Published in final edited form as:
Int J Min Sci Technol. 2021 January ; 31(1): 127–135. doi:10.1016/j.ijmst.2020.10.001.

A coal rib monitoring study in a room-and-pillar retreat mine

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Abstract

The National Institute for Occupational Safety and Health (NIOSH) conducted a comprehensive monitoring program in a room-and-pillar mine located in Southern Virginia. The deformation and the stress change in an instrumented pillar were monitored during the progress of pillar retreat mining at two sites of different geological conditions and depths of cover. The main objectives of the monitoring program were to better understand the stress transfer and load shedding on coal pillars and to quantify the rib deformation due to pillar retreat mining; and to examine the effect of rib geology and overburden depth on coal rib performance. The instrumentation at both sites included pull-out tests to measure the anchorage capacity of rib bolts, load cells mounted on rib bolts to monitor the induced loads in the bolts, borehole pressure cells (BPCs) installed at various depths in the study pillar to measure the change in vertical pressure within the pillar, and roof and rib extensometers installed to quantify the vertical displacement of the roof and the horizontal displacement of the rib that would occur during the retreat mining process. The outcome from the monitoring program provides insight into coal pillar rib support optimization at various depths and geological conditions. Also, this study contributes to the NIOSH rib support database in U.S coal mines and provides essential data for rib support design.

Keywords

Coal rib performance; Coal rib design; Coal rib monitoring; Coal rib failure; Load transfer; Retreat mining

1. Introduction

Skin-rib failures, which are failures of small blocks or slabs of rib, have been recognized as a safety concern in underground coal mines for many years. Most of the rib-fall fatalities in coal mines are attributed to skin failures. Skin failures do not usually involve failure of the support systems, but instead result from rock or coal spalling from between the support elements [1]. Rib and roof falls traditionally have been one of the leading causes

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of mine worker injuries and fatalities in underground coal mines. Based on Mine Safety and Health Administration (MSHA) reports, rib falls resulted in 16 fatalities, representing 50% of the reported ground-fall fatalities in underground coal mines in the United States over the past decade. More recently, within the past 5 years, this proportion has increased to 80% of the ground-fall fatalities in these mines. In 2018 and 2019, the vast majority of the ground-fall-related fatalities in U.S. underground coal mines were attributed to falls of rib or face falls [2]. To reduce rib failures in underground coal mines, the National Institute for Occupational Safety and Health (NIOSH) is working on a project to characterize the stability of coal ribs and to provide guidelines for proper selection of rib support. The work presented in this paper is part of the results from that project.

Some underground coal mines with a history of rib falls frequently experience rib support failures, such as bolt heads ‘‘popping off” as described by Smith [3]. Smith claimed that small radial forces applied to the rib wall could reduce the progression of rib failure. Dolinar, Tadolini and Dolinar discussed general coal rib stabilization and the effectiveness of wood dowels, resin bolts, and straps to provide pillar reinforcement [4,5].

The likelihood of rib failure increases during retreat mining due to elevated stresses near the pillar line because of the abutment loading. To understand this mechanism, NIOSH conducted a comprehensive monitoring program at two sites in a room-and-pillar mine. The two instrumented sites (site-1 and site-2) are in two adjacent panels at different depths of cover of 198.2 and 289.6 m. The two sites were chosen such that the rib profile, the mining height, and the geological conditions of the ribs were also different.

The main goal of the monitoring program is to understand the load transfer to coal pillars and to quantify the roof and rib deformation due to the progress of pillar retreat mining and, thereby, to better support the rib and ultimately reduce injuries and fatalities in underground coal mines. The instrumentation program provides the necessary data to calibrate three-dimensional models for the instrumented sites. These calibrated models were used to optimize coal rib design for a wide range of overburden depths and mining heights given similar geological conditions [6]. The modeling results indicated that the support pattern currently used at site-1 could be changed from H-shape to V-shape at a certain overburden depth [6]. In addition, the instrumentation results reported in this paper will enrich the NIOSH database of rib support determination in the U.S coal fields and can ultimately contribute to an empirical design approach and provide some guidelines for support determination. Colwell and Stone utilized an empirical approach to determine the minimum rib support density required during roadway development in coal mines [7,8].

2. Geological and mining conditions at instrumented site-1

The study mine produces bituminous coal by the room-and-pillar retreat mining method. The instrumented site-1 is in the #6 panel with a panel width of about 114.3 m and consists of six entries with barrier pillars between the subsequent panels. The dimensions of the pillars are about 22.8 m × 32.0 m center-to-center. The entries and cross-cuts are 5.4 and 5.9 m wide, respectively. No multiple seam interaction exists at the #6 panel. The depth of cover at site-1 is about 198.1 m, and the mining height is about 3.0 m. The study pillar at site-1 is located between entries #4 and #5 and between cross-cuts #24 and #25. Fig. 1 shows the rib profiles as surveyed from entry #4 and cross-cut # 24. The typical geology for the immediate and main roof from a borehole near the instrumented sites consists mainly of gray shale and sandstone.

During the development stage, the rib was supported with 1.5 m long #6 fully grouted bolts grade 60 with 0.5 m × 0.5 m pizza pans and a dome plate of size 20.3 cm × 20.3 cm. The rib support configuration is in the form of an H-shape when the mining height is more than 2.1 m as shown in Fig. 2, but it changes to the form of a V-shape when the mining height is less than 2.1 m. The roof was supported with four 1.8 m long #6 grade 60 fully grouted bolts. The bolt spacing is slightly longer near the center of the entry or the cross-cut than near the rib. Two cable bolts of 4.2 m length are used as a supplemental roof support at every two rows of roof supports. The intersection was supported by six cable bolts.

3. Geological and mining conditions at instrumented site-2

The instrumented site-2 is in the #7 panel, and the panel width is about 121.9 m and consists of 7 entries with barrier pillars between the subsequent panels. The dimensions of the pillars are about 20.7 m × 26.8 m center-to-center. The entries and cross-cuts are 5.7 m wide. No multiple seam interaction exists at #7 panel. The depth of cover at site-2 is about 289.6 m, and the mining height is about 2.2 m. The study pillar at site-2 is located between entries #5 and #6 and between cross-cuts #5 and #6. The immediate roof consists mainly of gray shale.

Fig. 3 shows the rib profile as surveyed from entry #6. The interface between the top shale band and coal seam is smooth, and a noticeable coal seam dilation was observed along this interface, particularly at cross-cut #6. The coal seam was affected by a joint set dipping at about 30°. The dominant face cleat orientation is about 23° with respect to entry direction. Rib spalling is characterized by large blocks of about 15.2 cm × 15.2 cm × 30.4 cm. The roof support at site-2 is similar to site-1. The rib support pattern used at site-2 is like site-1, while fully grouted fiberglass bolts were used at site-2. The corners of the pillars at site-2 were supported with #6 grade 60 fully grouted bolts.

