OVERVIEW OF COAL MINE GROUND CONTROL ISSUES IN THE ILLINOIS BASIN

G. M. Molinda, NIOSH, Pittsburgh, PA
C. Mark, NIOSH, Pittsburgh, PA
D. M. Pappas, NIOSH, Pittsburgh, PA
T. M. Klemetti, NIOSH, Pittsburgh, PA

Abstract

Some of the most difficult coal mine roof in the U.S. can be found in the Illinois Basin. Factors contributing to the high roof fall rate include: weak moisture-sensitive roof rock, high horizontal stress, and limited longwall mining. The depth of cover ranges from 90-1,000 ft and roof damage from horizontal stress can be severe. Moisture sensitive-roof rock is common above the Springfield-Harrisburg Herrin #5 and #6 seams in the Illinois Basin, and contributes to roof skin deterioration. The roof fall rate increases significantly in the humid summer months. The National Institute for Occupational Safety and Health (NIOSH) has shown, using lab and field studies, that highly moisture-sensitive roof rock can be directly correlated to poor roof conditions. Controlling the skin is the key to reducing rock fall injuries, and roof screening is, by far, the best remedy. Illinois Basin coal operators have been successful in reducing the number of rock fall injuries in recent years. NIOSH has documented best practices for screen installation which has resulted in safe, efficient operations. Other solutions to skin failure include: the use of denser five bolts per row patterns to reduce spans between bolts, systematic supplemental support in intersections, straps and large pans protecting operators, and air conditioning to remove moisture from the intake air.

Introduction

Rock fall injuries continue to present a significant hazard to U.S. coal miners. In addressing the problem, NIOSH has reviewed ground control issues contributing to this hazard. A number of these geotechnical issues are present in the Illinois Basin. The following overview will document the current state of coal mine ground control in the Illinois Basin, and the efforts operators have made to prevent rock fall injuries.

The Illinois Basin is a major coal-producing basin in the U.S., with over 95 million tons of coal mined in 2006 (MSHA, 2006). Ten million tons of coal were mined by longwall methods, 52 million tons were mined by room and pillar methods, and 33 million tons were surface mined. The basin includes Illinois, southwestern Indiana, and western Kentucky (Figure 1). More than 75 individual coal seams have been identified in the basin, of which 20 have been mined (Archer, 1975). The primary producing coal seams in the basin are middle Pennsylvanian in age, and are the Herrin #6 and the Springfield-Harrisburg #5. There are currently 30 underground coal mines operating in the basin (Figure 1). Twenty-seven of the mines are room and pillar operations and 3 are longwalls. (Two more longwalls mines are permitted but not yet operating). Annual production of the active mines ranges from 64,000 tons to over 7.2 million tons.

In 2005-2006 the Illinois Basin had a roof fall rate that was significantly higher than the other coal producing regions in the U.S. (Figure 2). One of the reasons for this is that the Illinois Basin has few longwall mines. Longwall mining has fewer roof falls than room and pillar mining, because there is far less entry development per ton of coal mined. The Illinois Basin has only 2 producing longwall mines (a third has not yet begun its first panel), and has only 15.6% of its production from longwall mining in 2005 and 2006 (MSHA, 2006). However, the lack of longwall mining cannot explain all of the increased roof fall rate. The southern Appalachian Basin has a similar proportion of longwall mining (15.0%), and yet its roof fall rate is 35% lower than that of the Illinois Basin. There may be two other reasons for the high roof fall rate in the Illinois Basin: (1) A strong biaxial horizontal stress field, and (2) weak, highly moisture-sensitive roof rocks.

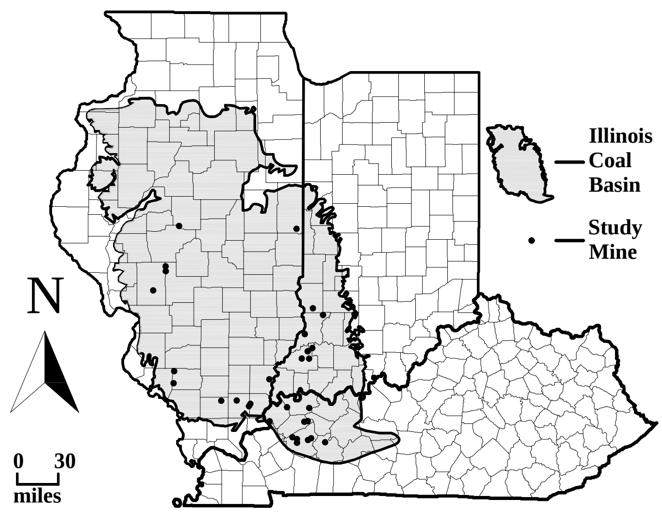

Figure 1. Underground mines in the Illinois Basin (2007).

