Longwall Shield Recovery Using Mobile Roof Supports

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ABSTRACT

Longwall mining has gained the reputation as being the safest extraction method in underground coal mines. However, one of the most difficult tasks associated with longwall mining is moving the face once a panel is completed. Based on Mine Safety and Health Administration (MSHA) fatality reports since 1996, longwall face recovery operations have claimed the lives of 5 U.S. miners and have resulted in numerous injuries. Recovery operations can be hazardous because they involve moving large pieces of equipment in very confined spaces. They are also conducted in highly stressed ground conditions due to front abutment loads generated by panel extraction. Shield removal is the most hazardous operation during face recovery because miners are constantly exposed to the unpredictable gob edge. To protect the miners, one or more walking shields, cribbing and/or other supplemental roof and standing supports are typically employed as breaker line supports as each shield is removed.

At the Harris No. 1 Mine in southern WV, mobile roof supports (MRS's) have been used in lieu of traditional walking shields on 17 face moves since 1997. MRS's are shield-like support units mounted on crawler tracks and are commonly used during room-and-pillar retreat mining operations. For longwall recovery, the two biggest advantages that MRS's have over traditional walking shields are that they are remotely controlled and are highly maneuverable. MRS's have contributed to safer shield recovery and shorter move times at the Harris No. 1 Mine. This paper will address both the safety and the operational issues associated with MRS usage during shield recovery. It will also discuss new developments, including the use of the inherently safer battery powered MRS's, which have been recently certified by the Mine Safety and Health Administration.

INTRODUCTION

Longwall mining is considered to be the safest extraction method employed in underground coal mines. However, based on Mine Safety and Health Administration (MSHA) fatality reports since 1996, longwall face recovery operations have claimed the lives of 5 U.S. miners and have resulted in numerous injuries (MSHA, 1996-2006). Three fatalities were attributed to meshing installation during recovery room preparation. Another fatality occurred during recovery operations while loading a shield on a flat car. And, the last fatality happened while trying to free an iron-bound shield in a recovery room. The mission of the National Institute for Occupational Safety and Health (NIOSH) is to help assure safe and healthful working conditions for men and women by providing research, information, education, and training in the field of occupational safety and health. In keeping with this goal, NIOSH Mining Program researchers, in conjunction with industry experts, examined a novel approach in removing shields during longwall face recovery operations. During this investigation, several State and Federal Roof Control Specialists were questioned about shield recovery operations and they all indicated that shield removal is the most hazardous operation conducted during longwall mining. In addition, every longwall operator and miner queried concurred. Miners in the teardown or recovery room area are exposed to highly stressed ground conditions due to front abutment loads generated by panel extraction. Additionally, the miners are in close proximity to the unpredictable gob edge, which can cave or flush into the working area, while trying to maneuver shields weighing over 20 tons in confined spaces.

Over the past few decades, longwall mining technology has evolved significantly. Longwall shield recovery operations are no exception. Initially, conventional wood cribs or timber posts were set in place for every shield recovered to break off the roof cave and prevent gob material from flushing into the working area. Later, some operators began employing walking shields in conjunction with engineered standing supports. It seems like a natural progression that inherently safer MRS's would replace walking shields. MRS's are shield-like support units mounted on crawler tracks. The Harris No. 1 Mine pioneered the successful usage of MRS's during shield recovery operations in the United States. MRS utilization at Harris has been responsible for injury reductions, both ground control and material handling related, and record move times. The purpose of this investigation is to expose other longwall mining operators to the advantages of MRS usage during shield recovery operations.

MINE SETTING, GEOLOGY AND HISTORY

The Harris No. 1 Mine is operated by Eastern Associated Coal Corporation which is a subsidiary of Peabody Energy. Harris is located in Wharton, WV and began operations in 1966 (figure 1).

Figure 1. Harris No. 1 Mine location map.

The topography at this site is fairly rugged. The valleys are narrow and "V" shaped and ridges are steep and prominent. These physiographical features can cause rapid changes in cover over relatively short horizontal distances. The overburden ranges from 100 ft at the drift to slightly over 1,400 ft under the highest ridges and the mining height ranges from approximately 6 to 7.5 ft. As is the case with most Central Appalachian coal mines, the overburden is relatively competent.

