BEST PRACTICES AND BOLTING MACHINE INNOVATIONS FOR ROOF SCREENING

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ABSTRACT

Rock falls in coal mines cause many injuries each year. Most of these injuries are not caused by major roof collapses, but from falls of smaller rocks from the immediate top or roof skin. Even though safety professionals and mine operators strive to reduce these types of injuries, there has not been a substantial decrease in the rock fall injury rate over the past decade. Various surface controls are used in mines to control the roof skin. One control that has proven to be very effective is roof screening. Roof screen effectively controls roof skin and provides a high roof surface coverage. Although many mines are reluctant to use screen for primary skin control because of the additional costs of time and materials, others are having great success at controlling both the costs and surface rock. In this study, injury data are presented that show a dramatic reduction in roof skin injuries when screening is used. Much of this success is due to the protection from falling rock that the operators receive from roof screen. Five case studies in which roof screen was used are presented along with the associated costs of materials, impact on bolting advance rates, and potential ergonomic risks. The effects of roof screening on skin control and safety are also included. Finally, this paper provides information about best practices and features of roof bolting machines that affect production and safety.

INTRODUCTION

Rock falls in coal mines cause serious injuries to miners every working day. From 1995 to 2001, an average of 650 reported injuries per year resulted from rock falls of coal mine roof. The majority of these injuries, about 99%, were not caused by a major roof collapse, but from falls of smaller rocks from the immediate roof where the average rock size was 76 x 46 x 10 cm (30 x 18 x 4 in) (Molinda, 2002). This type of rock fall, which does not extend more than one or two ft into the immediate roof, has also been termed skin fall. Most of the injuries caused by these skin falls happened under supported roof.

Even though the mining profession has become safer throughout the years, there was no significant decrease in skin fall injury rates from 1995 to 2000. Fortunately, there was a slight decrease in roof skin injury rates during the year 2001. Safety professionals and mine operators should continue to strive to reduce skin fall injuries.

One way to prevent these injuries is to better support the coal mine roof surface. The supports used to prevent skin falls are called surface controls. Greater use of surface controls has been found to maintain the integrity of the immediate roof, decrease the likelihood of an injury, and possibly reduce clean-up time due to less rock on the coal mine floor. Coal mines make use of various surface controls such as large roof bolt plates, steel straps, header boards, large bearing plates, and steel screen or mesh. Each control has its own application and effectiveness depending on the geology of the roof, moisture sensitivity of the rock, and the life of the entry in which it was installed. Some roof is of such poor quality that nothing short of full coverage will provide the correct protection.

The purpose of this investigation is to educate the mining industry about roof screening and the current related practices used today. Issues that prevent or support the use of roof screen as a skin support, routinely and on-cycle, will be addressed. Analyses of injury data pertaining to roof screening, along with a review of five case studies of roof screening, are included in this report. In addition, machine design innovations and a state-of-the-art roof bolting machine with a new material handling system (MHS) are discussed. Finally, a list of best practices for roof screening is provided.

Figure 1. Roof Screen effectively maintaining weak roof skin.

ROOF SCREENING: SKIN CONTROL

Figure 1 shows how roof screen can effectively control weak roof skin and support large pieces of rock. Unfortunately, roof screening is not a widely utilized skin control, especially when installed on-cycle. Only a handful of coal mines are routinely screening in the Eastern U.S. compared to a greater acceptance of screening in the Western and Central U.S.

A number of mines were visited to document their experience with controlling poor roof conditions and the methods used to control it. The immediate roof commonly consisted of clayshale, soapstone, or highly laminated shale; clay veins, slickensides, and/or potting were problematic. Roof surface fell immediately during mining or soon after between bolts because of three primary factors: weak rock, horizontal stress, and weathering. Partial surface controls such as pizza pans, roof straps, or Monster[1] Mats™ did not provide the protection desired by the mine operators. To achieve such protection, the mines began routinely implementing the use of roof screen.

An advantage of using roof screen over other supports is the large amount of roof coverage – close to 100% of the roof can be covered. A recent study conducted by the National Institute for Occupational Safety and Health (NIOSH) has shown that in a mine with 5.5-m (18-ft) entries, installing a 4.9 m x 15.2 cm (16 ft x 6 in) steel strap every 1.2 m (4 ft) of advance achieves an 11% roof coverage. However, if the mine used 4.0 x 1.5 m (13 x 5 ft) sheets of screen, it could achieve 72% coverage. Therefore, the use of roof screen would provide 61% more roof coverage (Molinda, 2002).

While some mines use plastic geogrid screen or chain-link fence as a screening material, most mines that routinely roof screen install steel wire sheets with a 10.2-cm (4-in) grid pattern. A smaller grid size can be used if rock flaking is a problem. These sheets can be ordered in many sizes depending on the coverage desired. Roof screen can also be ordered in different steel gauges, determined by the diameter of the wire, and each gauge of screen has a particular strength. These strengths along with the rock load height they support are shown in figure 2. The rock density used to calculate rock load height is 2,595 kg/m^3 (162 lb/ft^3). All the mines visited during this investigation, except for one, used 8-gauge steel sheets; these sheets can support 0.64 m (2.1 ft) of roof skin.

