Bleeder Entry Evaluation Using Condition Mapping and Numerical Modeling

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ABSTRACT

One of the most common critical areas of longwall mining in terms of ground stability are the gateroad and bleeder entries. These critical entries provide much-needed safe access for miners and allow for adequate ventilation required for dilution of hazardous airborne contaminants and must remain open during mining of a multi-panel district. This paper focuses on the stability of the longwall entries subjected to a single abutment load such as bleeders, first tailgate, and last headgate. First tailgate and last headgate are also referred to as blind headgates and tailgates. A study of a longwall district through conditions mapping, support evaluations, and numerical modeling was conducted and evaluated by researchers from the National Institute for Occupational Safety and Health (NIOSH). The condition mapping and support evaluations were performed on entries that spanned the previous five years of mining and relied on a diverse selection of supports to maintain the functionality of the entry. Numerical modeling was also conducted to evaluate various support types with further investigation and comparison to the condition mapping. The study demonstrated the importance of the abutment load decay versus distance from the gob edge, the potential for a reduction in material handling related injuries, as well as optimal usage of secondary and standing support.

INTRODUCTION

As longwall mining continues to take over more of the underground coal production around the world, safety and cost become more important and tend to compete. Two important concerns for longwall mining safety are entry stability and adequate ventilation. Often, these two safety concerns are integral to each other and must be considered at the same time. Critical areas for consideration of entry stability are the gateroad and bleeder entries. Gateroad entries can be subdivided into two categories: (1) those that will be used for access to two longwall panels and (2) those that will only be used to access one longwall panel. The gateroads that will only be used to access one longwall panel are often called blind headgates or tailgates. Blind gateroads along with the bleeder entries will be used for the entire longwall district to provide adequate ventilation

and to dilute any harmful contaminants in the air for an entire longwall district.

The long-term stability of the bleeder and blind gateroad entries depends on the size of protective pillars, local geology, and the support systems installed. The success of the pillars and support systems needs to be reevaluated periodically to ensure that the desired level of safety is maintained. The evaluation of the support systems needs to include the stability of the entries as well as the potential for material handling injuries. At times, the support needed to maintain safe entries may increase the potential for material handling injuries, indicating the need for improved material handling processes or support designs. Numerical modeling, instrumentation studies, condition mapping, and visual assessment of the standing support can all be used to evaluate these entries. Each method has its own benefits and costs. Numerical modeling relies heavily on the quality and correctness of the input factors yet can evaluate a wide range of conditions in a fairly short period of time. Instrumentation studies are very time consuming and expensive; however, they provide the necessary information to develop numerical inputs. Condition mapping is relatively fast and provides an opportunity to evaluate a large area but can be skewed because of damage caused by equipment, damage that occurred during development, and the limited ability to see beyond the surface of the entry. Visual assessments of the standing and secondary support provide the end outcome yet have similar pros and cons as condition mapping. In an ideal world, all available methods to evaluate these critical entries would be used all the time.

A study of an entire longwall district at a northcentral West Virginia mine, which is mining metallurgical grade coal in the Lower Kittanning coal seam, was conducted by National Institute for Occupational Safety and Health (NIOSH) researchers to evaluate the various support designs and time-dependent deterioration of the mine openings. In this case, the primary evaluation methods used were condition mapping, numerical modeling, and visual observation. These three methods were applied to bleeder entries and their associated blind gateroad entries in a district of seven

longwall panels. In addition, there was a single gateroad that was instrumented from development through first panel mining and until the second panel was just outby the instrumentation site. The instrumentation study was previously published and completed prior to the bleeder entry evaluations (Esterhuizen, Gearhart, and Tulu, 2017).

STUDY AREA GEOTECHNICAL INFORMATION

Mine Geometry and Support

The study mine is mining the Lower Kittanning seam using the longwall mining method. The depth of cover ranges from 350 to 750 feet, and the mining height ranges from 6 to 10 feet. The mains are typically six entries with pillars 85- to 120-feet long and 65- to 75-feet wide center to center. The entries and crosscuts are typically 18-feet wide. The longwall panels are 3,600 to 10,000-feet long and 1,200-feet wide. The three-entry gateroad system consists of two equal-sized pillars that are 100-feet wide and 150-feet long center to center. The study area includes rear bleeder entries and their associated blind gateroads in a district of seven longwall panels. The mining of the studied longwall panels began with panel 4 and continued in numerical order through panel 9S as seen in Figure 1.

The primary support installed throughout the study area consisted of a row of four 6-foot-long, number 6 fully grouted rebar bolts every 4 feet. The secondary support was typically a pair of 10-foot by 0.6-inch cable bolts with two resin cartridges installed through a strap every 8 feet. In addition, corner bolts were installed at 45 degrees on 8-foot spacing. The secondary support was typically installed between 60 and 100 feet behind the advancing face. In some of the studied areas, rib bolting was also part of the primary

Figure 1. Mine layout with study area highlighted.

support using a single 5-foot, number 5 mechanical anchor bolt spaced every 8 to 12 feet.

Standing support was also installed in the study area. There were three different standing support types used throughout the study area—pumpable cribs, Propsetters, and wooden cribs. These standing supports ranged from being installed continuously along the entries to a limited number of supports installed in the intersections only, depending on the area and proximity to the gob. In addition, there was a test area that used 10-feet-long, 0.6-inch-diameter tensional cable bolts instead of standing support. In this area, 10 tensional cable bolts within the intersection were supplemented by two rows of two cable bolts at all four edges of the intersection. The straights between intersections were supported by two cable bolts between every other row of primary bolts.

