Roof Screening for Underground Coal Mines: Recent Developments

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ABSTRACT

Falls of small pieces of rock from between roof bolts continue to cause fatalities and to injure hundreds of coal miners each year. Roof screen is the most effective way to prevent these incidents, but some mines are reluctant to use it because they believe installing screen can be awkward, expensive and time-consuming. The most common type of roof bolting machine used in mines today is the dual boom, outside-controlled roof bolter. Mines who install roof screen using these machines have developed some machine modifications and techniques to ease roof screen installation. This paper describes some successful techniques and machine modifications that are being used in productive mines to assist with roof screen installation. Since the material handling involved with roof screen installation can expose miners to an increased risk of musculoskeletal injuries, the National Institute for Occupational Safety and Health (NIOSH) ergonomists, designed machine modifications and implemented a series of tests to evaluate roof screen handling procedures for outside-controlled, dual boom roof bolting machines. Roof screen installation can also have a positive economic impact on a mine by reducing the cost of injuries, workers' compensation, required spot or re-bolting, and clean-up of long term travel and belt entries.

INTRODUCTION

Hundreds of injuries and usually one or two fatalities occur each year due to small rocks falling from between permanent roof supports. These small falls are not adequately controlled by conventional roof supports like roof bolts, large roof plates, steel straps, pizza pans, spider plates, or header boards. The 2005 Mine Safety and Health Administration (MSHA) accident data base lists list a total of 563 fall of ground injuries, including 9 fatalities. An analysis of the database suggests that 466 of the injuries were caused by roof skin failures (figure 1).

The key to controlling falls of the immediate roof or roof skin is maximizing the area of roof coverage and confining these relatively small loose rocks. Roof screen offers the most coverage of the immediate roof. Depending on the size of the screen, coverage of up to 94% of the roof area can be achieved (Robertson et al., 2003). Screen also offers a first line of defense for roof bolter operators by confining or deflecting small rocks that can come loose during drilling or bolt installation. Figure 2 shows an example of the protection screen provides during bolt installation.

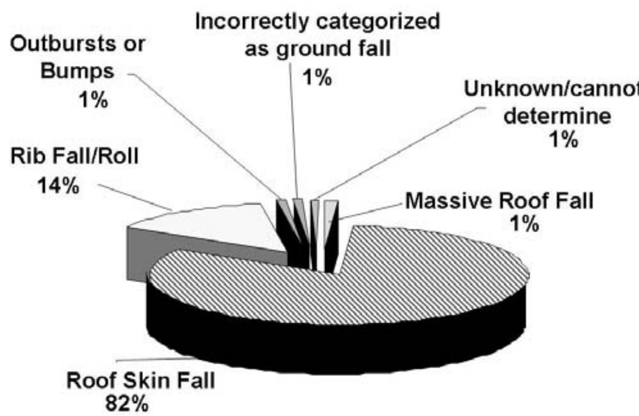

Figure 1. 2005 Ground Fall Injuries by Fall Type.

Figure. 2. Screen providing protection during bolt installation.

Although the benefits of screen are well known, mining companies in some areas of the U.S., mainly Northern Appalachia and the Illinois basin, are still reluctant to use screen on cycle. The costs associated with installation, material handling and possible ergonomic injuries are delaying the acceptance of screen as an on-cycle roof support tool. A few mines however, have decided that installing roof screen can be cost effective when compared to the cost of lost time accidents, training of replacement workers, or going back to clean and re-bolt already developed entries.

Being aware of conditions that warrant the use of roof screen could prevent fatalities, injuries and even improve a mine's bottom line. Local experience is of course the best tool for recognizing these hazardous conditions, such as:

- Bolter operators are having problems setting the Automated Temporary Roof Support (ATRS) due to irregular or high potted out roof,
- The mine roof consists of moisture sensitive fireclay or claystone that deteriorates over time, or;
- A mine sees production time losses due to cleaning up of outby travel ways to clear loose rock and re-bolt areas where plates become loose due to skin failures around plates and;
- Regular mine roof damage mapping can highlight problem areas and help to anticipate future problem areas, (Molinda et al., 2003).

