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FLOOR HEAVE MONITORING USING FLOOR INSTRUMENTATION

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ABSTRACT: Several underground coal mines in Australia have recently reported and anticipated significant floor heave in gateroads during longwall retreat. Floor heave on longwall retreat is typically attributed to a stress notch. To further understand the mechanisms of floor heave, *in situ* floor heave monitoring was conducted using floor instrumentation at two coal mines. This paper provides the field monitoring results along with the process of selecting the instruments and monitoring sites. To grasp the whole picture of the deformation of floor strata, the instruments for both the vertical and horizontal movements of floor units were considered. For the horizontal floor deformation, the strain gauged shear strips were used in both mines. For the vertical displacement of floor units, a remote reading tell-tale (RRTT) was chosen in Mine A, while a GEL extensometer specifically designed for this floor monitoring was selected in Mine B. As Mine A had negligible floor heave at the monitoring sites, no significant movement of the floor was captured. Although the level of floor deformation was minimal, there were indications of bedding separations as the longwall face approached the sites. In Mine B, minor floor heave was observed at the monitoring location. The data from the instruments showed that the horizontal movement of the floor strata occurred greater than approximately 4 m below the floor surface which may suggest the depth of floor failure. While several practical issues were identified from the field studies, the field monitoring results facilitated better understanding of the failure mechanisms.

INTRODUCTION

Several underground coal mines have recently reported significant floor heave in gateroads. Although the phenomenon is well-known in the mining industry, research on floor heave has been relatively limited. The Australian Coal Association Research Program (ACARP) project C26064 was initiated to better understand the floor failure mechanisms and controlling factors.

As part of the project, *in situ* floor heave monitoring was carried out using floor instrumentation at two underground coal mines in Australia. Since floor instrumentation is not a common practice, discussions on the selection of instruments and monitoring locations were held many times with the mine sites. The process of selecting the instruments and monitoring sites is detailed, followed by the monitoring results and discussion on the results.

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PREPARATION FOR FLOOR INSTRUMENTATION

Review on types of field monitoring

Various field monitoring techniques were reviewed and compared for the fieldwork. Many displacement monitoring devices including borescope, convergence rod and various types of extensometers have been used (Spearing and Hyett, 2014; Sweeney, 2015; Galvin, 2016). The term 'tell-tale' is commonly used in the mining industry for extensometers that have visual indicators of vertical strata movement (Bigby, *et al.*, 2010). The strain gauged shear strip is widely used to monitor the roof and rib in the Australian coal mining industry (Nemcik, 2003; Tarrant, 2005; Heritage, 2018). Several stress measurement techniques also exist while the ANZI cell and CSIRO cell are typically used in Australian coal mines for stress measurements (Worotnicki, 1993; Sweeney, 2015; Galvin, 2016; Mills and Puller, 2018).

Apart from the displacement and stress monitoring, there are other types of instrumentation. Tiltmeters, also known as inclinometers, measuring changes in tilt or slope, have been used to monitor ground movements (Logan, 2008; Mills, 2011; Spearing and Hyett, 2014). Time Domain Reflectometry (TDR) can also detect the movement of rock mass by interpreting cable deformation (Dowding *et al*, 1989; Dowding and Huang, 1995; Dussud, 2002). Laser scanning technologies and photogrammetry have been trialled to monitor the deformation of roadways in underground mines (Kukutsch, *et al.*, 2016; Slaker and Mohamed, 2017; Vazaios *et al*, 2017; Raval, *et al.*, 2019).

When it comes to floor monitoring, floor instrumentation including the extensometer, inclinometer, stress cell and strain gauged shear strip has been used (Speck, 1979; Kumar, 1990; Seedsman and Gordon, 1992; Wuest, 1992; Wang, 1996; Nemcik, 2003; Kang, *et a.l*, 2014; Zhu, *et al.*, 2014). Convergence rods were used to measure the clearance between the roof and floor and subsequently to identify the movement of the floor (Vasundhara, 1999; Unal, *et al.*, 2001). In a rare case, a test pit was created so that the cross-section of the floor could be seen (Whiteley, *et al.*, 2005). Eventually, displacement monitoring was selected to provide a complete view of the deformation of floor strata. Equipment for both the vertical and horizontal movements of floor units was considered.