Harris is mining in the Eagle Coalbed. Figure 2 is a generalized stratigraphic column of the mine roof above the Eagle Coalbed up to the No. 2 Gas Coalbed, which has been extensively mined. It should also be noted that the major sandstone and shale units shown in figure 2 vary in thickness. For example, in a few of the core holes the upper two sandstone units merge into a 100-ft-thick unit. The same can be said for the lower two sandstone units.

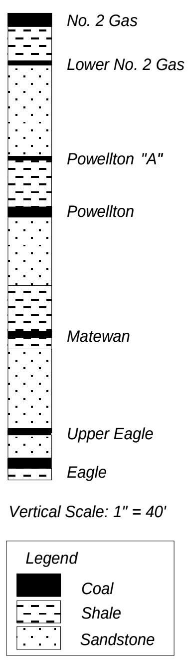

Figure 2. Immediate and main roof stratigraphy at Harris No. 1 Mine.

These rock unit thickness variations indicate ancient stream channel activity. Usually, the interburden contains 6 distinct rock units; however, the actual number varies from 4 to 7. In general, the interburden is rather competent, with the percentage of sandstone, sandy shale, and limestone ranging from 59 to 80 percent. The shale unit, shown in figure 2, directly above the Eagle Coalbed varies in thickness from 0 to 10 ft. In areas of the Harris Mine, this shale unit can either be laminated, sandy, or nonexistent (replaced by a sandstone scour). These fluctuations explain the range in Coal Mine Roof Rating values from 44 to 71 (Molinda and Mark, 1994). These values indicate that the immediate roof rock is of moderate strength to strong.

Harris has mined over 60 longwall panels in the Eagle Coalbed. Harris began longwall operations with a 300-ft-wide plow face and 40-ton walking frames in 1966. Since then, numerous technological innovations have led to improvements in the longwall systems and gateroad supplemental supports employed. Currently, Harris is mining 3.2 million clean tons of coal per year. Gateroad pillar design and supplemental support selection have also gone through an evolutionary process at Harris based on the performance of past longwall faces and gateroads. In fact, twelve different gateroad designs, which incorporated various elements of a 3-entry, 4-entry, and yield pillar system have been tried at Harris. The gateroad system design was progressively refined and calibrated through the back analyses of previous successful and difficult mining attempts.

For the past 9 years, Harris has been using a 3-entry gateroad system with entries on 90-ft and crosscuts on 140-ft centers. This system has worked well and no gateroad blockages have occurred since its usage began. Harris uses 5-ft, full column resin bolts on 4-ft centers in the headgate entry. In the remaining gates and bleeders, 4-ft, full column resin bolts on 4-ft centers are standard. The roof control plan also stipulates that a minimum of 2 cribs or equivalent supports be installed every 12 ft in the tailgate. Floor heave has always been a major concern at Harris. Because conventional cribs (both 4-and 9-point) are inclined to roll out when subjected to heave, Harris began using 30-in, engineered timber supports. These supports have performed well in that the floor tends to heave up around the supports without causing instability of the support.

The No. 2 Gas Coalbed is situated approximately 200 ft above the Harris workings. Both longwall and room-and-pillar retreat mining have been conducted in the No. 2 Gas. In many cases, remnant structures such as barrier pillars, isolated gateroads (gateroads with gob on both sides), etc. that were left in the 2 Gas have caused difficult ground conditions in Harris due to downward load transfer (Chase et al., 2005). Difficult mining conditions associated with high horizontal stresses have also been a problem at Harris. The engineers also use the LaModel program (Heasley, 1998) to identify high vertical stress areas which are caused by deep cover, abutment loads, and/or multiple seam stress transfer. In highly stressed areas, either two or four, 12-ft-long cable bolts are installed between each row of primary supports. Sometimes, additional engineered timber supports are warranted in tailgate locations. The spacing of these supports is dependent upon the expected level of stress.

Prior to MRS implementation, it became apparent that the injury rates sustained during longwall move operations were higher at Harris than during panel extraction. In fact, a statistical study conducted by Harris Mine officials indicated that when compared to normal face operations, injury rates were 26% higher during recovery operations. In an attempt to reduce these injuries, management turned to the novel approach of using MRS's during shield recovery.

SHIELD RECOVERY USING WALKING SHIELDS

After the shearer, pan line, and other longwall face equipment are removed from the recovery room area, shield recovery is commenced. At this point, most operators have already installed a spare set of new or rebuilt face equipment with the exception of shields in the setup room for the new panel. Only a few operations have an entire set of duplicate shields, so it is of paramount importance to safely recover, move, and transport the shields to the setup room so that the mining of the next panel can begin.