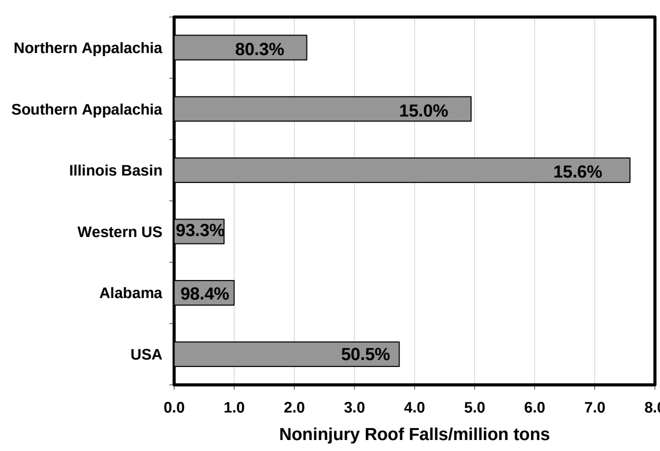

Figure 2. Roof fall rates in selected coal basins in the U.S. (2005-2006).

High regional horizontal stresses in Illinois, and the damage resulting from them, have been both measured and documented by underground observation and mapping (Mark et al., 2004; Mark and Mucho, 1994; Ingram and Molinda, 1988; Nelson and Bauer, 1987). The Wabash mine in southeastern Illinois (now closed) had hundreds of long, running roof falls. Entries oriented north-south had severe damage since the regional stress field is approximately N 80° E. In order to minimize the damage caused to entries oriented perpendicular to the regional stress direction, the mine turned its development 45° to the nearly E-W stress field. Roof conditions improved as a result of the reorientation.

Weak roof rocks are easily damaged by high stresses. Rusnak and Mark (2000) have documented the relative weakness of Illinois Basin mudrocks (clay-rich rocks) compared to similar rock types from the Appalachian Basin. There is also abundant evidence that roof sequences respond to changes in seasonal humidity, and that some mudrocks deteriorate when exposed to moisture. Data from the NIOSH roof rock moisture-sensitivity database shows a higher average moisture-sensitivity of roof rocks in the Illinois Basin than in roof rocks from the northern and southern Appalachian Basins (Figure 3). NIOSH has tested over 840 rock samples for moisture sensitivity. A wet/dry cycling test was used to determine moisture sensitivity. The index value representing moisture-sensitivity ranges from 0-100 %, with 100% indicating total disintegration of the sample (Molinda et al., 2006; Unrug, 1997). Rocks which deteriorate on contact with water can generate high swelling pressures which can bulk the roof and result in roof falls (Molinda et al., 2006). The roof fall rate (roof falls per 100 employees) increases in the humid summer quarter in most coal regions in the U.S., but it is most pronounced in the Illinois Basin (Figure 4). During the summer quarter (July, August, September) the roof fall rate in the Illinois Basin was over double the rate of most other U.S. regions through the 2004-2006 period. In response to these difficult mining conditions Illinois Basin operators have adopted roof control methods aimed at improving safety during mining.

Overview of Ground Control Issues and Practices in the Illinois Basin

Roof Geology

NIOSH has been actively gathering ground control information in the Illinois Basin in an effort to understand and control difficult mining conditions. The following information was gathered from numerous mine visits, and discussions with MSHA District 8 and District 10 roof control specialists and mine operators.

Thirty active underground mines are operating in 4 coal seams in the basin. Eighteen mines are currently working in the Springfield-Harrisburg #5 seam and 10 mines work the Herrin #6 seam (Figure 5). These seams will hereafter be referred to as the #5 and #6 seams respectively. In Kentucky the #5 seam is equivalent to the #9 seam, and the #6 seam is equivalent to the #11 seam. Two other seams are being mined, with one mine in the Danville #7 and one mine working the deeper Kentucky # 6 seam (Davis).

