ROCK MASS BEHAVIOR AND SUPPORT RESPONSE IN A LONGWALL PANEL PRE-DRIVEN RECOVERY ROOM

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An underground investigation was designed and implemented by the National Institute for Occupational Safety and Health (NIOSH) to evaluate the effectiveness of pre-driven longwall recovery rooms supported with pumpable concrete roof supports. The pumpable roof supports were instrumented with hydraulic pressure cells to measure support loading. Displacement of the support was also measured to assess the support reaction to ground movements. Movement up to 12.5 m (40 ft) into the roof was measured with sonic probes and multipoint extensometers. Borehole pressure cells were installed in the panel fender and outby pillars to evaluate load transfer. Shield loading was also assessed to determine the impact of the panel fender yielding on face loading.

The results show that the yielding of the panel fender produced uncontrollable convergence that caused yielding of the shields and stiff pumpable roof supports when the face was approximately 3.12 m (10 ft) from the recovery room. The shields continued to yield until the face advanced into the recovery room. Convergence in the pre-driven recovery room typically reached 15-20 cm (6-8 inches) once the pumpable supports yielded and shed load through a declining residual load capacity prior to being cut out by the longwall shearer. Roof deformations occurred beyond the 10 m (32 ft) horizon with total deformation ranging from five to 10 cm (2 to 4 inches), indicating that standing support was necessary to help control the span as the longwall face advanced into the pre-driven recovery room. Stability improved as the pumpable supports were cut out, thereby reducing the span between the shields and the outby pillars. In the end, the shields were successfully recovered under stable ground conditions. However, a disconcerting discovery was the load shedding of the outby pillars as the recovery room was mined into. This behavior was not expected with a relatively narrow room that is fully supported with standing support. If this mechanism is indeed occurring, the width of the room and performance of the standing support becomes even more critical. Premature failure of the support can lead to excessive convergence on the shield line that cannot be controlled even with modern shields, resulting in instabilities that can lead to catastrophic results. Understanding the load transfer mechanics associated with the advancement of the longwall face into the pre-driven recovery room and the widening of the room to recover the longwall shields is providing valuable information for the refinement of the NIOSH Ground Reaction Curve for standing and intrinsic roof support system design.

1.1 Introduction

Pre-driven recovery rooms provide opportunity to reduce the longwall move time by having a place where the mining equipment can be removed in a prepared (supported) entry before the longwall approaches the end of the panel. In such cases, the concept can also provide improved ground control. The weak shale roof in the Pittsburgh seam can be difficult to control in high stress environments such as those created when the longwall face is recovered. Screen and fabric mesh are typically installed to help control the immediate roof and prevent gob flushing into the face area as the shields are recovered. Problems have been experienced in the past with installing this mesh during the recovery operation as the damaged immediate roof would loosen and create cavities that impeded support advance during the final stages of the panel extraction and development of the recovery room. A pre-driven recovery room alleviates these problems by allowing the mesh and other support elements to be installed under conditions that are more benign and less hazardous to the mine workers.

However, the pre-driven recovery room must be adequately supported to ensure success. Failure to provide adequate ground control will create an extremely hazardous environment and can lead to catastrophic results with injuries to mine workers and loss of mining equipment. History has shown that it is very difficult to provide adequate support without the use of standing support to help control the large span of roof as the recovery room is mined into (Oyler et al., 1998 and 2001). Since the longwall shields must advance far enough into the room to allow removal, a requirement for the standing supports is that they must be cut by the longwall shearer so they can be easily removed as part of this process. The yielding of the last section of the longwall panel due to abutment stresses produces a component of convergence that is uncontrollable, requiring the standing supports to be able to yield accordingly and maintain support capability until the shields are fully into the room. Here too, history has shown that supports that are too stiff and non-yielding, despite their high capacity, fail prematurely and endanger ground control (Tadolini et al., 2002).

These requirements have caused the mine to utilize a pumpable roof support system for the recovery application in combination with roof bolts, cable bolts, meshing, and straps. Although the intrinsic support is necessary to build an immediate roof beam that helps support the main roof, movement above the bolted horizon is common, and the standing support can be the most critical component of the support system. The pumpable support used in this case was a 0.8 m (30-in)-diameter cementitious support in which the grout is pumped into an empty, reinforced fabric bag that is hung from the roof of the recovery room. The bag provides a containment form for filling the support, but more importantly, provides confinement of the cementitious grout to supply a sustainable residual support capacity after the grout is fractured and the peak support loading is exceeded due to the yielding of the longwall panel fender. This capability to provide residual loading is advantageous; particularly compared to conventional concrete cribs which do not have a useful residual load capacity. However, the pumpable supports are very stiff, and unlike conventional concrete cribs, don't use wood to soften their response. Therefore, their residual load performance is the key to their effectiveness in this application. One of the objectives of this study was to acquire additional data on loading response of the pumpable supports during the panel fender yielding and advancement of the face into the recovery room.

Although other studies of pre-driven longwall recovery room operations have been conducted, questions regarding the loading mechanics and support design requirements remained unanswered as evidenced by premature support failures (Tadolini et al., 2002), roof falls, and loss of shields (Oyler et al., 1998), while other operations were successful (Wynne et al., 1993). One local roof fall and excessive roof sag occurred at the completion of the previous panel at this mine using this same recovery room design and support plan with only minor differences.

The objective of this study is to develop a better understanding of the loading mechanics associated with pre-driven longwall recovery room operations so that optimum support techniques can be applied and more effective support systems can be designed to reduce the risk of failure.

2.1 Site Description and Recovery Room Instrumentation Profile

The approach utilized for the recovery plan is slightly different because the design considers an entry only partially (50 pct) pre-driven. To complete this, a 5-m (16-ft) wide entry at the end of the panel is pre-driven and supported long before the face approaches. After the face mines into the pre-driven room, the room is widened an additional 5-m (16 ft) to provide sufficient room for the recovery of the longwall equipment.

The B4 longwall panel was 453 m (1,450 ft) wide. The depth of cover averaged 187 m (600 ft). The immediate roof consists of clay shale, silty shale and rider coal, which is common to the Pittsburgh seam providing a relatively weak immediate roof structure. The area is overlain by 3.1 and 7.8-m (10 and 22-ft) thick limestone members and 3.4 and 7.8-m (11 and 25-ft) thick shale layers.