Mine Geology

The mine is located in northcentral West Virginia, which is mining metallurgical grade coal in the Lower Kittanning coal seam. The Lower Kittanning coal seam is found in the Kittanning formation of the Allegheny Group that averages 280-feet thick and covers areas of southwestern Pennsylvania, eastern Ohio, and northwestern West Virginia. The Kittanning formation is reflective of the cyclothem nature of deposits during coal deposition in the Pennsylvanian Period caused by a series of ice ages that changed global sea levels. Sequences of shale, limestone, sandstone, clay, and coals are found to occur in predictable patterns throughout the formation as shown in Figure 2 (Williams, 1960).

In the study area, the Lower Kittanning coal maintained an average height of 4.3 feet, and the total mining height averaged 8 feet. Rolls in the seam were common and possibly caused by sandstone paleochannels that caused additional load on the peat during coalification. Occasional slips and slicks were observed, but no other major geological features were present within the study area. The floor geology of the immediate mine entry consisted of 8.29 feet of alternating sequences of dark shales and fireclay that became calcareous near the Lower Kittanning seam. Floor conditions were generally unremarkable with exceptions where rolls in the coal seam created local depressions where water could accumulate, and minor floor heave occurred on an average of 2 inches. The mine cut out an average of 2 feet of floor below the coal in limited areas if clay or soft material was present to aid in equipment maneuverability.

The rib of the mine entry exposed 2 feet of shale or clay immediately below the coal bed if the decision was made to cut into the floor rock or the entry floor could coincide with the bottom of the coal if no soft floor was present. The coal seam main bench averaged 4.3 feet with a binder consisting of 5 inches of shale and a rider seam that is 2 inches thick above it. Above the rider seam is a sequence of alternating black and dark gray shales. On average, the first 2 feet of the roof shale is mined out to be a member of the rib, and the remaining 6 feet of the shale becomes the first member of the immediate roof. Above the alternating black and dark gray shales is the first of the Lower Kittanning Rider seams, which is 0.35-feet thick. Above the first Lower Kittanning Rider is a binder consisting of shale and sandstone streaks that is 3.8-feet thick, followed by the top Lower Kittanning Rider seam, which is 1-foot thick. The main beam of the roof is 3.41 feet of sandy shale and 3.4 feet of Johnstown Limestone (Figure 3).
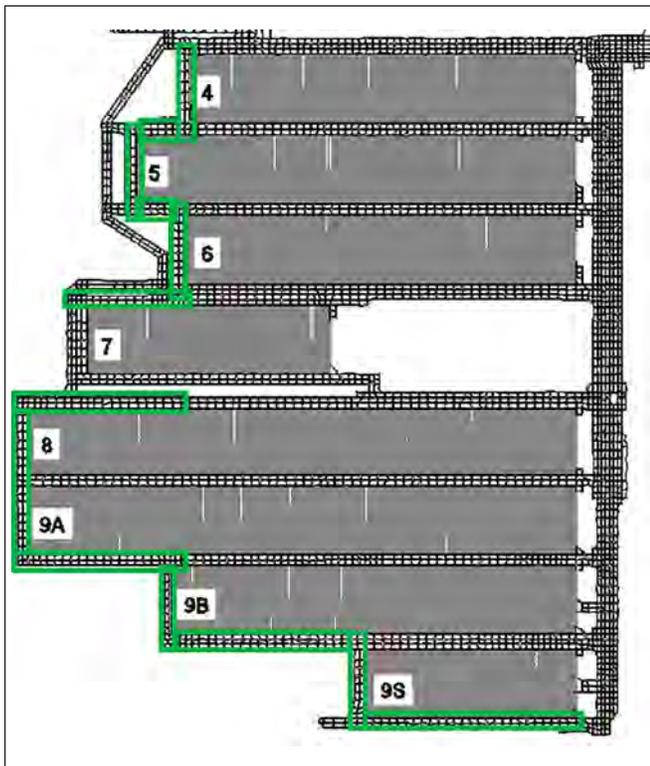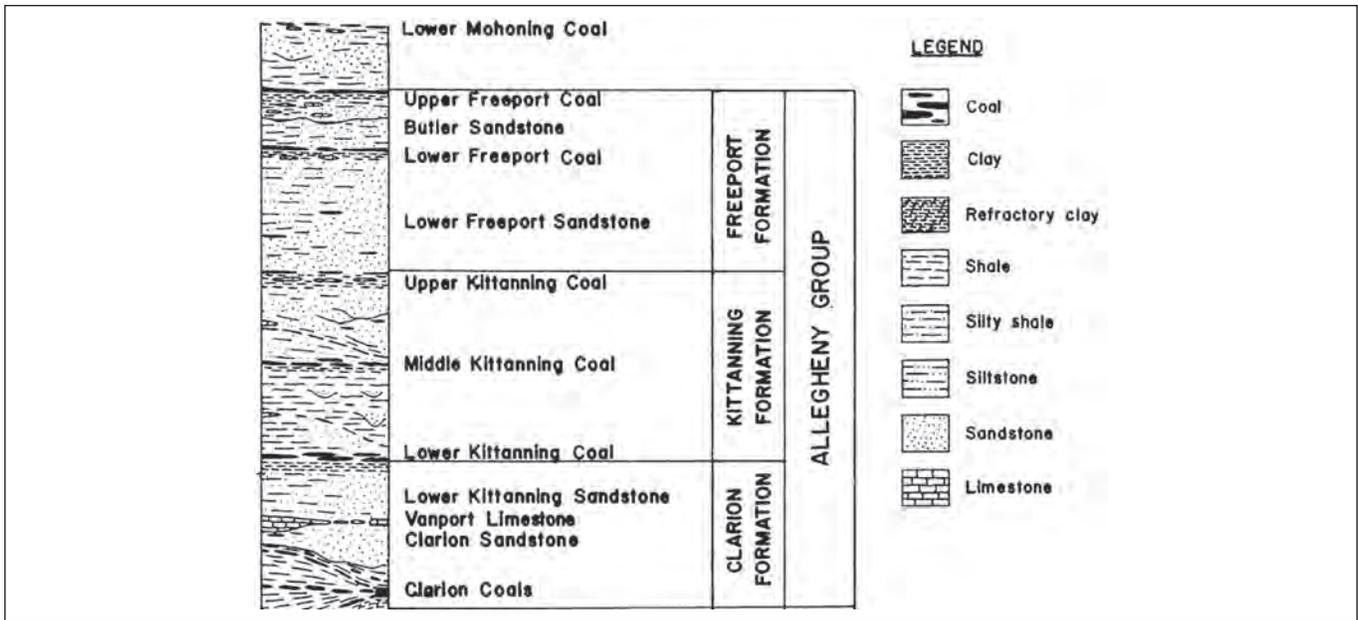
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Figure 2. Generalized stratigraphic column of the Allegheny group (after Williams, 1960).
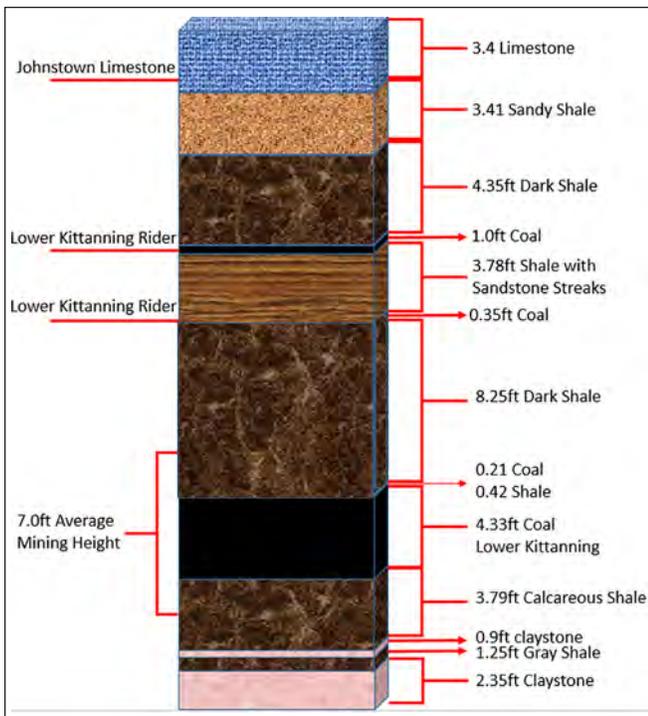