Black shale commonly occurs as the immediate roof rock in 20 of 30 operating mines. In the #5 seam this rock is known as the Turner mine shale, and in the #6 seam it is called the Anna shale. The black shale ranges from 0-6 ft thick and averages about 24 in. In both seams the black shale can transition into a gray shale facies. The black shale is resistant to moisture deterioration and can protect the overlying grey shale, which is typically moisture-sensitive.

Limestone can be present in the roof of both the #5 and #6 coal seams, and can dictate the roof conditions and support practices. Sixteen of the 30 operating mines have limestone within the bolted horizon, and many select roof bolt lengths in order to obtain anchorage in the limestone. In mines operating in the #6 seam, 8 of 10 have limestone which can occur in the bolted horizon. In the #5 seam, 8 of 18 mines have limestone which can occur in the bolted horizon. In the #5 seam the limestone is the St. David limestone and in the #6 seam it is called the Brereton limestone.

Thick gray shale is also an important component in Illinois Basin roof rock. Called the Dykersburg shale when it is above the #5 seam, and the Energy shale when it overlies the #6 seam, it is typically weak and moisture-sensitive. Gray shale forms the immediate roof rock in 9 of 30 operating mines. Various other rock types occur in the immediate roof, including stackrock and fireclay.

Eleven of 26 reporting mines have faults on the property large enough to cause mining issues; either adverse roof or change in mine plans. The major faulting is concentrated in the southern part of the basin, with most of the mines in extreme southern Illinois and western Kentucky reporting some sizeable faults on their property.

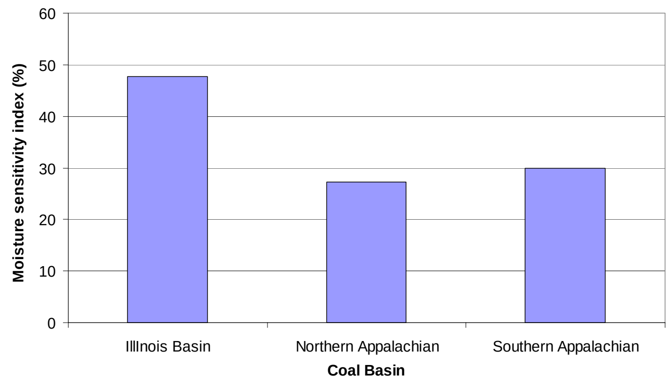

Figure 3. Average moisture sensitivity index of roof rocks in NIOSH database by basin.

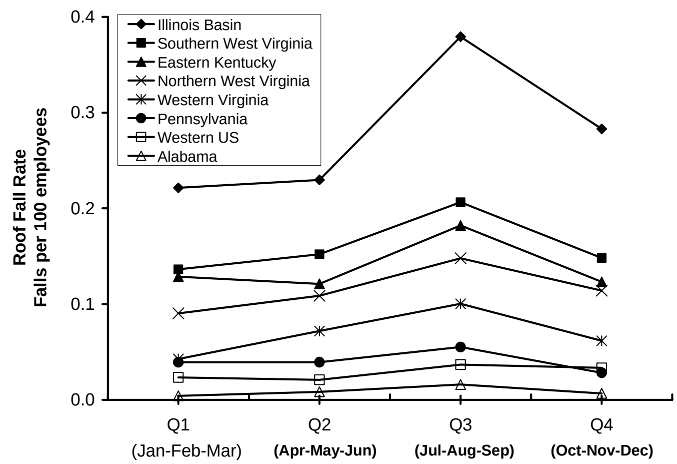

Figure 4. Seasonal roof fall rates for U.S. coal basins (2004-2006). The highest roof fall rates occur in the Illinois Basin during the summer months.

Moisture Sensitivity of Roof Rocks

Roof rocks which absorb humidity and swell can deteriorate over time causing skin control problems and roof falls (Molinda, 2006). Fourteen of 30 operating mines report problems with slaking roof. These problems range from thin skin flaking to chandeliered bolts to severe guttering requiring supplemental support (Figure 6). Roof falls in the Illinois Basin spike in August and September, indicating that high humidity in intake air plays a role in roof instability (Figure 4). NIOSH has tested roof rock for moisture-sensitivity and found extremely moisture-sensitive roof rock in a number of Illinois Basin mines (Table 1).

