# Overview of coal mine ground control issues in the Illinois Basin

**G.M. Molinda, C. Mark, D.M. Pappas and T.M. Klemetti**
Gerologist, mining engineer, civil engineer and mining engineer, respectively,
National Institute for Occupational Safety and Health (NIOSH), Pittsburgh, Pennsylvania

**Abstract**

*Some of the most difficult coal mine roof in the United States 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 27 to 300 m (90 to 1,000 ft), and roof damage from horizontal stress can be severe. Moisture-sensitive roof rock, which contributes to roof skin deterioration and roof fall, is common above the Springfield-Harrisburg Herrin #5 and #6 seams in the Illinois Basin. The roof fall rate increases significantly in the humid summer months. Using laboratory and field studies, the National Institute for Occupational Safety and Health (NIOSH) has shown 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/row patterns to reduce spans between bolts; systematic supplemental support in intersections; straps and large pans to protect 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 documents 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 United States, with more than 86 Mt (95 million st) of coal mined in 2006 (MSHA, 2006). Of this total, 9 Mt (10 million st) of coal were mined by longwall methods, 47 Mt (52 million st) were mined by room and pillar methods and 30 Mt (33 million st) were surface mined. The basin includes Illinois, southwestern Indiana and western Kentucky (Fig. 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, the Herrin #6 and the Springfield-Harrisburg #5, are middle Pennsylvanian in age. There are now 30 underground coal mines operating in the basin (Fig. 1). Twenty-seven of the mines are room and pillar operations and three are longwalls. (Two additional longwall mines are permitted but are not yet operating.) Annual production of the active mines ranges from 58 kt (64,000 st) to more than 6.5 Mt (7.2 million st).

In 2005-2006, the Illinois Basin had a roof fall rate that was significantly higher than other coal-producing regions in the United States (Fig. 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 two producing longwall mines (a third mine has not yet begun its first panel) and had only 15.6% of its production from longwall mining in 2005-2006 (MSHA, 2006). However, the lack of longwall mining cannot explain all of the increase in 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: A strong biaxial horizontal stress field and weak, highly moisture-sensitive roof rocks.

High regional horizontal stresses in Illinois, and the damage resulting from them, have been both measured and documented by underground observation and mapping (Nelson and Bauer, 1987; Ingram and Molinda, 1988; Mark and Mucho, 1994; Mark et al., 2004). The Wabash mine in southeastern Illinois