4. Instruments type/location at site-1

The entry and the cross-cut sides of the instrumented pillar at both site-1 and site-2 were monitored with the following: pull-out tests for short encapsulation rib bolts (SEPT) to measure the anchorage capacity of the bolts installed in coal and shale parings of the rib, load cells mounted on rib bolts to monitor the induced horizontal loads in rib bolts with the progress of pillar retreat, and borehole pressure cells (BPCs) installed at various depths in the pillar to measure the change in vertical pressure within the pillar during the retreat. These instruments provide valuable data about the stress transfer occurring on the pillar line during pillar retreat mining. Additionally, extensometers were installed in both the roof and the ribs to measure vertical roof sag and horizonal rib movements that occur during the retreat mining process. The instruments were placed near the middle of the pillar and relatively far from the pillar corner. The instrumentation results reflect only the effect of pillar retreat mining. Table 1 summarizes the instrumentation type, number, and anchorage location used at instrumented site-1. The value in the ‘‘Number” column in Table 1 represents the total number of instruments at both the entry and cross-cut sides of the instrumented pillar at site-1.

Figs. 4 and 5 show the layout of instruments at the entry and cross-cut sides of the instrumented pillar. The MPBX near the BPC at 6.0 m was located near the mid-pillar length, and the MPBX in Fig. 5 was located near the mid-pillar width.

5. Instruments type/location at site-2

Table 2 Summarizes summarizes the instrumentation type, number, and location used at site-2. The value in the ‘‘Number” column in Table 2 represents the total number of instruments for both entry and cross-cut sides of the instrumented pillar.

Figs. 6 and 7 show the arrangement of the instruments at the entry and cross-cut sides, respectively, of the instrumented pillar at site-2. In Fig. 6, the closest MPBX to the BPC is located at the pillar mid-length.

6. Pillar retreat plan

One continuous miner and two MRS were used to extract each row of pillars at site-1 and site-2. The retreat plan starts at entry #1, with a 9.7-m deep slab cut in the barrier pillar. A final stump was left unmined to provide roof support during the pillar recovery. The size of the final stumps was a minimum of 2.4 m × 2.4 m, but sometimes larger stumps were left because of the mining conditions. Fig. 8 shows the pillar layout and extraction sequence by dates at site-1 and site-2. The roof caving conditions were observed when the pillar line was at one and two breaks inby the instrumented pillar.

At site-1, the roof caved well inby the pillar line with no signs of roof overhanging. There was no sign of roof deformation outby the pillar line. Rib conditions looked good with little to no sloughing. Some cracks were observed in the pillar ribs; however, the crack width was small, which gives an indication that it does not extend deep into the rib. The caving conditions at site-2 were similar to site-1; however, the observed crack widths in pillar ribs are relatively larger.

7. Instrumentation results

Monitoring systems can provide advance notice to mine management of impending ground control failures or hazardous working conditions [9]. Instruments have been used increasingly in mines to measure deformation, stress, and load. Such measurements provide quantitative information about the mechanics of stability and in aiding engineering decisions. Secondly, they can be useful tools in calibrating numerical models [10–12]. Instruments were placed in the entry and cross-cut sides of the instrumented pillar to monitor the rib and roof responses at site-1 and site-2 during the progress of pillar retreat mining. The study sites are different in depth, geological conditions, and mining height.

8. Pull-out test results for rib bolts at site-1 and site-2

A total of nine pull-out tests, six at site-1 and three at site-2, were conducted to determine the anchorage capacity for short-encapsulated #6 grade 60 rib bolts. The bolt length was 1.5 m and the grouted length was about 50.8 cm for a cartridge length of 35.5 cm. Six bolts were tested in the coal seam, and three bolts were tested in the gray shale parting of the rib. Fig. 9 shows the typical load displacement curve obtained from the pull-out tests.

Table 3 summarizes the measured anchorage capacity of the tested rib bolts. The anchorage capacity of the tested bolts ranges from 16.3 to 21.4 kN/m. The anchorage capacity for coal at site-2 is slightly higher than at site-1. There is no significant difference in the anchorage capacity for rib bolts installed in coal or shale parting of the rib at site-1.

9. Pressure change in borehole pressure cells (BPCs) at site-1

Fig. 10 shows the pressure change in borehole pressure cells (BPCs) at the entry and cross-cut sides of the instrumented pillar of site-1 with the progress of pillar retreat. The *x*-axis of Fig. 10 (‘‘retreat ID”) reflects the cutting sequence shown previously in Fig. 8. The BPCs are located at 3, 4.5, and 6 m deep for the entry side, while they are located at 1.5, 3.0, and 4.5 m deep in the cross-cut side of the instrumented pillar, although the BPC located at 4.5 m in the cross-cut side was corrupted. The recorded pressure change represents the induced abutment load due to only pillar retreat mining. As shown in Fig. 10, when the pillar line was about two breaks inby the instrumented pillar (retreat ID #9), the pressure change in the BPCs was less than 0.13 MPa, while at retreat ID #16, a significant stress change started to build up in the pillar. When the pillar adjacent to the instrument pillar was mined out (retreat ID #22), the maximum pressure change in the BPCs at the entry and cross-cut sides of the instrumented pillar was 1.10 and 1.24 MPa, respectively. The pressure changes in the BPCs increased to 1.27 and 1.79 MPa for entry and cross-cut sides, while the instrumented pillar was being mined (retreat ID #23). The maximum pressure change at retreat ID #22 was about 25% of the pre-mining stress.

Good caving conditions and the large stumps left near the instrumented pillar at site-1 are among the main factors most likely limited the load transfer to the instrumented pillar, which was confirmed by visual observations of minor rib sloughing and no noticeable roof deformation. Similar rib conditions were observed near the pillar lines at other locations in the same panel.

10. Pressure change in borehole pressure cells (BPCs) at site-2

The pressure changes in the BPCs at 1.5, 3.0, 4.5, 5.1, and 6.0 m deep in the instrumented pillar due to pillar retreat mining at site-2 are shown in Fig. 11. The BPCs at the entry side of the instrumented pillar experienced more load than the cross-cut side because they are located closer to the gob. A significant pressure change started to build up in the BPCs when the pillar line was at retreat ID #131 (the pillar line was one-line inby the instrumented pillar). When the pillar adjacent to the instrumented pillar was mined out (retreat ID # 140), the maximum pressure change was about 6.20 and 5.86 MPa at the entry and cross-cut sides of the instrumented pillar, which is about 86% of the pre-mining stress. When the instrumented pillar was being mined (retreat ID # 141), the maximum pressure change in the BPCs was 17.24 and 12.41 MPa for the entry and cross-cut sides of the instrumented pillar, respectively, which are about 1.7 and 2.4-times pre-mining stress, respectively.