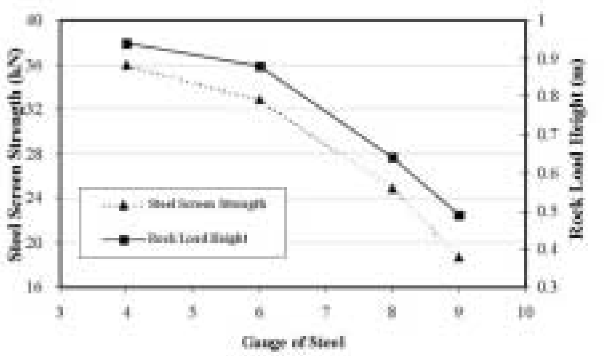

Figure 2. Different strengths and rock load heights for four steel gauges of screen (3).

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[1]Mention of any company name or product does not constitute endorsement by the National Institute for Occupational Safety and Health.

The deflection of roof screen varies depending on the rock load height, bolt spacing, and steel gauge of screen. A Canadian study determined that the center deflection of an 8-gauge sheet of screen installed on a 1.2-m (4-ft) bolting pattern with a rock load of 10.2 kN (2,300 lbs) or 0.3 m (1 ft) of rock was 16.0 cm (6.3 in). For a rock load of 20.4 kN (4,600 lbs), which is close to the strength limit for an 8-gauge sheet of screen, the average center deflection is about 25.4 cm (10 in) (Pakalnis, 1983).

Roof screen can be ordered with additional reinforcing wires – extra rows of wire – along the width and length of the screen in locations where roof bolts are installed. For example, a typical piece of screen is designed with a 10.2 x 10.2 cm (4 x 4 in) wire grid pattern. With reinforced screen, extra rows of wire are fabricated into the screen causing a 5.1 x 10.2 cm (2 x 4 in) grid pattern. This reinforced screen serves two purposes: it can prevent wires or welds from breaking around roof bolt plates and it provides a visual location where operators should install roof bolts. The latter helps operators to achieve the desired bolt spacing.

ROOF SCREENING: SAFETY AND ERGONOMICS

Rock fall injury data from four mines in the eastern U.S. were analyzed to determine the effect of screening on safety. A mine in northern Maryland had roof conditions that deteriorated to a point where roof screening was necessary everywhere. After screening was implemented, injuries dropped from an average of 14 to 2.2/yr (figure 3). At another mine in the Illinois basin, similar geologic circumstances were encountered that required roof screening. Injuries there subsequently dropped from an average of 8 to 0.25/yr (figure 4). Clearly, the use of screening dramatically reduced skin fall injuries at these mines.

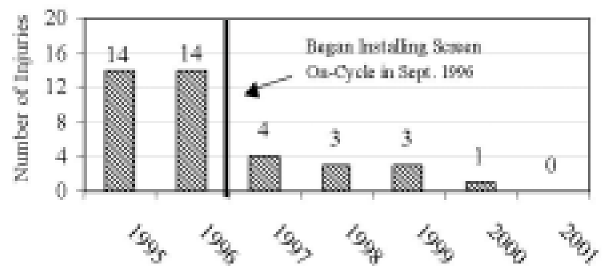

Figure 3. Number of skin fall injuries per year at a northern Maryland coal mine before and after the implementation of roof screening.

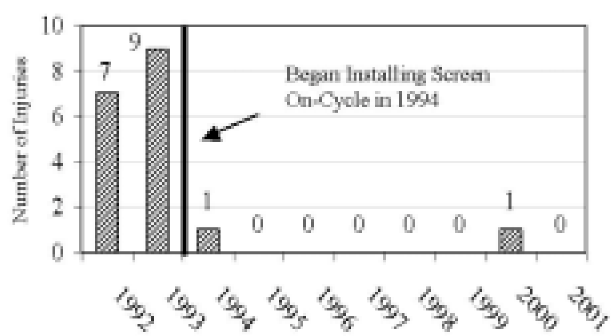

Figure 4. Number of skin fall injuries per year at a mine in the Illinois basin before and after the implementation of roof screening.

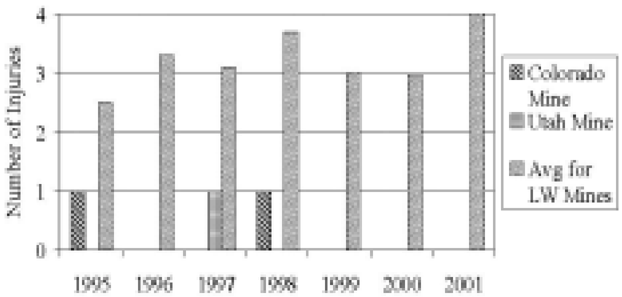

Figure 5. Number of skin fall injuries at two longwall mines in Colorado and Utah that routinely roof screen compared to all U.S. longwall coal mines.