For the most part, there are three general methods that operators employ in order to prevent gob flushing into the working area. The first method relies solely on primary and supplementary intrinsic and standing supports. Traditionally, the standing supports were two or three 4-point cribs installed for each face shield removed. One needs to keep in mind that a shield is being lowered and adequate support needs to be installed to maintain the immediate roof. Many operators have opted to use hydraulic or engineered timber props (figure 3) to reduce the amount of time required to install compared to a wood crib. This reduces miner exposure to the unpredictable gob edge and shortens the move time.

Figure 3. Engineered yieldable timber props equipped with active presetressing mechanical devices used as breaker line supports.

Another method which operators utilize to prevent gob flushing are walking or trailing shields. The majority of the mining community is accustomed to using the terms "walker" or "walking shields." Therefore, this paper will comply and will use this terminology. If one shield is used, a chain or 1-in-diameter steel wire rope is hooked to the shield's frame (legs or pontoons). The shield is moved out of the face area with a shield retriever. As shown in figure 4, some retrievers have a long boom with a hook on the end. The hook is manually placed in a large clevis that is attached to the chain or wire rope. The boom is raised and the shield is dragged out of the face so that the long axis of its canopy is situated parallel to the face (unmined block of coal) and perpendicular to the other face shields. This shield now functions as a walking shield, and is pressurized a few inches slightly in front of the shield tip and canopy corner to retrieve the next shield. After the next shield is removed, the walking shield is dragged forward

Figure 4. Shield retriever advancing walking shield.

and the process continues. Barring adverse ground conditions, less supplemental roof support (usually cable bolts and free standing support) is required when walking shields are used as compared to the first recovery method. Prior to MRS usage, a single walking shield was employed during shield recovery at Harris.

Some operators use two walking shields during recovery operations. These shields may be operated independently or in tandem. If the shields are not connected to each other, they are advanced separately as previously explained. Most operators have the shields joined together via a "F" or other type of bar which is anchored to the base plates. The bar attachment enables the shields to advance on their own. With one canopy lowered, the adjacent pressurized shield extends its hydraulic ram which pushes the connected bar ahead. The lowered shield then retracts its ram, thereby pulling or "walking" the shield forward. Thus the name walker or walking shield. There is a considerable amount of variability with the bar design. Some are designed in-house while others are manufactured at fabrication shops. As was the previous case, in general, less standing support is used when two walkers are employed as breaker line supports.

SHIELD RECOVERY USING MRS'S

The third method to prevent gob over-runs is to use MRS's as breaker line supports. MRS's were first utilized in the U.S. in 1988 at the Donaldson Mine, which was a room-and-pillar operation (Chase et al., 1996). Since then, their use in room-and-pillar operations has become widespread throughout the Appalachian Coalfields. MRS's are almost exclusively used during room-and-pillar retreat mining operations. They have proven to be inherently safer and more cost efficient than conventional timbering plans. MRS's technology was pioneered by the U.S. Bureau of Mines (Thompson and Frederick, 1986). Commercial units, which are currently being used underground, include those manufactured by J. H. Fletcher and Co. and Voest-Alpine. As the name implies, MRS's are mobile and also highly maneuverable. Based on Harris No. 1 Mine's experiences, MRS's have proven to be safer, more efficient, and also faster than walking shields for longwall recovery.