Figure 1 shows the support design for the recovery room. The recovery room was supported with 2.5-m (8-ft), grade 75, combination bolts. Combination bolts were also angled over the longwall panel and the outby pillar ribs to provide additional support as the face cut into and then widened the recovery room. Two and a half meter (8-ft) cable bolts on 1.25-m (4-ft) spacing were installed 62.5 cm (2 ft) from the panel rib to help support the roof when the first row of cribs were cut out, and 4.8-m (12-ft) cable bolts on 1.25-m (4-ft) spacing were installed 62.5 cm (2 ft) from the pillar rib to reinforce the roof from possible shear/tension fractures. The roof was glued with polyurethane resin (PUR) on the outby (pillar) side to strengthen the roof in the area adjacent to the pumpable cribs. The mine chose not to use PUR on the inby side, as was done on the previous panel, to facilitate caving of the immediate roof once the shields entered the room.

Three rows of 0.8-m (30-in) diameter pumpable roof supports were utilized in the recovery room as shown in figure 1. These were Calcium-Sulfo-Aluminate (CSA) grout filled supports that are identical to the supports used for the longwall tailgate except the spiral metal wire in the bag was replaced with a fiberglass wire that could be more easily cut by the longwall shearer. The performance characteristics of this support, as measured in the laboratory through full-scale testing in the NIOSH Mine Roof Simulator, indicate the pumpable support is very stiff with peak load occurring at less than 12.7 mm (0.5 in) of displacement. The support sheds load rapidly during yielding as the bag acts to provide confinement and maintain a residual loading capacity.

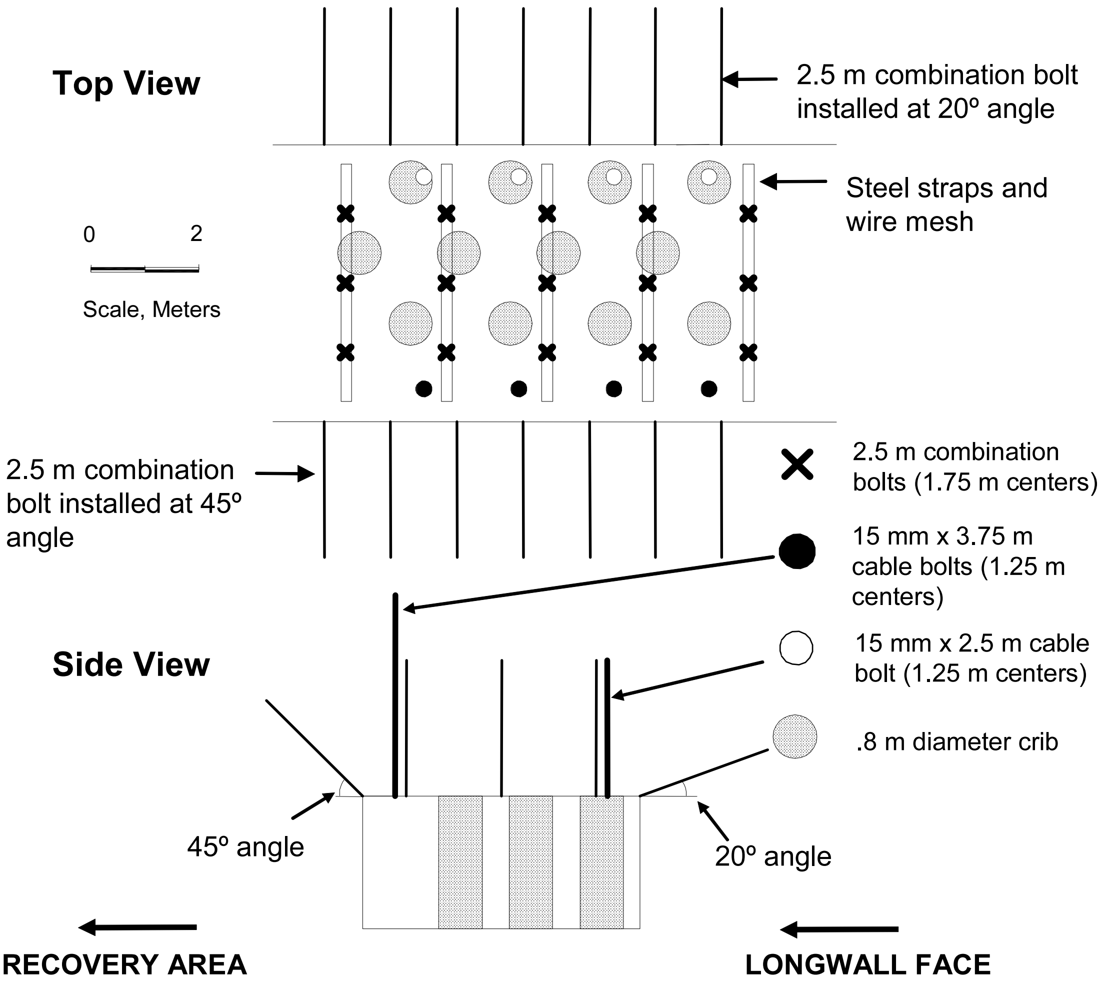

Figure 1. Support design for the longwall recovery room.

A diagram depicting the approaching longwall panel, predriven recovery room and outby pillar configuration is shown in figure 2. The instrumentation for this study was clustered in areas near Chutes C, F, and G and included:

- Shield leg pressures   Leg pressures were monitored by the DBT pressure transducers installed on each of the longwall shield legs. Data were collected every 10 seconds.
- Pumpable support loading   Specially-made hydraulic (water-filled) metal bladders, sized to fit the area of the pumpable support, were instrumented with pressure transducers and calibrated in the NIOSH Mine Roof Simulator to measure pumpable support load development.
- Support displacement   Wire-pull displacement transducers were mounted to the side of the pumpable support to measure support displacement.
- Sonic probes were used to measure roof deformation up to 7.5 m (24 ft) into the roof.

- Three-point mechanical extensometers attached to displacement transducers were used to measure roof deformation relative to the 8.1, 10, 11.9 m (26, 32, and 38 ft) roof horizons.
- Convergence rods with displacement measuring transducers were used to measure roof-to-floor convergence in the recovery room and in the outby C chute adjacent to the stress measurement locations.
- Borehole Pressure Cells (BPCs) were used to measure panel and outby pillar stress development in the C chute area. Figure 2 depicts the location of the cells. One cell was installed in the panel 3.1-m (10-ft) from the recovery room to measure yielding of the panel fender as the longwall face approached, two cells were installed in the outby pillars at a depth of 3.1-m (10-ft) and two other cells 6.2-m (20-ft) from the from the outby edge of the recovery room to measure load transfer from the panel to the outby pillars. Two more cells were installed 8.1-m (26-ft) from the outby edge of the recovery room in the adjacent pillar of the C chute location, again to measure load transfer from the longwall panel as the fender yielded.