Figure 3. General geologic column of the study mine.

GROUND CONDITION MAPPING

Condition mapping was conducted for the roof, rib, and floor over the bleeder entries exposed to one abutment loading. The roof, rib, and floor ratings (not depicted in Figures 5 through 9) were based on a 1 to 6 scale, with 1 being best and 6 being worst as shown in Figure 4. The condition mapping system used in this study is that same as presented by Van Dyke, Klemetti, and Compton (2020a).

The highest observed rating for the roof was a 4, for the rib a 5, and for the floor a 3. The observed conditions averaged to a 2 across the entire study area. Panel 4 rear bleeders had one worst overall rating with one of two 5 rated ribs, while panel 5 averaged a 2 with several 1s and 4s as shown in Figure 5. Panel 6 was mostly 1s with a couple of 2s and 3s, and panel 8 averaged a 2 with a few 1s and 4s as shown in Figure 6. Panel 9A had half 1s and half 2s split at the middle between the headgate and tailgate as can be seen in Figure 7. Figure 8 shows that panel 9B averaged 1.4 with a few 2s and 3s. Near the junction of panel 9B and 9S, the worst pillar and roof ratings were observed, with several 3s, 4s, and a 5. The area is shown in Figure 8 at the far left. Panel 9S averaged 2 with one 4 rating as shown in Figure 9. Overall, the blind tailgates and head-gates had lower ratings than the rear bleeders, however, not by very much. They were rated mostly as 1s or 2s with a single 5 and a few 3s and 4s. The worst rated blind gateroad was near the corner of panels 9B and 9S (Figure 8). Two of the worst conditions observed were in panels that were mined almost four years apart. Panel 4 was the first panel of the district, so it was exposed to the mine environment the longest of the study area. Panel 9B was the second to last and only exposed to the mine environment for a relatively short period of time prior to being observed.

