floor	Coarse-grained Sandstone	5.8	2 460	3.55	29	1.18
	Mud-stone	6.2	2 200	4.2	38	2.6
	Sandstone	3	2 740	3.06	33	1.52
Main Floor	Mud-stone	2.7	2 200	4.2	38	2.6
	Coarse-grained Sandstone	4.9	2 460	3.55	29	1.18
	Sandy Mud-stone	16.4	2 630	3.5	43	4.4

2.2 Analysis of Fracture Development Characteristics of Full-Cycle Floor Roadways

(1) Development Characteristics of Disturbance Zones of Floor Roadways and Coal Roadways During Excavation

The surrounding rock mass around an excavated roadway undergoes fragmentation and deformation due to stress disturbance. According to the degree of disturbance, it can be divided into the fractured zone, plastic zone, elastic zone, and virgin stress zone, as illustrated by the floor roadway and stress disturbance rings in Figure 1.

Chinese scholars have investigated the mechanism of coal roadway driving under the pressure-relief protection

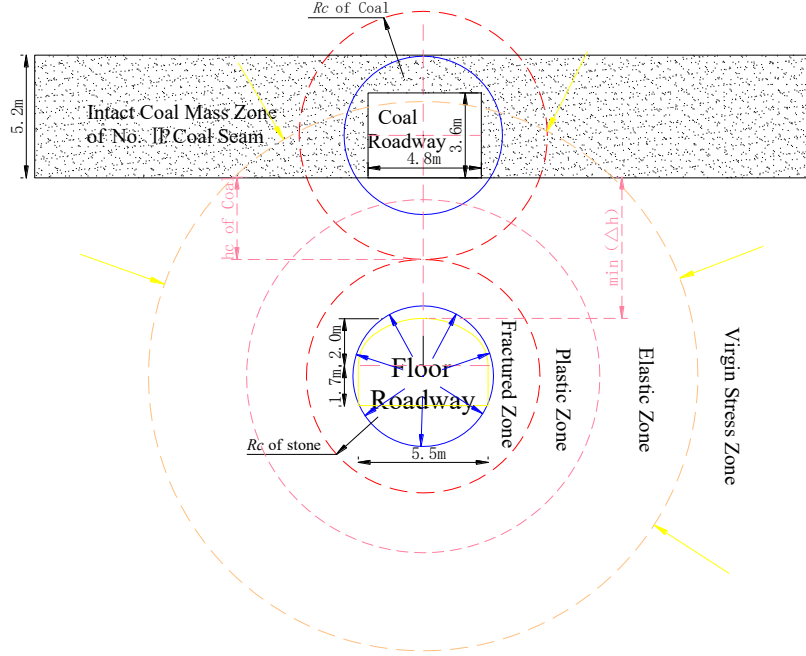


Fig.1 Schematic diagram of excavation disturbance zones in floor drifts and coal roadways

of floor roadways, and derived the reasonable distance Δh when the floor roadway is located directly beneath the coal roadway [22], as well as its variation with time. The corresponding mathematical expressions are presented in Equation (1) and Equation (2).

$$\Delta h \geq \delta (A_3 \ln t + B_3) \cdot (R_{0m} + R_{0y}) - \left(\frac{3}{2} C_1 - B_1 \right) \quad (1)$$

$$R_0 = \begin{cases} \sqrt{\frac{A_1^2}{4} + B_1^2} & \text{traight-wall semicircular arched rock roadway} \\ \sqrt{\frac{A_1^2 + C_1^2}{4}} & \text{rectangular coal roadway} \end{cases} \quad (2)$$

where Δh denotes the minimum spacing between the floor roadway and the coal roadway, in m; ξ denotes the superposition coefficient for the effect of secondary pressure relief, which takes a value of 1 herein; A_3 and B_3 denote the dimensionless fitting coefficients for the time-dependent evolution of the fractured zones of the floor roadway and the coal roadway, with values of 0.1275 and 2.4467 respectively [22]; t denotes the time elapsed since roadway excavation, in d; R_{0y} denotes the equivalent radius of the floor roadway, in m; R_{0m} denotes the equivalent radius of the coal roadway, in m; C_1 denotes the width of the coal roadway, in m; B_1 denotes the straight wall height of the floor rock roadway, in m; A_1 denotes the width of the floor roadway, in m.

The radii of the fractured zones of the floor roadway and the coal roadway in the Xin'an Coalfield at 300 d, 600 d and 900 d can be derived respectively from Equations (1) and (2).

Table2 Influence range of fracture zones in floor drifts and coal roadways over time in xinan coalfield

Cross-sectional Shape of Roadway	roadway dimensions (m)			equivalent radius (m)	extents of fractured zones of coal and floor roadways at different duration (m)		
	A1	B1	C1		300d	600d	900d
Semicircular Arch	5.5	1.7	/	3.23	16.08	16.63	16.96
Rectangle	4.8	/	3.6	3.00			

According to the calculation results in Table 2, for the floor roadway and coal roadway in the Xin'an Coalfield, the extent of the fractured zone reaches 16.08 m at 300 days after excavation, and 16.96 m at 900 days after excavation. Accordingly, the spacing between the floor roadway and the coal roadway should be no less than 16.96 m.