Rock fall injury data from two longwall mines in the western U.S. that screen routinely were compared to data from all other longwall mines. These two mines commonly encountered poor geologic conditions. Figure 5 shows that the skin fall injuries at these two mines were lower each year compared to all other longwall mines. According to mine management at both of these mines, roof screening was the reason for such low injury rates.

One reason roof screening provides a reduction in injures is because roof screening protects roof bolter operators while drilling. During this drilling process, rocks often become dislodged from the roof due to disturbances caused by the drill itself. When roof screening occurs, the screen is placed against the roof when the Automatic Temporary Roof Support (ATRS) is raised before the drilling operations begin. Hence, immediate protection is provided to roof bolter operators from rock falls. A study conducted by the U.S. Bureau of Mines in 1993 has shown that the activity of drilling is the most hazardous job task performed by the bolter operator, accounting for 31.4% of all roof bolting injuries. Out of these drilling injuries, almost half (45.9%) were due to falling rocks or coal from the roof (Klishis, 1993). Therefore, to receive the full benefit of roof screening on injury reduction, roof screen should be installed, on-cycle, during normal bolting operations.

Even though roof screening has been shown to reduce skin fall injuries, a legitimate concern remains during screen installation that material handling injuries may increase due to increased handling of materials and supplies. Additional materials and bolts, used in conjunction with roof screen, offer a challenge for the roof bolter operator because most roof bolting machines are not designed to accommodate the sheets of screen. Also, operators contend with not having enough storage area to easily retrieve supplies.

In addition, screen handling is also a challenge for the operators. The hand-loading of roof screen onto the machine often occurs on uneven and muddy floor conditions. If the screen can not be stored on the rear of the bolting machine, it is hooked to the bolting machine by chain and pulled on the ground. Thus, operators must exit the machine to retrieve each piece of screen. Overhead lifts and awkward positioning, along with lifting, pulling, and twisting movements may have negative ergonomic consequences on operators.

Finally, a sheet of screen can be cumbersome for operators to handle. A 4.9 x 1.5 m (16 x 5 ft) sheet of 8-gauge steel weighs approximately 13.6 kg (30 lbs). Therefore, handling screen may increase the chance of musculoskeletal injuries such as sprains/strains. As many as 29.7% of all mining industry lost-time days (1997 to 1999, excluding fatalities) were from strain/sprain injuries of the back, knee, or shoulder. Also, 27% of all lost-time days were from material handling injuries (Sacks, 2000). Therefore, an increase or difficulty in material handling is a major concern for mine operators.

A final safety note: It is a good practice to order roof screen so that the edges of the screen are flush-cut with no wires protruding from the ends. These wires create a potential for cut and puncture injuries. Also, if the screen is not flush-cut, the wires get tangled, making it difficult to separate the sheets. This can lead to possible sprain/strain types of injuries.

ROOF SCREENING: MATERIAL COSTS

Material costs for roof screen is one barrier that inhibits mine operators from purchasing the material. The cost of the roof screen will vary depending on the size of the screen and the gauge of the steel. To assess these costs, NIOSH recently conducted a study comparing the use of steel straps and roof screen (Molinda, 2002). Roof straps were chosen because they are another surface control used to combat poor roof conditions. The cost of a 4.9 m x 15.2 cm (16 ft x 6 in) steel strap was $8.00, and the cost of a 4.0 x 1.5 m (13 x 5 ft) sheet of 8-gauge steel screen was $10.32. Assuming a 1.2-m (4-ft) advance for each, the material cost per 0.3 m (1 ft) of advance for steel straps was $2.00; the cost for steel screen was $2.58. It should be noted that this study did not include costs of the roof bolts and plates needed to install roof straps and screen.

For the above scenario in a 5.5 m (18-ft) wide entry, the roof coverage would be 11% for steel straps and 72% for screen. Roof screen provided a significant increase in roof coverage (61%) for only a $0.58 per 0.3 m (1 ft) increase in cost over the use of steel straps. Moreover, the spacing between straps is commonly decreased when bad roof is encountered. For example, if the spacing is decreased from 1.2 to 0.9 m (4 to 3 ft), the cost per 0.3 m (1 ft) of coverage would increase to $2.67. In this instance, the cost of using steel straps would actually exceed the cost of using steel screen, without providing significantly improved coverage.