11. Rib-bolt load from load cell (LC) at site-1 and site-2

The variation of the rib-bolt load with pillar retreat mining for the entry side of the instrumented pillar at site-1 and site-2 is shown in Fig. 12. For the site-1 entry side of the instrumented pillar, two rib bolts with load cells were installed in the coal seam and two bolts were installed in the shale band of the rib. For the site-2 entry side of the instrumented pillar, four rib bolts with load cells were installed in the coal seam. As shown in Fig. 12a, the rib bolts installed in the shale band were loaded more than those installed in the coal seam. For site-1, when the pillar adjacent to the instrumented pillar mined out, the maximum measured rib-bolt load was about 15.57 kN, which is about 13% of the yield capacity of the steel rebar bolt. It jumped to about 24.92 kN while the instrumented pillar was being mined. For site-2, when the pillar adjacent to the instrumented pillar was mined, the maximum recorded rib-bolt load was about 31.15 kN, which is about 25% of the yield capacity of the steel rebar. It increased to 47.61 kN while the instrumented pillar was being mined. ‘‘LC 5_coal” and ‘‘LC 6_-coal” experienced more load than ‘‘LC 7_coal” and ‘‘LC 8_coal” because of their closer proximity to the gob. For the cross-cut side of the instrumented pillar, the maximum rib-bolt load was about 1.33 kN at site-1 and 6.67 kN at site-2. The anisotropy of the recorded rib-bolt load at the entry and cross-cut sides for both sites 1 and 2 could be attributed to the orientation of the maximum horizontal stresses.

11.1. Rib deformation at Site-1

The two main factors contributing to an increased risk of rib falls during retreat mining are thicker coal seams and higher stress levels [12,13]. The Multipoint Rib Extensometers (MPBX) were used to monitor deformation of the coal seam and the shale parting of the rib. MPBX # 2 and # 4 were closer to the inby direction during the pillar recovery. The deepest MPBX anchor, located at 9.1 m deep in the pillar, reflects the horizonal displacement of the rib edge. Fig. 13 shows the rib deformation and movement of the anchors with the progress of pillar retreat mining for the entry side of the instrumented pillar at site-1. The maximum deformation occurred at the rib edge. As shown in Fig. 12b, the horizontal displacement was almost zero at 1.2 m deep inside the pillar. A significant change in the rib displacement gradient occurred at retreat ID #16. The maximum rib displacement was 3.5 mm and occurred when the pillar adjacent to the instrumented pillar was mined out. Such small rib displacement was not expected to cause a significant fracture in the rib, which was confirmed by field observations. The measured rib displacement for the cross-cut side of the instrumented pillar was almost zero at all anchor points.

11.2. Rib deformation at site-2

Fig. 14 shows the measured rib displacement from the MPBX for the entry side of the instrumented pillar at site-2. The anchor locations of the MPBX are shown in Table 2. When the pillar adjacent to the instrumented pillar was mined out, the maximum horizontal rib-edge displacement was about 25.4 mm, and the horizontal displacement at 1.2 m deep in the pillar was about 15.2 mm. A big jump in the horizontal rib displacement of almost 25.4 mm occurred at MPBX #1, #2, and #3 when the instrumented pillar was being mined out. The MPBX #1 experienced more deformation than MPBX #4, most likely because it was closer to the inby side of the instrumented pillar.

Similar trends were experienced at the cross-cut side of the instrumented pillar; however, the maximum rib displacement was 12.7 mm when the pillar adjacent to the instrumented pillar was mined out. The anisotropy of rib deformation at the entry and the cross-cut sides of the instrumented pillar was confirmed from a similar anisotropy in the rib-bolt loads.

11.3. Roof deformation at site-1 and site-2

For both sites, the vertical displacement of the immediate roof was measured via one 4-point roof extensometer at both the entry and cross-cut sides of the instrumented pillar. No significant roof displacement occurred at site-1 during pillar retreat mining. When the pillar adjacent to the instrumented pillar mined out, the maximum roof displacement was less than 0.5 mm. Such small roof deformation coincides with the small rib deformation and small rib-bolt load experienced at site-1.

For site-2, the maximum roof sag was about 0.5 mm and occurred when the pillar adjacent to the instrumented pillar was mined out. The roof sag increased to 1.7 mm when the instrumented pillar was being mined out (Fig. 15). An explanation for the minimal measured roof displacement at site-2 could be that the deepest anchor may be in moving ground. The roof line displacement would be accurate only if the deepest anchor was installed in fixed/stable ground.

12. Summary and conclusions

This paper aims to better understand rib loading and rib deformation and to quantify the amount of load shedding that is due to pillar retreat mining at different geological conditions and depths of cover. A comprehensive in-situ monitoring program was conducted at two room-and-pillar retreat mining sites. The depths of cover for the instrumented sites are 198.1 m with a 3.0 m mining height and 289.6 m with a 2.2 m mining height. The rib profile and the geological conditions of the two sites are different. The vertical pressure changes, rib-bolt load changes, rib deformation, and roof deformation were measured at the two sites. Site-2 experienced significantly higher rib/roof deformation and stress changes compared to site-1. This difference could be attributed to higher overburden depth and geological features observed at site-2. The application of the monitoring results of this case study would be limited to mines of similar geological, caving and operating conditions. The monitoring results reported in this paper were used to calibrate numerical models to optimize coal rib support design for a wide range of overburden depths and mining heights [6].

The instrumentation results are summarized as follows:

1. The anchorage capacity for short encapsulation rib bolts installed in the coal or shale parting of the rib ranges from 16.3 to 21.4 kN/m of grout. There is no significant difference in the anchorage capacity of bolts installed in the coal or shale parting.

2. When the pillar adjacent to the instrumented pillar was mined out, the maximum pressure change due to the pillar retreat mining was 1.24 and 6.20 MPa, which increased to 1.79 and 17.24 MPa at site-1 and site-2, respectively while the instrumented pillar was being mined.

3. The maximum load on the instrumented rib bolt was 15.57 kN at site-1 and 31.15 kN at site-2 when the pillar adjacent to the instrumented pillar was mined out and increased to 24.92 and 47.61 kN while mining the instrumented pillar.

4. The roof deformation at site-1 was less than 0.50 mm, and at site-2 it was about 1.77 mm.

5. For site-1, when the pillar adjacent to the instrumented pillar was mined out, the maximum horizontal rib-edge displacement was 3.55 mm, and the rib deformation of 1.2 m deep in the rib was insignificant.

6. For site-2, when the pillar adjacent to the instrumented pillar was mined out, the maximum horizontal rib-edge displacement was 25.4 mm, and the rib deformation of 1.2 m deep in the pillar was about 15.24 mm. A large increase in the rib deformation occurred while the instrumented pillar was being mined.

7. With a high degree of certainty, the rib support density at site-1 has the potential to be reduced from an H-shape to a V-shape because of the small measured rib deformation and the low stress change.

Acknowledgement

The authors want to thank Todd Minoski for preparing the data collection system and James Addis and Cynthia Hollerich for help with installing the test instruments.