It has also been suggested that the Coal Mine Roof Rating (CMRR) could be used as a guide when considering the use of roof screen. If the CMRR of the roof is below 35, installing roof screen could help control roof skin failures, and maintain long term stability in travel and belt entries (Gadde et al., 2005).

The paper describes recent developments in roof screen installation for underground coal mines, and:

- Evaluates procedures mines have developed to ease the installation of roof screen;
- Discusses machine modifications made to ease the transportation and installation of roof screen;
- Evaluates devices and techniques developed to assist with getting screen over the bolter and into installation position;
- Describes developments being made in machine manufacturing to assist with the ergonomics of screen installation, and;
- Gives a description of the economic impacts of roof screen installation.

PROCEDURES DEVELOPED AT WORKING MINES TO ASSIST ROOF SCREEN INSTALLATION

The majority of room and pillar coal mines in the U.S. utilize an outside-controlled dual boom roof bolting machine, especially in seam heights of less than 6 ft. This type of roof bolting machine was not designed to store, transport or assist with screen installation. Each coal mining company that uses these machines to install screen on a routine basis has developed its own procedures and machine adaptations to ease the installation of screen panels.

NIOSH has observed that the best and most efficient technique for handling and installing roof screen is simple good house keeping and organization. In the most efficient operations the roof bolting machines are very clean and well organized; all supplies have a designated area on the bolter that can be accessed quickly and safely. This is the case whether screen is stored on the bolter or along the rib. The supply areas on the section are also very clean and organized. Usually the screen will be delivered to the section and stored in a cross-cut with good scoop access to allow unobstructed loading of screen and to keep the screen flat and ready to install.

Before roof screen can be installed, it must be supplied to the bolting machine. The most common method observed in our study was to hook a chain to the panels and drag them to the last open cross-cut, then lift them up, one or two at a time, and lean them against the rib or leave them lying on the mine floor. The operators then walk back to the cross-cut and get them as needed. Unfortunately dragging the screen panels can damage screen and tends to bury them in mud. Broken, bent and muddy screen is much more difficult to handle, and is more likely to get caught on everything from the rear of the bolter to the ATRS, making it harder for the operators to get screen into installation position.

The most efficient supply method observed was the use of racks or rails (figure 3) installed on the bolting machine that are capable of holding enough screen to complete the bolting of roof exposed from a full cut of coal. Curtain boards, approximately 3 in x 2 in x 15 ft, are laid between the racks to keep screen from sagging onto supplies.

Figure 3. Rack used to hold and transport screen.

The storage racks, some originally designed to hold steel straps, are built between 18-22 in above the bolter deck. They must be high enough to allow access to bolting supplies stored underneath, but low enough to keep them from dragging on the roof of the mine. These racks are angled upward, or have a post protruding on the ends, to keep screen in place while tramming between places.

When storage racks are used, screen panels can be supplied to the bolter in several different ways. At one mine the scoop operator, sometimes assisted by the person installing ventilation curtains, loads panels onto the top of the scoop to keep them from being damaged and out of the mud. The screens are then transported to the last open cross-cut and leaned against the rib. While tramming from one face to another, the bolting machine is stopped. Both bolter operators then load the screen, one or two panels at a time, onto the storage racks. This takes only a couple of minutes to accomplish. Leaning the panels against the rib means the roof bolters do not have to bend over as far to lift the panels, therefore decreasing the amount of exertion needed to lift the panels onto the machine.

An even more effective method used at this mine is for the scoop operator, with the help of the ventilation person, to pull up immediately behind the roof bolter and load the panels directly onto the racks on the bolting machine while the bolter operators are installing bolt. This lets the bolters move directly to the next place without delaying, to load screen. Both of these supply procedures worked very well and the one used was determined by how busy the scoop operator was during a particular shift.