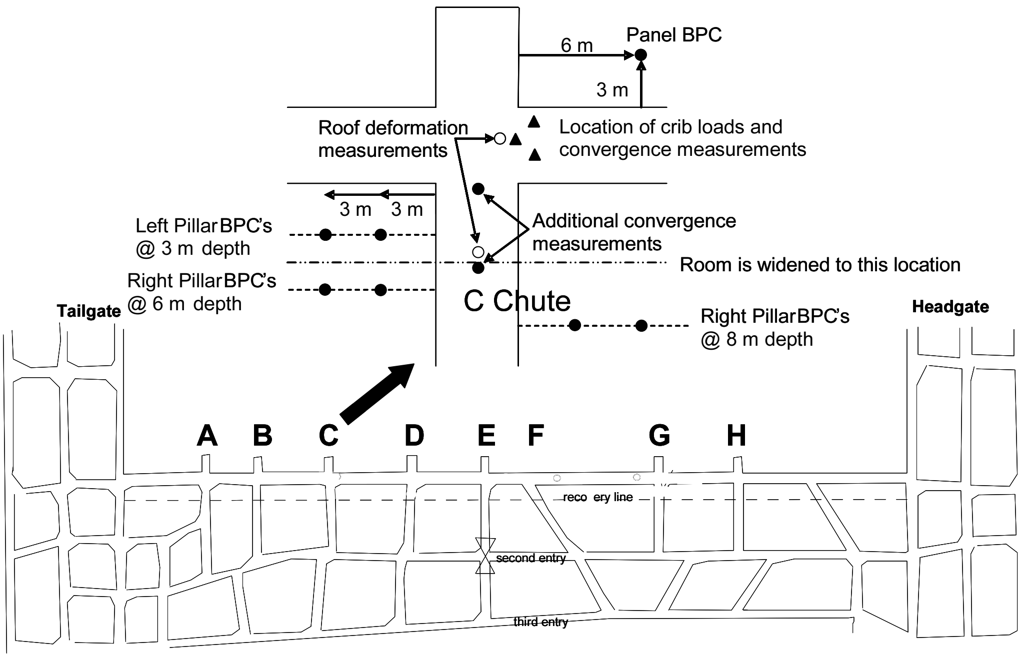

Figure 2. Diagram showing instrumentation in the longwall recovery room.

3.1 Support and Ground Response During Mining Phases

An evaluation of the support and ground response is made according to the progression of the mining process in the following order: (1) mining of the longwall panel to observe front abutment effects prior to yielding of the panel fender, (2) extraction of the remaining 7.8 m (25 ft) of the panel to evaluate yielding of the panel fender, (3) removal of the standing supports and advancement through the pre-driven recovery room, and (4) widening of the pre-driven recovery room.

3.1.1 Mining of the Longwall Panel Prior to Fender Yielding

The effects of the front abutment pressure began to manifest in the recovery room with increased pumpable support loading when the face was approximately 30.2 m (100 ft) away. The increase in loading rate remained very gradual until the face was approximately 7.8 m (25 ft) from the recovery room. Overall, the three instrumented pumpable supports increased in load by 400 kN (90 kips) (panel side support), 278 kN (63 kips) (middle row support), and 342 kN (77 kips) (pillar side support) during this period, representing 21%, 23%, and 35% of the observed peak loading on the supports.

An interesting discovery was revealed concerning the development of the pumpable support loading in response to the panel mining. The pumpable support loads were well correlated to the shield cycles even when the face was 31.2 m (100 ft) away from the recovery room. The support loading increased rapidly as the shearer passed the face location adjacent to the support location in the recovery room, with very little load increase during the remainder of the shield cycle although the leg pressures were increasing significantly throughout the shield cycle. As expected, the shields are responding to the immediate roof and the main roof activity while the recovery room supports at this juncture are seeing the main roof activity. Figure 3 shows an example for shield number 175 (adjacent to Chute C in the recovery room) as the face advanced from a location 23.4 m (75 ft) away to 15.6 m (50 ft) away the recovery room. As the face advanced closer than the 15.6 m (50 ft) location, the pumpable supports began to increase in loading during the full shield cycle, but the majority of the load increase continued to be consistent with the shearer passage and a step-type function in the load development continued.

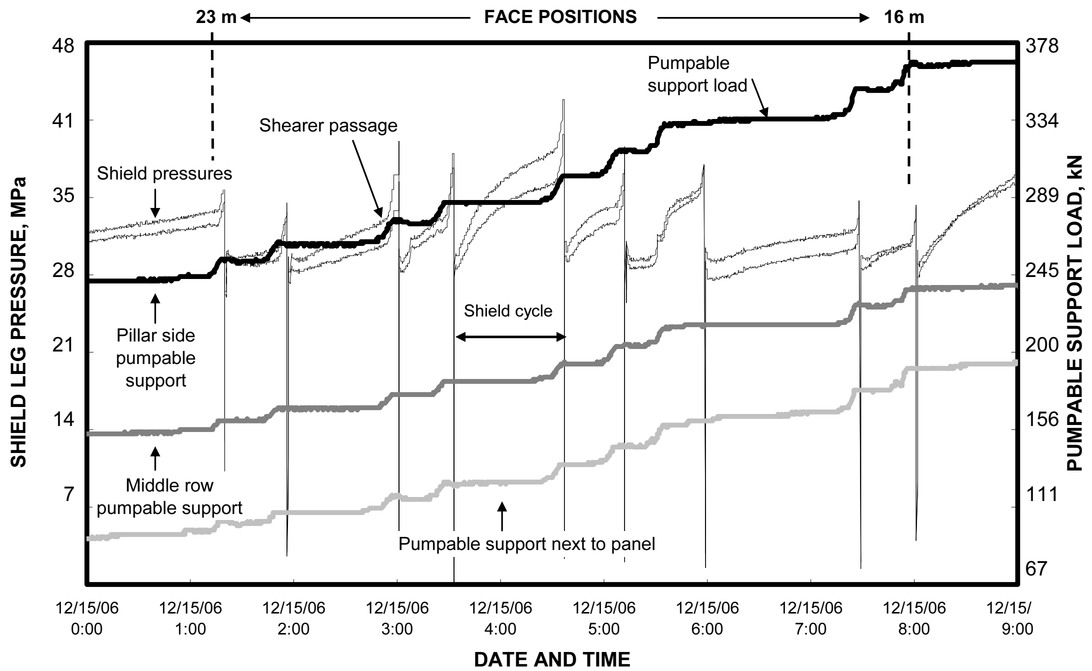

Figure 3. Correlation between pumpable support load and #175 shield cycles showing load increase during shearer passage.