(2) Study on Development Scope of Floor Disturbance Fractures During Mining

During the mining period of the working face, plastic failure occurs in the floor due to uneven stress distribution. According to the failure characteristics, the floor can be divided into the active failure zone, transitional failure zone,

and passive failure zone. Among them, the surrounding rock deformation in the passive failure zone is the smallest, which is most favorable for the stability of the subsequent floor roadway. If the floor roadway is arranged in an outward staggered layout, although the influence of the "three zones (active failure zone, transitional failure zone, and passive failure zone)" can be avoided, it will inevitably affect the production of adjacent working faces. Therefore, the inward staggered layout is preferred, and it shall avoid the limit zone of active failure and the limit zone of transitional failure. That is, the vertical distance shall be greater than the maximum failure depth H , or the inward staggered distance shall be greater than the distance L corresponding to the maximum failure depth, as shown in Figure 2.

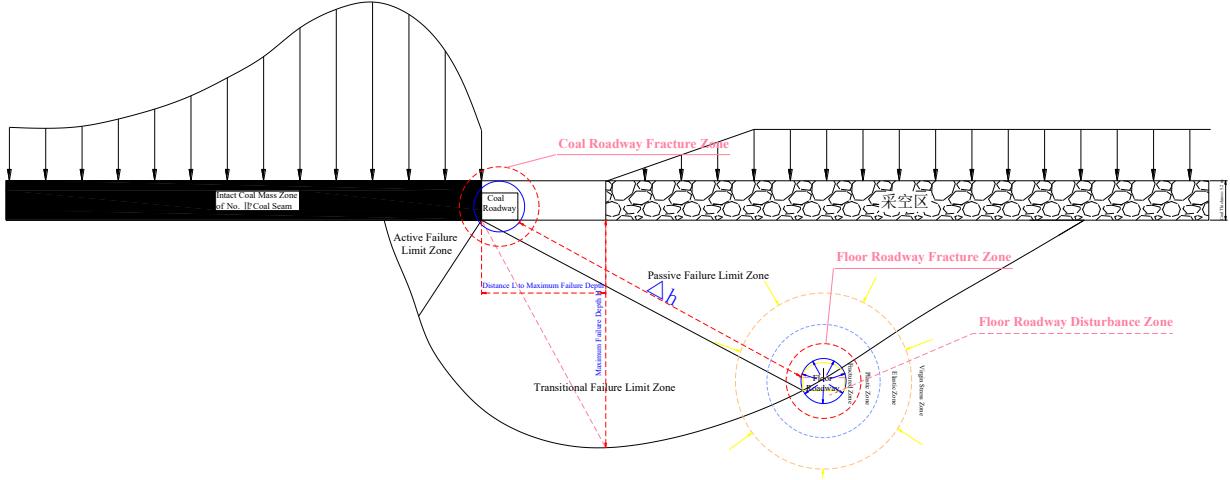


Fig.2 Schematic diagram of the relative position between the floor drift and the floor failure zone of the mining face

Chinese scholars have conducted extensive research on the failure of coal seam floors. Academicians Zhang Jincai and Liu Tianquan [23] derived basic Equations (3), (4) and (5) for the maximum floor failure depth H and the corresponding position L . On the basis of these basic equations, Liu Weitao et al. [24] sorted them out and obtained Equation (6), which are respectively expressed as follows:

$$H = \max \left\{ \begin{aligned} & \frac{n+1}{2\pi} h \cdot \left(\cot \varphi - \frac{\pi}{2} + \varphi \right) - \frac{C}{\gamma \tan \varphi} - mh \\ & \frac{0.015h \cos \varphi}{2 \cos \left(\frac{\pi}{4} + \frac{\varphi}{2} \right)} \cdot e^{\left(\frac{\pi}{4} + \frac{\varphi}{2} \right) \cdot \tan \varphi} \end{aligned} \right. \quad (3)$$

$$L = \frac{0.015h \cdot \sin \varphi}{2 \cos \left(\frac{\pi}{4} + \frac{\varphi}{2} \right)} \cdot e^{\left(\frac{\pi}{4} + \frac{\varphi}{2} \right) \cdot \tan \varphi} \quad (4)$$

$$L = \frac{0.015h \cdot \sin \varphi}{2 \cos \left(\frac{\pi}{4} + \frac{\varphi}{2} \right)} \cdot e^{\left(\frac{\pi}{4} + \frac{\varphi}{2} \right) \cdot \tan \varphi} \quad (5)$$

$$H = \frac{M \cos \varphi \cdot e^{\left(\frac{\pi}{4} + \frac{\varphi}{2} \right) \cdot \tan \varphi}}{4\xi f \cdot \cos \left(\frac{\pi}{4} + \frac{\varphi}{2} \right)} \cdot \ln \frac{K\lambda h + C_m \cdot \cot \varphi}{\xi C_m \cdot \cot \varphi} \quad (6)$$