Table 1 shows a number of moisture sensitivity values over 40%. Mines which have roof rock moisture sensitivity values over 40% have had roof damage from slaking (Molinda, 2006). Typically, gray shales are much more sensitive to moisture than the black shale immediate roof. Where black shale is present it serves to seal the overlying moisture sensitive gray shale from moisture, preserving it. NIOSH has documented poor roof conditions directly related to the lack of a protective black shale layer. At one western Kentucky mine the immediate black shale roof was removed to increase the roof height. The exposed gray shale weathered quickly in contrast to the flat roof in the adjacent crosscut (Figure 7). Black shale provides a natural barrier to humidity exposure, but spray-on roof sealants have also been effective in stopping moisture infiltration (Molinda, 2007). In extreme cases, weathering around roof bolts can compromise roof bolts. "Ker-Thobs" or other tensioning devices are used to re-establish rock contact and restore plate loads (Figure 8). The Ker-Thob[2] is a pipe extension inserted between the loose roof bolt plate and the roof that allows re-establishment of roof/plate contact.

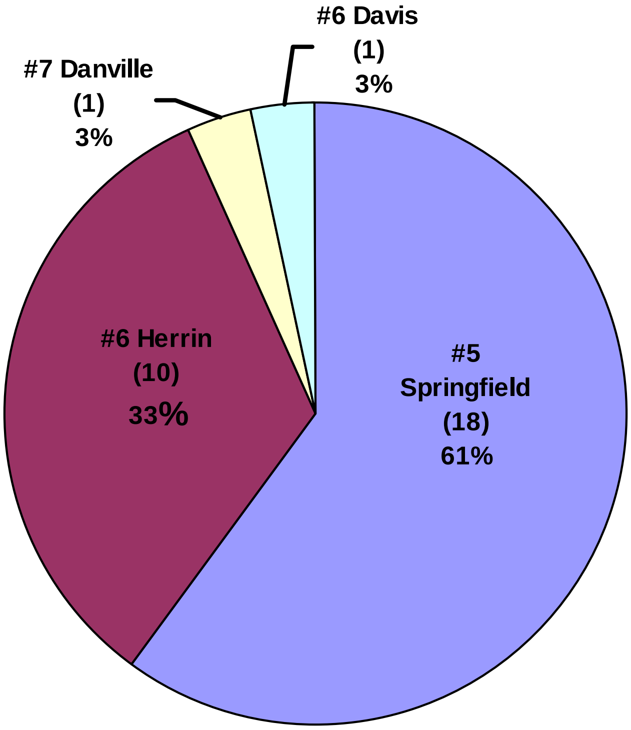

Figure 5. Underground coal mining by seam in the Illinois Basin (2007).

Figure 6. Roof fall in moisture-sensitive roof.

An Illinois mine in the #6 seam used air conditioning as a novel remedy for extreme weathering. In addition to causing injuries, extensive seasonal deterioration of weak clay shale around bolts was blocking airways, and required extensive cleanup. The mine installed surface air conditioners to cool the humid summer air to within 4 degrees of the ambient mine air. This effectively reduced roof slaking. Additionally, a cost analysis showed that the reduced cost of cleanup and resuport would be enough to pay for the cost of the air conditioning (Laswell, 1999).

Table 1. Moisture-sensitivity of roof rocks for selected mines in the Illinois Basin.

Mine	Sample #	Rock Type[1]		Moisture Sensitivity Index % (Avg.)	
A	AQW-1	Gray shale (124)		63.8	
	W-702	Gray shale (124)		1.2	
	W-709	Gray shale (328)		19.3	
	W-715	Gray shale (333)		28.3	
B	W-497	Gray shale (124)		73.3	
	W-510	Gray shale (124)		65.3	
	W-517		Black shale (114)		8.3
C	W-465	Gray shale (124)		73.6	
	W-469		Black shale (112)		27.7
	W-483	Gray shale (124)		78.3	
D	W-305	Gray shale (127)		32.7	
	W-312	Gray shale (127)		73.9	
E	GW-1	Gray shale (124)		48.8	
F	VG-1	Gray shale (122)		96.3	
G	W-321	Gray shale (137)		100.0	
	W-327		Black shale (114)		84.5
	W-336		Black shale (112)		5.6
H	W-345	Gray shale (124)		18.6	
	W-354	Gray shale (324)		20.6	
	W-364	Gray shale (324)		33.5	
	W-374	Gray shale (324)		49.0	
Average				51.6	31.5

[1]The number in parentheses refers to the "Ferm" rock classification number (Ferm, 1981).