VISUAL ASSESSMENT OF SUPPORT

The condition mapping focusing on roof, rib, and floor provides a significant amount of information relative to the success of the mine design and support implementation. To supplement this information and provide more specific insight into the support condition or utilization, visual assessment of the supports installed at the study mine was performed. This evaluation included the standing supports, primary bolts, cable bolts, rib bolts, and roof and rib mesh. For the Propsetters, the condition was determined by observing the condition of the cuts at the base of the supports and the amount of compression of the wedges. For the wooden cribs, the compression of the crib blocks and the wedges were used to determine relative conditions. For the pumpable cribs, the condition
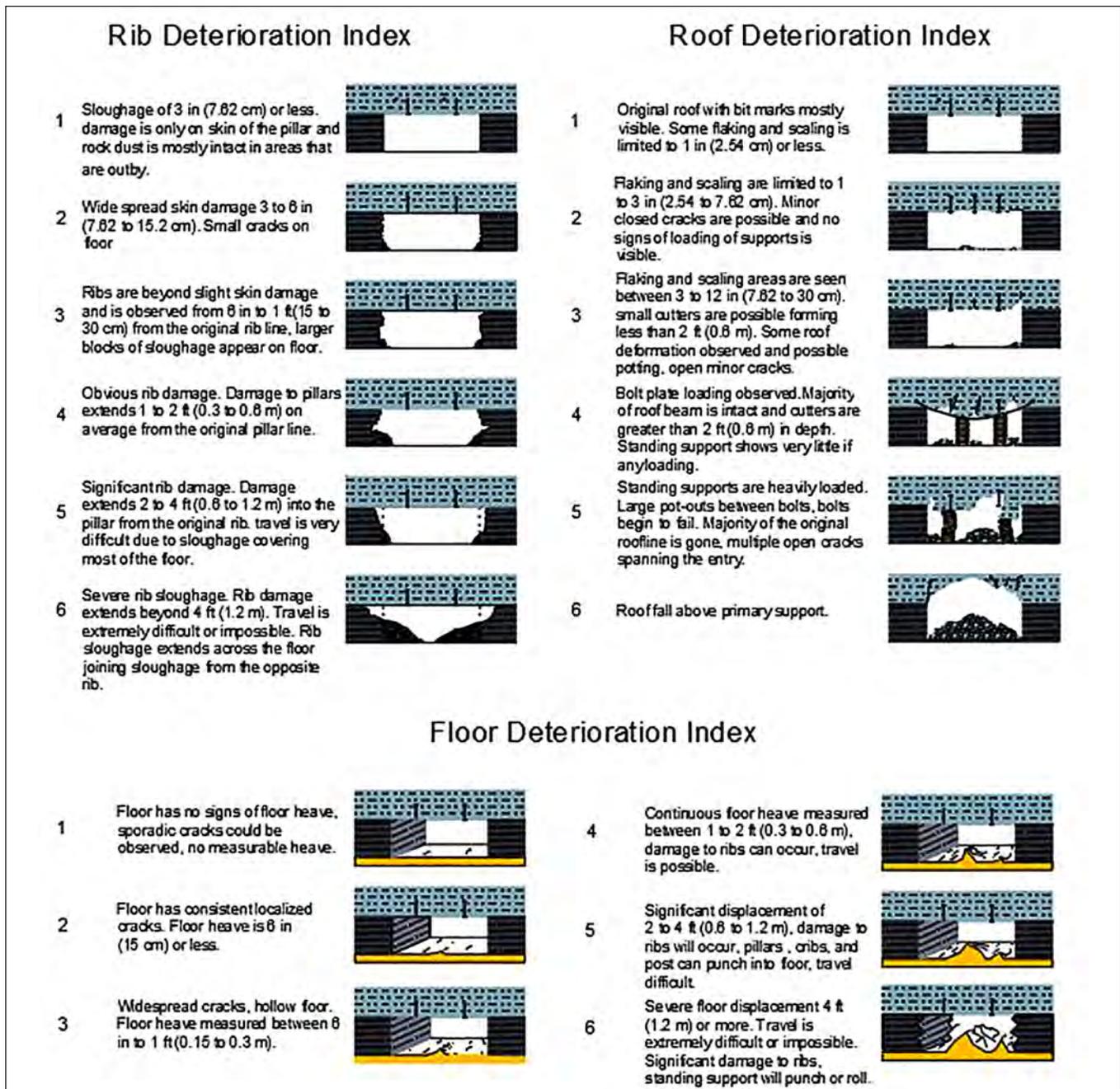
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Rib Deterioration Index

1 — Sloughage of 3 in (7.62 cm) or less. damage is only on skin of the pillar and rock dust is mostly intact in areas that are outby.

2 — Wide spread skin damage 3 to 6 in (7.62 to 15.2 cm). Small cracks on floor.

3 — Ribs are beyond slight skin damage and is observed from 6 in to 1 ft (15 to 30 cm) from the original rib line, larger blocks of sloughage appear on floor.

4 — Obvious rib damage. Damage to pillars extends 1 to 2 ft (0.3 to 0.6 m) on average from the original pillar line.

5 — Significant rib damage. Damage extends 2 to 4 ft (0.6 to 1.2 m) into the pillar from the original rib. travel is very difficult due to sloughage covering most of the floor.

6 — Severe rib sloughage. Rib damage extends beyond 4 ft (1.2 m). Travel is extremely difficult or impossible. Rib sloughage extends across the floor joining sloughage from the opposite rib.

Roof Deterioration Index

1 — Original roof with bit marks mostly visible. Some flaking and scaling is limited to 1 in (2.54 cm) or less.

2 — Flaking and scaling are limited to 1 to 3 in (2.54 to 7.62 cm). Minor closed cracks are possible and no signs of loading of supports is visible.

3 — Flaking and scaling areas are seen between 3 to 12 in (7.62 to 30 cm). small cutters are possible forming less than 2 ft (0.6 m). Some roof deformation observed and possible potting, open minor cracks.

4 — Bolt plate loading observed. Majority of roof beam is intact and cutters are greater than 2 ft (0.6 m) in depth. Standing support shows very little if any loading.

5 — Standing supports are heavily loaded. Large pot-outs between bolts, bolts begin to fail. Majority of the original roofline is gone, multiple open cracks spanning the entry.

6 — Roof fall above primary support.

Floor Deterioration Index

1 — Floor has no signs of floor heave, sporadic cracks could be observed, no measurable heave.

2 — Floor has consistent localized cracks. Floor heave is 6 in (15 cm) or less.