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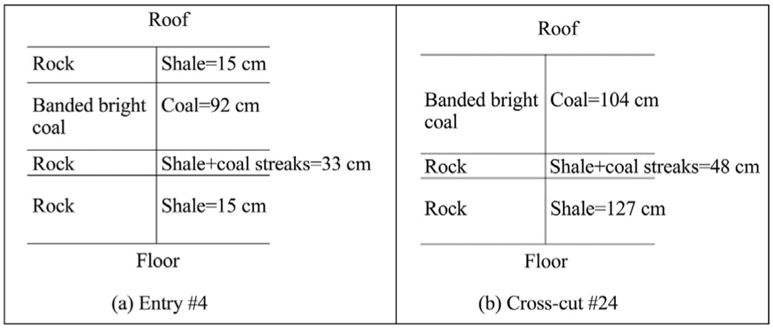


Fig. 1.
Rib profiles of the study pillar at an instrumented site-1.

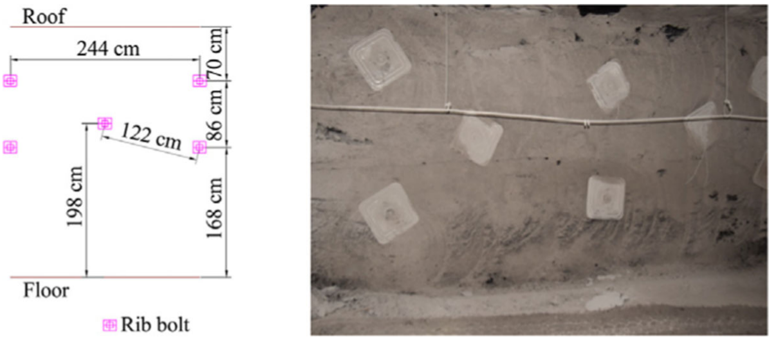
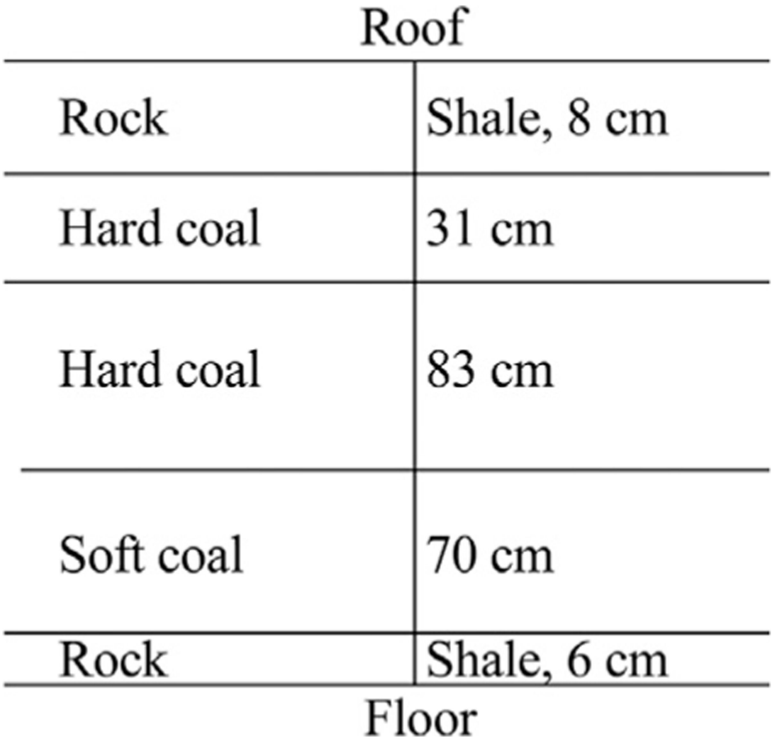


Fig. 2.

Typical rib support pattern at site-1 for a mining height of more than 2.1 m.



Roof

Rock	Shale, 8 cm
Hard coal	31 cm
Hard coal	83 cm
Soft coal	70 cm
Rock	Shale, 6 cm

Floor

Fig. 3.

Rib profile of the study pillar at instrumented site-2.

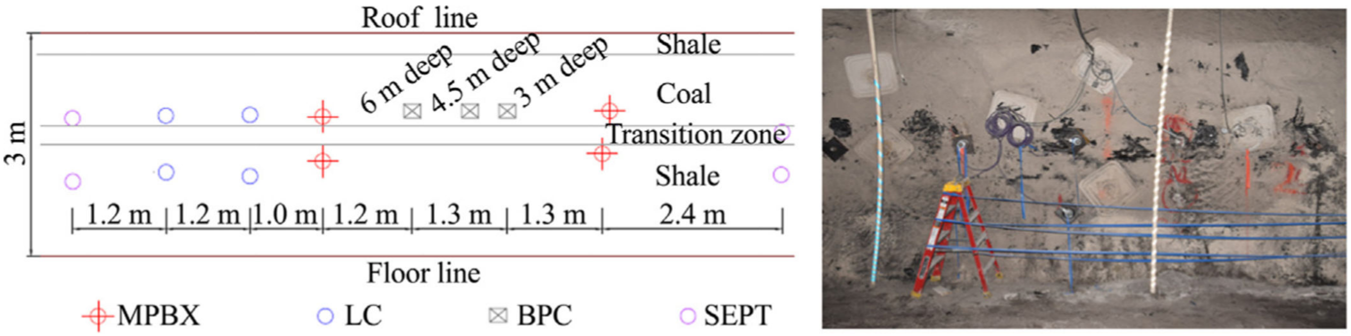


Fig. 4.

Instrumentation type and location for the entry side of the instrumented pillar at site-1.

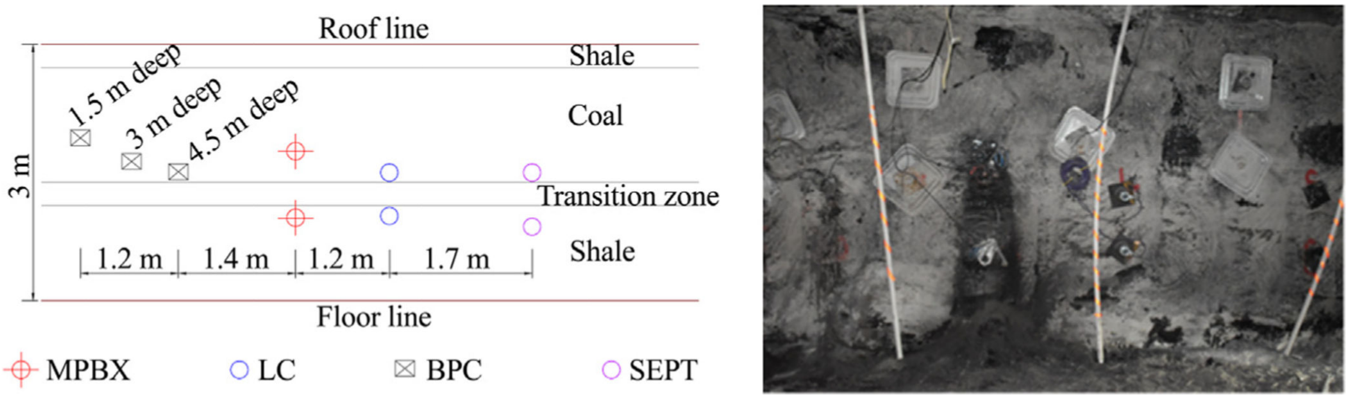


Fig. 5.