INSTALLATION TECHNIQUE WITH ROOF SCREEN STORED ON THE BOLTING MACHINE

The installation technique observed where racks were used to store screen panels on the machine worked seamlessly with an experienced crew. The operators would also use the stored screen panels as a platform to help rotate and slide the roof screen into the installation position. Keeping the screen stored off of the floor significantly reduced the amount of bending and lifting usually associated with screen installation. Compared to other techniques observed, this system appeared to be the easiest and quickest.

When initiating a new cut it is important to position the machine with the ATRS outby the last row of bolts before positioning the screen panel. After the screen is secured to the ATRS, the machine can be trammed into position to install the first row of bolts (figure 4a). After installation of the first row of bolts is complete, the following step by step procedure is used to install each screen panel:

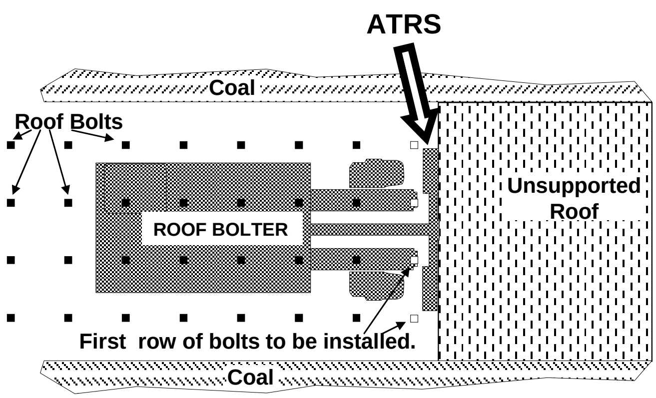

Figure 4a. Roof bolter location when ATRS is set and bolts are ready to be installed.

1. Lower the ATRS and personal canopies enough to allow screen panel to be carried over and positioned on top of the ATRS with minimal effort.
2. Back the roof bolter up until the ATRS is outby the last row of bolts by at least 12 to 18 inches. Total maximum distance needed to back up the machine is approximately 3-1/2 to 4 ft (figure 4b). Backing up is necessary to ensure that the operators do not reach inby the last row of permanent support.
3. The forward end of the top screen stored on the rack is then pushed toward the operator deck-side of the bolting machine, minimizing the distance the other operator has to reach to get a hold of the screen. The off-side operator then walks to the back of the screen, and together both the operators lift and carry or slide the screen panel over the personal canopies and onto the ATRS. Pre-measured marks are put on the ATRS to allow positioning the screen correctly and quickly. The marks on the ATRS can be adjusted so rib bolts are placed at the desired distance from rib.
4. Once in position, the screen is secured by bending over a piece of 12-gauge wire that is secured to the ATRS (figure 5). This technique holds the screen in position until the bolter is moved forward into position and the ATRS is set against the roof.
5. When the row of bolts is installed, the ATRS is lowered and the 12-gauge wire will pull away from the screen panel. The steps are then repeated for each successive installation of rows of roof bolts.

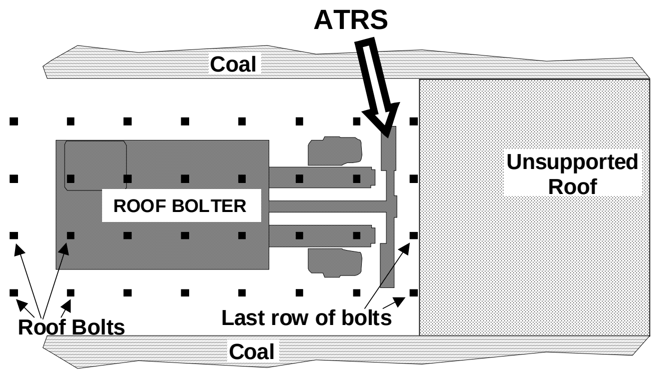

Figure 4b. Position of roof bolter after backing up so the next screen panel can be positioned on the ATRS.