where H is the floor failure depth, in m; h is the mining depth, in m; C is the average cohesion of the floor, in kPa; C_m is the cohesion of coal mass, in MPa; φ is the average internal friction angle of the floor, in $^\circ$; n is the maximum abutment pressure coefficient; m is the pressure reduction coefficient of the goaf; γ is the average bulk density of the floor, in kN/m^3 ; l is the open-off cut length, in m; M is the mining height of the coal seam, in m; α is the coal seam dip angle, in $^\circ$; λ is the bulking factor of the roof caving zone in the goaf; ξ is the triaxial stress coefficient of coal mass, with $\xi = (1 + \sin \varphi) / (1 - \sin \varphi)$; K is the lateral stress concentration coefficient; f is the friction coefficient at the interface between the coal seam and its roof and floor.

During the calculation, it is found that parameters h , φ , m , l and M have the most significant influence on the calculation results, among which only parameter m (pressure reduction coefficient of the goaf) is a variable parameter that cannot be accurately measured. In the research of Academician Zhang Jincai [23], Equation (3) was established to describe the combined influences of m and mining depth on floor fracture depth, and Equation (4) was established

to describe the influence of mining depth on the fracture depth of the floor roadway. Liu Weitao established Equation (6) to describe the influence of mining depth on the fracture depth of the floor roadway. The three equations above share the same calculation objective. Therefore, taking "fracture depth" as the target orientation, the optimal pressure reduction coefficient for the Xin'an Coalfield can be determined by evaluating the concentration degree of the calculation results from the three equations. Existing research conclusions only indicate that this coefficient is greatly affected by mining depth, working face length and mining height, but no clear power function relationship between m and the three influencing factors has been established.

Compared with variance and standard deviation, the comprehensive mean deviation is more robust: it will not distort the evaluation results due to extreme values, and can reduce the interference of subjective weight assignment. Accordingly, the comprehensive mean deviation A_h is adopted to determine the optimal pressure reduction coefficient. The mean deviation A_m of the fracture development depth H calculated by Equations (3), (4) and (6) is computed respectively when m ranges from 0.10 to 0.15 (with an interval of 0.01) and the mining depth is 400 m, 500 m and 600 m. The m value corresponding to the minimum comprehensive mean deviation A_m is taken as the optimal m value.

Its calculation formula is expressed as Equation (7).

$$A_m = \sum A_h = \sum \left| \sum H_{mh} / i - H_{mh} \right| \quad (7)$$

where A_m represents the comprehensive mean deviation of fracture zone depth corresponding to different goaf pressure reduction coefficients; A_h represents the mean deviation of fracture zone depth corresponding to different goaf pressure reduction coefficients; H_{mh} represents the floor fracture depth at different mining depths under a given m , in m ; i denotes the three calculation methods adopted, i.e., Equations (3), (4) and (6).

The mining depth of mines in the Xin'an Coalfield is mainly 400–600 m. Combined with the example m values given in the research of Academician Zhang Jincai [23], this study focuses on the floor fracture depth under the conditions of buried depth starting from 400 m with an increment of 100 m and m value starting from 0.1 with an increment of 0.01. Specifically, the comprehensive mean deviations are calculated when h takes values of 400 m, 500 m and 600 m, and m takes values of 0.10, 0.11, 0.12, 0.13, 0.14 and 0.15, respectively. The parameters used in Equations (3), (4) and (6) are subject to the corresponding parameters of the Xin'an Coalfield in Table 4, and the calculation results of the comprehensive mean deviation are shown in Table 3.

Table3 Extreme Difference of Fracture Depth in Floor Drift Under Different Mining Depths and m -Values

Cross-sectional Shape of Roadway	roadway dimensions (m)			equivalent radius (m)	extents of fractured zones of coal and floor roadways at different duration (m)		
	A1	B1	C1	R0	300d	600d	900d
Semicircular Arch	5.5	1.7	/	3.23	16.08	16.63	16.96
Rectangle	4.8	/	3.6	3.00			

By plotting the calculation results from Table 3 into a 3D scatter plot, it is found that when m takes a value of 0.14, the calculated depths of the floor roadway fracture zone present a relatively concentrated distribution, mainly ranging from 10 m to 20 m, and the corresponding results are physically reasonable, as shown in Figure 3. Further comparison based on the comprehensive mean deviation A_m in Table 3 indicates that the comprehensive mean deviation A_m reaches the minimum when $m = 0.14$. Therefore, the optimal value of m for the Xin'an Coalfield is determined to be 0.14.

Subsequently, the optimal m value is substituted into the other engineering parameters of the Xin'an Coalfield. Equations (3), (4), (5) and (7) are adopted to calculate the extents of the floor fracture zone under different mining depths in the Xin'an Coalfield respectively. In addition, the numerical simulation results from Liu Xiaoming et al. [25] (corresponding to Equation (6)) are summarized, as presented in Table 4.