ROOF SCREENING: BOLTING ADVANCE RATES

Another barrier to the widespread use of screen as a skin control installed on-cycle is the additional time and labor required to handle and install the material. Five in-mine studies to document the impact of screening on-cycle on bolting advance rates are presented below. For these studies, only activities that delayed the bolting advance rates were classified in terms of time to handle roof screen. For example, a scoop operator delivering screen to a mining cut does not slow down the process of bolting. However, the time taken by the roof bolt operators to load the screen onto the bolter and then handle these sheets does slow down bolting activity.

When considering these five cases, the reader should keep in mind that the following five factors influence the bolting advance rate and labor costs as well as safety when handling and installing screen:

1. Design of the bolting machine in relation to screen storage and maneuverability, positioning of the roof bolt operators, material handling innovations, and machine height.
2. Installation procedures for handling/installing screen and loading it onto the roof bolting machine.
3. Number of persons involved in handling screen.

4. The amount of training and experience the operators have in installing roof screen.
5. The amount of mining height available to handle screen.

<u>Case 1</u>

A mine in central West Virginia recently began roof screening because of difficulties with a weak claystone, weathering, clay veins, and potting. In general, the newly exposed roof skin shows little damage, but can be expected to deteriorate in 3 to 4 months after an area has been mined. This mine installs screen on the intake, belt, and track entries.

Two roof bolter operators and a helper install the screen. Operators utilize a twin boom bolting machine with mast feed that enables angle bolting. Mining height is 165 to 190 cm (65 to 75 in) and entries are 5.5 m (18 ft) wide. The miners install 8-gauge steel sheets of screen that are 4.0 m (13 ft) long and 1.5 m (5 ft) wide that are fabricated with flush-cut edges. The effective roof coverage is 72%.

The sequence of activities to handle and install the roof screen are the following: The scoop pulls up behind the bolting machine loaded with screen. The roof bolter helper and scoop operator then load approximately 10 sheets (enough for 1 or 2 mining cuts) onto the rear of the machine on top of bolting supplies. During this time, primary roof bolting operations and screen installation are not interrupted. Before a sheet of screen is installed, the ATRS is lowered and a drill steel is placed into the chuck to help control movement of the screen on the ATRS. Operators then lift and carry the sheets from the rear to the front of the machine, then onto the ATRS. Operators center the screen across the ATRS, maneuver into position for a slight overlap between sheets, and raise the ATRS. At this point, the screen handling time is completed unless the screen needs to be adjusted. Only screening activities that delayed the bolter operators from advancing were considered to be time delays. Therefore, no time delay was attributed to screen loading onto the rear of the machine because the bolter helper and scoop operator performed this task.

On two different occasions, a time study was performed observing the same roof bolter operators with the same bolting machine. The first investigation occurred 18 months before the second, when the roof conditions were poor. Roof conditions during the second study were fair to good. During the first study, it took an average of 1.72 mins to handle each sheet of screen. It took an average of 0.85 mins to handle each sheet of screen for the second investigation (table 1).

Table 1. Roof screen installation information including the number of persons involved, bolting machine type, and screen handling times for five case studies.

	Persons Installing	Bolting Machine	Load Time (min. per sheet)	Install Time (min. per sheet)	Total Handling Time (min. per sheet)
Case 1 Study 1/Study 2	3	Twin Boom with mast feet drill	0	1.72 / 0.85	**1.72 / 0.85**
Case 2	3	Walk-through (Centered) Rib bolter attached	0	0.42	**0.42**
Case 3	3	Walk-through (Centered)	0.40	0.50	**0.90**
Case 4	2	Walk-through (Off-Centered)	0.73	0.72	**1.45**
Case 5	2	Fletcher CHDDR walk-thru with MHS	0.16	0.68	**0.84**

During the latter study, operators installed screen twice as fast than in the previous study. This can be explained by a combination of two reasons. First, the operators had more practice and became more efficient with their installation procedures over the 18-month time interval. Also, during the first study, irregularities from the bad top made it difficult to raise the screen against the roof without the screen sliding. Even though the operators placed the screen over the top of the drill steels to control movement, the uneven roof caused the screen to tilt and shift. Therefore, operators repositioned the screen numerous times. The operators also bolted from the side of the machine, and reaching out from this location to reposition the screen was sometimes demanding. Additionally, the sheets were sometimes cumbersome to handle and involved lifting, pulling, reaching, and twisting motions. Occasionally, the edges of the sheets that hung off the back of the machine became damaged when tramming around corners, making it difficult for operators to pull the sheets apart.

In this case, the screen effectively controlled the roof. The timely use of screening minimized skin hazards in high-travel entries and reduced clean-up time. However, even with a three-person crew, the miners *struggled* with the installation procedures during the first study. This was partially due to the operators' inexperience with screen installation at this mine and the poor roof conditions. Practice and better roof conditions contributed to quicker installation times during the second study.