Horizontal Stress

A strongly biaxial regional horizontal stress field is currently acting upon coal mine roof in the Illinois Basin. Maximum horizontal stresses ranging from 1,207 to 3,191 psi and oriented from N73°E to N86°E have been measured, using a variety of methods (Ingram and Molinda, 1988). As a result, significant roof damage in the form of N-S oriented falls and cutter roof has occurred. Eight of 29 mines reported moderate to severe roof damage, including guttering, kink zones, and running falls (Figure 9). The depth of cover for mines currently operating in the Illinois Basin ranges from 90-1,000 ft (Figure 10). Seventeen of 30 mines operate under shallow-moderate cover between 200 and 400 ft, and four mines have 800-1,000 ft of cover. Three of 4 mines working in cover 800-1000 ft have moderate-severe

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[2]Reference to company name or product does not imply endorsement by the National Institute for Occupational Safety and Health.

roof damage from horizontal stress. Stress damage is not just related to cover. Two mines with cover of 90-200 ft also have cutter roof and horizontal stress damage. At the deepest part of the basin in Wayne Co., Illinois, the #5 seam will be under 1,200 ft of cover.

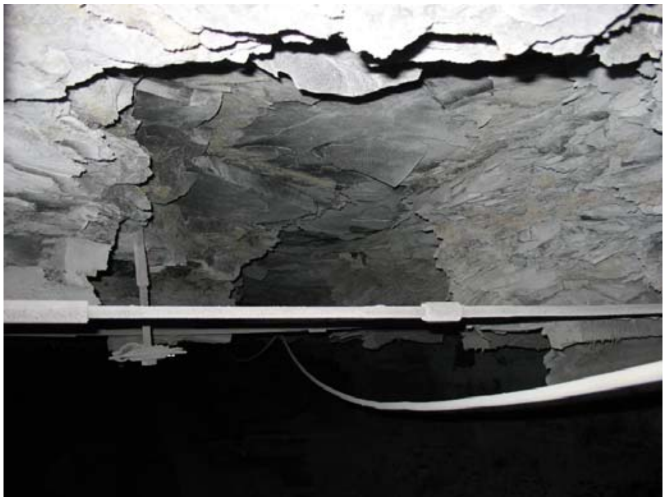

Figure 7. Gray shale weathers badly after protective black shale in removed.

Figure 8. A "Ker-Thob" is used to re-establish plate contact with the roof and maintain roof bolt integrity.

Many times reorienting the mines to minimize drivage in the N-S direction has provided some relief. In other cases, roof rock is so weak that even minimum stress magnitudes are enough to cause roof damage (Mark et al., 2004).

Roof Support

Primary roof support in the Illinois Basin varies with the mine and roof condition. Of the 30 mines, 14 use a fully grouted bolt system. Completely encapsulating the bolt with resin locks in the strata from horizontal movement, keeps excessive loads off the plate, and prevents humidity from entering the bolt hole. In very weak strata with high horizontal stress, fully grouting a bolt can be very important.

Tensioned roof bolt systems were used in 16 of the 30 mines. Three of these mines were using conventional roof bolts, and the rest were using resin. When the tensioned bolts function by suspending the shale from the nearby limestone, their length is determined by the bolter who may carry as many as 4 different bolt lengths depending on the limestone location. Often the goal in limestone roof is to achieve at least one foot of anchorage in the strong limestone. If the limestone was thin or absent, a longer bolt was used for beam building. In many cases shorter or lighter support was used in panels (4 ft fully grouted bolts was typical) with longer bolts or tensioned systems used in mains. Only 4 mines mixed bolt lengths in a row of bolts.