Instrumentation type and location for the cross-cut side of instrumented pillar at site-1.

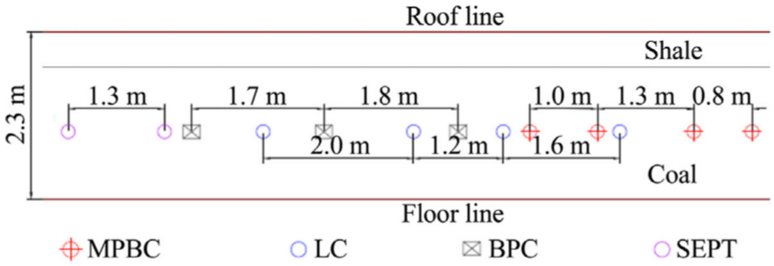


Fig. 6.

Instrumentation type and location for entry side of the instrumented pillar at site-2.

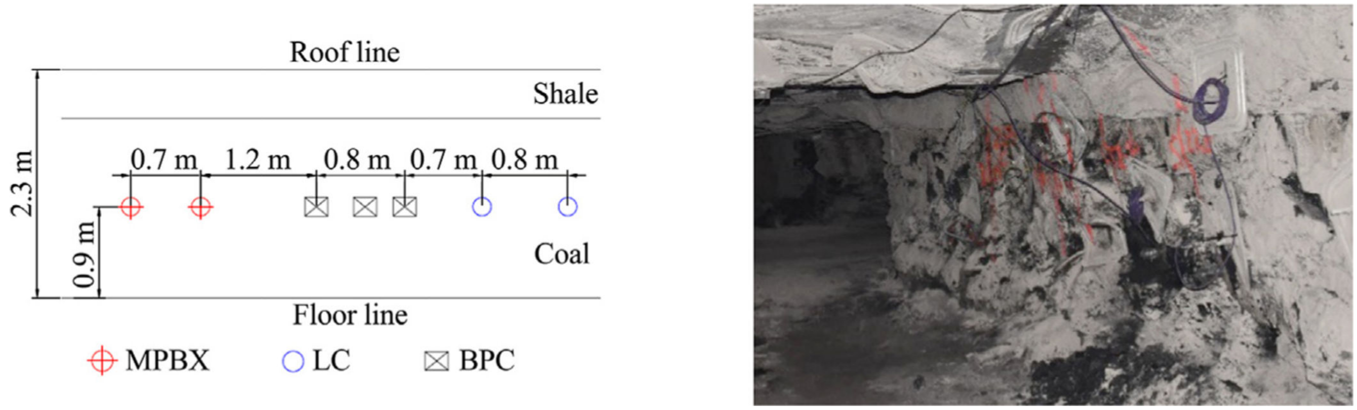
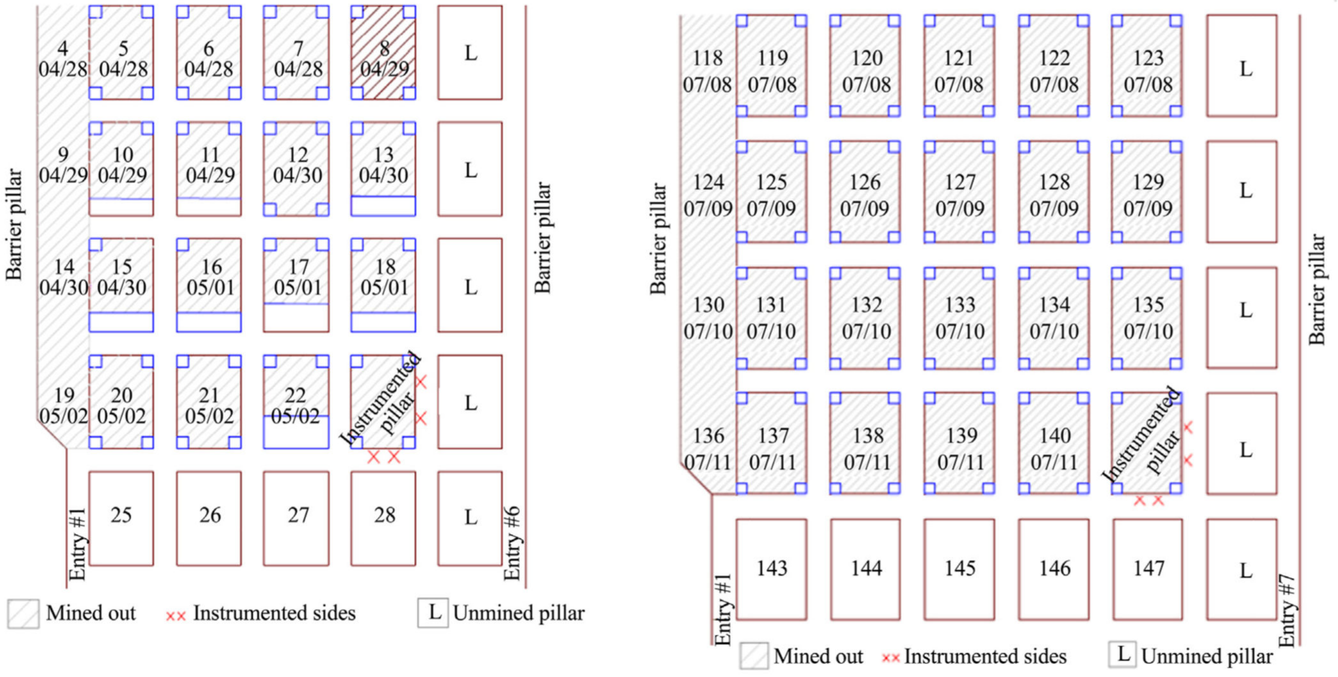


Fig. 7.

Instrumentation type and location for the cross-cut side of the instrumented pillar at site-2.



(a) Site-1

(b) Site-2

Fig. 8.

Retreat plan and cutting sequence at site-1 and site-2.