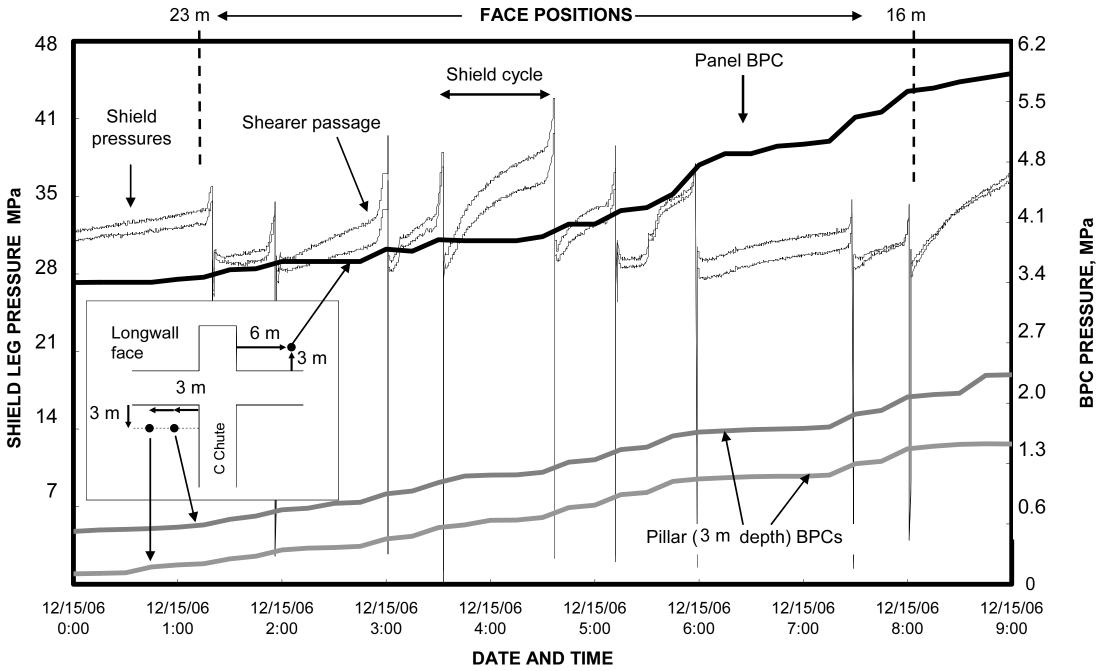

Figure 4. Correlation between borehole pressure cells and shield cycles.

3.1.2 Yielding of the Panel Fender as Face Approached the Recovery Room

As the face advanced within the 7.8-m (25-ft) location from the recovery room, the ground and support responses began to change dramatically, again revealing several interesting observations. Prior to this, the abutment effects were almost totally caused by the shearer passage. Now, more localized behavior, most likely involving the immediate roof activity, was causing the support loads and panel stress to increase during the full shield cycle (figure 4). The pumpable supports, panel BPC, and longwall shields all yield during this period as the load capacity of the panel fender is exceeded. The sequence of events that describe the load mechanics are as follows:

- Panel BPC yields The BPC in the longwall panel, located 3.1 m (10 ft) from the leading (inby) edge of recovery room measuring change in stress as the longwall face approached, began to increase in loading rate when the face was approximately 7.8 m (25 ft) away from the recovery room or 4.7 m (15 ft) from the BPC position (figure 5). The pressure in the cell increased from 14.5 MPa (2,100 psi) at the 7.8-m (25-ft) location to approximately 36.5 MPa (5,300 psi) when the face was 5 m (16 ft) from the recovery room or just 1.9 m (6 ft) from the BPC. During the next shield cycle, the change in pressure reached a maximum of 51.7 MPa (7,500 psi), and then dropped to about 39.6 MPa (5,750 psi) at the end of the shield cycle. At the time when the cell was cut out by the shearer, the cell pressure was approximately 28.9 MPa (4,200 psi).

  The shield leg pressures provide further insight into the loading mechanisms associated with the panel fender yielding. The panel stress measurements are located adjacent to the C Chute location and shield number 175 (see figure 2), which is about 312.5 m (1,000 ft) from the headgate on this 453 m (1,450 ft) long face. For bidirectional cutting, the shield cycles are likely to alternate between short and long cycles since the support is located away from the center of the panel where the shield cycle time differential would be minimized. As shown in figure 5, the panel fender yielded during a long cycle (114-minute duration) as the shearer had to move to the headgate and back to complete the loading cycle. It was somewhat surprising to observe that the peak BPC stress occurred not when the shearer passed by this location, but when the shearer was over 312.5 m (1,000 ft) away at the headgate, particularly given the close proximity of the longwall face to the stress cell (approximately 1.9 m (6 ft) away). This could be the result of the time dependent properties of the coal, in which the highly stressed coal will continue to deform (strain) even under static load conditions. The unloading rate is also nearly the same as the loading rate during this shield cycle. The detail of the loading is magnificent as exemplified by the temporary stop in load shedding as the shearer passes back in front of the pressure cell (see figure 6).