Selection of instruments and monitoring locations

Two typical types of extensometers include the sonic probe extensometer and roadway deformation indicators also known as tell-tales (Sweeney, 2015). The sonic extensometer allows more detailed monitoring with a greater number of anchors compared to the tell-tales (Corbett and Payne, 1995; Bigby and DeMarco, 2001; Nemcik, 2003). However, the sonic extensometer is vulnerable to damage and more expensive; thus, the tell-tales were chosen over the sonic probe extensometer to monitor the vertical displacement of the floor. In Mine A, the remote reading tell-tale was used (Bigby and DeMarco, 2001; Bigby, *et al.*, 2010; Buddery, *et al.*, 2018). In Mine B, the GEL extensometer (Shen, *et a.l*, 2006; Sweeney, 2015) particularly designed for floor monitoring was used with a higher travel range of 400 mm. For the lateral floor displacement in both mines, the strain gauged shear strip was chosen.

Also, the specific locations for monitoring were chosen where floor heave was expected and traffic could be avoided as much as possible. In Mine A, it was hypothesised that the interburden thickness between the coal seam being mined and the lower coal seam would affect the occurrence of floor heave. Thus, four locations along the roadways in LW603 were selected as shown in Figure 10. In Mine B, significant floor heave was frequently observed around the areas near the longwall finish lines. Therefore, one location around the finish line of LW425 was selected as shown in Figure 11a.