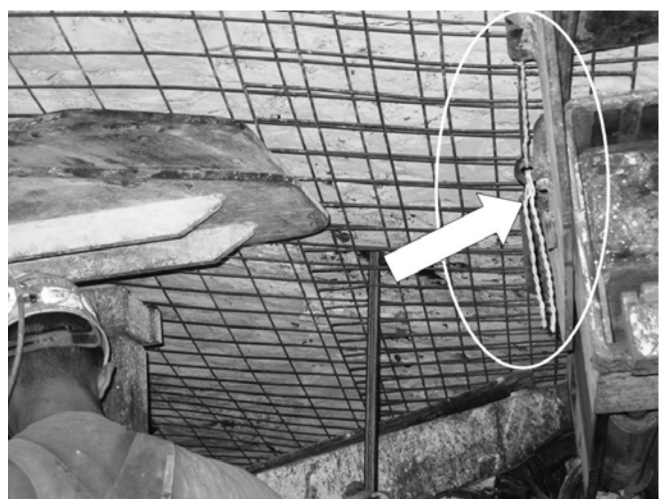

Figure 5. Roof screen held in position on ATRS with twisted 12-gauge wire.

LOW COAL SCREEN INSTALLATION TECHNIQUE

The following technique has been developed in a mine with a seam height too low to use a rack/rail on top of the bolting machine. This procedure is slightly slower than previous one, due to having to retrieve screen from the cross-cut one at a time. However, installation was very smooth with an experienced crew. In a new cut, roof screen is attached to the ATRS before moving the roof bolter into position for the installation of the first row of bolts (figure 6a). After the first row of bolts is installed, the following steps are completed:

1. Lower the ATRS and personal canopies enough so the operators can reach over them easily.
2. Back up the bolter until the ATRS is approximately 6-8 ft outby last row of permanent support (figure 6b).
3. One of the operators retrieves a screen panel from last open cross-cut. The operator retrieving the screen will be the one closest to where screen is stored depending on the entry to be bolted.
4. The screen is then carried by one person along the side of the roof bolter and lift it up onto the ATRS.
5. The operator, staying on the outby side of the ATRS, will swing the screen panel around the inby side of the ATRS and hand it to the operator on the opposing side of the machine. Careful attention is necessary at this point. The opposing-side operator must avoid going on the inby side of ATRS to reach the screen panel.
6. The screen panel is then positioned on top of the ATRS and held in place by twisting a piece of 12-gauge wire around the screen.
7. The machine is trammed into position and a row of bolts installed. The procedure is repeated for installation of each successive row of bolts.

A technique was observed that did not require backing the roof bolter up for each panel installation. The procedure is very similar

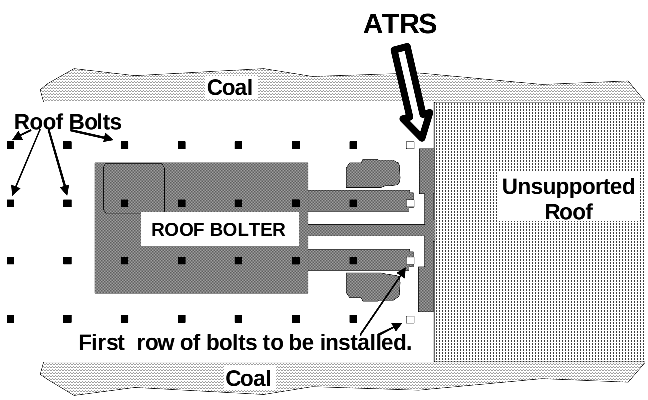

Figure 6a. Roof bolter location when ATRS is set and bolts are ready to be installed.