<u>Case 2</u>

A mine in the northern Maryland has been screening because of difficulties with clay shale roof, which is highly slickensided and brittle. It appears wet during visual inspection, but is actually glassy due to the extreme number of slickensides. Loose rock typically falls immediately upon mining and also spalls out because of mine humidity. Miner operators cut up to 76.2 cm (30 in) of drawrock and try to hold the rest with screen. They install screen mine-wide. Mine management claims that without the use of screening, mining would be very difficult due to increased clean-up time, higher risk of injury, and slower bolting advance rates.

Entries average 5.0 m (16.5 ft) wide and the mining height is close to 2.4 m (8 ft). Operators install 8-gauge steel sheets of screen that are 4.3 m (14 ft) long and 1.5 m (5 ft) wide. The effective roof coverage is 85%. The sheets extend to within 0.5 m (1.2 ft) from the rib after screen installation; some guttering occurs along the ribline. The sheets are fabricated with flush-cut edges. Two roof bolter operators and one bolter helper, also serving as a rib bolter, install the roof screen. In the mine's approved roof control plan, roof screening and rib bolting must occur on-cycle. The rib bolter operator installs two rib bolts for each advance and still has time to help the operators handle roof screen. The bolting machine is a walk-through bolter with a rib bolting machine retro-fitted onto the rear. Therefore, there is no storage space on the bolting machine for roof screen.

The sequence of activities to handle and install the roof screen are the following: The screen for each cut is placed and hung along the rib by the scoop operator and rib bolter operator. The rib bolter operator lifts the screen onto the machine from either the back or the side – during this study, he chose to carry the screen along side of the bolter. He then lifted the screen up to the roof bolt operators where they grab and pull the screen up and across the ATRS. Operators center the screen across the ATRS; maneuver into position for a six-inch, screen overlap; and then raise the ATRS. At this point, the screen handling operations are complete unless screen adjustments are required.

For this case, it takes an average of 0.42 minutes for roof bolt operators to handle and install each piece of screen per 1.2-m (4-ft) advance (table 1). Any adjustment of screen position is also included. The total bolting time per advance, including drilling, installing, maneuvering, setting the ATRS, and handling screen is 8.36 minutes. Screening time takes up only 5% of this total. Mine management feels that the benefit of superior roof coverage and a major safety improvement (figure 3) outweigh the cost of the additional time.

Some concerns are that the screen edges can get damaged when moved around by the scoop, making it difficult to pull apart the sheets. Also, the rib bolter operator chose to lift the screen up to the other operators while standing along the rib. This subjected him to a possible rib fall injury. Carrying the screen onto the bolter from the back of the bolting machine would decrease this risk. Whether lifting the screen from the side or the back, the screen must be lifted from the ground to an elevated or overhead position, which puts the person at risk of musculoskeletal injury.

Roof bolter operators at this mine have over six years of practice installing roof screen and are comfortable with the installation procedures. Operators do not have difficulty keeping the screen from sliding on the ATRS because of the position of the operator on the machine. While under support, one operator holds the screen in place from the center while the other raises the ATRS. This is an advantage of using a walk-through bolter. In Case 1, operators had difficulties holding the screen in place because of positioning in relation to the machine; they operate from the sides of the roof bolting machine.

Case 3

A longwall mine located in Colorado has been routinely roof screening, on-cycle, for over ten years. This mine has had great success in maintaining very low skin fall injury rates. From 1995 to 2002, there were just two injuries due to skin falls (figure 5). The immediate roof is 1.2 m (4 ft) of mudstone followed by 10.7 to 12.2 m (35 to 40 ft) of stack rock. Miner operators try to leave 0.5 m (1.5 ft) of head coal. When the roof is exposed, the mudstone slakes and the roof is difficult to maintain. Roof screen is the preferred surface control at this mine to maintain good roof conditions.

The mining height averages 3.0 m (10 ft). Entries are 5.0 m (16.5 ft) wide and the roof screen dimensions are 4.2 x 1.7 m (14 x 5.5 ft) for an effective roof coverage of 85%. The sheets are made with 9-gauge steel and fabricated with flush-cut edges. They are also reinforced with extra wires where roof bolts are installed. Two bolter operators and a bolter helper handle and install the roof screen. The bolting machine has a centered walkway which prevents screen storage on the machine. Instead, the sheets are hooked to the back of the roof bolting machine by chain and dragged to the bolting face.

The sequence of activities to handle and install each sheet of screen is the following: The bolting machine is trammed to an outby location where a bundle of roof screen is located. Operators then lay 4 to 6 sheets of screen on the ground behind the machine, then hook them up with a chain. The bolting machine is then trammed to the next location pulling the roof screen behind it. When ready for a sheet of screen, the ATRS is lowered and one bolter operator (the one who finishes installing his bolts first) exits the machine to retrieve a piece of the screen. This operator and the bolter helper lift and carry the screen onto the machine shown on figure 6. The other operator then grabs the screen and both bolter operators lift and place the screen across the ATRS. Next, the operators bend a set of heavy wires over the screen which prevents the screen from moving when the ATRS is raised. This wire assembly, which is a homemade machine innovation, is shown in figure 7. Once the ATRS is raised, the screen handling operations are complete.