Figure 9. Severe guttering due to horizontal stress.

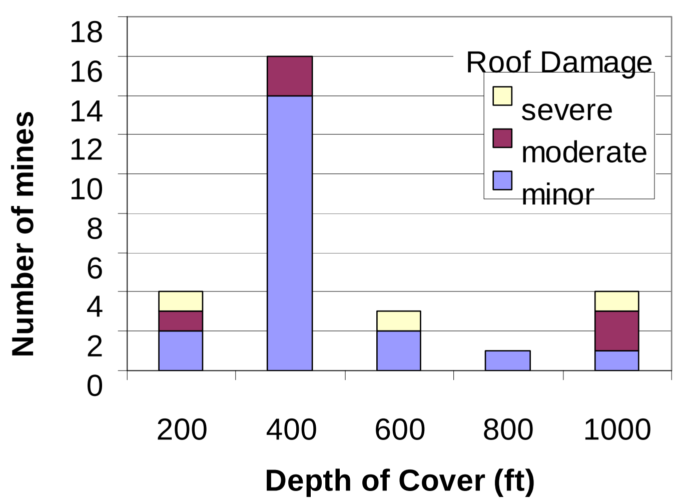

Figure 10. Distribution of Illinois Basin mines by depth of cover (bars include mines at all depths between that bar and the previous bar).

The predominant roof bolt row pattern employed 4 bolts per row. Five mines out of 30 used 5 bolts across in a row. In looking at 2006 data, mines using a 5 bolt pattern had a slightly lower roof fall rate than mines using 4 bolts across (Figure 11). In addition to building a stronger beam, the 5 bolt pattern has value in reducing the span between bolts, particularly in very weak rock. One mine in Illinois also uses a 4 ft "cutter" bolt in the corners on the same row or staggered between rows. This bolt is designed to support highly stressed corners and prevent the propagation of cutter roof, in addition to supporting roof screen close to the rib.

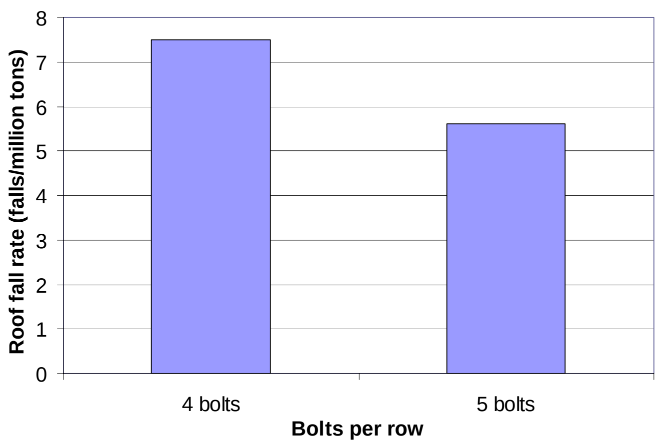

Figure 11. The effect of roof bolt pattern on the roof fall rate for Illinois Basin mines (2005-2006).

In the Illinois Basin an estimated 75-80% of roof falls occur in intersections. In response, 13 of 30 mines install systematic supplemental support to reinforce intersections. Systematic support is usually installed in mains and at the panel mouths. Intersection support includes cable bolts, longer double lock bolts, mega bolts, trusses, and timbers. There is some variation in cable bolt patterns and number of bolts used in the intersections. An "X" pattern consisting of 5 bolts with one center bolt is used. A variation on this pattern is the "diamond pattern" which is a rotated "X" pattern. A "box in box" pattern consisting of 4 corner bolts with an inside pattern of 4 more corner bolts is used by several mines. While not installing systematic intersection supplemental support, a number of mines would install intersection support "triggered" by absent limestone. In these cases, when the limestone thickness is insufficient for roof bolt anchorage, the roof control plan calls for the installation of supplemental support.

Surface Control

Illinois Basin operators have responded to moisture-sensitive roof rock with increased skin control. A number of mines use straps and large pans to increase surface coverage.

Ten Illinois Basin mines currently use welded steel screen in a systematic application to control sloughing roof and prevent rock fall injuries. With limestone present above, the contact between the limestone and underlying shale unit is sharp. The underlying black shale can separate and fall away with time. An 8 gauge screen is capable of holding 12-24 inches of scale which would otherwise be on the floor (Figure 12). The alternative would be to take down the draw rock which could result in increased waste product.