3 — Widespread cracks, hollow floor. Floor heave measured between 6 in to 1 ft (0.15 to 0.3 m).

4 — Continuous floor heave measured between 1 to 2 ft (0.3 to 0.6 m), damage to ribs can occur, travel is possible.

5 — Significant displacement of 2 to 4 ft (0.6 to 1.2 m), damage to ribs will occur, pillars, cribs, and post can punch into floor, travel difficult.

6 — Severe floor displacement 4 ft (1.2 m) or more. Travel is extremely difficult or impossible. Significant damage to ribs, standing support will punch or roll.

Figure 4. Condition mapping for the roof, rib, and floor (after Van Dyke Klemetti, and Compton, 2020a).

was evaluated based on the bag bulging, wires breaking, or tears in the bags. For the bolts, the primary focus was on the bolt plates, headers, and straps deformation, or bolt heads being pulled through the plate. For the mesh, the condition was based on the bagging of the mesh as well as the overall condition of the rib or roof, depending on where the mesh was installed. Figures 10–16 show the conditions of the entries in panels 4, 5, 6, 9A, 9B, and 9S.

The standing supports, regardless of type and installation pattern, showed little to no observable loading in the entire study area.

The Propsetters, wooden cribs, and pumpable cribs appeared to be similar with less than 50% of their capacity being used to support the openings. No compression of the wedges, the posts themselves, bottom or top plates, and of the individual crib layers was shown in 99% of the posts and wooden cribs. There were observed cribs that were not in complete contact with the roof any longer, possibly because of drying, installation, or moisture in the floor. The pumpable cribs showed no bulging bags, broken bags, or broken wires. The roof bolts, including both primary and secondary, showed almost no signs of plate loading, no bolt chandlering, no bolt heads
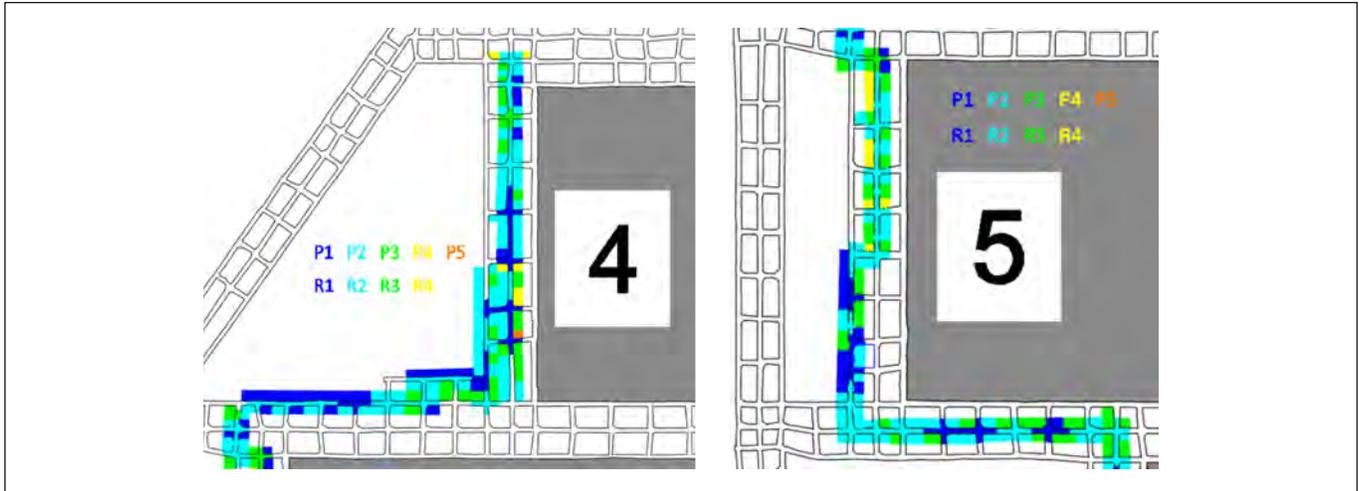
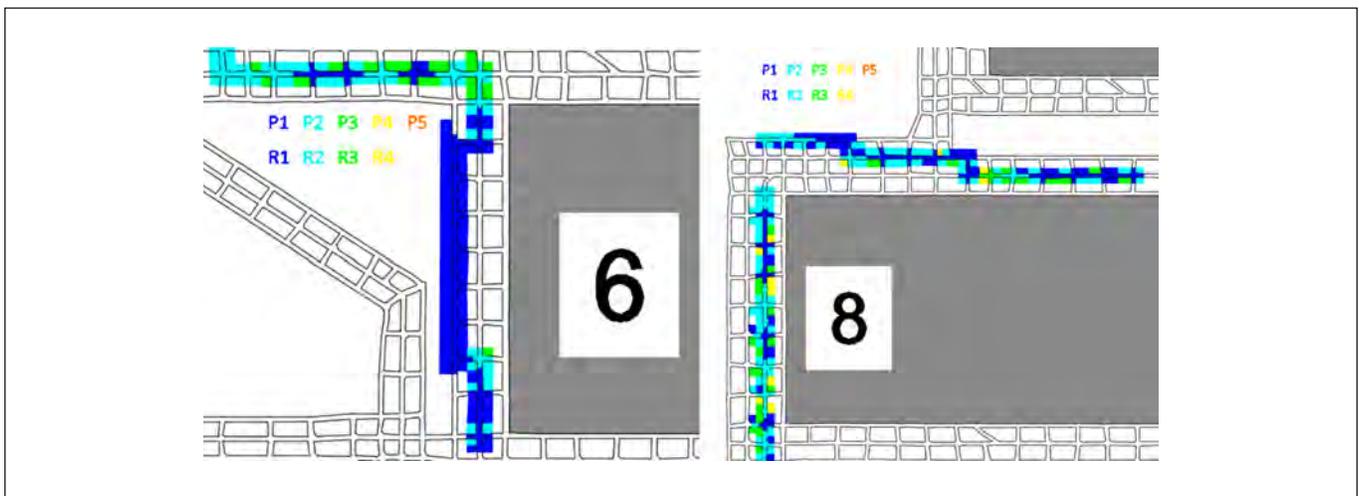**Figure 5. Condition mapping for the bleeder entries of panels 4 and 5.**

