up to 10 cm (1.0 mm/d) in the mine roof and ribs. Visual and range-finder monitoring confirmed both the magnitude and location of the convergence.

Conclusion

Our study shows that MLS lidar data conform to or exceed the required quality to detect geotechnically relevant changes, and MLS monitoring can outperform static lidar scanning in target- and site-level coverage, uniformity of spatial sample distribution, and efficiency. In combination with advanced SLAM features like loop closure and scan registration, MLS data have the potential to become an effective and ubiquitous data source for rapid, accurate and comprehensive geotechnical inspections. More work will be required to test the sensitivity of change detection accuracy to SLAM-based alignment and the possible improvements of site-level accuracy by tightly integrating ground-control-point constraints for the SLAM algorithm. ■

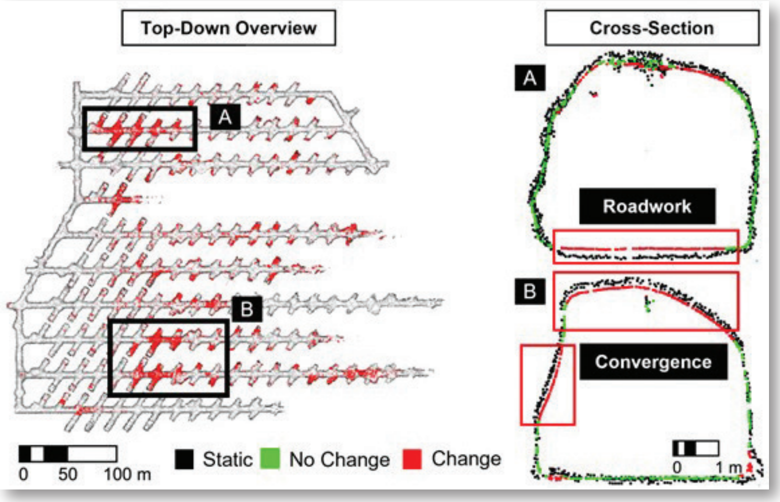

Fig. 2 Results of SLAM MLS survey at Mine-A with Stencil 2, with significant changes detected based on multiscale model-to-model cloud comparison distance calculation.

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Collection on Ground Control in Mining

Roof stability and support strategies associated with longwall-induced horizontal stress changes in belt entries

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Keywords: Roof stability, Belt entries, Horizontal stress

Roof stability in the belt entry is critical for safe and continuous production of coal during longwall mining. Previous studies of roof falls that occurred in belt entries have shown that the roof falls were largely associated with high in situ and longwall-induced horizontal stresses [1,2,3,4]. To properly support the roof in a belt entry, it is important to understand how longwall-induced horizontal stress changes can affect roof stability in the belt entry. Monitoring of horizontal stress changes was conducted in the belt entries of two Pittsburgh seam longwall panels oriented unfavorably to the major horizontal stress. Numerical models were also set up to investigate how horizontal stress concentrates and relieves in the belt-entry roof near the face as panel orientation changes. Both measurements and modeling results show that high horizontal stress concentrates in the belt entry roof within about 15 m outby the face. The study demonstrates that longwall-induced differential horizontal stress can be used to evaluate the horizontal stress concentration factors. The horizontal stress concentration factors change with panel orientation, resulting in high stress concentrations at orientations between 20 and 110° and low stress concentrations between 130 and 180°. Roof support strategies are given for the belt entries under the influence of high horizontal stress. For unfavorably oriented panels in weak roof conditions, supplementary support should be installed during development, and cable bolts should be anchored into a stable roof horizon. The bolting pattern should be designed to cover both entry corners and the entry center to prevent potential roof cutters and sagging.

Introduction

The stability of the belt entry in longwall mines is crucial for longwall safety and continuous production of coal from the longwall face. Any roof fall in the longwall belt entry would not only result in substantial interruption of coal production but potentially cause injuries or fatalities. Even though the roof in the belt entry is carefully supported to accommodate both abutment pressure and horizontal stress, roof falls still occasionally occur in belt entries in U.S. longwall mines, and they are mostly associated with high horizontal stress. This paper addresses how longwall-induced horizontal stress affects belt-entry roof stability by horizontal stress monitoring and numerical modeling.