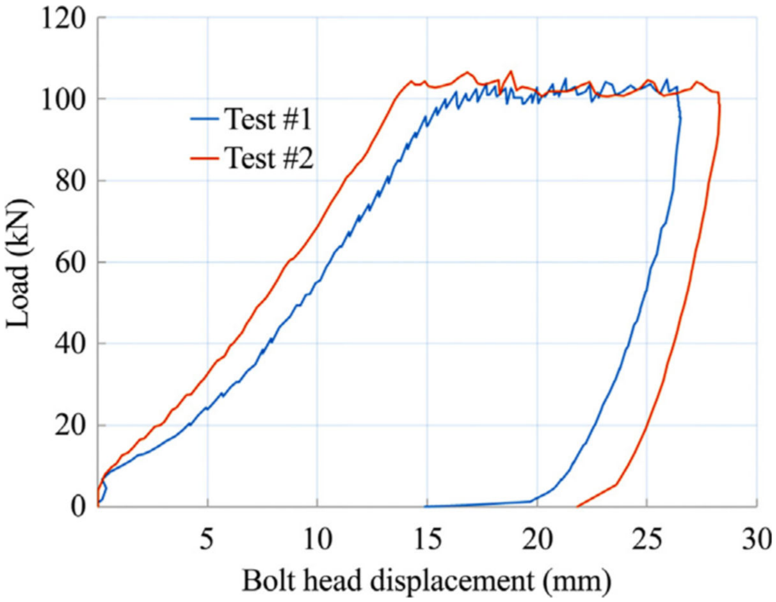


Fig. 9.

Typical load displacement curve for the pull-out test.

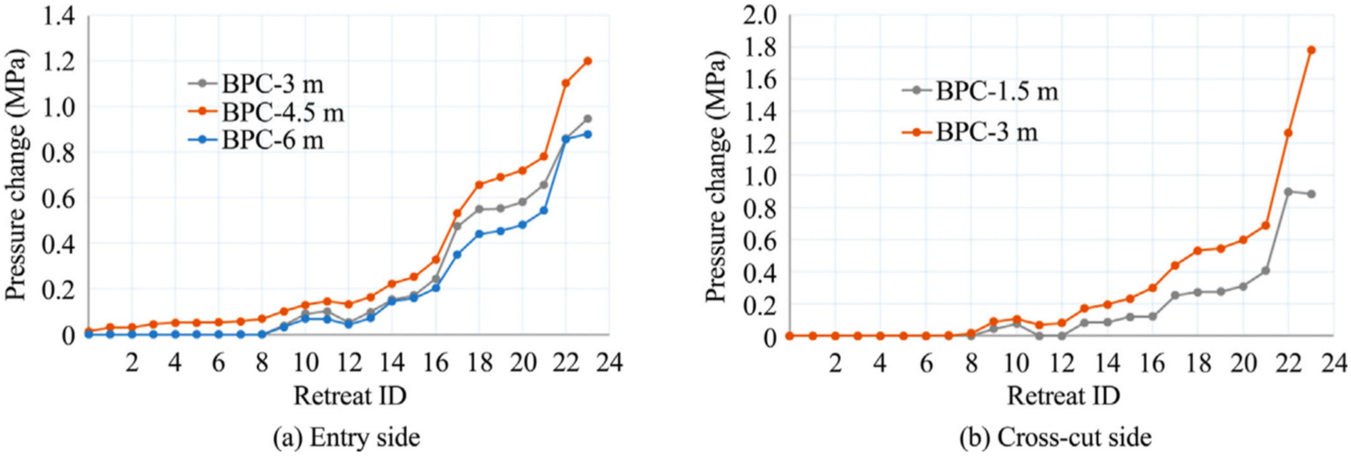
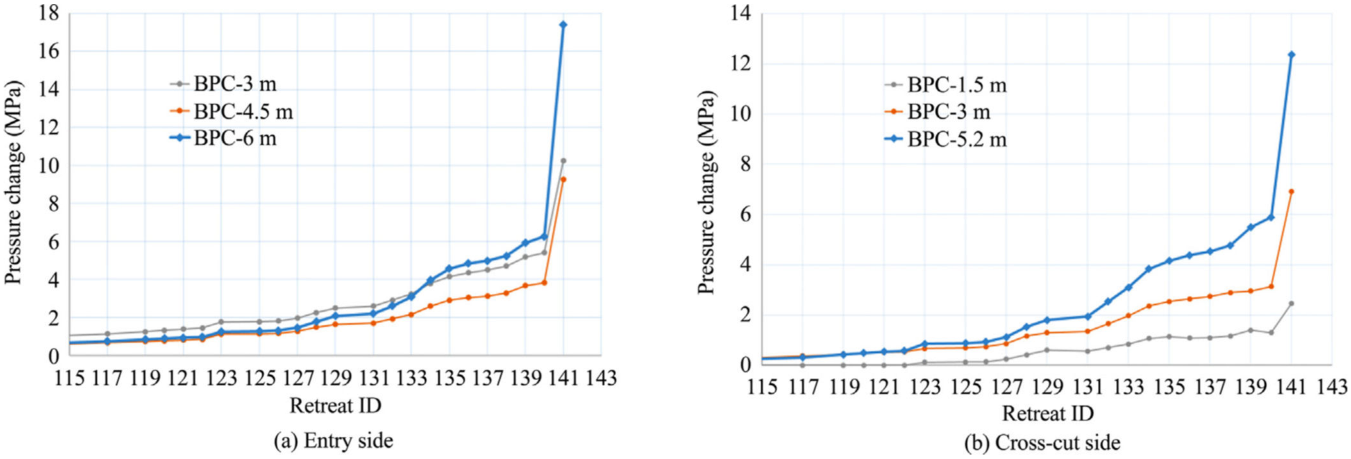


Fig. 10.

Pressure change in the BPCs for the entry and cross-cut sides at site-1.