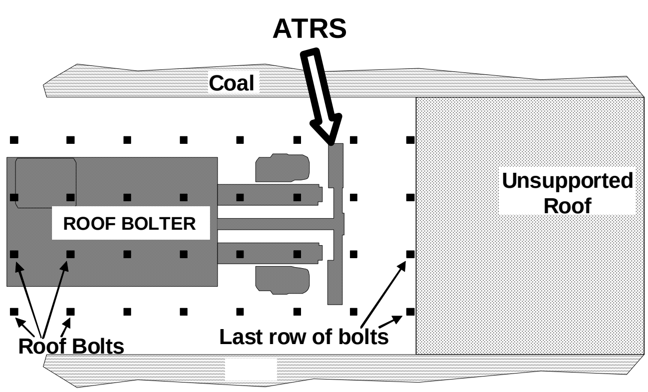

Figure 6b. Position of roof bolter after backing up so the next screen panel can be positioned on the ATRS.

to the two previous methods, except that the machine is not backed up to allow the screen panel to be fastened to ATRS. Instead a tool was made from an old fiberglass roof bolt with a hook fashioned on one end. The screen panel is brought up to the front of the bolter and laid on top of the personal canopy and the ATRS. The screen panel is held in position with this tool while machine is trammed into position for installation of the next row of bolts.

The operators then, using the tool, position the screen on the ATRS and raise the ATRS up against the roof where it holds the screen panel in position. This works well most of the time, but the screen can fall inby if the tool slips off of screen panel. When this happens, the operators are tempted to reach inby last row of permanent support to retrieve screen. This delays the setting of the ATRS and would expose the operator to unsupported roof. In the author’s opinion, the time lost by backing the machine up to secure the screen panels is minimal, and under no circumstances is it recommended that the workers be exposed to unsupported roof

ERGONOMIC STUDIES OF SCREEN HANDLING TECHNIQUES

Using what was learned from observing various roof screen installation techniques in the field, NIOSH developed several combinations of rails or bars that could be easily retrofitted to existing bolting machines. The initial design was tested on a Roof Ranger II dual boom roof bolter loaned to NIOSH by J. H. Fletcher and Company and later on a full-scale wood mock-up of a outside-controlled bolting machine built by NIOSH at the Pittsburgh Research Lab. NIOSH ergonomists designed tests that would evaluate different techniques of lifting and carrying roof screen based on the relative risk of back injury. Each test subject was fitted with EMG (Electromyogram) monitors to measure major muscle activity in the arms and torso areas. The subjects also wore a Lumbar Motion Monitor (LMM) which looks and acts like a spinal column and is worn as if it were a back pack attached at the shoulders and waist (figure 7). These instruments are capable of measuring trunk position, velocity, and acceleration in the sagittal, lateral, and twist planes of the body (Kotowski et al., 2006).

The initial design consisted of a pair of rails that ran from the back of the roof bolter and ended just before the canopy (figure 8). The first set of tests was conducted using eight subjects. Test subjects picked up the screen from the back of the bolter and either slid the screen on the rails (RAIL-condition) or lifted the screen manually (CARRY-condition) up to the ATRS.

The RAIL-condition required an initial lift to get the screen on the rails and another smaller lift to get the screen over the canopies once the rails ended. Sliding the roof screen on the rails was found to significantly reduce the muscular demands of the back and forearms compared to carrying the screen. In addition, it was found that the test subjects flexed their spines to a greater degree in the morning compared to later in the day, which suggests that there might be an increased risk of injury when handling screen in the morning. However, the rail system used in the first study was thought to be in need of improvement due to the fact that the screen still had to be lifted over the canopies as the end of the rails was reached. It was thought that the rails could be extended so that the screen could be slid from the rear of the bolter all the way up to the ATRS. The rail system was modified and a second set of tests was performed.

