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# Response and control technology for entry loaded by mining abutment stress of a thick hard roof

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## 1. Introduction

In underground mining operations, the four entries developed along the retreat direction on both sides of every panel are called the Four-Entry System to prevent coal bumps and severe floor heave in many US longwall coal mines.[1,2] The One-Entry System has been widely and successfully used in recent years in China.[3–5] With longwall mining, the Two-Entry System has also been widely used worldwide.[6–9] As shown in Fig. 2, tail entry II, which was 5.5 m wide, 3.8 m high and 3000 m long, was excavated from the beginning to the end along the coal seam floor with a 20-m-wide coal pillar before the adjacent working face began to retreat. The working face used the longwall top coal caving method to retreat 4–6 m every day, and the spontaneous caving method was used to handle the roof above the gob.[10–12] The problem is whether tail entry II can be retained to serve panel II after panel I retreats when there are two thick hard roofs near the mining coal seam.

The stress state for any point around the entry will vary when the adjacent working face retreats.[1,6] For example, Mark et al.[6] published the measured vertical stress distribution obtained by borehole stress monitoring for two coal mines when the adjacent working face retreated (Fig. 1). The vertical stress acutely varies, where the peak increases from 4.71 MPa to 10.65 MPa in the chain pillar for Crimum coal mine, and the peak increases from 12.5 MPa to 47.9 MPa and subsequently decreases to 37.8 MPa in the chain pillar for West Wallsend coal mine. The evolution of horizontal stress in the roof, which was obtained using the NIOSH seismic system, was significantly affected by the longwall face location under a similar engineering condition.[13,14] The side abutment pressure under different geological conditions such as lithology, burial depth, geometric dimension, and fracture position for rocks near the coal seams has been obtained and revelled with borehole stress monitoring and numerical simulation after the main roof over the adjacent gob is stable.[15] The front abutment pressure induced by longwall mining has also been analysed with borehole stress monitoring,[16–19] passive seismic velocity tomography[20] and numerical simulation,[21] which is beneficial to forewarningly arranging the advanced support in front of the longwall mining face. However, few studies have reported the evolution of the abutment stress induced by the entire process of fracture and movement for the main roof, which is affected by the adjacent working face in the in situ test.

The entry in the state of reinforced support will suffer a strong response such as huge deformation or rock burst because of the abutment stress from the fracture and movement of the main roof when the adjacent working face retreats.[7,22] Compared with the deformation caused by the weak section along the entry,[23–25] the retreating of the adjacent working face generates a much larger and more rapid deformation. The rib-to-rib convergence for the entry first linearly and smoothly increases and subsequently rapidly and steeply increases when the distance between the working face and the monitoring station decreases.[26] Field measurement results show that the deformation of the entry in the close upper coal seam (20 m in space) slowly increases in front of the lower working face, subsequently dramatically increases in the back of the lower working face and

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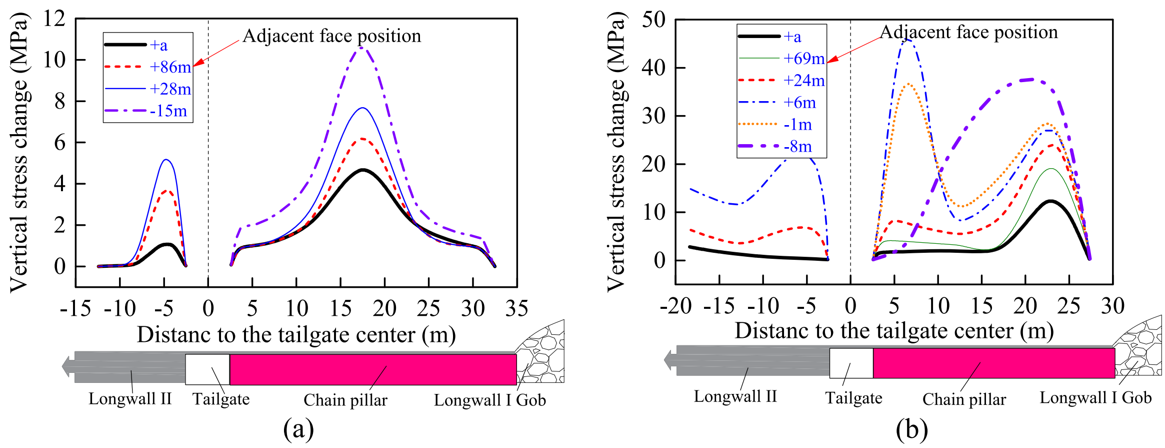