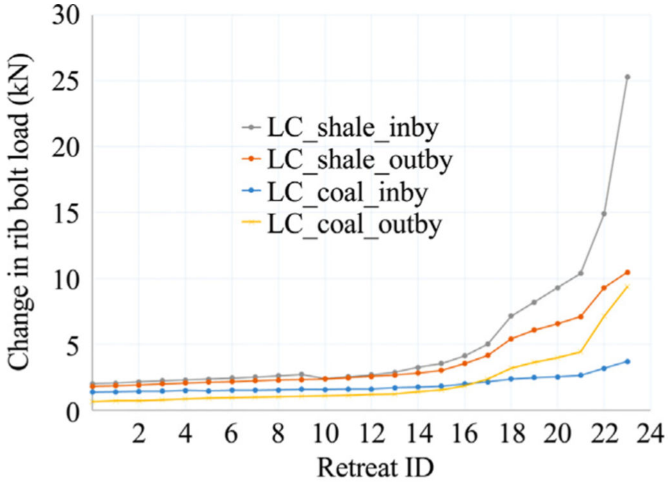


(a) Entry side

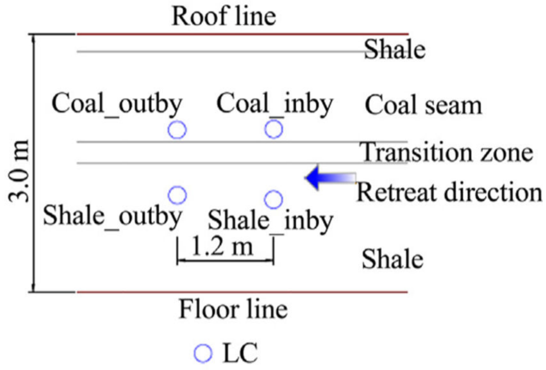
(b) Cross-cut side

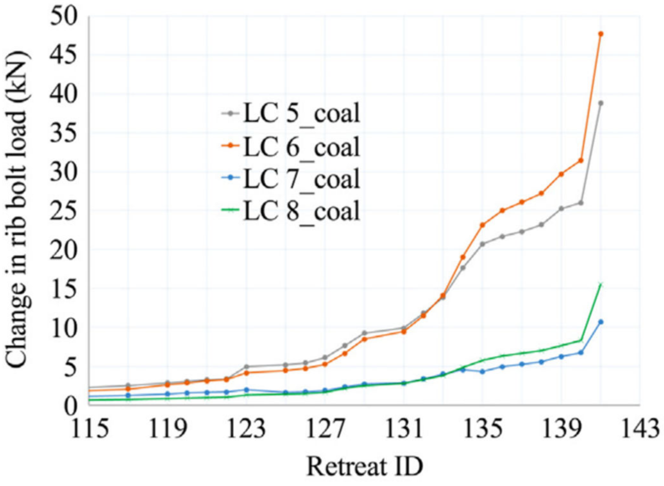
Fig. 11.

Pressure changes in the BPCs for the entry and cross-cut sides at site-2.



(a) Site-1

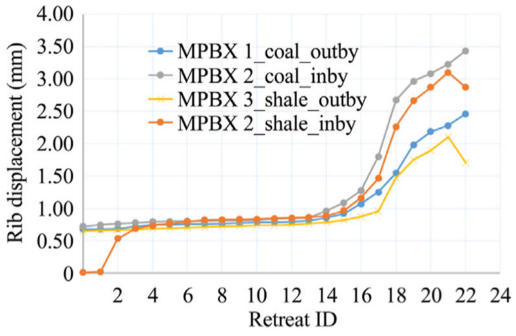




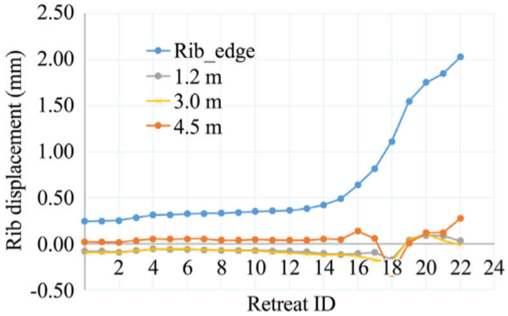
(b) Site-2

Fig. 12.

Change in rib-bolt load for the entry side at site-1 and site-2.



(a) Rib-edge displacement



(b) MPBX 1_coal_outby

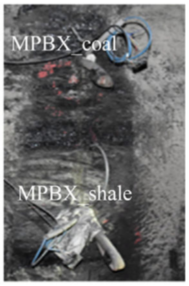
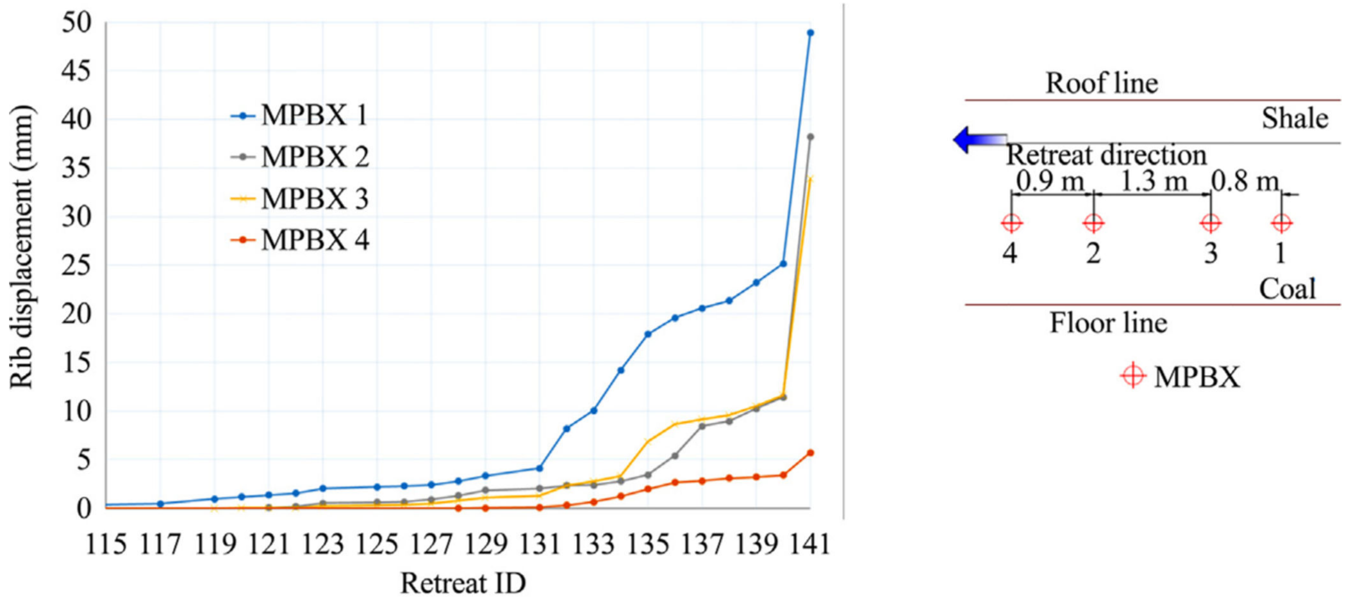
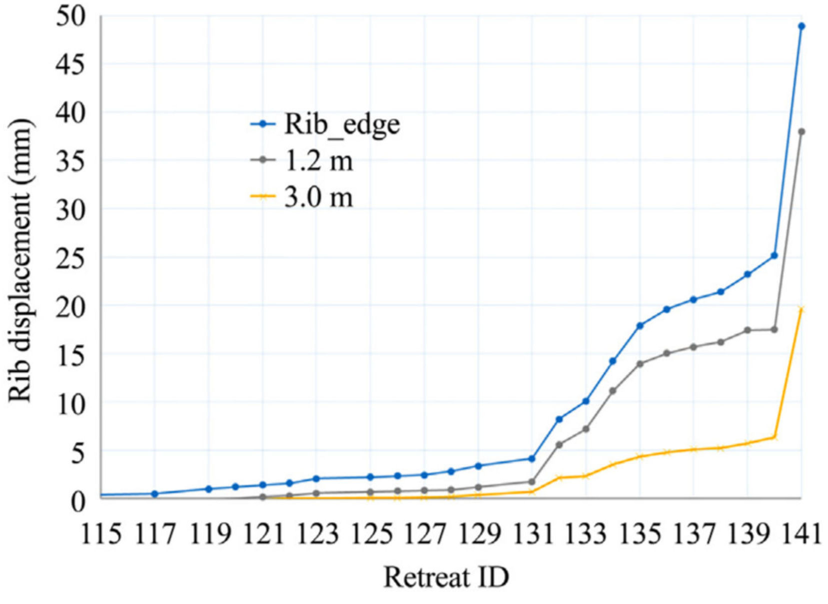


Fig. 13.