One question is whether the yielding of the BPC cell located in the panel, 3.1 m (10 ft) from the edge of the recovery room, indicates that the remainder of the panel fender has also yielded. Here, too, the shield data provides valuable information. Analysis of the shield data suggests that the panel fender has not yet yielded. The shield data (see figure 5) shows that on the cut immediately following the BPC yielding, the shield loading behavior is similar to that observed prior to the yielding of the BPC, while on the next cut, the shield load increases quickly after the shield is set and reaches yield load without the shearer being in the immediate vicinity. The panel fender may not be completely yielded but the steady

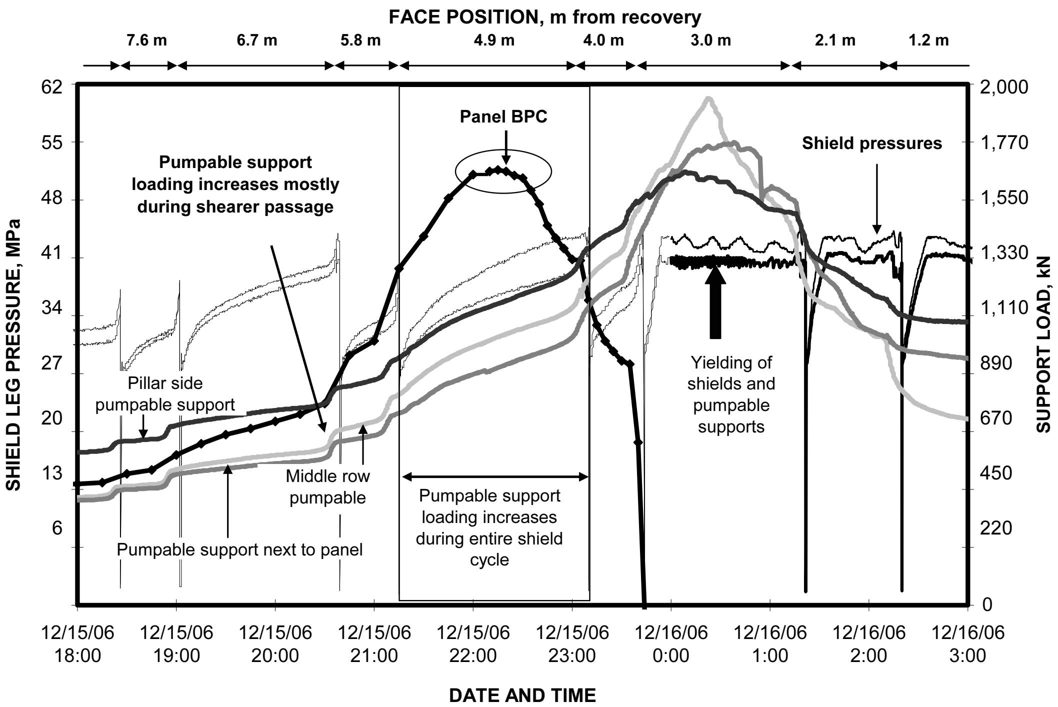

Figure 5. When the longwall face was approximately 5 m (16 ft) inby the recovery room, the pumpable support loading increased during the full shield cycle.

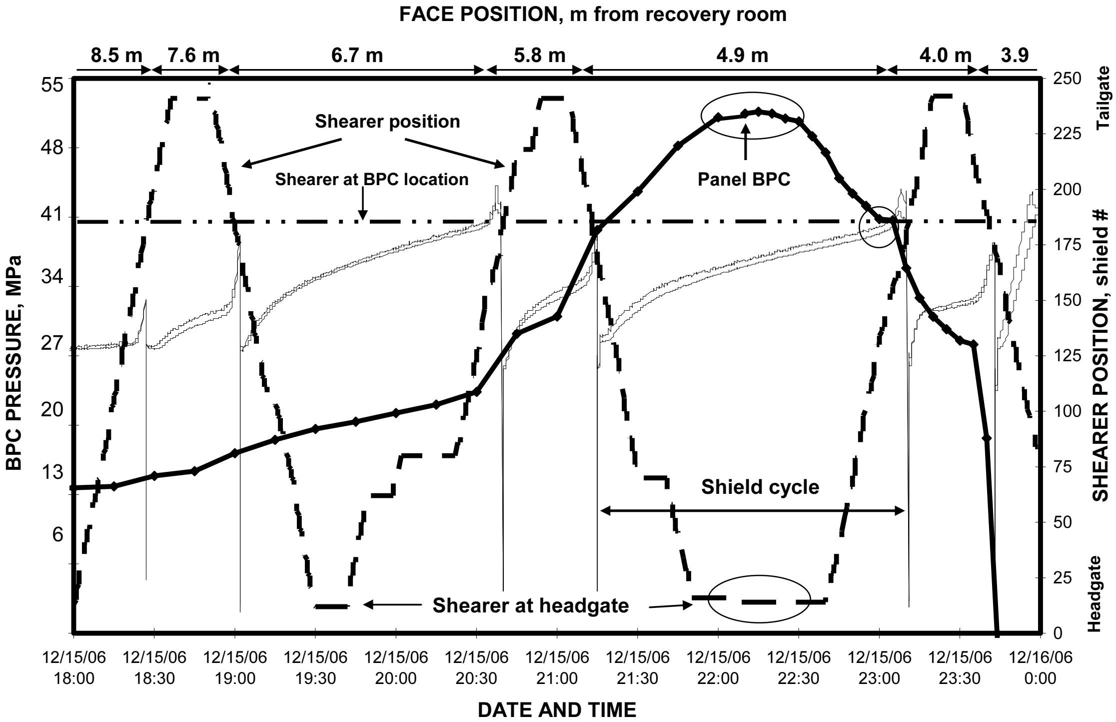

Figure 6. Yielding of panel BPC occurred when the longwall shearer was approximately 302 m (1,000 ft) away from the cell location.

decline in the BPC pressure (before being cut) and the rapid increase in shield pressure may suggest that the fender continues to yield during the time when the shearer has moved away from this zone.

- Pillar fender BPCs shed load The stress cells installed in the outby pillar rib (3.1 m (10 ft) from the edge of the recovery room) also increased in concert with the panel stress cell. This indicates that some of the abutment stress is transferring across the recovery room, but the magnitude of the stress change is much less in the pillar than in the panel. These two cells peak and then gradually shed load during the shearer passage on the shield cycle following the peak loading of the panel cell. Since the stress levels on the pillar cells were only 25% of the level that caused yielding of the panel cell, it is unlikely that the coal pillar at the cell location was actually yielding due to loading beyond the coal strength during this load shedding event. However, some rib spalling did occur to a depth of 0.6-0.9 m (2-3 ft).

- Yielding of the shields and pumpable roof supports The pumpable roof supports in the recovery room continue to develop load as the panel and pillar BPCs shed load as previously described (shown in figure 5). The pumpable supports yield two shield cycles after the panel BPC yields and one cycle after the pillar BPC shed load, putting the yield of the supports at a face position of approximately 3.1 m (10 ft). The shields also yield during this cycle. Again, the nature of the shield loading provides insight into the load mechanics. After being set, the shield-loading rate is significantly higher than on previous shield cycles and the shields quickly reach their rated capacity and begin to yield. They continue to yield even though the shearer is moving away from the shields toward the headgate in a long shield cycle.