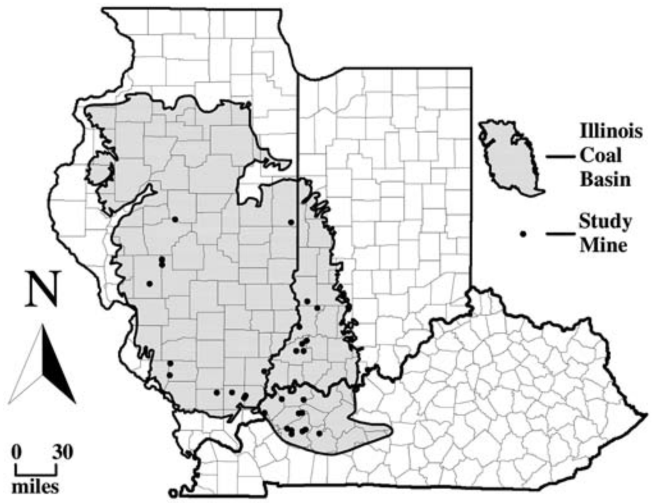


**Figure 1** — Underground mines in the Illinois Basin (2007).

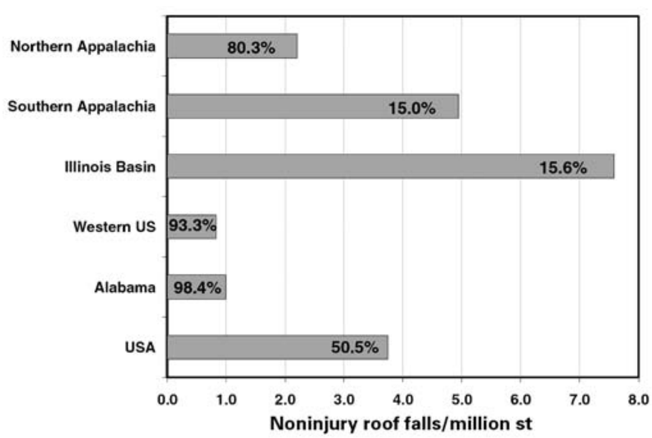


**Figure 2** — Roof-fall rates in selected coal basins in the United States (2005 through 2006).

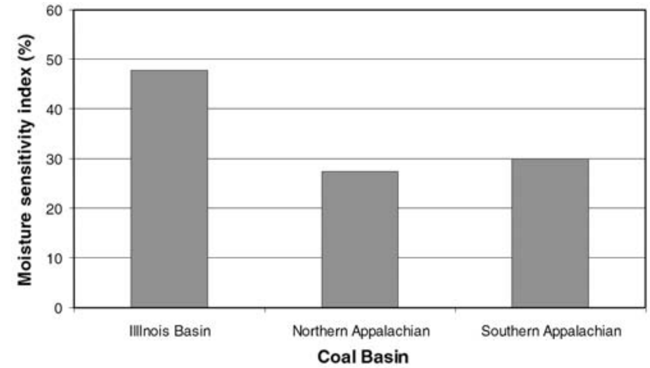


**Figure 3** — Average moisture sensitivity index of roof rocks in NIOSH database by basin.

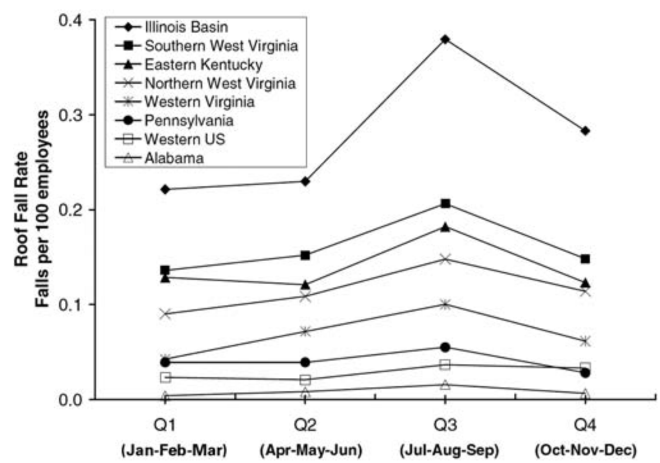


**Figure 4** — Seasonal roof fall rates for U.S. coal basins (2004 through 2006). The highest roof fall rates occur in the Illinois Basin during the summer months.

(now closed) had hundreds of long, running roof falls. Entries oriented north-south had severe damage because the regional stress field is approximately N80°E. 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) 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 (Fig. 3). NIOSH tested more than 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% to 100%, with 100% indicating total disintegration of the sample (Unrug, 1997; Molinda et al., 2006). Rocks that deteriorate on contact with water can generate high swelling pressures that 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 United States, but it is most pronounced in the Illinois Basin (Fig. 4). During the summer quarter (July, August and September) the roof fall rate in the Illinois Basin was more than double the rate of most other U.S. regions through the 2004-2006 period. In response to these difficult mining conditions, Illinois Basin operators 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 from

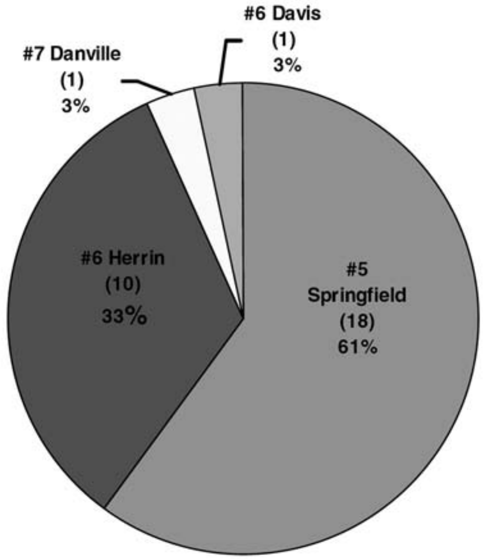


**Figure 5** — Underground coal mining by seam in the Illinois Basin (2007).

discussions with MSHA District 8 and District 10 roof control specialists and mine operators.