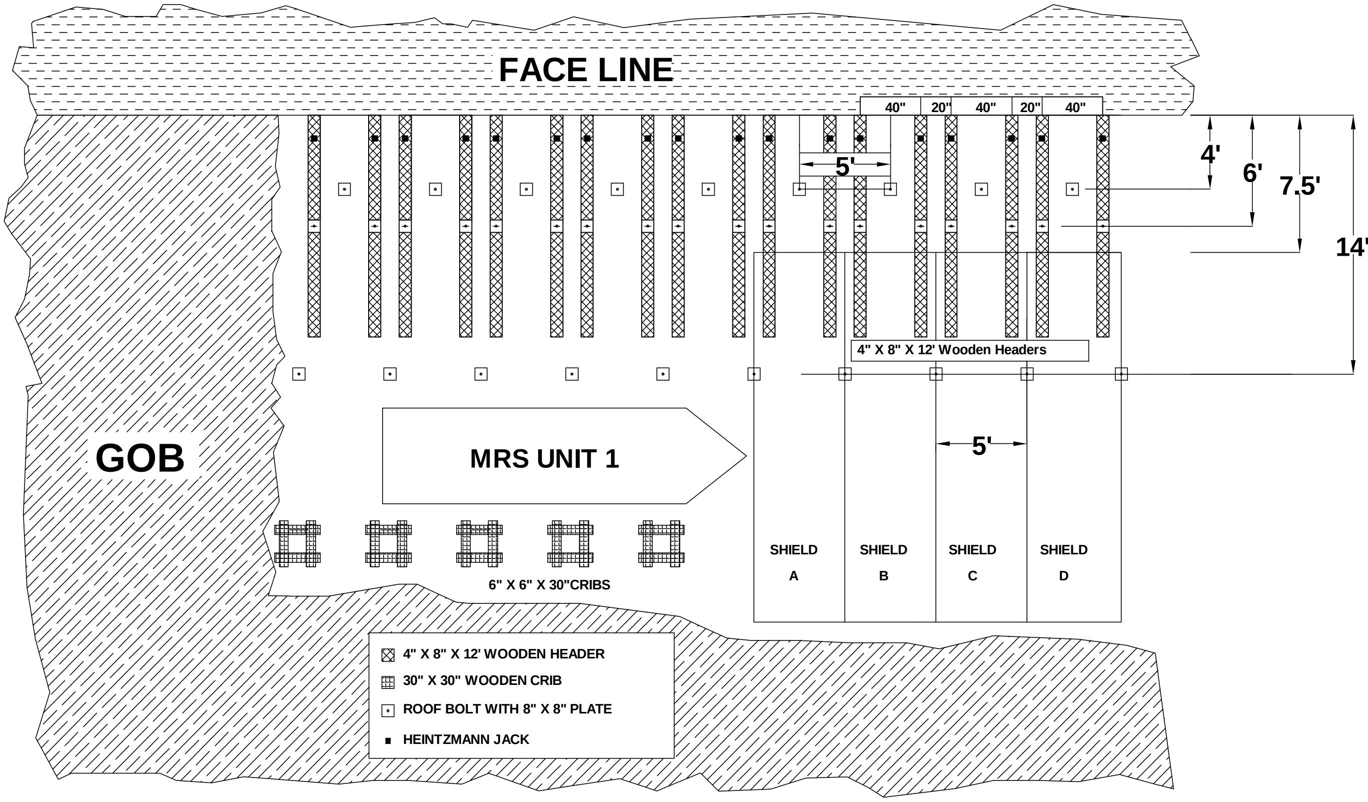

Figure 5. Harris No. 1 Mine shield recovery plan.

Figure 5 depicts the current support plan and MRS positioning for shield recovery operations at Harris. If ground conditions permit, Harris pulls shields from mid-face to both the headgate and tailgate, or bidirectional. As figure 5 suggests, after shield "A" is retrieved and begins being dragged to the tail (or to the right in figure 5), a crib is built in its place, in line with the previous ones shown. Then the MRS is lowered, trammed forward and reset. As the operator trams the MRS forward to recover the next shield, they align the canopy edge of the MRS with the leg socket connection to the shield's canopy as shown in figure 5. The process then repeats itself. As previously indicated, walkers are pressurized only a few inches in front of the shield canopy of the next shield to be recovered. Based on the manufacturer, the cable reel and/or plow necessitates the MRS's canopy to be pressurized approximately 3-4 ft away from the shield toward the gob side as illustrated in figure 5. This has not constituted a problem at Harris; however, under weak immediate roof rock conditions it should be considered. MRS's used on previous models at Harris had 4-ft extensions welded on the canopy's duck bill enabling them be situated a few inches from the shield corner, similar to walkers.

Harris has determined that MRS's usage has improved both the safety and efficiency of longwall shield recovery operations. Since MRS utilization began, only one non lost-time injury has occurred at Harris during shield recovery. A review of the accident indicated that the injury would have most probably occurred regardless of what breaker line support was being used. During the last longwall teardown operation in April 2007, a record 189 shields were recovered in 6.5, 8-hour shifts (15 shields per crew in an 8-hour shift).

Figure 6 illustrates a MSHA-approved plan employing two MRS's that was submitted by another mining company. As compared to figure 5, significantly less support is required when using two MRS's. Harris has opted to use a single MRS due to the restricted width of the recovery room. The MRS canopy width for the model used at Harris is greater than that of a standard shield. This places the side of a second MRS in close proximity to the roof caving area, and gob flushing causes frequent machine fouling.