The shields continue to yield for the next two cycles as the face mines into the recovery room. This behavior suggests that the panel fender yielded as the shearer cut was reducing the face position from the 3.1 m (10 ft) location to approximately 2.2 m (7 ft).

The yielding of the pumpable supports trigger roof movements and convergence in the recovery room before the face even gets there. The pumpable roof supports are very stiff supports, capable of developing over 1,775 kN (200 tons) of load capacity in less than 12.7 mm (0.5 in) of displacement. Prior to the yielding of the pumpable supports, the roof remained intact as a composite structural unit without additional separation among rock layers. As the pumpable supports began to rapidly increase load while the panel fender was yielding, the data indicate that the roof was moving slightly “upward”, as shown in figure 7. This apparent “upward” movement is most likely compression of the immediate roof structure or closing of preexisting fractures along bedding planes or elsewhere within the first 8.1 m (26 ft) of roof. Since the support requires compression to build load, it is also possible that the floor ahead of the panel fender in the recovery room was also moving upward (heaving) as the panel fender yielded.

The roof-to-floor convergence also increased dramatically with the yielding of the pumpable supports. By the time the face mined into the recovery room, the convergence measured from the middle row support displacement reached 12.7 cm (5 in), while the roof deformation at this time was approximately 3.7 cm (1.2 in). This indicates that about 75% of

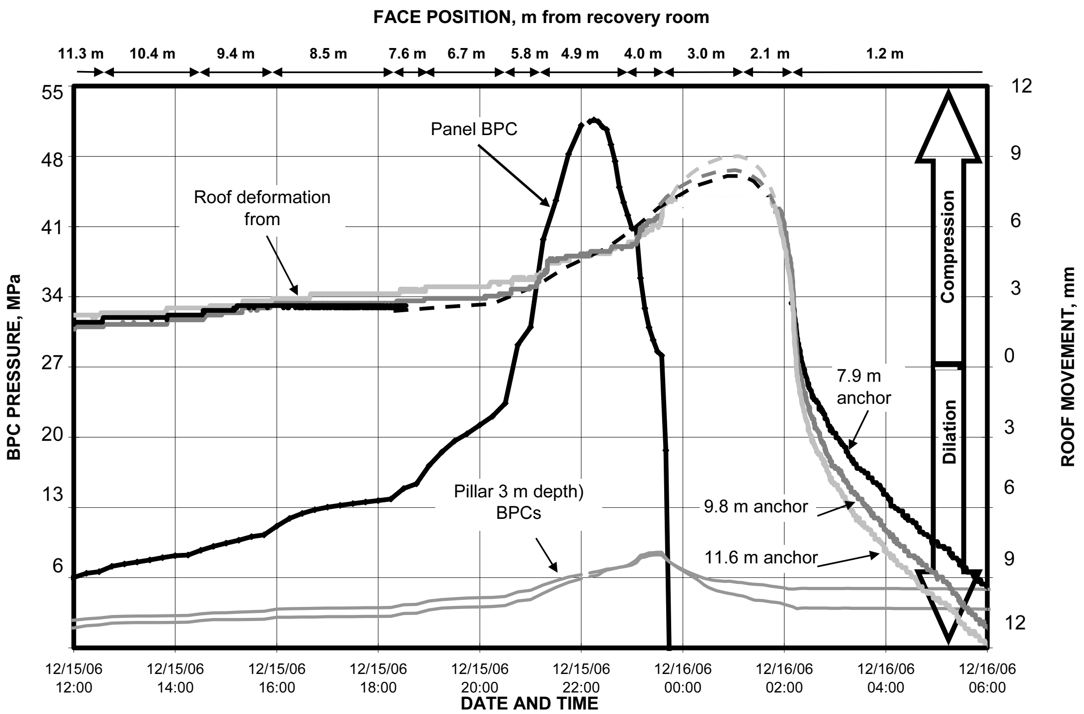

Figure 7. Roof initially is compressed during yielding of panel fender and then begins to deform downward into the recovery room.

the convergence was from floor heave and/or main roof movement beyond the 11.9-m (38-ft) horizon during the panel fender yielding.

3.1.3 Removal of Standing Supports and Advancement Through the Pre-Driven Recovery Room

The next phase of the mining operation was to cut out the pumpable supports and advance the face to the pillar line to prepare for widening of the face. During this phase, no coal was being mined, however since the pumpable supports were helping to control the roof span and deformation process, the removal of the supports can be critical to the stability of the recovery room. At the C chute location, the shield loading decreased as the supports were extracted and the face advanced toward the pillar line (see figure 8). As the first row of supports was being extracted, the shield loading remained high but below the yield rating. As the second row of pumpable supports was being extracted, the shield loading did not change much after being set and this condition remained throughout the advancement through the pre-driven recovery room. The pillar stress, as measured by the cells at both the 3.1- and 6.2-m (10- and 20-ft) locations from the edge of the recovery room, remained fairly constant during this process. The roof continued to deform slightly in the chute as measured by a three-point extensometer in the center of the entry located 5 m (16 ft) from the outby edge of the pre-driven recovery room, but the deformations were nearly an order of magnitude less than that seen in the recovery room. An additional 25.4 mm (1 in) of closure occurred for a distance of about 6.2 m (20 ft) in the C chute crosscut as measured by electronic closure meters measuring roof-to-floor displacement.