Figure 6. Roof bolting operators handling roof screen on a walk-through bolting machine.

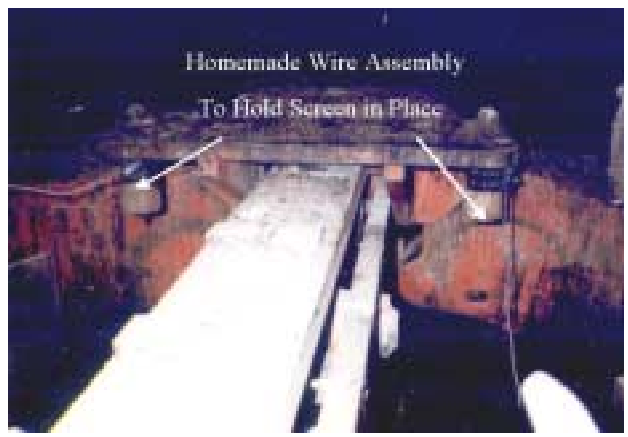

Figure 7. Wire assembly retrofitted onto an ATRS to control the movement of roof screen.

Once the bolting machine is trammed to where the bundle of screen is located, it takes about 0.40 minutes to hook up each sheet of screen behind the bolter. It then takes an average of 0.50 minutes to handle and install each sheet. This total time of 0.90 mins makes up 17% percent of the total bolting time for a 1.4-m (4.5-ft) advance as shown in table 1.

There are some safety concerns when dragging the roof screen behind the bolter. Operators must exit and enter the machine for each sheet of screen. When doing this, the bolting machine cable and the chain that hooks up the screen to the machine must sometimes be stepped over, creating a slipping or tripping hazard. Exiting, entering, and walking across the machine repeatedly will also induce fatigue. To combat this problem, NIOSH personnel recommend that anti-fatigue mats be fitted on top of the walkway. The mats are rubber cushions designed to more evenly distribute a person's weight on the foot. They provide a comfortable surface causing less fatigue in the feet and shins.

Similar to Case 2, roof screening at this mine has been proven to dramatically decrease roof skin injuries. It also effectively controls the roof surface. The reinforced screen helps to maintain the integrity of the screen and maintain correct bolt spacing. The positioning of the operators on the walk-thru bolter and the wire assembly on the ATRS help operators to better control movement of the roof screen. This mine has been screening for over 10 years and installation procedures have become routine. Installation time was not as low as in Case 2, 0.90 versus 0.42 mins per sheet, mainly due to the time spent loading and retrieving the screen. As in the previous cases, the screen can get damaged when tramming, especially when being dragged on the ground, making it difficult for operators to separate the sheets. Also, operators must lift the screen from ground level to an elevated position causing a potential for musculoskeletal injury.

Case 4

This mine, located in the Illinois basin, has a weak and laminated shale roof, and degrades from horizontal stress and weathering. The mine has found that steel screen helps maintain the integrity of the roof and dramatically reduced injuries due to rock falls from an average of 8 to 0.25/yr (figure 4).

Two bolting operators load and handle the roof screen. The bolting machine is a walk-thru bolter with a walkway off-centered to the right. The left-side rear compartment, used as a storage area for bolting supplies, is wider than the right side. It is wide enough for screen to be loaded on top of the bolting supplies. Most J.H. Fletcher and Co. walk-through bolting machines manufactured after 1995 have this off-centered, walk-through design.

The mining height ranges from 2.3 to 3.0 m (7.5 to 9 ft). Entries are 4.9 m (16 ft) wide and the dimensions of the screen are 4.5 x 1.5 m (15 x 5 ft). Roof screen extends to within 15.2 cm (6 in) from the rib for an effective roof coverage of 94%. The sheets are made with 8-gauge steel and fabricated with flush-cut edges. To avoid the screen wires from breaking or being cut by roof bolt plates, the mine installs 30.5 x 30.5 m (12 x 12 in) plywood boards between the roof bolt plates and the roof screen.

The sequence of activities to handle and install the roof screen is the following: The scoop operator places screen at an outby entry. Bolter operators back up the bolting machine to where the screen is located, then load enough sheets (5 to 7) to bolt the next cut. Before each sheet is installed, the ATRS is lowered and one bolter operator walks back to the screen location. Next, the operator lifts and pulls the screen towards the front of the bolter, swings the screen towards the other operator, and they then place it across the ATRS. One operator holds the screen in place from the middle of the machine, while the other raises the ATRS. At this point, the handling time is over unless the screen needs adjusted.

For this case, it takes an average of 0.73 mins to load each sheet onto the rear of the bolter. It then takes 0.72 mins to place the screen onto the ATRS, including any adjustment for sliding. The total time for handling screen is 1.45 mins per sheet (table 1). With the walk-through bolter, the sliding of screen is minimal because an operator is able to hold the screen in place. Case 4 differs from Cases 1, 2, and 3 in that only two operators are used to handle the screen instead of three.