Typically mines that use screen will install it in the belt, travelway, one of the intakes, and one of the return entries. By installing screen in a total of four entries and in the crosscuts between the belt and travelway, these mines can cover approximately 50% of the total exposed roof in a typical 7 to 9 entry development mining system. This systematic coverage is typically used only in mains or other long term entries. Only one longwall mine was screening the roof everywhere.

One of the major barriers to increased use of screen is seam height. It is difficult to handle screen in low seams. Twenty-eight percent of mines in the #5 seam (avg. seam height of 65 in) use screen systematically, while 50% of mines in the thicker #6 seam (avg. seam height is 75 in) install screen systematically. Several mines have documented a significant reduction in injuries coinciding with the onset of systematic roof screening (Figure 13).

Figure 12. Roof screen loaded with rock.

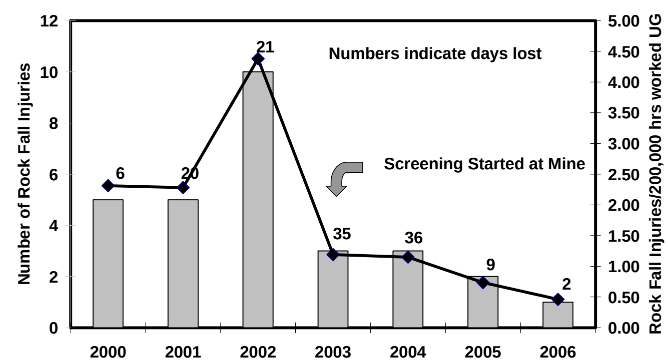

Figure 13. Reduction in rock fall injuries at an Indiana Mine after this introduction of on-cycle screening.

Several simple procedures can dramatically increase the safety and efficiency of screen installation (Compton et al., 2007):

1. To insure screen handling does not take place inby supported roof, after each row of bolts is installed the bolting machine should be backed up one row of bolts and safely located under supported roof.
2. Rails can be installed on top of either side of the roof bolter to facilitate screen handling. The screen is loaded onto the rails from the rear of the machine, and then slid up the machine over the ATRS and into place. This practice reduces snags on the machine and the potential for back injuries.
3. Screen storage racks can be installed on the bolter to provide easier handling and less damage to the screen.
4. Once the screen is in place on the ATRS it can be secured in place with wire ties. This insures correct location when the ATRS is raised to the roof and eliminates shifting of the screen.

Operators should be alert to several hazards that may occur during the screen installation. As the roof bolter is installing bolts and moving towards the face, it may become impossible to install the last screen without having extra screen hanging down from the roof. This screen would be torn up by the continuous miner as it advanced the next cut. As a result, some operators may finish bolting the place without installing the last screen. This leaves a gap in the roof coverage when screen installation is resumed after the next cut. Injuries have occurred from rock falling through this gap (Figure 14). It is better to double bolt the last row when starting to bolt and screen the next cut in order to anchor the next screen. This practice will ensure no screen gaps are left.

Figure 14. Gaps left in roof screen coverage have resulted in injuries.

The roof may break into very small pieces, depending on the composition and weathering characteristics of the roof rock. One mine had injuries from small pieces of rock falling between the 4 inch openings on a standard 8 gauge screen. They went to a screen with 3 inch openings to solve the problem. Corners are always an area of concern because screens typically do not extend to the rib. One mine in Illinois typically extends screen all the way to the rib. They use an extra 4 ft angled, conventional bolt to fasten the screen at the rib line. In places where the room is cut a little wide and the screen does not reach the rib, the corner cuts and gutters several feet above the corner. This gutter has lead to time-dependant roof falls. At this mine roof screen is now installed around the roof corner and about half way down the rib. Where this rib screening has been installed, the corner stays intact. The condition of the returns and travelways has dramatically improved due to rib and corner screening. In this case, not only does the screen function as a surface control, but it also prevents roof falls that occur with time. Short channel extensions can also be used on the last bolt in the row to support wider screens reaching closer to the rib.