Method, results and discussion

Horizontal stress monitoring and numerical modeling. The stress changes in the immediate roof in the belt entries were monitored for two longwall panels in the Pittsburgh seam. Hollow inclusion cells (HICells) were installed in the roof at an intersection in each of the belt entries, and stress changes were monitored as the longwall face was approaching and passing the intersection. Figure 1 shows the panel layout and HICell locations at the monitoring sites. The panels were oriented at 37° to the major horizontal stress. The overburden depths were 259 m at both sites, and mining height was 2.3 m. The horizontal stress monitoring showed that the longwall-induced horizontal stress changes occurred within about 12 m outby the face in the limestone roof 6 m above the roofline at the intersections in the belt entries.

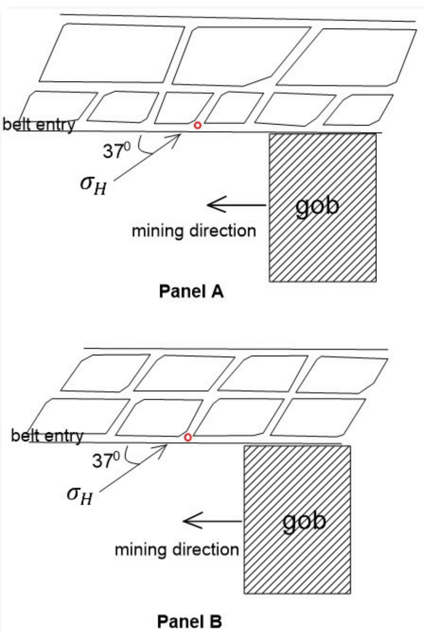

Fig. 1 Panel layout and HICell locations at the monitoring sites.

FLAC3D models were set up to calculate longwall-induced stresses in the belt-entry roof. The predicted horizontal stress changes were generally in good agreement with the measurements. The model predicted that horizontal stress across the entry and horizontal shear stress along the entry concentrate within about 15 m outby the face, but horizontal stress along the entry relieves within about 15 m outby the face. Among the three stress components on the horizontal plane, the greatest stress change induced by longwall retreat is the shear stress, which would significantly change and rotate the principal stresses on the horizontal plane.

Effect of panel orientation on belt-entry roof stability. Longwall mining induces principal horizontal stress changes in the belt-entry roof outby the face. The difference between the two horizontal principal stresses, referred to as differential horizontal principal stress, can be used as an indicator for the degree of horizontal stress concentration. The differential horizontal stress is defined by:

$$\sigma_{diff} = ½\,(\sigma_1 - \sigma_2) \qquad (1)$$

where σ_1 and σ_2 are the major and minor horizontal principal stresses in the belt-entry roof.

To understand how panel orientation affects roof stability, the model is used to calculate the differential horizontal stress at different panel orientations. The differential horizontal stress concentration factors are calculated at the T-junction corner on the panel side 2.4 m above the roofline and 3.0 m outby the face. Figure 2 shows differential horizontal stress concentration factors at different panel orientations. The horizontal stress concentration factors change with panel orientation, with high horizontal stress concentration at 20 to 110° and low horizontal stress concentration at 130 to 180°. The figure is also plotted with reported cases of roof falls and good roof conditions in the Pittsburgh seam belt entries. The results from this study indicate that roof falls occur at high differential horizontal stress concentration factors of 1.9 to 2.4, and that good roof conditions are experienced at low stress concentration factors of 1.0 to 1.4.

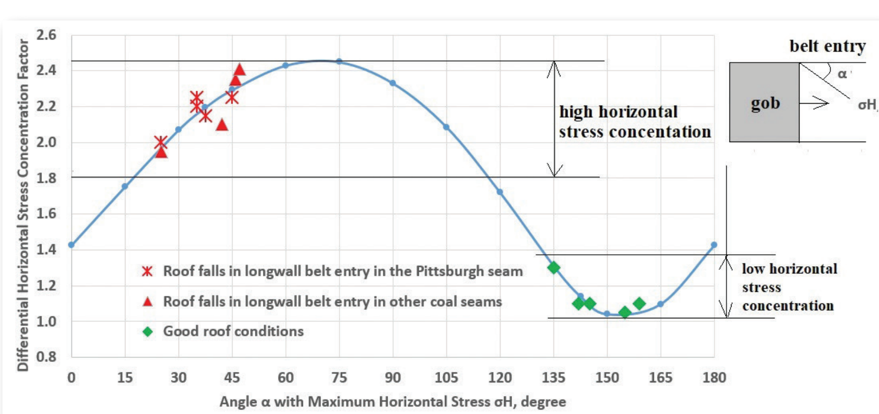

Fig. 2 Differential horizontal stress concentration factors at different panel orientations.