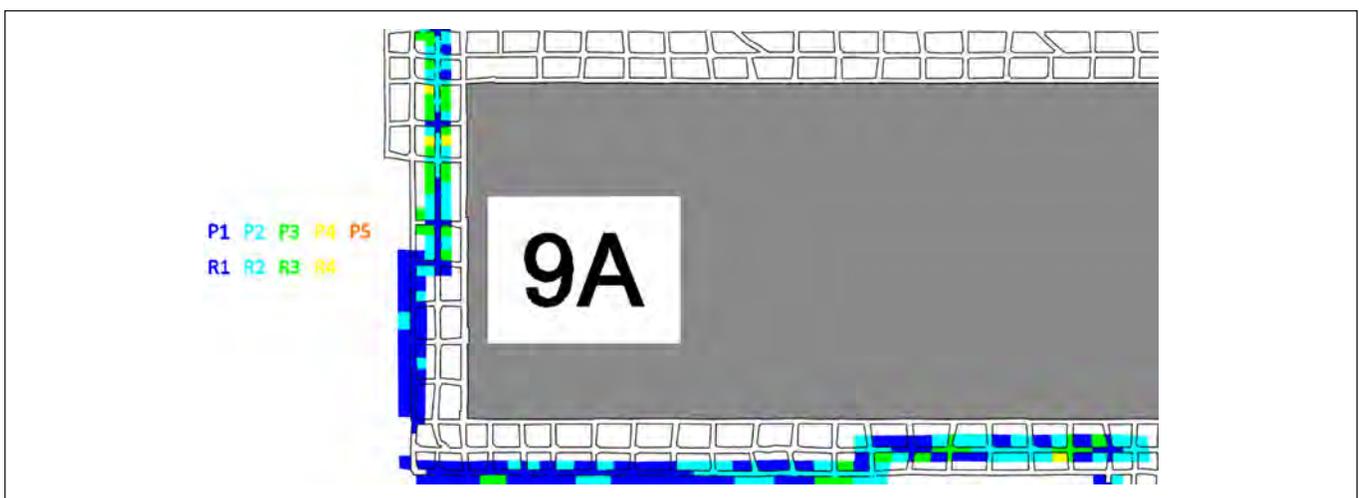**Figure 6. Condition mapping for the bleeder entries of panels 6 and 8.**

Figure 7. Condition mapping for the bleeder entries of panel 9A.
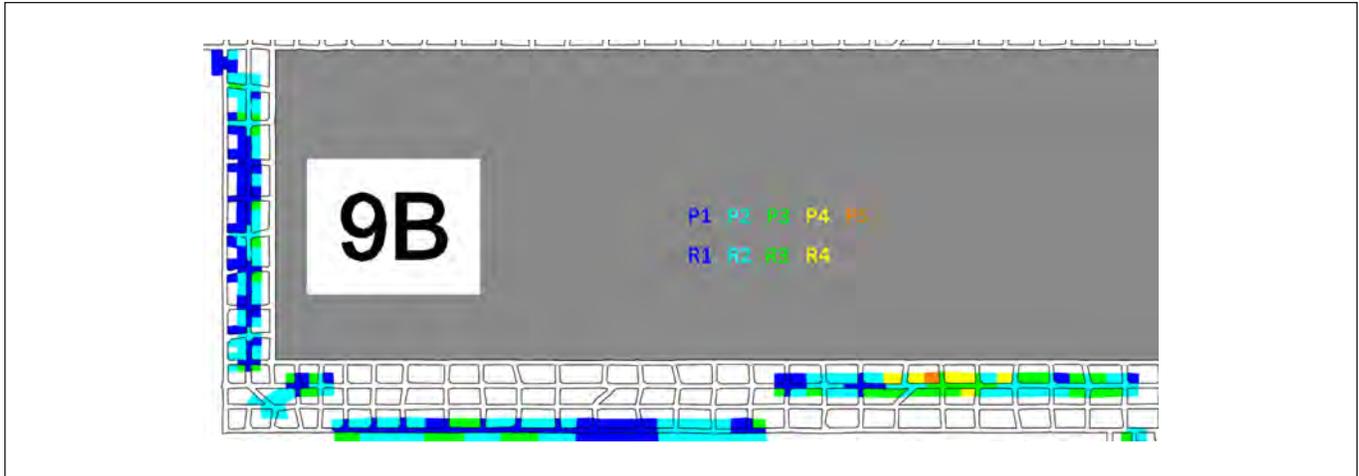
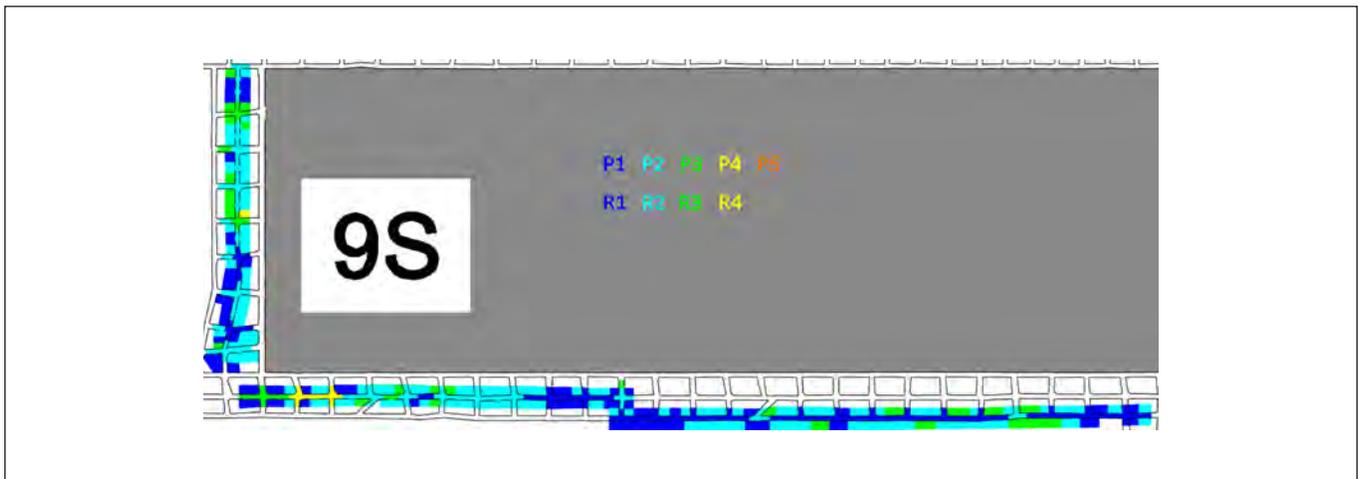**Figure 8. Condition mapping for the bleeder entries of panel 9B.**