One operator experimented with installing a lighter gauge wire screen (10 gauge) in order to save money. The wire itself was strong enough but the screen failed at the welds. NIOSH is currently conducting tests on screen products in order to determine the limits of rock load that can be carried. One mine uses a screen handling system on a roof bolter with inside controls and a central walkway (Fletcher walk thru bolter). The walkway keeps bolters away from dangerous ribs. The handling system includes a winch to pull a screen bundle onto a lift which raises the screen in place. The system reduces material handling injuries. The walk thru bolter also protects operators from rib, brow, or cutter falls where screen does not reach the rib. Two other Illinois Basin mines currently use walk thru roof bolters without the material handling system. Unfortunately, many of the operators cited low mining height as a barrier to using walk thru bolters.

While additional steel products installed on the roof will add to support costs, data compiled by NIOSH show that the additional cost of installing screen could easily be overtaken by the cost of a single rock fall injury (Compton, 2007). Further savings can be realized from the use of steel screen. Since workman's compensation premiums are directly tied to accident rates, a reduction in premiums can be realized by a reduction in rock fall accidents (Bhatt, 2007). Another perceived barrier to screen installation is the additional time requirement. Many super sections today have plenty of roof bolter capacity to make up for the additional installation time.

Data from U.S. longwalls shows that mines that use roof screen can also be very productive, as well as being safer (Figure 15). At numerous safe and productive longwall mines, screen installation has not impeded development or negatively effected production.

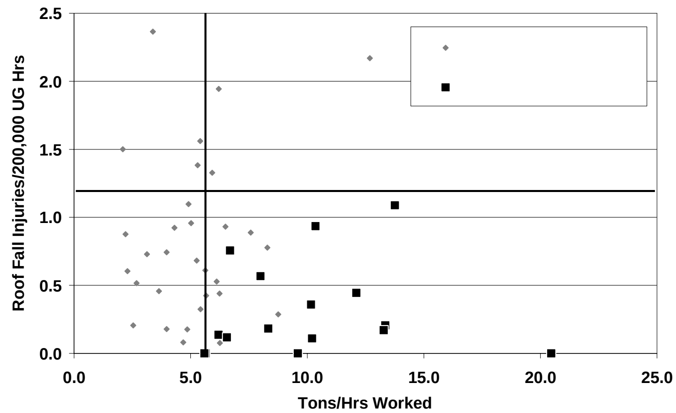

Figure 15. Safety and productivity in U.S. longwall mines that use roof screen vs longwall mines that do not use roof screen (2003-2005).

Multiple Seam Interactions

Currently, 8 of 30 mines report multiple seam mining situations somewhere on the property. Seven of the 8 cases involve the #5 and #6 seams. There is only one case where ground interactions have been reported.

Retreat Mining

Although full retreat mining has been done in the past in the Illinois Basin, no mines report any current full retreat mining activity. A practice called perimeter mining was reported by several mines. This type of mining is primarily for increased recovery, but has also been used for stress control. Perimeter mining involves taking 40 ft cuts in the solid boundary on one side of a panel. No roof bolts are installed, but the opening seldom caves. Similar cuts are taken on the opposite solid boundary of the panel on the way out of the panel.

Summary

Coal mining in the Illinois Basin is making a comeback due to the rise of clean coal technologies and reduced reserves in the Appalachian Basin. However, difficult roof conditions resulting from horizontal stress and weak, moisture-sensitive coal rock have made safety a top priority for mine operators. NIOSH is currently conducting research into developing diagnostic tests which would accurately predict the onset of weak roof rock. A large number of roof rock samples have been tested for moisture sensitivity, and a database has been compiled. Some roof rocks from the Illinois Basin show extreme deterioration when exposed to moisture. Field observation of slaking roof confirms the value of rock testing, and provides a guideline for predicting future roof deterioration. The most difficult roof conditions are being managed by reorienting mine openings to minimize horizontal stress damage, and installing supplemental support in intersections. Surface control is the single most effective intervention in preventing rock fall injuries, especially when installed at the face. Mine operators in the Illinois Basin have been proactive in introducing wire screen and developing innovations which make the installation process efficient and productive. Injury reductions show the effectiveness of wire screen. Continued vigilance, and a willingness to adopt new technologies in controlling the roof will make Illinois Basin coal mines safer.

Disclaimer

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

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