Table4 Extent of the maximum fracture zone in the floor drift of xinan coalfield under different mining depths

2.3 Theoretical Optimal Parameters of Full-Cycle Floor Roadways

Based on the calculation results of Table 2 and Table 4, and considering that the buried depth of the main mining areas in the Xin'an Coalfield is approximately 500 m, it can be concluded that the optimal layout range of the floor roadway over its full service cycle shall ensure a vertical distance of no less than 16.96 m and a horizontal distance of no less than 10 m. Combined with the lithological characteristics of the floor, it is determined that the floor roadway shall be arranged in the coarse sandstone stratum 17 m below the floor of the No. 2₁ coal seam. For the horizontal layout, three schemes are selected for field tests: 10 m inward staggered, 10 m outward staggered, and directly beneath the coal seam.

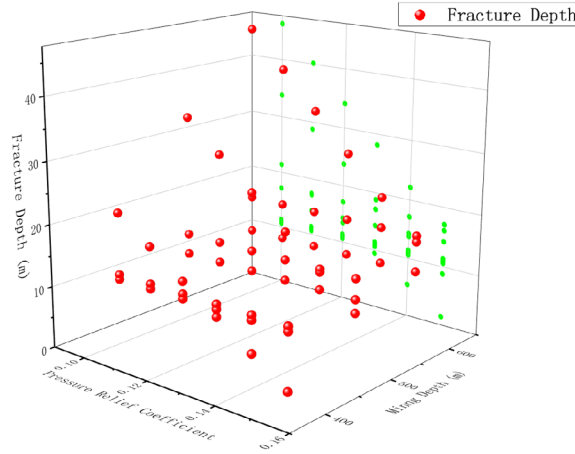


Fig.3 3D scatter plot of fracture depth with different m-values

Table4 Extent of the maximum fracture zone in the floor drift of xinan coalfield under different mining depths

Relevant Parameters																Eq. (3)	Eq. (6)	Eq. (5)	
h	C	Cm	φ	n	m	γ	l	M	α	λ	ξ	K	P	β	f	H	L	H	H
(m)	(kPa)	(MPa)	(°)	—	—	(kN/m ³)	(m)	(m)	(°)	—	—	—	MPa	—	—	(m)	(m)	(m)	(m)
400	490	1.8	35	2.5	0.14	25	200	5.2	—	—	5.04	—	—	—	0.7	6~12	8	10.6	—
500	490	1.8	35	2.5	0.14	25	200	5.2	—	—	5.04	—	—	—	0.7	14~15	10	11.0	—
600	490	1.8	35	2.5	0.14	25	200	5.2	—	—	5.04	—	—	—	0.7	18~23	12	11.2	—
600	—	—	42	—	—	25	150	5	15	1.3	—	2.0	3.0	1.04	—	—	—	—	17

3 Numerical Simulation and Analysis on Stability of Full-Cycle Floor Roadways

3.1 Contents and Basis of Numerical Simulation

Stress calculations are performed using the FLAC3D numerical simulation software in accordance with the Mohr–Coulomb failure criterion [26].

Deformation and failure of the floor roadway mainly occur during working face mining. Therefore, this study mainly simulates the effects of mining on the failure and deformation of the floor roadway under three layout schemes: 10 m inward staggered, directly beneath, and 10 m outward staggered relative to the coal roadway, with the floor roadway located at the horizon 17 m below the coal roadway, so as to comprehensively evaluate the influence of the floor roadway on working face mining over its full service cycle.

3.2 Parameter Setting of the Numerical Model

The model has a length of 100 m, a width of 5 m and a height of 58 m, with a dip angle of 9°. The floor roadway adopts a straight-wall semicircular arch section, with a vertical distance of 17 m from the coal seam. The boundary conditions of the model are set as follows:

(1) Horizontal constraints are applied to the front, rear, left and right boundaries of the model, i.e., the horizontal displacement of these boundaries is zero;

(2) The bottom boundary of the model is fixed, i.e., both horizontal and vertical displacements of the bottom boundary are zero;

(3) The top of the model is set as a free boundary, and the self-weight of the overlying strata is equivalent to a uniform load applied to the upper boundary of the model.

A vertical stress of 13.5 MPa induced by gravity stress is applied in the vertical direction, and a lateral stress of 8 MPa induced by gravity stress is applied in the horizontal direction. The overlying strata of the model have a thickness of 500 m and a bulk density of 25 kN/m³, corresponding to a self-weight stress of 13 500 kN/m². The physico-mechanical parameters of the coal seam and rock strata adopted in the model are listed in Table 1, and the original stratigraphic model is shown in Figure 5.