Figure 9. Condition mapping for the bleeder entries of panel 9S.

Figure 10. Images of the entry adjacent to panel 4's longwall face.

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Figure 11. Images of panel 5's rear bleeder travelway.

Figure 12. Images of panel 6's rear bleeder entry.

being pulled through plates, and no observed bolt failures. The rib bolts showed no signs of loading either. There was very minor sagging of the mesh on either the roof or the rib throughout the study area and no significant bagging of the same mesh. The mesh did not show signs of broken wires or welds, which occurs much before overall failure of the mesh panel (Batchler, Klemetti, and Matthews, 2018).

There were about five supports in the studied area where visible evidence of loading was noted. The supports were Propsetters installed in the crosscut between the travelway and the gob to act as a barrier to stop any loading or failure from migrating to the crosscut and beyond. The visual evidence on the Propsetters manifested in two different ways: (1) buckling of the cuts at the bottom of the support and (2) compaction of the bottom plates between the floor and the

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Figure 13. Images of panel 9A's rear bleeder entry.

Figure 14. Images of panel 9B's rear bleeder entry.

Propsetter as can be seen in Figure 17. These loaded Propsetters were evidence of the effective design of the support to interrupt the progression of failure from the gob to the nearby entries.

NUMERICAL MODELING

The numerical modeling effort consisted of two phases. The first phase was the development of a calibrated FLAC3D model, and the second phase was a parametric study of various standing supports using the calibrated model developed in phase 1 of this study. Phase 1 was completed and published by Esterhuizen, Gearhart, and Tulu (2017). Phase 2 is part of recent NIOSH research on gateroad ground stability (Esterhuizen et al., 2020). The calibrated model consisted of a three-dimensional (3-D) slice taken at right angles to the long axis of the entry being modeled. This model was developed to study the progressive loading of an instrumented gateroad that was measured from slightly after development through the first panel loading and until the second panel's longwall face was v80 feet inby the instrumentation site. The primary focus of the instrumentation and numerical modeling study was the response

Figure 15. Image of panel 9S's rear bleeder entry.

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Figure 16. Images of panel 9S's blind headgate entry.

Figure 17. Images of the two types of observed loading on the Propsetters.

of the entry to the second panel passing or when the instrumented gateroad was an active tailgate. The results of the model were then compared to the measured bolt and cable bolt responses. The response of the cribs were also compared between the field and model. The calibrated model provided realistic rock failure and deformation results as well as support responses. Esterhuizen, Gearhart, and Tulu (2017) stated that the support system was more than adequate to control the ground conditions up to the longwall tailgate corner. They also concluded that the standing support only had minimal load when they were located at the tailgate T-junction, and significant loading only occurred after the cable bolts started shedding load when the face was inby the instrumentation site.

The second phase included evaluation of (1) primary support only, (2) plus intrinsic secondary support, and (3) plus standing support. The primary support was the typical 6-foot bolts in the standard pattern. The intrinsic secondary support evaluated was 10-foot cable bolts. The standing support assessed included pumpable cribs, 9-point wood cribs, and 10-inch Propsetters. For this particular geologic and mining setting, the benefit of standing supports was

minimal until about 3 inches of displacement, which was equivalent to a stress increase of about 1,500 psi in the model, as shown in Figure 18. Once the entry is about 100 feet away from the gob, the increase in stress is only around 100 to 200 psi, well below the 1,500-psi increase that demonstrated the need for additional support based on the calibrated numerical model.

TIME DEPENDENCY

One concern with bleeder entries is their life span versus the time required to complete the district. Often, they are expected to be open for both ventilation needs and walkways for 5 to 10 years or more. The mine anticipates closing the study area rather soon leading to a necessary life span of about seven years, including development. Because the study area contained longwall panels and entries that were mined over a minimum of a five-year period, the time-dependent deterioration of the bleeder entries could be assessed. The first panel mined was panel 4 and the last was 9S.