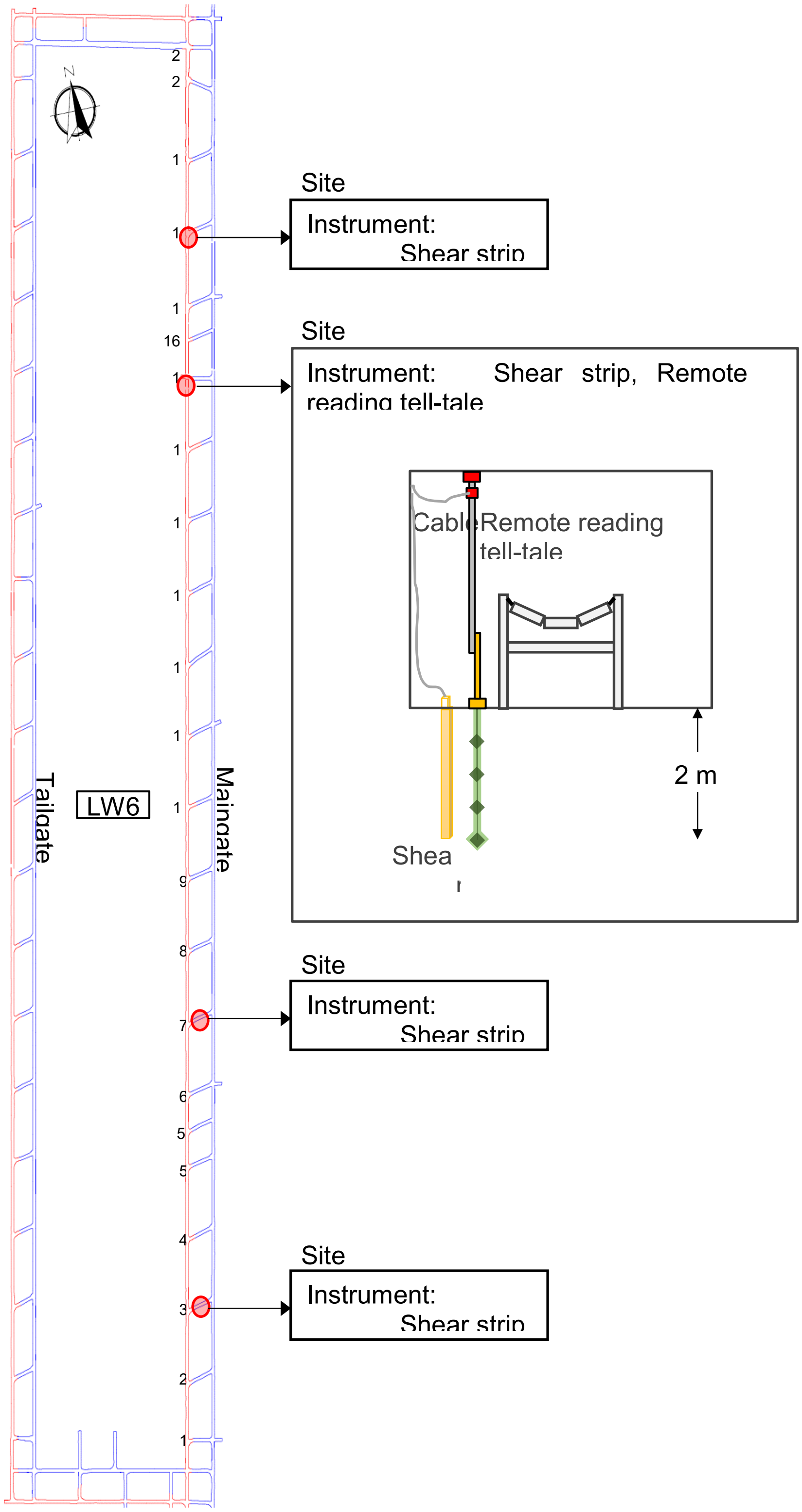

Figure 10: Monitoring locations in Mine A with types of instrument and interburden thickness between the coal seam being mined and lower coal seam

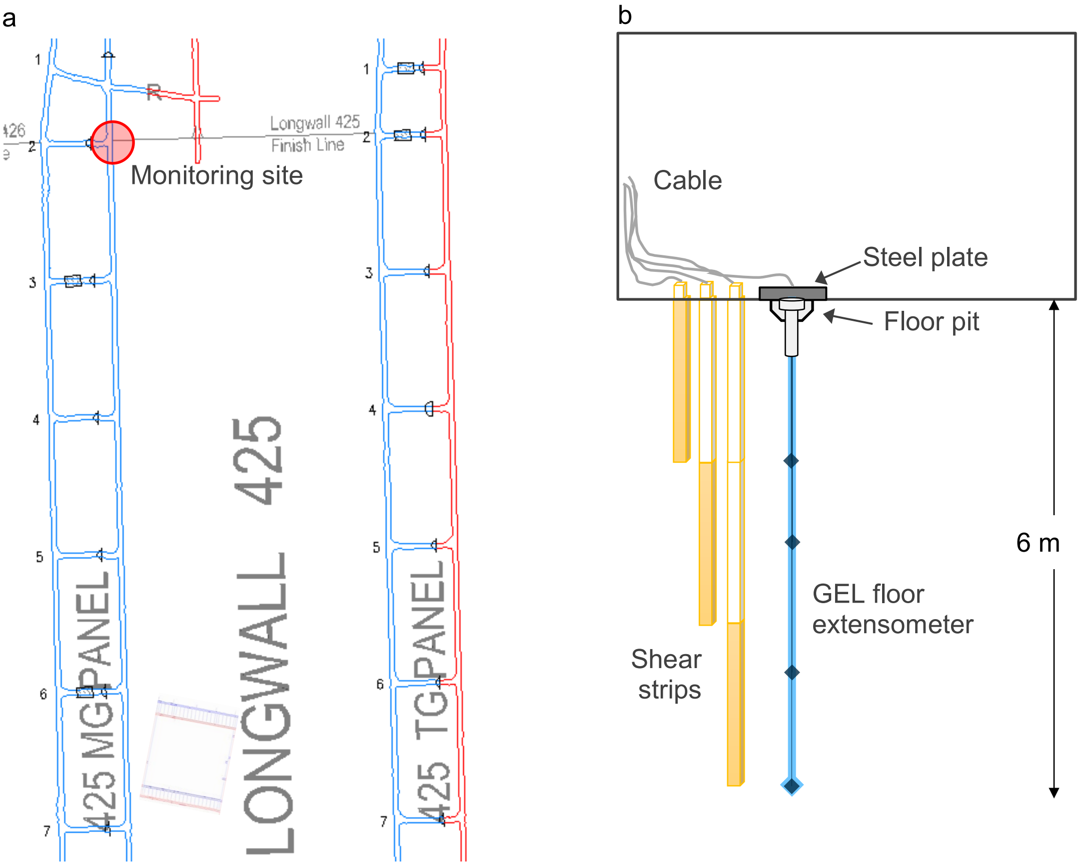

Figure 11: Floor instrumentation at Mine B (a: monitoring location, and b: types of instrument)