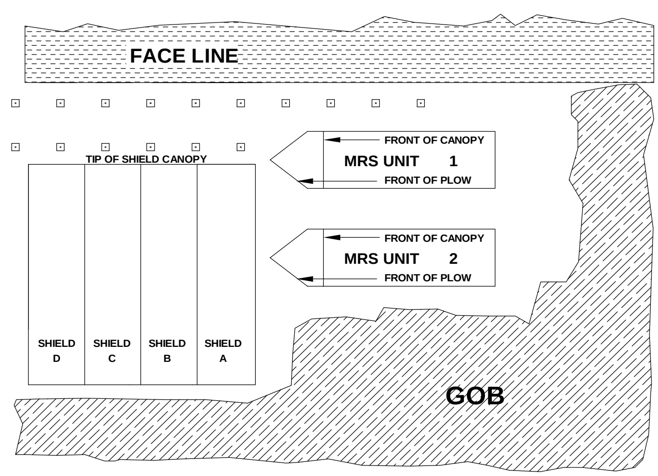

Figure 6. Shield recovery plan using two MRS's.

Only two mines in the U.S. have MSHA-approved Roof Control Plans to use MRS's for shield recovery operations, and the following safety precautions are listed in the plans:

1. A MRS may be used as roof support while roof bolting the longwall face line in lieu of timbers or safety jacks.

2. The distance between the fronts of the plow of the MRS to the shield shall not exceed 7 feet.
3. The MRS and adjacent shield shall be against the mine roof before a crib is installed.
4. All personnel shall maintain adequate clearance under shields or stay a minimum of ten feet away from the unit when the MRS is being raised or lowered.
5. The MRS cable hangers shall be light and disposable to eliminate the need of entering the unsupported area to retrieve hangers or unhook the cables.
6. Should the MRS become disabled, cribs or timbers will be installed before work is attempted.
7. Manual operation of the MRS unit(s) shall be for maintenance purposes only. If the unit is set against the mine roof, adequate temporary roof support shall be installed prior to lowering the unit manually.
8. If the support relief pressure is being reached, the operator shall stop and notify the foreman.
9. When using two MRS's, both units will not be lowered at the same time and the units should not be offset more than one half unit length from its companion unit.

MRS SAFETY AND COST SAVINGS ADVANTAGES

When examining the safety and other advantages associated with the three recovery support methods previously discussed, it should be noted that all have proven to be safe. In this section, the advantages and disadvantages with each of the first two methods are compared with those for MRS usage.

When evaluating supplemental roof and standing support usage as longwall recovery support against MRS's, there are considerable differences. In addition to the supplemental roof support, which usually consists of some combination of regular bolts, cable bolts and/or other specialty bolts, meshing, 1-in-diameter steel or nylon rope, steel beams, etc, standing supports are also installed for each shield removed. Usually, these standing supports are engineered wood cribs or timber props, hydraulic jacks/props, or standard cribbing. Only the hydraulic jacks/props and engineered wooden props with prestressing bags or bladders have a limited active loading capability. Cribs are passive supports and require 2-4 inches of convergence before they achieve significant (greater than 40 tons) load bearing capacity. A least two and sometimes three cribs or equivalent supports must be installed for each shield removed. Therefore, miners are subjected to the face, roof, and gob edge for longer periods of time, and material handling issues also have to be considered. In contrast, MRS's are active supports that can achieve several hundreds of tons of support immediately and provide much greater roof coverage. When using MRS's, exposure to the gob edge and the highly stressed unmined coal face is reduced as compared to the other breaker line methods.

A MRS system is also superior to a single walking shield approach based on safety and lost productivity issues. When miners hook up the retriever to the walking shield, they are highly exposed during the minute or so it takes to find and attach the clevis. Under adverse or highly stressed ground conditions, rib bolts have occasionally been known to shoot out of the unmined coal face. In 1994, a miner sustained a severe head injury by a shooting bolt when working under a walking shield near the face. Rib rolls and bounces are other possible hazards due to the close proximity of the miners to the face. Another problem which has occurred while trying to drag shields is that the chain or wire rope can break in a "whip-like" manner due to the large amount of strain energy stored in the rope. The latest fatality occurred in 2004 and involved a chain. Prior to that, a wire rope pulling a walking shield snapped and fatally injured a Pennsylvania coal miner. Obviously, the time spent hooking and dragging the walking shield is time lost recovering face shields. On a recent examination of a longwall move in the Pittsburgh Coalbed using a single walking shield, an average of 7 to 10 shields were recovered during a normal eight-hour shift and ground and roadway conditions were excellent. The mine was pulling shields in only one direction and was using recovery chutes.