Some safety concerns are noted with screening at this mine. Even though the left rear compartment on the bolting machine is large enough to stack sheets of screen, the screen still hangs off the ends and can get damaged while making a turn. Sometimes the screen gets caught on the bolting materials that are stored underneath. This makes it difficult for operators to remove the sheets from each other or from the supplies. In addition, it is strenuous to lift and pull the screen to the front of the bolter. The operator must lift the screen overhead and then twist before the other bolter handles the sheet. The screen must be lifted over the bolter canopies and on top of the ATRS. These actions increase the potential for musculoskeletal injury.

Case 5

Case 5 is from the same Illinois mine in Case 4, but in a different section. All the mining conditions are the same except that this section uses a Fletcher CHDDR walk-through bolter equipped with a material handling system (MHS) shown in figure 8. This state-of-the-art system has many machine innovations that reduce material handling and address ergonomic concerns. Some examples are a mechanized screen tray and detachable material pods (figure 8), a winch rope built onto the machine, and remote control operations.

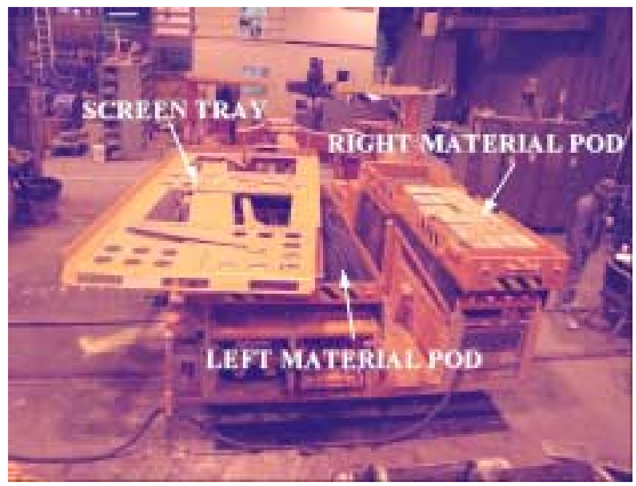

Figure 8. The J.H. Fletcher material handling system, featuring left and right material pods and roof screen tray.

The sequence of activities to handle and install the roof screen is the following: The scoop operator drops off a bundle of screen containing 25 sheets behind the bolter. A mechanized screen tray, located above the left material pod, is extended toward the rear of the machine by remote control operations. The front and rear lift cylinders decline the tray towards the mine floor. The tray is placed at a ramped angle making it easier to pull screen onto the tray. A winch, which is also operated remotely, is used to pull on the bundle. The screen tray can move in eight directions so that the bundle is pulled on straight. The tray is then secured in place with a pin and sleeve assembly and the winch attachment is then disconnected. Before tramming, the tray is lowered and moved toward the center of the machine. This protects the screen from being damaged. At the beginning of the next cut, the screen tray is raised to an ergonomically friendly elevation (around shoulder height) so that each sheet is pulled straight off without the operator having to lift the sheets. The screen is then handled and installed exactly as described in Case 4.

For this case, it takes a total of 3.9 mins to load a bundle of screen onto the tray, which is an average of 0.16 minutes per sheet. This does not include cutting off the metal straps on the bundle that secure the screen. It then takes 0.68 mins to handle each sheet of screen. The total time for handling and installing is

0.84 mins per sheet (table 1). Compared to Case 4, the time for installing the screen, once loaded onto the bolter, is almost the same. But because of the MHS, load times are lower by as much as 0.6 mins per screen. In addition to the saved time, the operators' exposure to ergonomic injury is significantly decreased.

The strain/stress is significantly reduced in handling screen because the operator can pull off the screen at a more comfortable level. Also, the screen has less chance of becoming damaged because the bundles are handled less and do not get damaged when turning corners. Roof bolters do not have to struggle to retrieve bolting materials because the screen tray is separate and elevated. Fatigue is reduced because operators do not hand-load the screen. During installation, the elevated tray minimizes lifting. Finally, the tray can also be positioned so that the screen does not cover the walkway, providing a clear exit off of the machine.

For this case, roof screening effectively controls the roof surface and has been proven to dramatically decrease roof skin injuries. The material handling system practically eliminates the hand-loading of screen and provides an easier method for screen handling, reducing ergonomic risks to the operators. The screen handling time was lower in Case 5 than in Case 4 from 1.45 to 0.84 mins per sheet. This is due to the quicker loading procedure of the screen using the MHS. At the same time, the handling time was slightly higher in Case 5 than in Case 2 from 0.42 to 0.84 mins per sheet, but only two roof bolter operators were used instead of three.