Flaking of the mine roof and spalling of the pillars in the older entries was observed that may be attributed to moisture sensitivity,
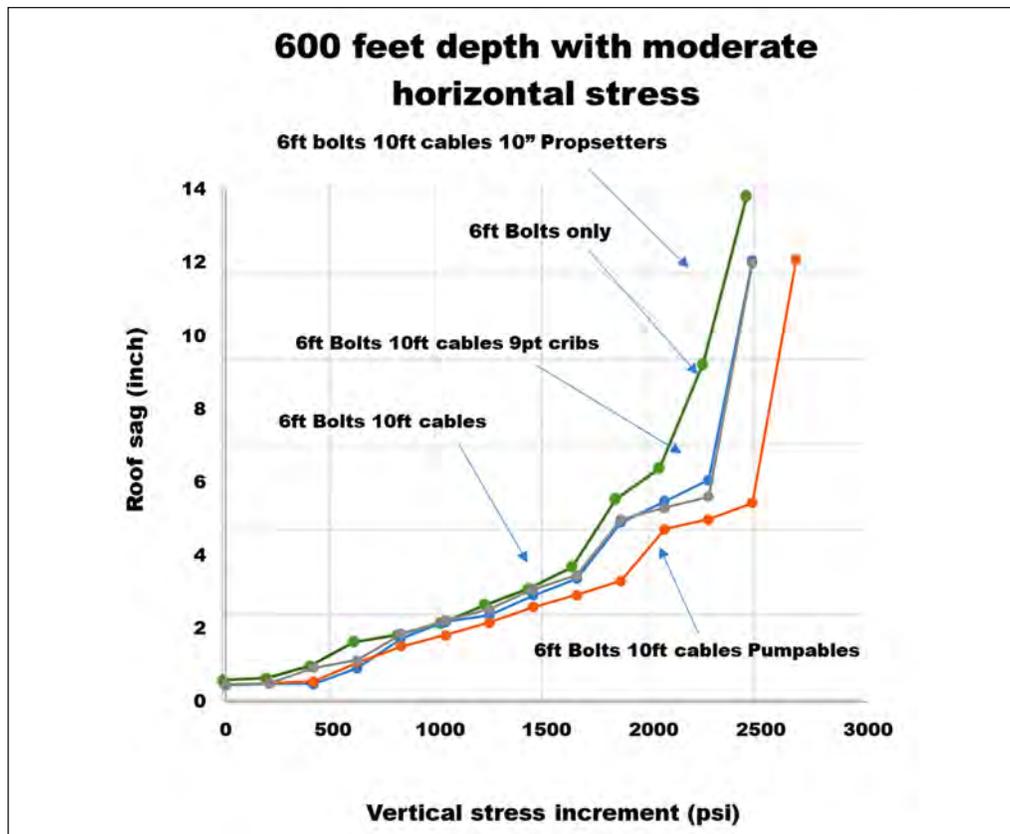
Figure 18. Chart showing modeled roof sag versus vertical stress change for different support designs.

time-dependent deterioration, and lack of screening and rib bolting in areas. Panel 4 had the worst average ratings for the roof, pillar, and floor. However, the final panel in the study area, 9S, did not have the best average ratings. Panels, 6, 9A, and 9B had the best average rating, indicating that time-dependent decay of ground conditions was not a significant factor. This mine did not exhibit serious deterioration of the metal supports installed—bolts, mesh, straps, and plates, which may have benefited the entry conditions over their life span.

Although there was a significant time lapse between the first and last panel being mined, the support loading and entry conditions were not substantially different panel by panel, indicating that time-dependent deterioration was not a significant factor in this area of the study mine. This could be because of the rocks surrounding the entry having a low moisture sensitivity and low salinity, lack of season changings in humidity and water, or extremely strong rocks relative to the loading conditions.

CONCLUSIONS

The main outcomes of this study can be divided into observed and modeled conclusions. From the observational component of this study, it is apparent that the conditions of the roof, rib, and floor were not largely affected by the various types of installed standing support. Additionally, the supports appeared to be well below their yield load as there was no observable damage to the supports. The only exception was the handful of Propsetters that either exhibited compression of the cuts or base plates. The inclusion of

mesh and rib bolts appeared to be more critical for minimizing the deterioration of the entries and the pillars in the studied areas.

In terms of the modeling, an established numerical model was used to perform comparison studies for various supports under the loading conditions measured at the mine previously. The model showed that the expected and measured increased stress would not lead to excessive deformation of the roof under the applied loads regardless of the secondary standing support installed. This was confirmed by the in-mine observations.

The combined modeling and observational study showed that under similar geological and geotechnical conditions, the various pillar and support designs used in the study area were more than adequate to maintain serviceable entries. Although the various pillar and support designs were adequate in the studied area, deviations from these designs should be weighed against the changes in the geological settings. Roof that is much stronger or weaker may require changes to pillar and support designs to provide serviceable entries under the same loading conditions.

The results of these studies agree with the other instrumented study sites that have been completed in the past three years (Klemetti et al., 2019; Van Dyke et al., 2020b). The abutment loading caused by a single longwall is minimal once the entry is 100 feet away from the gob. This applies to front, rear, and side abutment loads so long as there is only one gob nearby. In such cases, measured standing support load and convergence has shown that 99% of standing

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supports are using less than 50% of their capacity. Different depths of cover, geological settings, support designs, life spans, and local conditions could lead to standing supports being fully utilized in terms of their support capacity. In terms of global stability, so long as the primary support and pillars are adequate, standing support may not be necessary; however, there can be local conditions that require support to provide surface control and walkway protection.

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. Mention of any company or product does not constitute endorsement by NIOSH.

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