A pair of connected walking shields has the advantage of being able to advance themselves, as compared to a single walking shield. There are benefits to using a single or two walking shields over MRS's. For example, they are already owned by the mine, and they are at the face where they are readily available for recovery operations. Another potential advantage is that the shields have a higher support capacity than a standard MRS. However, a 600-ton MRS seems to do the job just fine at Harris, and 800-ton units are also available. Finally, as previously discussed, shields may be able to maneuver closer to the shield being recovered than MRS's. One disadvantage of the walkers, as compared to MRS's, is that they are advanced via a thin electrical umbilical cord that is connected to a control box or "packman." With this packman, the walking shield's electro-hydraulic control system can be activated causing the shields to rise, lower, or advance remotely with the operator safely under a face shield. Unfortunately, this cord is not durable and, depending on conditions, it can be severed by falling rock which necessitates repairs. Sometimes miners will enter into the area housing the shield's hydraulic controls to advance the walkers manually. In contrast, MRS's are remotely operated by radio control.

The advantages of MRS's are most evident in adverse conditions. Figure 7 exemplifies some less than desirable conditions in which MRS's have performed well at Harris. This recovery room's roof was highly fractured due to multiple seam stress load transfer and horizontal stress damage. The shield behind the MRS was abandoned because the conditions were extremely difficult at this location and because the shield was nearing the end of its useful life. The decision was made not to

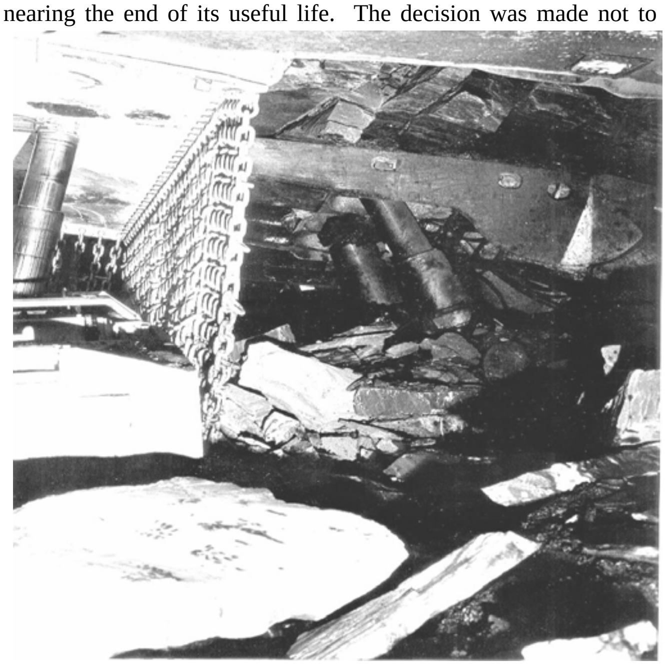

Figure 7. Shield recovery under adverse conditions.

take the risk or spend the time recovering the shield under such adverse conditions. MRS's also have the ability to bulldoze their way through excessive floor debris (figure 8). With walking shields, it is more likely that some of the debris may have to be removed to facilitate their advance.

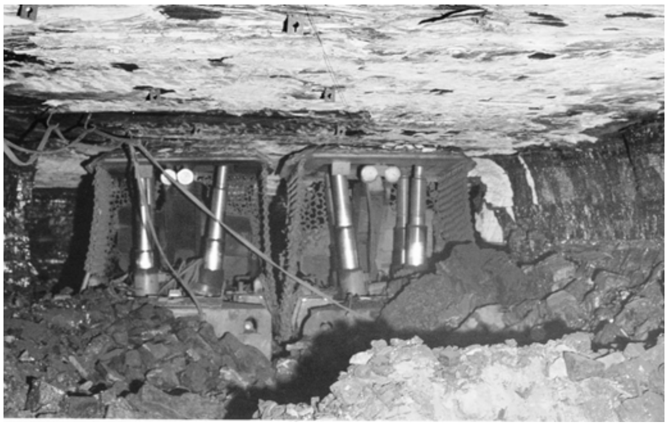

Figure 8. MRS's plowing floor debris.