3.3 Simulation of the Influence of Full-Cycle Floor Roadways on Mining Working Faces

By setting relevant parameters, this study focuses on investigating the pressure relief effect of the floor roadway on

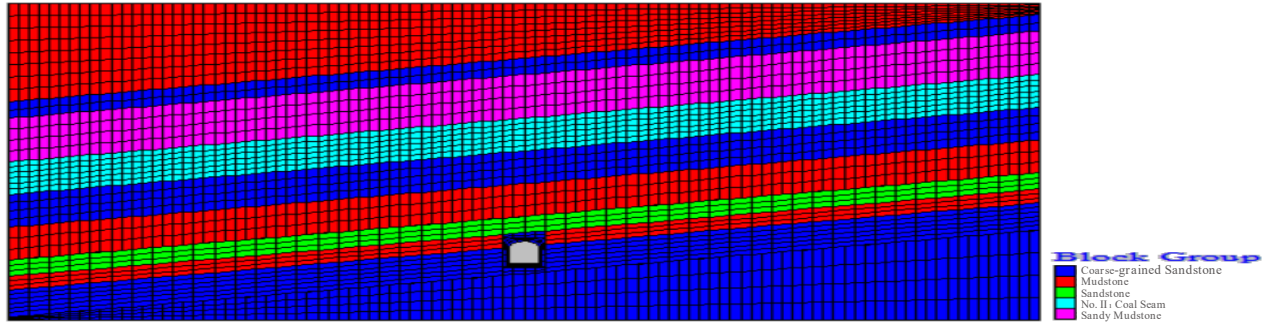


Fig.5 Original strata map

the working face floor and the risk of connection with the working face open-off cut during mining. The simulation results are presented as follows.

As shown in Figure 6, when the floor roadway is arranged 10 m inward staggered from the working face, the failure range is limited to the surrounding area of the floor roadway and cannot affect the coal seam. However, when the floor roadway is located directly beneath the coal roadway of the working face or arranged outward staggered, the coal seam floor and the roof of the floor roadway interact with each other under mining disturbance, and the failure range extends from the roof of the floor roadway to the coal seam floor.

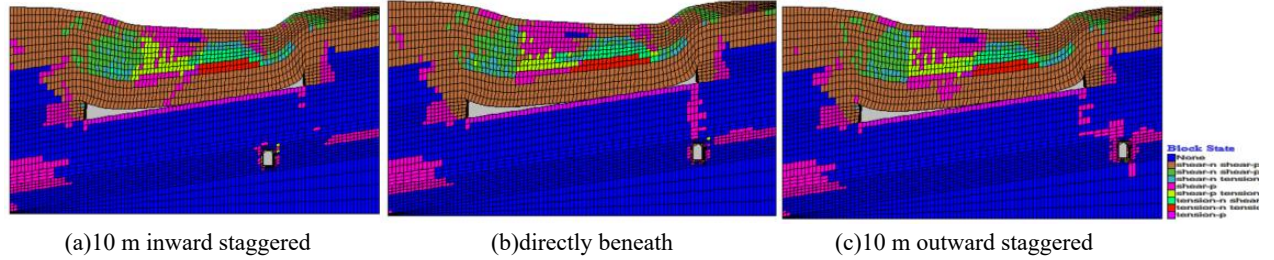


Fig.6 Plasticity contour simulation of stoping affected by floor-coal roadway distances

As can be seen from Figure 7, during working face mining, the pressure relief zone or low-stress zone below the working face presents an inverted triangular distribution. Specifically, the floor roadway with a 10 m inward staggered layout is completely located within the low-stress zone. This phenomenon is related to the mechanism that after the immediate roof caves in the goaf, the key roof bears the gravity of the overlying strata, which indirectly reduces the overburden weight borne by the goaf floor. In contrast, the floor roadway directly beneath the coal roadway is completely outside the influence range of the low-stress zone. In particular, the outward staggered layout bears the maximum stress, and is subjected to the dual effects of face end support stress and boundary abutment stress of the adjacent working face, which is unfavorable for the long-term stability of the floor roadway.

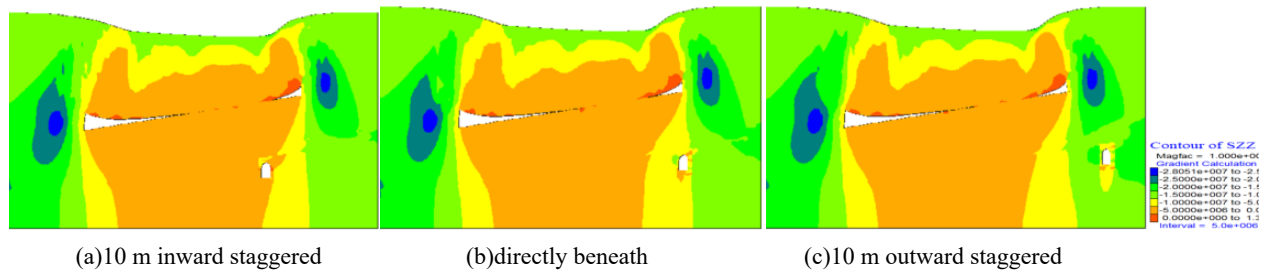


Fig.7 stress contour simulation of stoping affected by floor-coal roadway distances

As shown in Figure 8, during mining, the stability range of the rock mass below the working face is greatly affected by the relative position between the working face and the floor roadway. This stability range gradually narrows as the floor roadway shifts from 10 m inward staggered to 10 m outward staggered, which is attributed to the increasing overlying stress borne by the floor roadway. When the floor roadway is arranged 10 m outward staggered, the displacement of its overlying rock mass is significantly larger than that of the 10 m inward staggered layout, which will impair the floor stability during working face mining.