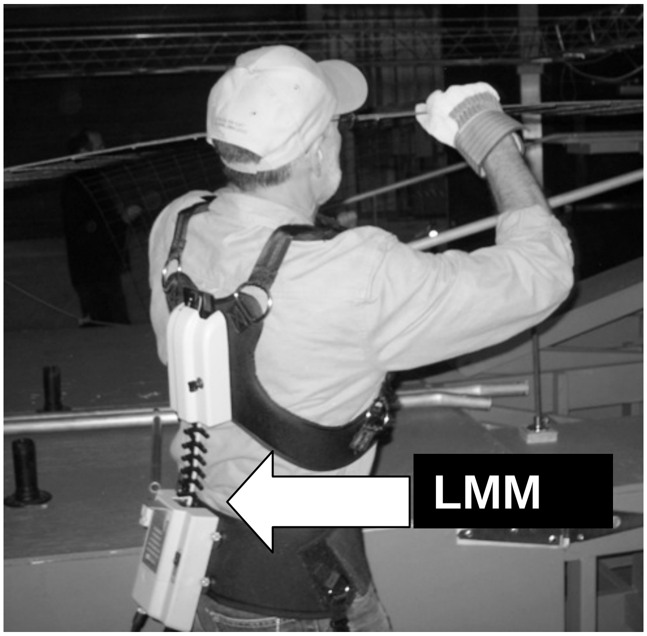

Figure 7. Test subject fitted with Lumbar Motion Monitor (LMM).

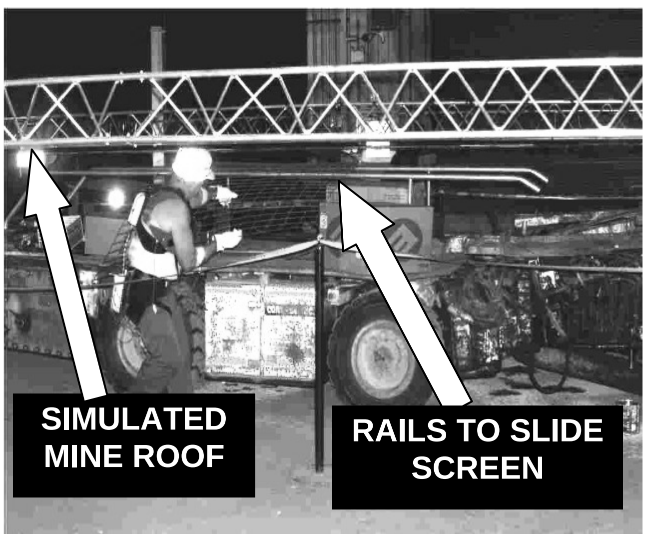

Figure 8. Test subjects sliding screen on rails in first experiment.

The second set of tests also involved eight male subjects. These subjects had underground experience ranging from actual underground bolting experience to men who have only been underground a few times. A full-scale wood roof bolter mock-up was fitted with a system of rails that facilitated sliding the roof screen from the back of the bolter over the canopies and all the way to the ATRS (figure 9).

The tests involved lifting and transporting eight full sheets of roof screen up to the ATRS to simulate the requirements for screening a typical cut. Three methods of screen storage/installation were examined. These included: 1) lifting the screen from the ground behind the bolter and manually carrying it to ATRS (i.e. rails uninstalled), 2) lifting the screen from the ground and sliding it on the rails up to the ATRS, and 3) with

Figure 9. Full scale wooden mockup of bolter with rails that permit sliding of screen across canopies.

screens stored leaning against the rib, screens were lifted two at a time and stacked on the rails, and from this position the screens were slid using the rails to the ATRS. As in the previous tests, subjects wore the LMM to assess back motion and risk. The time it took to complete the installation of 8 sheets of screen was recorded.

Results of this study illustrated how slight differences in installation techniques can have a significant impact on the risk of injury to the lower back. The method of lifting the screen from behind the bolter and sliding it on the rails up to the ATRS required only 19 seconds to complete. However, this method was found to require significant torso flexion (>45 degrees of lumbar flexion) during the process of lifting the screen from the ground. The manual carrying condition also involved hazardous forward bending during the initial lift (again >45 degrees), but also took about 3 seconds per screen longer compared to sliding the screen on the rails. The two-step process of first stacking the screens on the rails and then sliding them one at a time to the ATRS took an average of only 8 seconds more per screen than the sliding condition. Even with the supply time included, the method avoided the risks associated with repeated full flexion of the torso required to lift the screen from the ground behind the bolter required by the other methods. Maximum forward bending for the latter technique averaged less than 25 degrees, which represents a considerable reduction in risk for back injury. If the roof screens are supplied onto the racks of the machine by supply personnel, then this method is not only less risky for the operators, it also becomes faster than having screen lying on the ground behind the machine.