Another positive feature of MRS's is that they have two pressure gauges mounted on the front of each support (figure 8). These gauges can be visually monitored by operating personnel to determine loads and rates of loading on the units. In addition, MRS's are equipped with a lighting array which can also be used to examine loading conditions. This array can be seen from farther distances compared to the pressure gages. Green, yellow, and red pulsating lights indicate different total load levels or incremental changes in loading. If a fall seems imminent based on either or both of these systems, the mobile can be quickly trammed out of harm's way. Walkers on the other hand have been trapped, gone iron-bound, and lost because they leapfrog much more slowly. In the event of a high roof cavity or fall, walkers cannot advance if the canopy doesn't pressurize against the roof. If this occurs, the walkers must be dragged with the retriever. Sometimes, the miners will place cribbing on top of the shield so that when the canopy is raised the cribbing will contact the roof allowing the walkers to advance. Obviously, this significantly increases miner exposure to hazardous conditions. MRS's are also better designed for use in mines with floor abnormalities or excessively muddy roadway conditions.

Gob flushing and face spalling pose another problem for walkers. If a sufficient amount of debris enters into the shield's cavity where the hydraulic controls and hoses are located, miners must leave their safe location under the face shields and using a sledge hammer and slate bar, break and pry out the material. MRS's have a steel chain curtain draped from the canopy and down the sides of the units to protect the interior compartment from gob flushing (figures 8 and 9).

Shields are designed to be loaded vertically and also laterally along the long axis of the shield from the tip to the back. When shields are used as walkers, they are subjected to side loading, a type of loading which they were not designed for. Side loading occurs because the roof tends to deflect or rotate downwards as it cantilevers back towards the gob. The canopy on MRS's is designed to tilt side-to-side in relation to the base structure. This better accommodates side loading conditions and allows the canopy to conform to most types of roof and floor orientations (Barczak and Gearhart, 1997). These concepts are exemplified in figure 9, which shows the canopy canted to the right or gob side of the photograph. The right side of the MRS is riding up on floor debris and the frame is articulated in relation to the canopy.

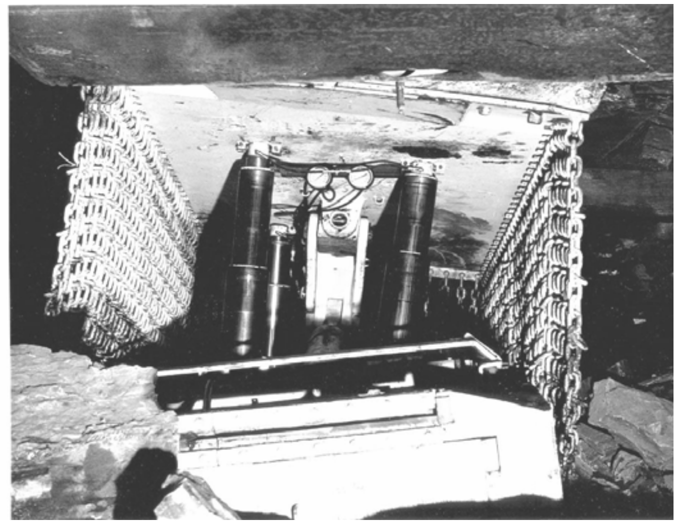

Figure 9. Articulated MRS frame and canopy.

BATTERY POWERED MRS'S

As previously mentioned, cable handling has been a major concern of MSHA and various State Regulatory Agencies since the inception of MRS technology into the coalfields. In fact, cable handling was cited as a contributing factor is a recent double fatality on a pillar line in southern WV by the State of West Virginia Office of Miners' Health, Safety & Training (2007). In order to prevent the MRS power cables from being cut by equipment, they are hung close to the roof on bolt plates. Initially, insulated "J" hooks were used. However, these hooks were so strong that the only way to release the cable was to manually remove it from the hook. Since the adjacent coal has just been pillared or mined out in the lift, this activity places miners in a compromising area. Cable removal is even more risky in high coal where the miner must climb a step ladder to remove the cable. In order to alleviate this situation, MSHA has begun requiring break-away disposable cable hangers. With these hangers, a miner can stand outby and pull down the cable. However, when the cable is retracted by the MRS to minimize slack before mining, the first hanger will often release and the weight of the cable causes the others to do the same. Then, all the cables have to be re-hung, which results in downtime. A MRS operator indicated that no matter how careful or good you are at "goosing" the cable intake control, the hangers often "pop off." Time studies conducted by the third author of this paper at two WV mining operations indicated that cable handling required an average of 10 minutes per lift, which equates to 25 pct downtime. Cables also cause clearance problems and are aggravating during shield recovery operations. In general, you want to avoid any cables in the recovery area. However, Harris has determined that the advantages of using MRS's far outweigh their disadvantages.