Different approaches to gathering data in terms of depth of floor failure were used for each mine. In Mine A, a monitoring depth of 2 m into the floor was targeted since the impact of the immediate floor units was considered critical. Hence, four strain gauged shear strips were arranged for each monitoring location and a 2-m-long remote reading tell-tale with four anchors located every 0.5 m in the 2 m floor horizon were added to one of the monitoring sites as shown in Figure 10. In Mine B, the greatest movement of the floor strata was expected at around 4 m below the floor surface due to the location of the soft clay matrix. Therefore, a monitoring depth of 6 m into the floor was considered to cover the deformation of the soft material. As a typical length of the strain gauged shear strip is 2 m, three strain gauged shear strips were prepared to cover the 6 m floor horizon. In addition, a 6-m-long GEL floor extensometer with four anchors was prepared as shown in Figure 11b. The anchor depths of the GEL extensometer were 2 m, 3 m, 4.5 m and 6 m.

Installation

After the monitoring locations and types of instruments were determined, the equipment was installed. Figure 12 shows the site where the shear strip and remote reading tell-tale were installed together adjacent to the conveyor belt in Mine A. As described in Figure 10, only one shear strip was installed at the other three locations in the mine.

To install the GEL floor extensometer in Mine B, an auger hole with a diameter of 500 mm and a depth of 250 mm was produced to recess the instrument (Figure 13a). Then the extensometer was installed into the hole (Figure 13b), followed by placing a steel plate with a thickness of 6 mm to protect the head of the extensometer from excessive groundwater (Figure 13c). Three sets of shear strips were also installed close to the GEL extensometer. Finally, the instrumented site was barricaded to protect it from traffic and to limit access to the instruments.

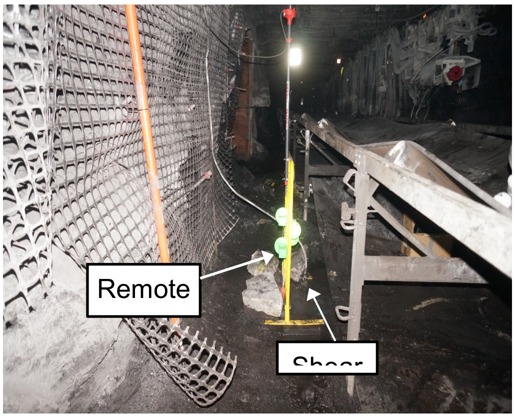

Figure 12: Shear strip and remote reading tell-tale installed in Mine A

Figure 13: Installation of GEL floor extensometer (a: top of the hole reamed using auger, b: GEL extensometer placed into the hole, and c: steel plate covering the instrument)

RESULTS

The effect of longwall retreat on floor heave was monitored as Mine A anticipated floor heave and Mine B experienced significant floor heave on longwall retreat.

Mine A

During the monitoring period from June 2018 to December 2018 as LW603 retreated, Mine A rarely experienced floor heave in the maingate where a stress notch was present. Consequently, the data obtained from the floor instrumentation did not capture significant movement of the floor. Figure 14 illustrates the results from one of the strain gauged shear strips. Many shear planes appeared to exist such as around 0.25 m, 0.35 m, 0.6 m, 0.85 m, 0.95 m and 1.15 m below the floor surface. The biggest movement was captured around 0.6 m below the surface. As the uppermost floor unit of Mine A is coal with a thickness of approximately 0.5 m, the shearing may indicate that a bedding plane exists between the coal floor and the underlying floor unit. While the magnitudes of the shear displacement were not significant, the shearing seemed to accelerate where the longwall face was 60 m inbye the monitoring location. The data showed the maximum displacement of shearing where the longwall face was 24 m away.