Thirty active underground mines are operating in four coal seams in the basin. Eighteen mines are currently working in the Springfield-Harrisburg #5 seam, and 10 mines work the Herrin #6 seam (Fig. 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 to 1.8 m (6 ft) thick and averages about 0.6 m (2 ft) thick. 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 gray 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, eight of 10 have limestone that can occur in the bolted horizon. In the #5 seam, eight of 18 mines have limestone that 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 nine 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 that are 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.

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

| Mine | Sample No. | Rock Type[1] | Moisture sensitivity index, % Gray shales | Black shales |
|---|---|---|---|---|
| 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] Numbers in parentheses refer to the "Ferm" rock classification number (Ferm, 1981).

**Moisture sensitivity of roof rocks.** Roof rocks that absorb humidity and swell can deteriorate over time causing skin control problems and roof falls (Molinda et al., 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 (Fig. 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 (Fig. 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 greater than 40%. Mines that have roof rock moisture sensitivity values greater than 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

**Figure 6** — Roof fall in moisture sensitive roof.

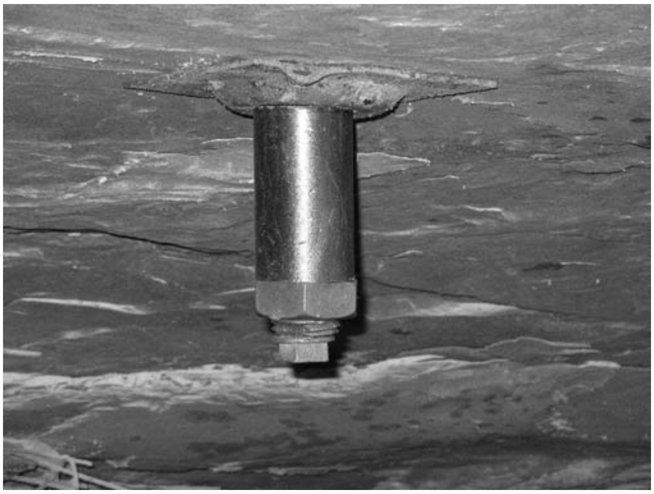

**Figure 8** — A "Ker-Thob" is used to reestablish plate contact with the roof and maintain roof bolt integrity.

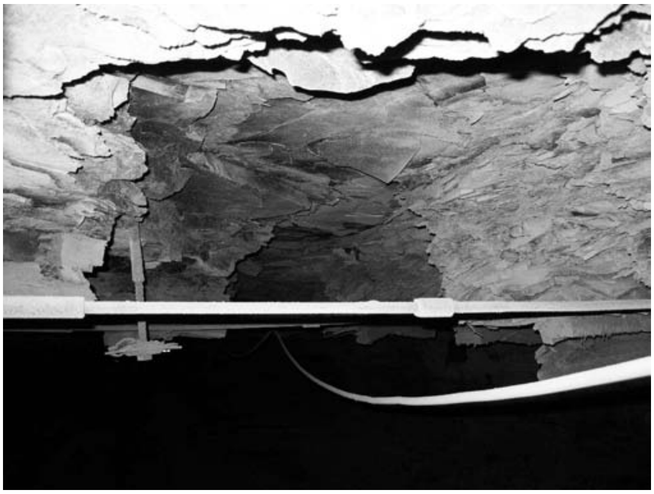

**Figure 7** — Gray shale weathers badly after protective black shale in removed.

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 (Fig. 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 reestablish rock contact and restore plate loads (Fig. 8). The Ker-Thob[1] is a pipe extension inserted between the loose roof bolt plate and the roof that allows reestablishment of roof/plate contact.