In addition, to facilitate intuitive quantification of the influence of the floor roadway on the mining face over the full service cycle, the number of affected grids from the rock horizon above the mud-stone (where the floor roadway

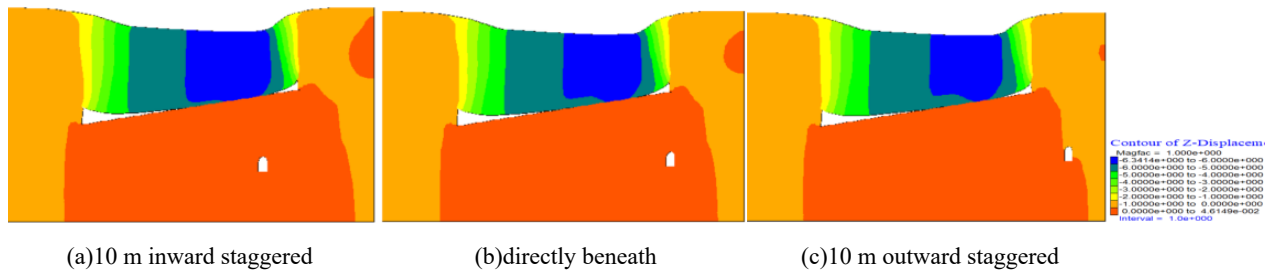


Fig.8 displacement contour simulation of stoping affected by floor-coal roadway distances

is located) to the floor of the No. 2₁ coal seam in the plastic contour plot (Figure 6) is counted, and compared with the field-measured deformation height and deformation degree of the floor roadway after mining, as shown in Table 5.

Table5 Affected grids in mining and height conditions of floor roadways

Floor Roadway Layout	Number of Affected Grids /(N)	Deformation Height of Floor Roadway /(mm)	Field Deformation Degree of Floor Roadway
10 m inward staggered	10	450~550	Moderate
directly beneath	25	600~750	Collapse
10 m outward staggered	32	800~950	Sever

Note: The deformation height of the floor roadway and the occurrence of collapse are derived from on-site field investigation.

According to the simulation results in Figure 6 and the statistics of affected grids and floor roadway deformation in Table 5, the 10 m inward staggered layout yields the smallest number of affected grids and the minimum deformation height of the floor roadway, which can minimize the risk of floor roadway collapse and connection with the open-off cut. By contrast, the 10 m outward staggered layout results in the largest number of affected grids and the maximum deformation height, with a high probability of floor roadway collapse and connection with the open-off cut.

However, according to the collapse status of the floor roadway in Table 5, the deformation degree of the 10 m inward staggered floor roadway is consistent with the simulation results, while the deformation directly beneath the gateway is more severe than that of the 10 m outward staggered layout. This may be attributed to the superposition of periodic roof weighting impact and stress transfer from the roof of self-advancing supports at the gateway end, which causes a sharp stress increase in the gateway area near the open-off cut, further leading to fragmentation and collapse of the surrounding rock at the roof of the floor roadway beneath the gateway.

Without considering the superposition effect of periodic roof weighting and stress from end self-advancing supports, the influence degree of different relative positions between the floor roadway and the gateway follows the order: 10 m outward staggered > directly beneath > 10 m inward staggered. However, considering actual on-site production conditions, the influence degree follows the order: directly beneath > 10 m outward staggered > 10 m inward staggered.

4 Field Engineering Test

4.1 Layout of Field Engineering Practice

To enhance the comparability of the field tests, three adjacent mines within the Xin'an Coalfield are selected for the trial: Xin'an Coal Mine (10 m inward staggered layout), Xinyi Coal Mine (directly beneath the gateway), and Yi'an Coal Mine (10 m outward staggered layout). All three mines belong to the Xin'an Coalfield, with comparable coal seam occurrence conditions and roof-floor lithology at the test working faces. Two sets of measuring points are installed in the floor roadway of each test face to monitor variations in the height and width of the floor roadway during working face extraction.

For safety considerations, a number of temporary boreholes are reserved in floor roadways with favorable stability for secondary gas extraction in the dynamic pressure zone of the mining face. This setup is adopted to comparatively analyze the variation of gas concentration in the return airflow of working faces with secondary gas extraction, and to investigate the influence of the full-service-cycle floor roadway on gas emission from the working face.

According to field test observations, the roof of the floor roadway within the 20 m mined-out range of the working face corresponding to the 10 m inward staggered layout remains relatively intact. Therefore, the zone covering 20 m

in the mined-out area and 10 m ahead of the working face (corresponding to the 10 m inward staggered floor roadway with good stability) is designated as the secondary gas extraction zone in the dynamic pressure zone. Cross-measure boreholes in this zone (excluding boreholes connecting with the return gateway) are put into temporary continuous extraction. In contrast, for the floor roadways directly beneath the gateway and with 10 m outward staggered layout, severe deformation and even collapse have occurred on the roadway roof near the open-off cut. The gas extraction pipelines must be dismantled and recovered 10 m ahead of the working face, hence temporary continuous extraction is not implemented.