Conclusions

The following conclusions are made based on horizontal stress monitoring in the belt entry in a longwall mine in the Pittsburgh seam, numerical modeling of stress changes in the longwall belt entry, and the experience of roof control in Pittsburgh seam longwall mines:

- Under the influence of high horizontal stress, the roof in the belt entry could fail in the form of cutters and sagging. Horizontal stress monitoring and numerical modeling show that the influence zone of longwall-induced horizontal stress is within about 15 m outby the face.

- The horizontal stress concentration factors change with panel orientation, with high stress concentration at 20 to 110° and low stress concentration at 130 to 180°.
- Optimizing panel orientation is the first step to prevent roof falls in belt entries. For unfavorably oriented panels in weak roof conditions, supplementary support should be installed during development, and cable bolts should be anchored into a stable roof horizon. The bolting pattern should be designed to cover both entry corners and the entry center to prevent potential roof cutters and sagging. ■

Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention (CDC). Mention of any company or product does not constitute endorsement by NIOSH.

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Creep damage model for rockburst at Mufulira Mine in Zambia

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Keywords: Rockburst, Copperbelt, Stress analysis, Brittle creep

This paper describes a creep damage model that was proposed to clarify the rockburst mechanism for the Mufulira underground copper mine in Zambia. Cumulative rock damage was evaluated for the edge elements of each sidewall of the mining drives based on normal stresses by the 3-D displacement discontinuity method (DDM) (Crouch and Fairhurst, 1973). The rockburst occurrences were well hindcasted.

Background

In January 2018, the Mufulira Mine recorded a rockburst at 1,440 mL underground with a magnitude of 2.8 (Fig. 1a). We conducted a study on the M2.8 (#12) rockburst based on field investigation, rock testing and numerical elastic stress analysis [1], and calculated the normal stress to the orebody at the M2.8 rockburst and its variation with face advance using 3-D DDM. However, the elastically predicted stress at the rockburst site was not high and barely increased with the face advance. The present study applies DDM with a larger model to investigate other rockburst events from 2016 to 2018 and re-examine the M2.8 rockburst. Again, it is shown that the normal stress value or its increase with face advance cannot explain the rockburst occurrences. Therefore, the creep damage model is proposed under an assumption that the rockbursts could be brittle creep failure of the relatively intact rock mass.

Method

Minewide stress analysis. Three-dimensional elastic stress analyses by DDM were carried out, assuming the hydrostatic stress state is equal to the overburden pressure. A similar approach to that in Sinkala et al. [1] was followed, using the input parameters listed in Table 1, considering a larger minewide model. Fujii et al. [2] explained the conceptual equations applied in this method. The lithostatic state of stress was assumed for simplicity:

$$\sigma_v = \sigma_H = \sigma_h = \gamma h \qquad (1)$$

where σ_v is the vertical component of stress, σ_H is the maximum horizontal stress, σ_h is the minimum horizontal stress, γ is the unit weight of the rock mass, and h is the overburden depth.

Creep damage model. The basic concept of the creep damage model on the rate of creep damage D is shown in:

$$\frac{dD}{dt} = S_{SC}^n \qquad (2)$$

where S_{SC} is the stress severity for compressive failure, and n is a constant which represents the degree of time-depen-

Table 1 — Input parameters for numerical analysis.

Rock	Unit weight (N/m³)	Tangent modulus (GPa)	Poisson's ratio
Hanging wall and footwall	27,000	12.33	0.222
Orebody	27,000	10.23	0.241

Table 2 — Input parameters for brittle creep model.

UCS (MPa)	n	t (d)
80	25	1