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 resupport would be enough to pay for the cost of the air conditioning (Laswell, 1999).

**Horizontal stress.** A strongly biaxial regional horizontal stress field is currently acting on coal mine roof in the Illinois Basin. Maximum horizontal stresses ranging from 8.32 to 22.00 MPa (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 (Fig. 9). The depth of cover for mines currently operating in the Illinois Basin ranges from 27 to 300 m (90 to 1,000 ft) (Fig. 10). Four mines have less than 60 m (200 ft) of cover. Seventeen of 30 mines operate under shallow-moderate cover between 60 and 120 m (200 and 400 ft), and four mines have 240 to 300 m (800 to 1,000 ft) of cover. Three of four mines working in 240 to 300 m (800 to 1000 ft) of cover have moderate-severe roof damage from horizontal stress. Stress damage is not just related to cover. Two mines with cover of 27 to 60 m (90 to 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 less than 365 m (1,200 ft) of cover.

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.

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

**Figure 9** — Severe guttering due to horizontal stress.

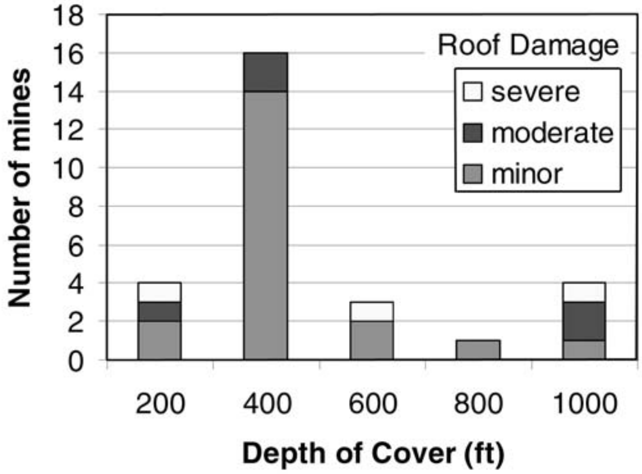


**Figure 10** — Distribution of Illinois Basin mines by depth of cover (bars include mines at all depths between that bar and the previous bar).

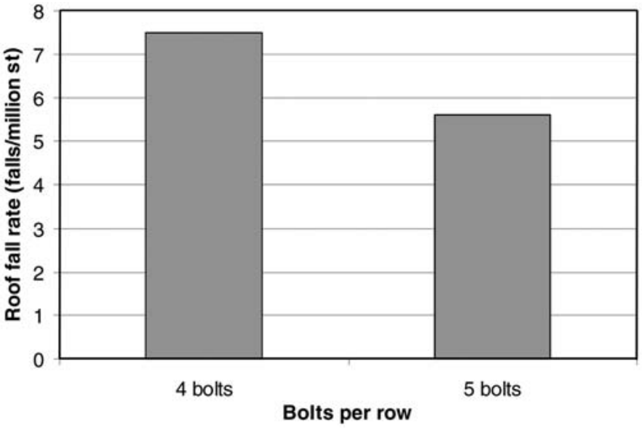


**Figure 11** — The effect of roof bolt pattern on the roof fall rate for Illinois Basin mines (2005 through 2006).

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 fully grouted 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 four different bolt lengths depending on the limestone location. Often the goal in limestone roof is to achieve at least 0.3 m (1 ft) 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 — 1.2 m (4 ft) fully grouted bolts was typical — with longer bolts or tensioned systems used in mains. Only four mines mixed bolt lengths in a row of bolts.

The predominant roof bolt row pattern employed four bolts per row. Five mines out of 30 used five bolts across in a row. In looking at 2006 data, mines using a five-bolt pattern had a slightly lower roof fall rate than mines using four bolts across (Fig. 11). In addition to building a stronger beam, the five-bolt pattern has value in reducing the span between bolts, particularly in very weak rock. One mine in Illinois also uses a 1.2-m (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.