**Fig. 1.** Measured vertical stress distribution when the adjacent working face retreats.[6] The plus sign (+) represents the monitoring point that is in front of the adjacent working face; the minus sign (−) represents the monitoring point that is behind the adjacent working face; and +a denotes that the monitoring point is sufficiently far to avoid the effect of the adjacent working face. Both a and b are vertical cross sections of the longwall face. (a) Abutment load profiles at different locations of the longwall face (Crimum Coal Mine) with highly cleated coal. (b) Abutment load profiles at different locations of the longwall face (West Wallsend Coal Mine), where the tailgate load is extremely aggressive.

gradually stabilizes with the impact range of 65 m in front of the lower working face and 85 m behind it.[27] Therefore, we must clarify both the evolution of the abutment stress and the strong response of the entry under this type of engineering and geological condition, which is beneficial to find a practical and feasible control method to secure the entry.

In this work, a case study was analysed to reveal the evolution of abutment stress and the strong response of the entry under this type of engineering and geological condition. The method to control the fracture and movement of the main roof was tentatively recommended, where hydraulic fracture is applied to the main roof, which has been verified using an in situ test.

## 2. Case study

### 2.1. Engineering geology conditions

The selected panels in Majialiang coal mine are located near the city of Shuozhou, Shanxi Province, China (Fig. 2a). Panel I is a longwall top coal caving face, which is the first coal mining face in Majialiang coal mine. The mining face is 3000 m along the strike and 250 m along the dip. The average thickness of coal seam 4 is 9.78 m, and the average dip angle is 2°, which is buried at 639.25 m. The immediate roof is mudstone with an average thickness of 0.49 m. The main roof is sandstone with an average thickness of 8.49 m. The immediate floor is carbon mudstone with a thickness of 1.16 m. The main floor is sandstone with a thickness of 3.98 m. More importantly, there are two thick hard rock layers above coal seam 4 with thickness of 8.49 m and 11.84 m, respectively (Fig. 3). The lithology, thickness, depth, and uniaxial compressive strength of the rock layers near coal seam 4 are shown in Fig. 3.

### 2.2. Entry support system

The support system runs in two steps: primary support and reinforced support. The primary support is used during the entry development and plays a role throughout the service life of the entry. The reinforced support is used when the adjacent working face retreats and plays a role until panel II (Fig. 2) has been mined out. According to the existing successful experience for the other case with similar geological and engineering conditions in the coal mine of Datong Coal Mine Group Co., the primary support for the entry was proposed without considering the reinforced support in the beginning. The primary support is fairly effective to control the entry deformation during the entry development as shown in Fig. 7b. However, when affected by the mining operation of the adjacent working face, the primary support will suffer from fracture for the bolts, and the entry will suffer from a large deformation in a short time. Thus, reinforced support for the entry was used to control the large deformation when the adjacent working face retreats, which was proposed based on the primary support.

The detailed support materials in Table 1 and Fig. 4 show that in total, there were 19 anchor bolts and 3 anchor cables around the entry section for primary support, and there were 14 anchor bolts and 6 anchor cables of high strength around the entry section for reinforced support. The primary and reinforced supports were distributed in different rows along the axial direction of the entry. The anchor cables and anchor bolts were also arranged in different rows for both primary and reinforced supports.

### 2.3. Abutment stress with borehole stress monitoring

We measured the abutment stress using borehole stress metres. The selected stress metres in the boreholes were YHY60 (II) with the measurement range of 0–60 MPa, and the accuracy was 1.0% FS based on the Chinese National Standards (GB 3836-2010, MT/T1059-2008, Q/RLKJ01–2010). The continuous borehole stress metre system, which is characterized by continuous recording, automatic storage, and infrared receiving, is sufficiently intelligent to set the time interval for the record every 30 min. The system consists of four components: the recording and monitoring apparatus, the instrument for infrared data transmission and acquisition, the adapter for data communication, and data-processing software, as shown in Fig. 5. The stress data obtained from the stress metre are automatically recorded and stored in the recording and monitoring apparatus; then, they are delivered to the infrared data transmission and acquisition instrument. Then, the stress data can be imported into the data-processing software with the adapter for data communication. Finally, they can be comfortably handled in the computer.

The monitoring instruments were used to measure the change in stress conditions around the entry when the adjacent working face passes. When the equipment of borehole stress metres named YHY60 (II) is used, several important matters must be noted. The service time for the recording and monitoring apparatus is limited to half a year because of its storage capacity of the battery. The minimum data record cycle of the recording and monitoring apparatus is 30 min. The borehole stress metre with a diameter of 59 mm can be installed at any position within a borehole of 62 mm in diameter and 30 m in depth. Three or four points should be monitored to improve the method reliability. The borehole condition is limited to the drilling

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