Overall, several conclusions can be taken from these laboratory investigations. First, the data show that muscular demands are reduced when sliding roof screen on rails rather than manually carrying them. This reduced muscle activity indicates lower loading of the joints and muscles and a lower risk of repetitive trauma injury. Secondly, sliding screens on the rails was faster on average than manual carrying. Both of these findings strongly support the use of rails and/or racks to assist with screen installation. However, lifting screens from the ground when they are dragged behind the bolter requires a significant degree of forward bending which puts the spine at risk. This risk can be reduced if screens are stored against the rib and stacked/stored on the rails mounted on top of the machine.

RECENT MATERIAL HANDLING INNOVATIONS FOR OUTSIDE-CONTROL, DUAL BOOM ROOF BOLTERS

Roof bolter operators are arguably the hardest working persons in the mine. They are constantly lifting, bending, pulling and carrying materials they need to control the roof of the mine. Adding roof screen installation to this already labor intensive job increases the risk of stress and strain injury to the operators. Material handling injuries continue to sideline hundreds of underground workers each year. Lost time material handling accidents constituted 33.3% of all lost time accidents in underground mining between 2000 and 2004 according to the MSHA data base (www.msha.gov).

In 2000, J. H. Fletcher and Company introduced the walk through CHDDR roof bolter with a complete material handling system (MHS). The system consists of removable pods for bolter consumables, which are hoisted onto the bolter. The system also includes a mesh tray that loads and holds roof screen. The mesh tray can be moved in eight different directions so it can be moved out of the walkway while bolting and also position the roof screen for easier lifting during installation to help reduce fatigue. Remote control operation also improves visibility for the operator while tramming between cuts making it safer for everyone on the section (Robertson, et al., 2003).

J.H. Fletcher and Company now offers a slightly modified version of the MHS for the Roof Ranger II roof bolter. The system includes a similar pod system for consumables. The Roof Ranger II is designed to be used in seams of eight feet or less, so instead of a mesh tray, they have designed a Goal Post type of storage rack positioned along the center of the bolting machine to store roof screen (figure 10).

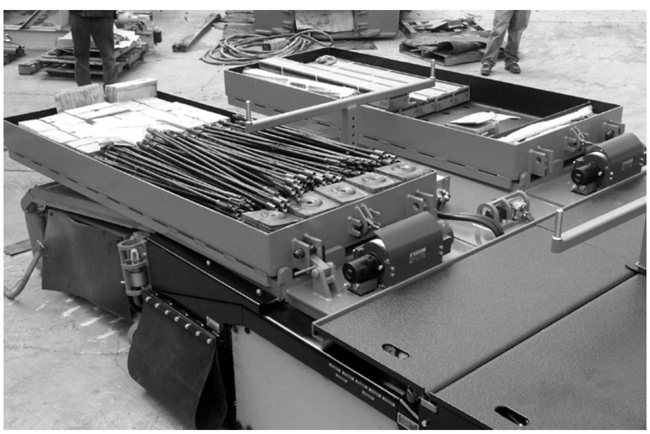

Figure 10. Roof Ranger II with Material Handling System (MHS).

The operator deck has been replaced by remote control operation. This allows the operator much greater visibility while tramming the machine and provides additional room on the deck for the material handling system (MHS). A tapered rear deck allows a roll off capability of pods. Pods are low profile to fit under a scoop ram. A powered winch loads the pods into position on the rear deck, the pods are then held in position with pins.

The machines are equipped with rounded edges on ATRS pads and flat tops on the canopies to ease screen positioning during installation. There are spring pins mounted on the ATRS outby deflector pads to hold screen in position until ATRS can be set. All of these modifications are meant to reduce some of the repetitive motions and awkward positions roof bolter operators encounter routinely while performing their jobs. Reducing the number of lost time injuries and transferring difficult tasks from the worker to the machine can also lead to higher job satisfaction and improved workforce morale.