Measured rib displacement at rib edge and multi-anchor points inside the pillar for the entry side at site-1.



(a) Rib-edge displacement



(b) MPRX 1

Fig. 14.

Measured rib deformation at rib edge and multi-anchor points inside the pillar for the entry side at site-2.

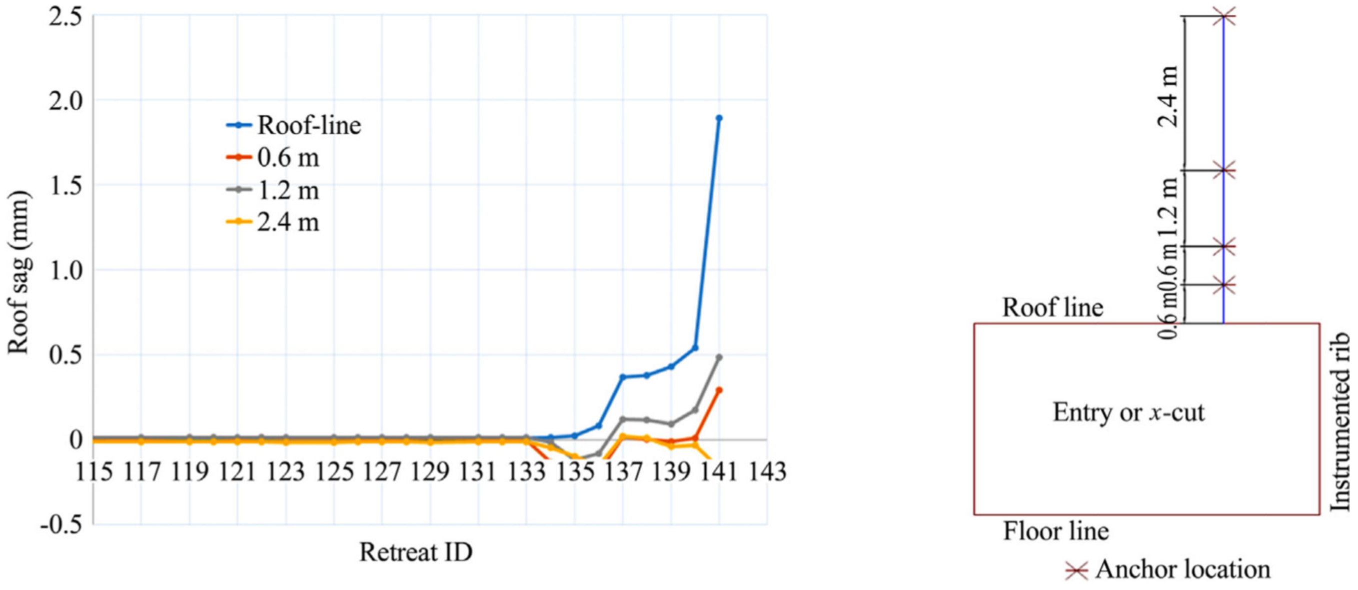


Fig. 15.

Measured roof displacement at site-2 and schematic for anchor locations.

Table 1

Summary of instrumentation for the entry and cross-cut sides at site-1.

Instrumentation type	Number	Location
Roof extensometer (RX)	2.0	Anchors located at 0.6,1.2,2.4, and 4.8 m deep in the roof. One extensometer was installed in the entry and the other one in the x-cut
Multipoint borehole rib extensometer (MPBX)	6.0	Anchors located at 1.2, 3.0, 4.8, and 9.1 m deep for both entry and cross-cut sides of the instrumented pillar. Three MPBX were installed in the entry side, and three were installed in the x-cut side of the instrumented pillar
Rib bolt load cells (LC)	6.0	Mounted on #6 grade 60,1.5 m long rib bolt with 71.1 cm of grout. Four LCs were installed in the entry side and two were installed in the x-cut side of the instrumented pillar
Borehole pressure cells (BPC)	6.0	BPCs are located at 3.0, 4.5, and 6.0 m deep for entry side of the pillar, while they are located at 1.5, 3.0, and 4.5 m deep for the cross-cut side of the instrumented pillar. Three BPCs were installed in the entry side and three were installed in the x-cut side of the instrumented pillar
Short encapsulation rib bolt for pull-out tests (SEPT)	6.0	#6 rib bolt, grade 60, 1.5 m long rib bolt with 35.5 cm of grout. Four SEPT were installed in the entry side, and two were installed in the x-cut side of the instrumented pillar

Table 2

Summary of instrumentation for the entry and cross-cut sides at site-2.

Instrumentation type	Number	Location
Roof extensometer (RX)	2.0	Anchors located at 0.6, 1.2, 2.4, and 4.8 m deep in the roof
Multipoint borehole rib extensometer (MPBX)	3.0	Anchors located at 1.2, 3.0, 4.5, and 9.1-m deep in the pillar for the entry side
Multipoint borehole rib extensometer (MPBX)	3.0	Anchors located at 1.8, 3.6, 5.4, and 9.1 m deep in the pillar for the cross-cut side
Rib bolt load cells (LC)	6.0	Mounted on #6 grade 60, 1.5 m long rib bolt with 71.1 cm of grout
Borehole pressure cells (BPC)	6.0	For the entry, BPCs are located at 3.0, 4.5, and 6.0 m. For the cross-cut, they are at 1.5, 3.0, and 5.1 m
Short encapsulation rib bolt for pull-out tests (SEPT)	2.0	#6 grade 60, 1.5 m long rib bolt with 35.5 cm of grout

Table 3

Pull-out tests results for rib bolts at site-1 and site-2.

Test #	Site	Location	Anchorage capacity (kN/m)
1	Site-1	Cross-cut (coal seam)	18.7
2	Site-1	Cross-cut (shale parting)	19.5
3	Site-1	Entry (coal seam)	18.7
4	Site-1	Entry (coal seam)	18.7
5	Site-1	Entry (shale parting)	16.3
6	Site-1	Entry (shale parting)	19.5
7	Site-2	Entry (coal seam)	18.7
8	Site-2	Entry (coal seam)	21.4
9	Site-2	Entry (coal seam)	19.5