In the Illinois Basin, an estimated 75% to 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 five 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 four corner bolts with an inside pattern of four 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 0.3 to 0.6 m (1 to 2 ft) of scale, which would otherwise be on the floor (Fig. 12). The alternative would be to take down the draw rock, which could result in increased waste product.

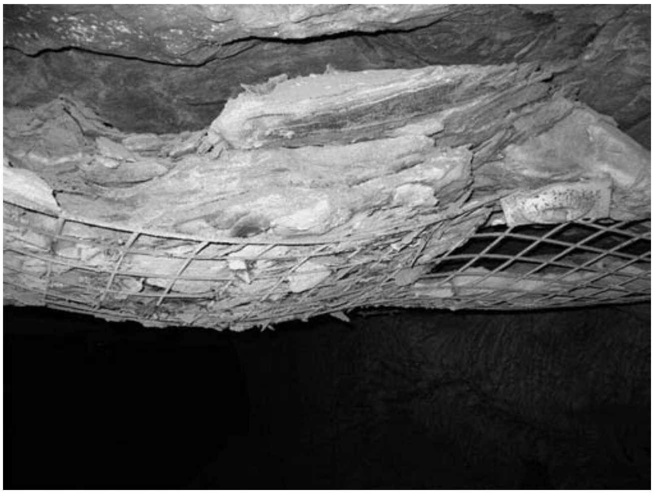

**Figure 12** — Roof screen loaded with rock.

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 seven to nine 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, with an average seam height of 1.65 m (65 in.), use screen systematically, while 50% of mines in the thicker #6 seam, with an average seam height of 1.9 m (75 in.), install screen systematically. Several mines have documented a significant reduction in injuries coinciding with the onset of systematic roof screening (Fig. 13).

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

- To insure that screen handling does not take place inby supported roof, after each row of bolts is installed, the bolting machine should be backed up by one row of bolts and located under supported roof. Then screen can safely be loaded on to the ATRS.
- 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.
- Screen storage racks can be installed on the bolter to provide easier handling and less damage to the screen.
- 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. The continuous miner would tear up this screen 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 (Fig. 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.

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 100 mm (4 in.) openings on a standard 8-gauge screen. They went to a screen with 75 mm (3 in.) 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 100 mm (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

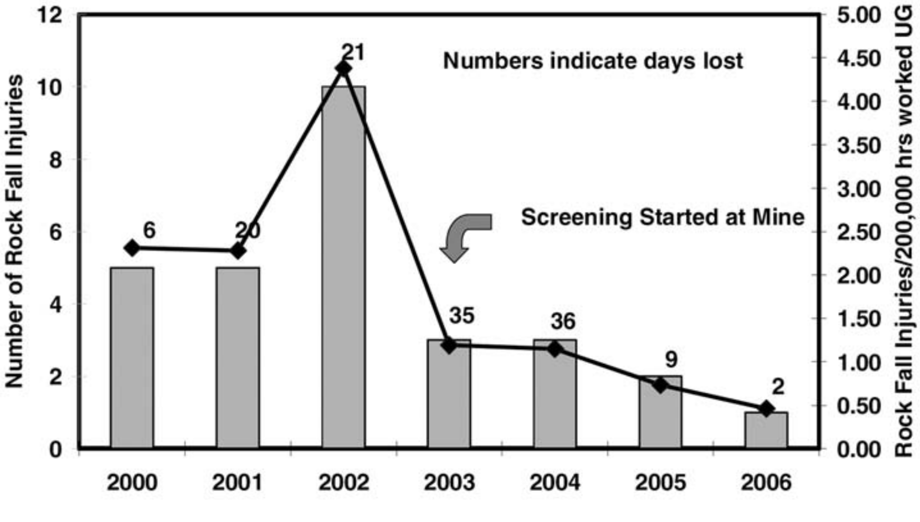


**Figure 13** — Reduction in rock fall injuries at an Indiana mine after this introduction of on-cycle screening.

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) to save money. The wire itself was strong enough, but the screen failed at the welds. NIOSH is currently conducting tests on screen products 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 that 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. Because 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 (Fig. 15). At numerous safe and productive longwall mines, screen installation has not impeded development or negatively effected production.