THE ECONOMICS OF ROOF SCREENING

When the best available practices for screen installation are employed, together with simple modifications to the roof bolting machine, the impacts of screen installation on the overall mining cycle can be minimized. For example, Peabody's Francisco Mine, located near Evansville, IN, has routinely installed screen in about 50% of its drivage since it was opened in 2004. Francisco is also one of the nation's most productive room and pillar mines, with 67 underground employees producing nearly 1.2 million tons of clean coal per year, with a productivity of 6.6 tons/hour (MSHA, 2007).

Moreover, there are substantial potential economic benefits to the use of screen. The most valuable is the opportunity to reduce the cost associated with rock fall injuries. NIOSH studies have found that a "struck by rock" injury can easily cost in excess of one hundred thousand dollars, and a permanent disability could cost 1 million dollars. Because injuries are so expensive, workman's compensation costs for underground coal mines typically average 20% to 40% of payroll in the eastern U.S. Industry wide, rock falls account for about 10% of these costs, and at many mines the percentage is considerably higher.

A simple example shows how a program of screen installation can actually save a mine money. A key assumption is that roof bolting is not the bottleneck in the production process—in other words, that screen installation can be added without decreasing the footage of advance per shift. This situation is not unusual when two, double-boom roof bolters are used on a super section (as at Francisco). Some other assumptions:

- The section advances 400 ft/shift in a 5-ft thick coal seam.
- Straps, costing $8 per piece, are currently installed in all headings and crosscuts.
- Screen installation requires an additional 10 minutes per 40 ft of advance.
- Screen, costing $16 per piece, will replace the straps in 50% of the drivage.
- Labor cost (fully loaded) is $40/hr.

The incremental costs associated with the roof screening program can be calculated as follows:

- Cost of screen = $2/ft.
- Cost of labor to install screen = 0.25 minutes/ft two roof bolt operators = $0.33/ft.
- Cost of supplying screen to the section is approximately $0.10/ft.

The total cost for installing screen is therefore approximately $2.43/ft or $0.58/ton. If screen is installed in 50% of the drivage, the cost per ton for the mine drops to $0.29/ton. If this one-section mine produces one million tons annually, the yearly cost for the screen installation is $240,000. A single rock fall injury could cost more than that amount. Indeed, if the screen program succeeds in reducing workman's compensation premiums by just 25% at this mine, the savings could be sufficient to pay for the entire program.

In fact, the economic benefits of roof screening go well beyond a reduction in direct injury costs. An effective screening program that brings down the rate of rock fall injuries can also save money by:

- Reducing the costs associated with replacing injured workers,
- Reducing labor turnover and improving workforce morale,
- Reducing requirements for extra spot bolts to support loose roof, and,
- Reducing the costs associated with long-term clean-up and re-support.

CONCLUSIONS

Roof screen has the potential to prevent hundreds of injuries caused by the fall of small rocks between permanent roof supports. The ability of screen to cover all of the gaps between permanent supports makes it by far the most effective method for stopping the fall of these relatively small rocks. Simple modifications and installation procedures can substantially increase the efficiency of outside controlled dual boom roof bolting machines used to install roof screen. Supplying roof screen to racks/rails fitted on bolters or at least leaning screen against the rib instead of leaving it on the ground can significantly reduce the risk of a back or strain injury to roof bolter operators. Material handling systems that are available now on J. H. Fletcher & Co. roof bolters can greatly reduce the stress and strains associated with roof screen installation as well as reduce the time necessary to complete screen installation. Basic machine modifications, well planned supply methods, and using best practice installation techniques can minimize the economic effects of roof screen installation on a mine's overall mining cycle. Reducing the number of rock fall injuries at a mine will also have a very positive effect on the economics of a mine and it can improve the morale of the entire workforce.

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