In light of the above, a West Virginia-based, MRS leasing concern designed and fabricated the first battery powered MRS's (figure 10). These units are powered by a single 1,000-amp-hour battery housed in a one-inch-thick steel compartment. The total weight of the battery and compartment is six tons for a total machine weight of 31 tons. The battery compartment is located at the front of the unit (figure 10) and is mounted onto the frame with a large hinge pin. The compartment can be moved up or down for clearance or to plow floor debris. A specially-designed, double bank charger is normally located at the charging station. A fully charged battery will power the unit for 5 to 6, 8-hour shifts. Twelve hours prior to being discharged, a battery indicator light will come on. This allows the battery to be switched-out at the most convenient time, for example, during a shift change. Usually, a scoop will bring a fresh battery to the MRS and battery switch-out time is approximately 5 minutes. The spent battery is then recharged for 8 hours, allowed to cool for 8 hours, and then is ready for reuse.

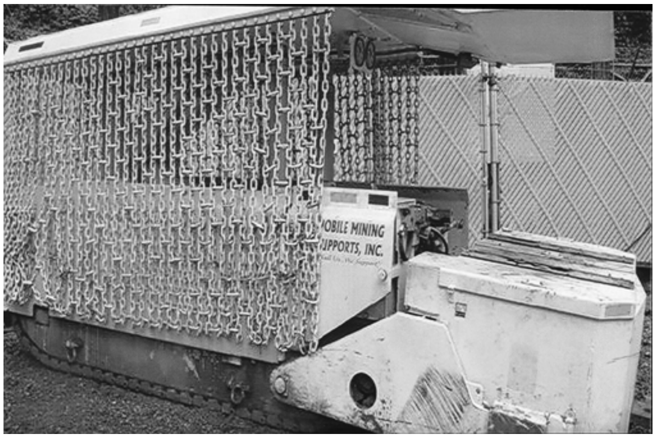

Figure 10. Battery powered MRS.

Battery powered MRS's have been certified by MSHA and successfully field tested at two room-and-pillar retreat mining operations. By eliminating the problems associated with cable handling, the battery powered MRS's increase safety and minimize downtime. In fact, the increased mining time was determined to be as much as two additional hours per 8-hour mining shift. Although battery powered MRS's have proven to be field worthy in room-and-pillar mines, they have not been tested in recovery room operations. It should be noted that the battery housing extends out six more inches than a standard MRS. Therefore, if they are to be used for shield recovery, a 4.5-ft extension might be warranted in weak roof. To date, Harris has not indicated an interest in trying battery units.

SUMMARY

The keys to a successful longwall move are to avoid injuries at all cost and move the equipment to the next face as quickly as possible. The personnel from management on down at Harris No. 1 are convinced the MRS utilization is safer and faster than other recovery methods. After 17 successful moves, including a complete move in less than four days, Harris is committed to MRS usage. As was previously mentioned, all the methods described in the paper are safe. However, MRS's have demonstrated that they are superior in all conditions, with the biggest advantage being realized under difficult to adverse conditions.

Using face shields as walking shields has logistical and financial advantages. However, if a company has another longwall or room-and-pillar retreat mining operation in the area, it may make economic sense to consider the capital expenditure to purchase MRS's. MRS's can also be leased from companies that have the personnel to train miners on how to use them. As previously stated, the purpose of this paper is to make other longwall operators aware of the technology and success that Harris has had using MRS's during shield recovery operations. It introduces a new approach of recovering longwall face equipment in a safe and more efficient way. Due to the importance and risk involved in moving a face, mine managers and longwall coordinators rely heavily on their past experiences and are reluctant to change. Mining history indicates that people become comfortable doing things the same way and resist change. This paper was written for their consideration, and attempts to provide them with successful examples of this emerging technology for longwall recovery.

ACKNOWLEDGMENTS

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