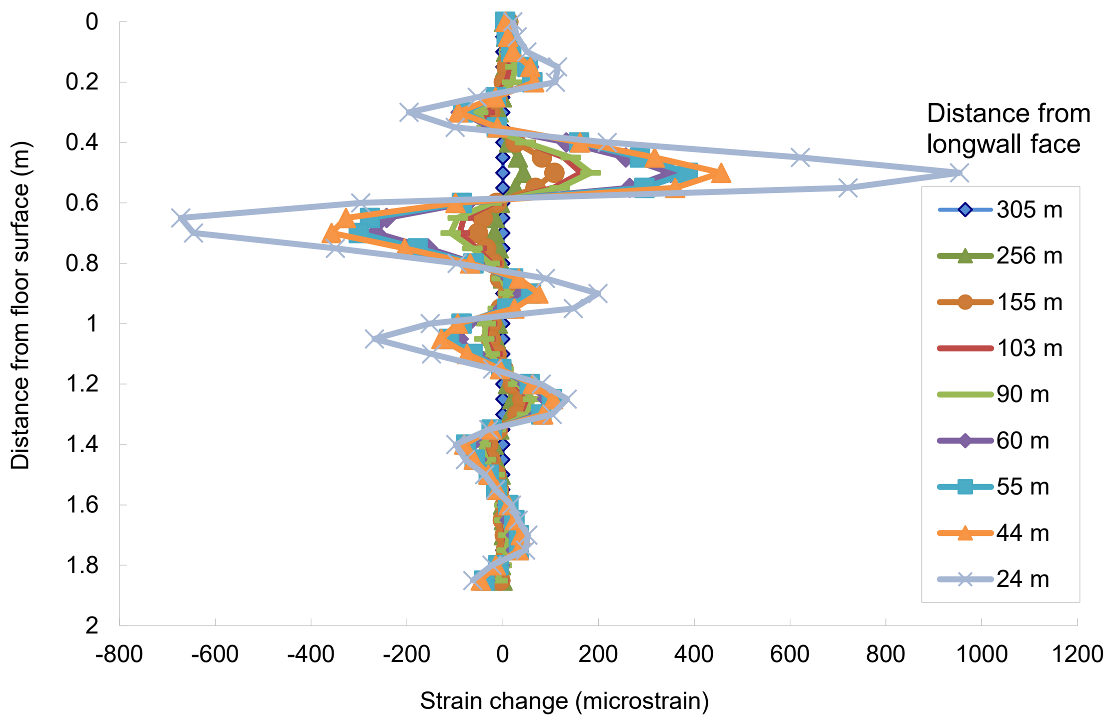

Figure 14: Strain change data from shear strip at Site 1 in Mine A

Figure 15 illustrates the monitoring data from the remote reading tell-tale. As floor heave at the monitoring location was negligible, it appeared that erroneous results were obtained from the instrument. The spikes on 28 July and 19 August 2018 were thought to be caused by the impact of some materials off the conveyor belt. The distances from the longwall face were approximately 500 m on 28 July and 260 m on 19 August. The fluctuation of the displacement data was possibly due to vibrations caused by the belt structure right next to the instrument.