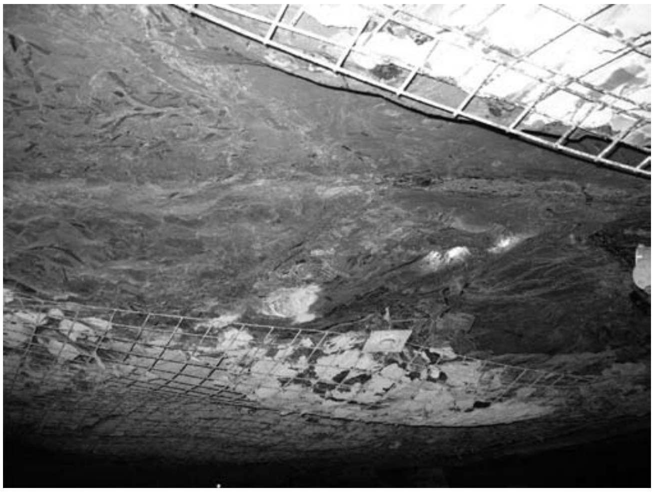

**Figure 14** — Gaps left in roof screen coverage have resulted in injuries.

**Multiple seam interactions.** Currently, eight of 30 mines report multiple seam mining situations somewhere on the property. Seven of the eight 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. Several mines reported a practice called perimeter mining. This type of mining is primarily for increased recovery, but has also been used for stress control. Perimeter mining involves taking 12 m (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.

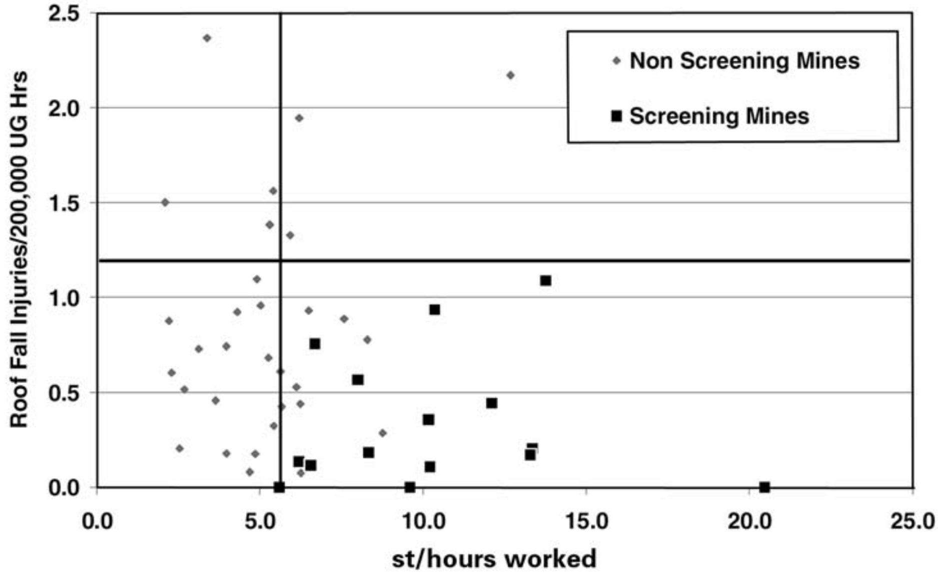


**Figure 15** — Safety and productivity in U.S. longwall mines that use roof screen vs. longwall mines that do not use roof screen (2003 through 2005).

## 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 roof rock has made safety a top priority for mine operators.

NIOSH is currently conducting research into developing diagnostic tests that 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 by 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 that 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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