4.2 Failure and Deformation of Surrounding Rock of Floor Roadways During Mining

Statistics on roof deformation and collapse of the floor roadways at the test sites are summarized in Table 6.

Table 6 Deformation and collapse numbers of floor roadway roof during mining working

Floor Roadway Layout	Number of Affected Grids /(N)	Deformation Height of Floor Roadway /(mm)	Field Deformation Degree of Floor Roadway
10 m inward staggered	10	450~550	Moderate
directly beneath	25	600~750	Collapse
10 m outward staggered	32	800~950	Sever

Note: The deformation height of the floor roadway and the occurrence of collapse are derived from on-site field investigation.

Meanwhile, the deformation of floor roadway height and width at the two measuring points of each test floor roadway is monitored, with the line graphs presented in Figures 9 and 10.

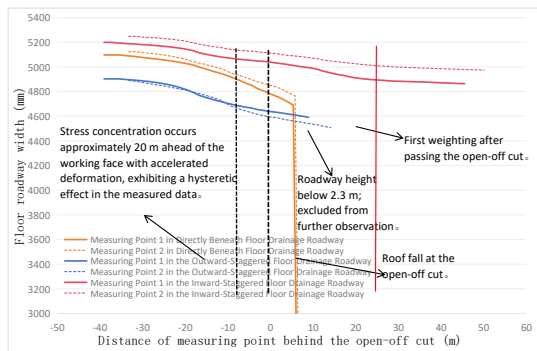


Fig.9 Width variation of floor roadway at different positions during mining working

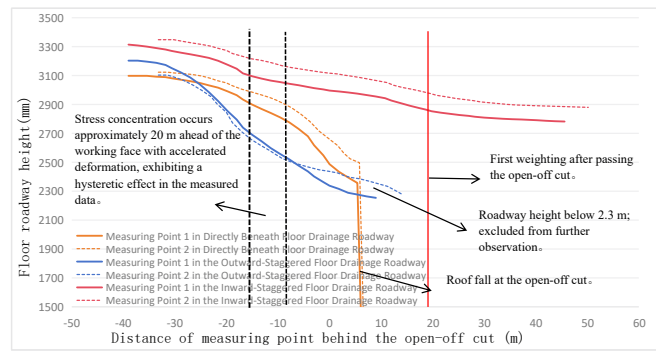


Fig.10 Height variation of floor roadway at different positions during mining working

4.3 Gas Drainage Performance of Temporary Boreholes in Dynamic Pressure Zone of the Mining Face

The floor roadway with the 10 m inward staggered layout features good roof integrity, enabling temporary continuous extraction via cross-measure boreholes in the dynamic pressure zone around the open-off cut (from 20 m inside the goaf to 10 m ahead of the open-off cut). Metering devices are installed for comparison with working faces without continuous extraction in the floor roadway. Production data are collected from two working faces in the same mining district (within the same geological unit) of a mine in the Xin'an Coalfield, and the corresponding line graph is plotted as shown in Figure 11.

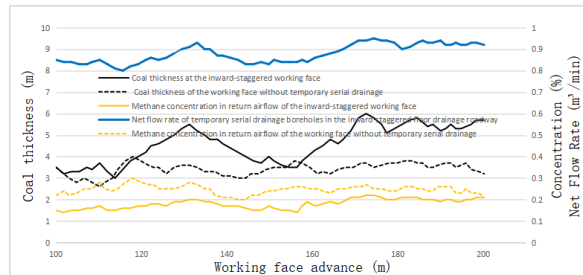


Fig.11 Gas concentration and emission rate in return air flow during mining working

5 Analysis of Test Effects

5.1 Influence of Working Face Mining on Service Life of Floor Roadways

Under the influence of mining disturbance, working face extraction is the period with the most severe deformation

of the floor roadway, and it exerts the most significant impact on the service life of the floor roadway. As shown in Table 6, during working face extraction, the floor roadway with the 10 m inward staggered layout has the longest service life, with no occurrence of floor roadway roof collapse or open-off cut collapse. The floor roadway with the 10 m outward staggered layout ranks second in service life, accompanied by floor roadway roof collapse but no open-off cut collapse. The floor roadway arranged directly beneath has the shortest service life, with both floor roadway roof collapse and open-off cut collapse observed.

This indicates that the 10 m inward staggered floor roadway can avoid the stress concentration zone of the working face and is free from the influence of articulated stress formed after roof collapse, thus presenting favorable stability. It can also effectively reduce the workload of roadway maintenance and extend the service scope and service life of the roadway. Theoretically, the deformation degree of the floor roadway arranged directly beneath should be smaller than that of the outward staggered layout. However, due to the superposition of periodic roof weighting impact and roof stress transferred by self-advancing end supports, its deformation is more severe than that of the outward staggered floor roadway, and the phenomenon of connection with the open-off cut floor of the working face occurs.