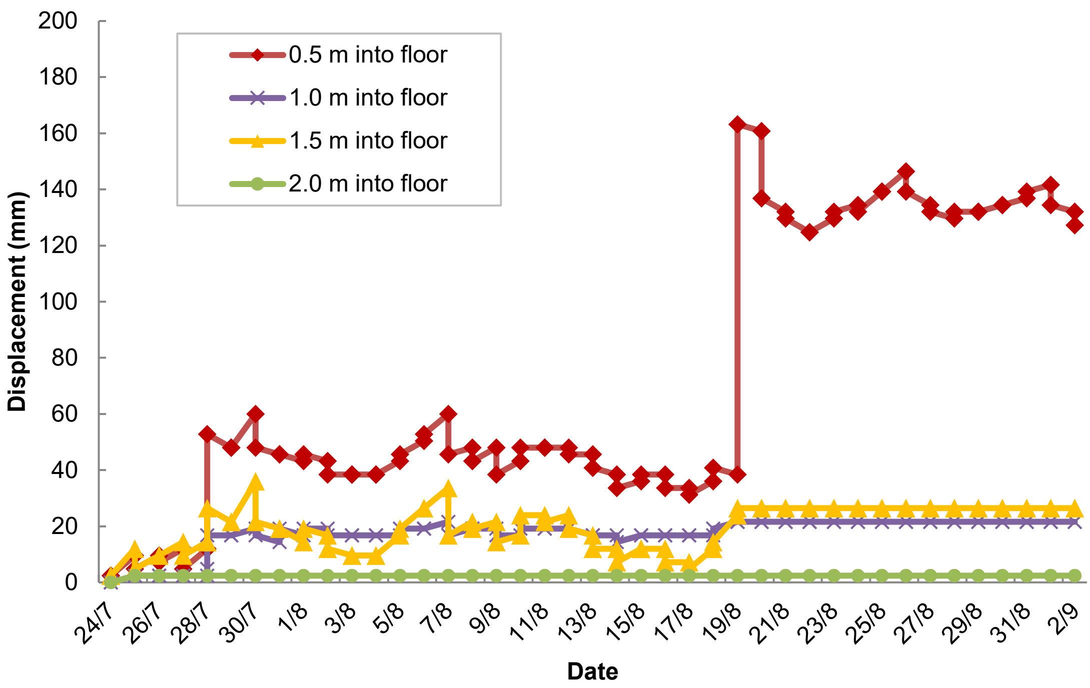

Figure 15: Displacement data from remote reading tell-tale at Site 2 in Mine A

Mine B

Mine B showed minor floor heave around the location of floor instrumentation during the monitoring period from March 2019 to August 2019. Figure 16 shows the results from the shear strips installed in the mine, with a predominant shear plane 3.8 m below the floor surface. It was difficult to drill beyond the 4 m floor horizon, which indicated a strong floor unit. The predominant shear plane possibly indicates a bedding plane between the soft clay matrix and the underlying strong unit.

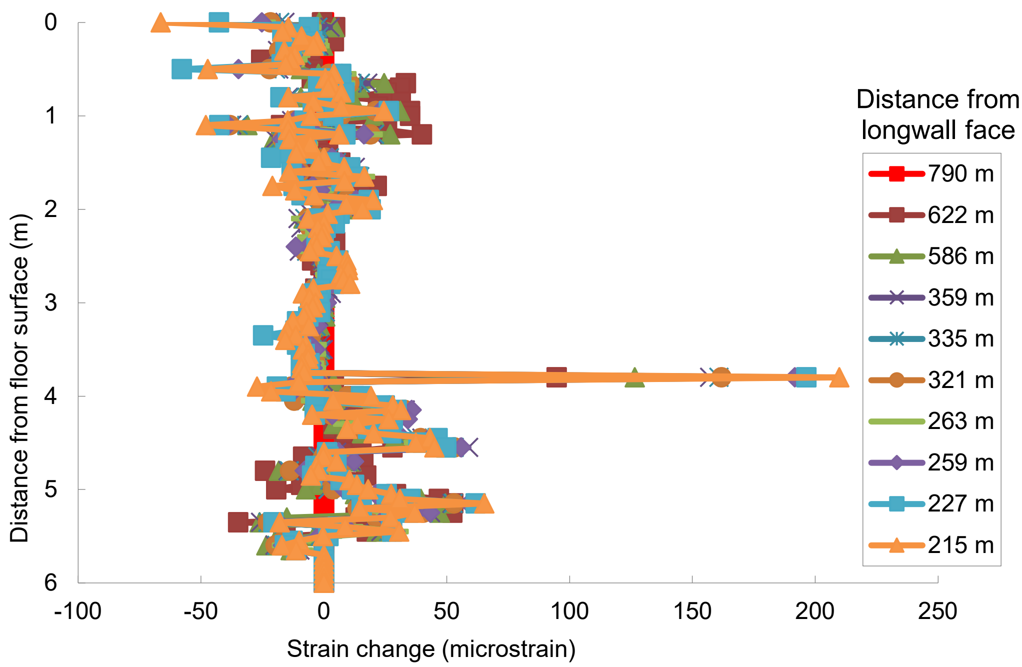

Figure 16: Strain change data from shear strip in Mine B

Due to other operational issues, the monitoring stopped when the longwall face was 280 m inbye from the installation site. The magnitude of the deformation detected from the shear strips was minor. The displacement from the GEL extensometer was also negligible.

DISCUSSION

Results at Mine A

Although the floor instrumentation in Mine A did not show significant floor movement, the field monitoring results from the strain gauged shear strips showed the shear movements along the bedding planes between the floor units. This indicates the bedding separations might be part of the mechanisms of floor failure. Also, the shearing intensity tended to increase as the longwall face became close to the instrumented sites.