The time-weighted average shield pressure varied across the longwall face during the phase

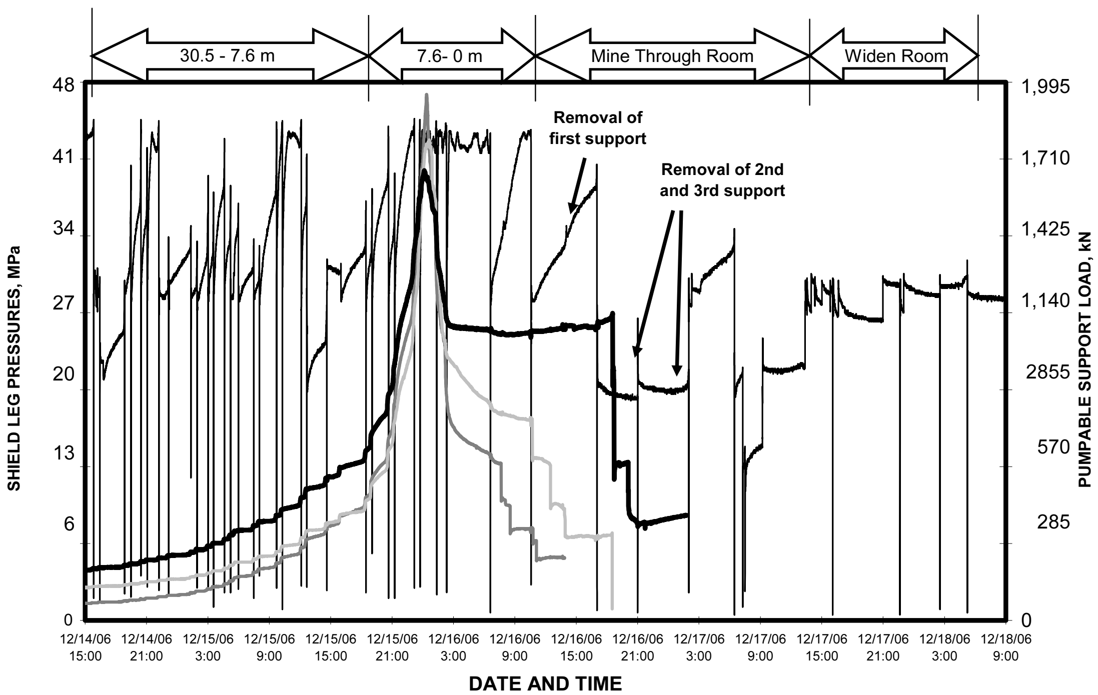

Figure 8. Shield loading decreased as the pumpable supports were extracted from the longwall recovery room.

of mining in which the supports were cut out and the face was advanced through the pre-driven recovery room. The shield loading at some locations was considerably higher than that observed at the three instrumentation sites. For example, shield number 185 yielded on all cycles during the extraction of the pumpable supports and advancement through the pre-driven recovery room compared to shield 175 which had little change in loading during and following the extraction of the last row of supports. There was no obvious visual physical difference in the recovery room condition. Without instrumentation, it is difficult to determine with certainty what causes this difference in behavior. The persistent yielding of the shields indicates there was considerably more closure at these locations. This could be caused by: (1) longer cantilever of main roof indicative of periodic weighting, (2) less control of the immediate roof structure allowing deformation to greater heights into the roof, or (3) greater yielding of the pillar due to the abutment stress.

3.1.4 Widening of the Pre-Driven Recovery Room

The next phase of the recovery process was to widen the room by extracting an additional 5 m (16 ft) of the coal pillars to create sufficient room to recover the longwall equipment. This phase requires a variation in the typical longwall mining process in that extensions are included to the face conveyor advance rams to allow advancement of the shearer and cutting of the last portion of the pillar without advancement of the supports. The mesh was deployed and exposed roof was bolted after each cut to provide a fully supported room for recovery. The shields developed little, if any, loading during the extraction of the pillars to widen the room. On several occasions, the shields struggled to maintain set pressure, with the positive set control feature activating to re-supply pump pressure periodically during the shield cycle (figure 8). This behavior indicated that the immediate area is largely destressed. What would cause this? One possibility is that the front abutment loading on the pillars has dissipated or has been pushed well ahead of the face area.

The BPCs located in the pillar at depths of 3.1 and 6.2 m (10 and 20 ft) from the recovery room again document the impact of the shearer passage on the loading mechanics. As the face cuts to the 3.1 m (10 ft) location, the measured pressure change in the cells located there spiked to 19.7 MPa (2,860 psi) and then shed load rapidly as the cell and/or contact condition is damaged from the shearer activity. As recorded, the pillar stress measured at the 6.2 m (20 ft) location increased with each shearer passage and remained fairly constant once the shearer cut was made until the next mining cycle. Overall, the load increments were much smaller than that observed with the panel fender yielding. These pillars do not yield. The convergence measured from the electronic convergence meters also continued to increase during the pillar extraction at about the same rate as when the pre-driven room was mined through. As the extraction approached the location of the convergence rods, the convergence rate increased significantly as expected.

4.1 Discussion of Results - Unexpected Discoveries

- Panel fender pressures The BPC in the panel recorded a maximum pressure change of nearly 51.7 MPa (7,500 psi). This was higher than expected given the overburden and proximity of the BPC to the panel edge at the time the peak stress was measured. The depth of cover was approximately 187 m (600 ft) at this location. Assuming an abutment stress of 3-5 times the insitu stress, this provides an abutment stress of 12.4 to 20.7 MPa (1,800 to 3,000 psi). Furthermore, the cell was only about 1.9 m (6 ft) from the longwall face when this pressure was recorded. As such, the confinement provided by the yield zone was relatively small, and it was not expected that it would be sufficient to develop stress readings that were 2.5-4.2 times the abutment stress. Mark and Iannacchione (1992) indicated that BPC instruments tend to read significantly higher (by as much as a factor of 2) than vibrating wire instruments which correlate better to pillar strength formulas. This could account for the apparently high reading, although applying a reduction factor would also result in very low stress on the pillar side. It should also be noted that none of the measurements in Mark and Iannacchione's study were in fender pillar applications. Measurement of panel stress change during advancement into a full-width pre-driven recovery room in a previous study at this mine were typically around 17.2 MPa (2,500 psi) (Oyler et al., 2001), again with vibrating wire stress gages.

- Difference in panel stress and pillar stress The expected load transfer mechanics is for the front abutment stress to transfer from the panel to the outby pillars as the panel fender yields and is no longer able to sustain load. The pillar cells located 3.1 m (10 ft) from the recovery room did show stress increase as the panel fender yielded, but the stress change of about 6.9 MPa (1,000 psi) was much smaller than that seen in the panel cell which increased by nearly 51.7 MPa (7,500 psi). It was expected that the stress changes would be of similar magnitude to account for the load balance that must occur. Numerical modeling by Zhang and measurements taken in previous longwall studies support this expectation (Zhang et al., 2006 and Oyler et al., 2001). If the panel measurement is correct and the stress development in the pillars was indeed much smaller, this would suggest that the load was distributed over a greater area to reduce the stress. The measured pillar stress was similar to that measured in previous studies (Oyler et al., 2001).