5.2 Relationship Between Service Life of Floor Roadways and Surrounding Rock Deformation

The service life of the floor roadway is greatly affected by the failure and deformation of its surrounding rock. According to field test results, roof fall at the open-off cut occurred in the directly beneath floor roadway during working face extraction, making close observation impossible. For the 10 m outward staggered floor roadway, the roadway height drops below 2.3 m, leading to difficulty and danger in accessing the corresponding goaf area, which also prevents close observation. The service lives of the above two test floor roadways are both terminated prematurely, making secondary gas extraction in the dynamic pressure zone of the mining face unfeasible.

Comparison between Figure 9 and Figure 10 shows that the sudden increase in the width and height deformation of the floor roadway mainly concentrates in the section near the open-off cut (the section from 18 m to 8 m ahead of mining marked in the figure, and the first roof weighting at approximately 19 m after extraction). This also reflects that the stability of the floor roadway is significantly affected by coal seam stress concentration and periodic roof weighting during working face extraction.

For the 10 m inward staggered floor roadway, the roof height variation ranges from 450 mm to 550 mm, and the width variation ranges from 250 mm to 350 mm. For the 10 m outward staggered layout, the values are 800–950 mm and 510–520 mm respectively. This indicates that the deformation degree of the 10 m inward staggered floor roadway is significantly smaller than those of the directly beneath and 10 m outward staggered layouts. Compared with the 10 m outward staggered layout, the 10 m inward staggered layout reduces the height deformation of the floor roadway by 42%–43% and the width deformation by 32%–50%.

5.3 Influence of Periodic Weighting on Service Life of Floor Roadways

As can be seen from Figure 9 and Figure 10, stress concentration during working face extraction accelerates the failure and deformation of the surrounding rock of the floor roadway, leading to premature termination of its service life. For example, when the measuring point is approximately 18 m ahead of the open-off cut, the width and height deformation of the floor roadway begins to accelerate, resulting in early termination of the service life. Periodic roof weighting at the open-off cut causes permanent damage to the floor roadway arranged directly beneath. For instance, roof fall and severe sidewall bulging occur at the measuring point approximately 7 m behind the open-off cut, making continuous observation impossible and severely shortening the service life of the floor roadway.

5.4 Analysis of Gas Control Effect by Temporary Continuous Drainage from Floor Roadways

As shown in Figure 11, the working face with the inward staggered layout has a coal thickness 1–3 m larger than that of the working face without temporary continuous extraction (directly beneath layout). Under the same air distribution volume (1200–1300 m³/min for both working faces), the gas concentration in return airflow during extraction is 0.05%–0.1% lower than that of the working face without temporary continuous extraction. The pure gas extraction flow rate of the temporary continuous extraction boreholes (approximately 25–30 boreholes) reaches 0.8–0.95 m³/min, accounting for 25%–30% of the total gas emission of the working face.

This indicates that temporary continuous extraction boreholes in the dynamic pressure zone of the mining face with an inward staggered floor roadway can effectively reduce the gas concentration in return airflow and gas emission quantity of the working face. It delivers a remarkable effect especially on gas control for remaining coal in the goaf, adsorbed gas in the floor, and gas in the dynamic pressure zone of thick coal working faces.

6 Conclusions

This paper proposes a systematic research methodology for investigating the influence of full-service-cycle floor roadways on mining working faces. The numerical simulations and field tests presented in this study are conducted in mines with consistent geological conditions in the Xin'an Coalfield, and the findings provide sound guidance for mines under similar geological settings.

For mines with significantly different geological conditions, the comprehensive mean deviation method shall be reapplied to analyze and determine the optimal goaf pressure reduction coefficient m , so as to derive the theoretically calculated maximum depth and width of floor fracture development. Only by guiding field tests based on theoretical research results can more accurate test outcomes be obtained.

In addition, the research results of this paper can be further validated through field trials in mines with geological conditions distinct from those of the Xin'an Coalfield. Test data shall be collected and analyzed to examine the systematic errors of the research method induced by varying geological conditions, so as to obtain richer and more comprehensive experimental data and research conclusions. The main conclusions were as follows:

- (1) In the theoretical analysis and calculation of the floor fracture development depth of the working face, the optimal goaf pressure reduction coefficient m can be determined via the comprehensive mean deviation A_m , and the maximum depth and width of floor fracture development of the working face can be further derived, which provides a quantitative basis for the reasonable parameter selection of full-service-cycle floor roadways.
- (2) When the full-service-cycle floor roadway adopts a 10 m inward staggered layout with a vertical distance of 17 m, its service life can be extended to approximately 900 days. Meanwhile, the deformation and failure degree of the floor roadway is effectively reduced, with the height and width deformations controlled within 510–520 mm and 250–350 mm respectively.
- (3) The longer the service life of the floor roadway, the more favorable it is for gas control during working face extraction. Temporary continuous extraction boreholes in the full-service-cycle floor roadway can efficiently control gas within the dynamic pressure zone of the mining face, reduce the gas emission from the thick coal zone of the working face by 0.95 m³/min, and ensure that the gas concentration in the return airflow is kept below 0.22%.

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