The mine experienced floor heave in the tailgate of previously mined panels, LW111 and LW112. This was attributed to the difference in the magnitudes of horizontal stresses exerted in each longwall panel. In LW111 and LW112, floor heave was observed where the depth of cover reached 350 m while LW603 is located at depths of cover ranging from 260 m to 305 m. In addition to this LW603 was the first longwall panel developed and mined in the area (virgin block), therefore horizontal stress concentrations were not adversely impacted by surrounding goafs. Also, the angles between the major horizontal stress and the headings where floor heave took place were approximately 25° in LW111 and LW112 while those in LW603 were typically less than 10°. The depth of cover generally correlates with the magnitude of horizontal stress (Mark and Gadde, 2008), and floor heave on longwall retreat is attributed to the horizontal stress notching effect (Thomas and Wagner, 2006). Overall, it was suggested that the magnitude of horizontal stress was not high enough to cause floor failures in LW603. Since finalising the results, the adjacent longwall block LW604 commenced and experienced intense floor heave of up to 0.5 m in the belt road and up to 1.0 m in the cut-throughs 30 m inbye of the retreating face.

Results at Mine B

Although minor floor heave was noticed near the monitoring location, both the shear strips and GEL extensometer did not capture significant floor movement. This is possibly due to the instruments installed close to the rib. As they were not installed in the middle of the roadway, the floor movement may not have been captured. Multiple sets of instruments at a location will be more effective to provide a full view of floor deformation from a research point of view.

It is worth noting that the high level of water and coal fines in the roadway, adjacent to the monitoring site, could have impacted the readings, particularly the GEL extensometer which is not water proof.

Limitations of floor instrumentation

Several practical issues were identified from this fieldwork using the floor instrumentation. For instance, the instruments in the floor need to be connected to the readout units through cables. The equipment tends to protrude from the floor a few tens of centimetres to connect the cables to the readers unless completely recessed. Thus, the instruments were installed close to the ribs, not at the centre of the roadways, to avoid interfering with underground traffic or equipment. Where cables are exposed, particularly on the floor, they are more susceptible to damage.

Water flowing on the floor was another issue at Mine B. This causes a muddy floor which, in turn, can limit access to the floor instrumentation. Moreover, installing equipment in the floor immediately after development was not possible in practice due to other operational requirements while the floor deformation shortly after excavation was considered crucial to measure. Future work requires novel technologies that can prevent the floor instrumentation from being interrupted by traffic or mining operations.

Data gathering was another practical issue. Most of the instruments used in this study required portable readout units, and thus, data gathering was only possible during underground trips with limited personnel available. The frequency of data is critical, particularly when the longwall face approaches the instruments, for an accurate and representative insight into ground behaviour. Therefore, a remote reading system would be beneficial in future monitoring sites.

SUMMARY AND CONCLUSIONS

Floor heave monitoring using floor instrumentation was carried out at two underground coal mines. In Mine A, four locations in a longwall panel were selected to investigate the influence of the interburden between the coal seam being mined and the lower coal seam. Four shear strips were installed at each location and a remote reading tell-tale was additionally used for one location. A depth of 2 m into the floor was monitored since the influence of the immediate floor units was considered critical. In both mines, the impact of longwall retreat on floor heave was investigated. In Mine B, one location around the finish line of a longwall panel was chosen as the mine experienced significant floor heave around the finish lines of previous panels. The strain gauged shear strips and GEL floor extensometer were installed at a depth of 6 m into the floor, to capture the deformation of the soft floor unit typically located at around 4 m below the floor surface.

Mine A experienced negligible floor heave around the monitoring locations. Consequently, the data obtained from the instruments did not capture significant movement of the floor. However, minor shear movements were detected between 0.25 m to 1.15 m floor horizon, which may indicate the bedding separations that could be part of floor failure mechanisms. The remote reading tell-tale produced erroneous results possibly due to the impact of the belt structure adjacent to the instrument. The shear strips installed in Mine B showed a minor shear movement 3.8 m below the floor surface while negligible deformation was detected from the GEL extensometer.

Although field measurements using floor instrumentation can be advantageous in understanding the behaviour of the floor, the implementation and routine monitoring of such measurement tools is still challenging. While several practical issues were identified from these field studies, the selection of the monitoring locations was one of the most challenging issues mainly due to underground traffic in an operational mine. Future work is needed to develop new technologies that can prevent the floor instrumentation from being interrupted by traffic or mining operations.

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