- Shedding of pillar stress The increase in pillar stress, as measured by the first set of cells 3.1 m (10 ft) from the pillar edge, was followed by a near equal shedding of stress in a relatively short time frame (one shield loading cycle) following the yielding of the panel fender. Since the same cells increase in pressure as the pillars are mined to widen the recovery room, the load shedding is not due to yielding of the coal. So what caused the pillar stress to decrease? It was postulated that the drop in stress is caused by a decrease in load caused by a reduction in span. Since the panel fender is no longer capable sustaining load, it implies that the rear "abutment" moves forward closer to the shield line causing the reduced span and drop in load. The lower load then explains the drop in pillar stress. This load shedding behavior has been observed in previous longwall recovery rooms which were not stable (Oyler et al., 2001). When the panel fender yields or abruptly loses its load carrying capacity, the abutment must transfer across the recovery room onto the pillars. This is a shock to the overall system which apparently produces significant changes in the loading mechanisms. Also an important consideration is the pillar BPCs behavior is similar to the shields at this time, exhibiting lower loads. This implies that they are being more affected by the immediate roof as compared to the main roof during further inby mining.

- Lack of shield loading during widening of recovery room   The shield loading did not increase above the set pressure during the widening of the recovery an additional 5 m (16 ft) by extraction of the pillars. In many areas of the face, the shield pressure development was small once the pumpable supports were extracted. Again, this indicates that the face area was destressed and the abutment pressures were dissipated. This supports the rear abutment hypothesis postulated above.

5.1 CONCLUSIONS

Front abutment pressures increase as the longwall face advances toward the recovery room. As the panel advances toward the recovery room, this pressure causes stress increase in the panel, the pumpable roof supports, and the outby pillars suggesting that the load is bridging across the recovery room prior to the yielding of the panel fender. These effects begin to occur when the face is approximately 31.2 m (100 ft) away and gradually increase until the face is about 7.8 m (25 ft) away, at which time the loading rates increase significantly. When the face is close enough such that strength of the panel fender is exceeded to the point where it can no longer support load, which in this case was about 3.1 m (10 ft), the yielding of the panel fender triggers a cascading sequence of events, which cause yielding of the shields and pumpable supports. The yielding of the pumpable supports in the recovery room then triggers another sequence of events in which the roof in the recovery room above the supports deforms downward and closure of the recovery room increases dramatically.

The shedding of the pillar stress is a significant discovery with potentially major consequences. The surprising event in this process was that the load shedding of the panel fender also coincided with stress shedding of the outby pillar stress (to a depth of at least 3.1 m (10 ft)) and this occurred just prior to the yielding of the pumpable supports. First, the stress shedding of the pillar itself is surprising, but if this is going to occur, the expectation is that the pumpable supports would yield prior to the stress shedding of the pillar stress. It is postulated that the cause of the stress shedding of the pillar may be due to advancement of the rear abutment toward the recovery room, thereby reducing the span that the main roof is bridging from the gob over the recovery room. It may also be just coincidental in this specific case, the periodic weighting interval coincidentally occurred when the face entered the recovery room. The effect of this stress rotation would be a reduction in main roof loading, which would account for the reduction in pillar stress. While this may initially seem like a good thing, the advancement of the rear abutment stress would be caused by a large of amount of convergence close to or in the recovery room. Although the outby pillars may shed load, they are not yielding. Therefore, the convergence profile would be described as minimal at the pillar area and increasing quickly through the recovery room toward the panel (rear abutment). This bending of the strata can produce high tensile stresses in the immediate roof beam that can cause failure at the maximum bending moment somewhere over the outby pillars. If this stress would cause failure of the main roof beam, the weighting of this coupled with the large convergence could lead to catastrophic weighting and roof failure.

Obviously, this did not occur in this case. The room was stable and the supports were recovered without incident. Nonetheless, if this mechanism is indeed the process that is occurring, several significant design implications are revealed.

- Standing support is critical to achieving successful stability of recovery rooms, even in partially pre-driven recovery rooms such as these. The support must be able to control the immediate roof since it fails or separates above the bolted horizon, even with the application of cable bolts. Without them, the roof must span from the outby pillars to the longwall shields.

- Premature yielding of the standing supports can be very detrimental to the roof control process, particularly with supports that shed load upon yielding, as is the case with the pumpable supports used in this study. It appears that the standing supports can help to delay the process of the roof deformation and load shedding of the pillars, essentially by helping to control the roof span. Premature yielding would increase this span and place greater demand on the shields, but since the shields are already being pushed into persistent yielding during most of the shield cycle when the panel fender yields, there is little if any additional work that the shields can provide.

- The pre-yield capacity of the pumpable supports is not the issue; they would yield regardless of their capacity (within the design capability of these supports systems). The critical design parameter for the pumpable support is the residual load capacity and their ability to sustain residual loading until the longwall shields are fully advanced into the recovery room. The pumpable cribs used in this study are very stiff supports, reaching yield load at less than 12.7 mm (0.5 in) of convergence, shedding load rapidly after the cementititious grout strength is exceeded.

- Higher capacity shields are not likely to make much difference. The yielding of the panel fender transfers load beyond the capacity of any modern shield. However, poorly maintained shields, ones that have leaking leg cylinders, are likely to cause excessive convergence that can lead to failure of the arching capability of the main roof and collapse of the recovery room.

In conclusion, an understanding of the loading mechanisms associated with longwall recovery using pre-driven rooms is critical. While safer from a roof support installation perspective, the concept of using a pre-driven room increases the risk of the equipment recovery, and a better understanding of the loading mechanisms can help to ensure that catastrophic weighting failures will not occur. Some surprising results were revealed in this study, particularly the load shedding of the pillar stress prior to the advancement of the longwall face into the recovery room and the largely destressed condition that existed during the widening of the room. It is recommended that additional studies be conducted to further evaluate the loading mechanics associated with pre-driven longwall recovery rooms. Numerical modeling by Zhang et al. (2006) did not show the load shedding of the pillar stress, indicating that the models are not yet fully simulating the loading conditions. Additional numerical modeling studies, perhaps using FLAC (Itasca, 2001) that can more accurately simulate the post failure rock behavior should be constructed to further study this problem. In addition, efforts to improve the loading characteristics of the pumpable supports should continue. Reducing the stiffness and/or load shedding as well as increasing the yield displacement and residual loading capacity should be pursued if this support is to continue to be used for longwall recovery rooms.

Disclaimer

The findings and conclusions in this report have not been formally disseminated by the National Institute for Occupational Safety and Health and should not be construed to represent any agency determination or policy.

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