ADDITIONAL FEATURES OF THE MATERIAL HANDLING SYSTEM

The MHS has many additional features beyond those described above. Bolting supplies are not hand-loaded onto the bolter while underground, but are loaded outside into material pods (figure 8). These pods are then taken underground on supply cars. A larger left pod and smaller right pod contain supplies such as bolts, plates, cap board, and boxes. At the face area, material pods are pulled onto the bolting machine by a winch that is operated remotely. For roof bolter operators, the only hands-on activity is to hook up the winch rope to the material pods and operate the remote controls.

Time can be saved when loading bolting supplies with the MHS. To demonstrate, a comparison was made of operators loading supplies in Case 4 and Case 5. In Case 4, it takes 3 men approximately 13 minutes to hand-load a shift's worth of supplies onto the bolter. In Case 5, it takes 2 men about 6.0 minutes to load the left and right material pods onto the bolter, including the removal of the empty pods, based on accounts of bolter operators and mine personnel. Each pod contains a shift's worth of materials. Also in comparing Case 4 and 5, there is a significant decrease in exposure to injury due to the MHS. The risk of sprain/strain, slip/trip, crush, or cut type injury is reduced because trips made to the roof-bolting machine while hand-loading supplies are eliminated.

Material pods are easily pulled onto the scoop bucket because the pod height is low enough to be pulled under the scoop ram. Both the left and right pods can fit into the scoop bucket. The pods are pulled onto the bolting machine directly off the scoop. The machine has a rear lift system that places the rear bumper on the mine floor. This creates a ramp that allows the material pod to be pulled onto the machine. The pod is manufactured with guides on each side that run its full length and mate with the runners on the machine frame. These guides also secure one pod atop another for transportation into and out of the mine. The bottom of the pod is exposed to rollers on the frame which reduce the force required to pull the pod onto the machine. Once loaded, pins are placed through the pods and machine frame to keep the pod in place. These pods are loaded by remote control without the necessity of an operator being near the machine. These remote controls allow the operator better visibility because he has freedom to move around the machine.

Designed into the MHS are flat-top canopies and rounded ATRS edge pads. These features decrease the physical effort required to move the screen into place and reduce the likelihood of material snagging. There is a final safety feature for controlling the movement of screen: Clamps are built onto the ATRS which hold the screen in place while being raised. Once the ATRS is against the roof, these clamps retract.

BEST PRACTICES FOR ROOF SCREENING

In the course of this investigation, a list of best practices has been compiled to assist mines in attaining safe and efficient roof screening installation procedures. These suggestions or practices were obtained through underground observations, meetings with mine management, and working with equipment manufacturers.

1. Roof screen with flush-cut edges will help avoid material handling difficulties and lessen injury potential.
2. Roof screen that is fabricated with reinforcing wires can help sustain the integrity of the screen and aid in proper bolt spacing.
3. Sheets of plywood or matting can be installed between the roof bolt plate and screen to prevent the plates from cutting the screen wires.
4. Anti-fatigue mats, fitted on top of the bolting machine walkway, will provide a more comfortable surface, resulting in less fatigue on the feet and shins.
5. An ergonomic analysis of installation procedures will determine the safest and most efficient installation procedures (e.g., how many persons, best positioning, safest method).
6. Design or engineering innovations of bolting machines will aid with installation speed and material handling. Some examples are the following:

    $ Rounded edges on bolter canopy tops to reduce material snagging.
    $ Clamps or a wire assembly on ATRS to hold the screen in place.
    $ The use of a separate tray to better handle roof screen retrieve bolting supplies.
    $ Remote control operations, wines, material pods, or any other machine innovation that will eliminate or reduce material handling difficulties.

SUMMARY AND CONCLUSIONS

Roof screening has been found to be an effective method for controlling poor roof skin conditions. Compared to other skin controls installed on-cycle, roof screening provides the most coverage for the mine roof. Analyses thus far from mines using roof screen have shown that injuries from rock falls have been reduced dramatically. This may be due in part to the protection roof bolter operators receive during the hazardous drilling process. Increased acceptance of regular, on-cycle roof screening in adverse conditions should help reduce the number of skin fall injuries annually.

Time studies documenting the handling and installation of screen have been presented. Results show significant variation in the additional time necessary for screening; however, this reflects the experience and resources of the individual mine. A lower bolting advance rate is a barrier that can be reduced with time and practice. There is a concern, though, that injuries from handling screen may increase due to the additional materials, lifting, and awkward positioning.

The design of the roof bolting machine affects the costs of loading and handling screen times, manpower requirements, and ergonomic exposure to risks. Material handling design innovations will make roof screening safer and more efficient. The new state-of-the-art J.H. Fletcher materials handling system decreases material handling of roof screen and supplies. It also significantly reduces the risk of injury, screening time, and damaged materials. In particular to reduce skin fall injuries, mine operators should continue to seek and implement safer work practices and apply machine innovations to create a safer workplace for miners.

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