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Skin Failure of Roof and Rib in Underground Coal Mines

Eric R. Bauer, Mining Engineer
Deno M. Pappas, Civil Engineer
Dennis R. Dolinar, Mining Engineer
Frank E. McCall, Mining Engineer
Daniel R. Babich, Mining Engineer

National Institute for Occupational Safety and Health
Pittsburgh Research Laboratory
Pittsburgh, PA

ABSTRACT

Skin failures of roof and rib in underground coal mines continue to be a significant safety hazard for mine workers. Skin failures do not usually involve failure of the support systems but result from rock or coal spalling from between the support elements. For instance in 1997, over 800 miners were injured by roof and rib falls, of which 98 pct were the result of skin failures. Also, nearly 80 pct of the roof and rib failure injuries occurred at or near the working faces in development sections. The face area is a zone where the potential for skin failure accidents and injuries and roof and rib failures, in general, is high because of mining activity, ground readjustment due to changing stress conditions, and the higher exposure of mine workers. In addition, failures occur where the roof and rib are unsupported. This paper features a review of the roof and rib accident statistics resulting from skin failure, highlighting the incidences by average days lost, in-mine location, state, MSHA District, and worker activity at the time of injury. A detailed analysis of recent fatalities caused by skin failure is included. Also discussed are the causes of roof and rib skin failures, current methods and support materials for skin surface control, as well as a historical literature review of skin failures and control methods.

INTRODUCTION

Falls of roof and rib have traditionally been one of the leading causes of mine worker injuries and fatalities in underground coal mines. From 1993 through 1997, nearly 35 pct of all reported underground incidents resulted from falls of roof and rib. These falls of roof and rib resulted in almost 4,800 injuries, or over 15 pct of the total reported underground injuries. Also, skin failures, the failure of small blocks or slabs of roof and rib, have been a recognized problem in the coal mining industry for many years. Detailed analyses showed that in 1997 alone, approximately 98 pct of the roof and rib injuries were from skin failures. This suggests that as many as 4,700 injuries may have resulted from skin failures of the roof and rib during this five-year period.

Reference to skin failures are found in the literature as far back as the late 1920's. Most of the early references discussed the effect of moisture and humidity on roof failures (*1, 2*). Other authors addressed ways to condition mine air such as water sprays and tempering entries to prevent roof deterioration (*3, 4*). Considerable work was presented on the effectiveness of various sealants to coat mine strata including coal tar (*5*), Ebonol (*6*), asphalt-based paints (*7*), sulfur based coating materials (*8*), cement and cement mixtures (*9*), shotcrete (*10*) and polymeric sealants (*11*). More recently, researchers have investigated the mechanisms of shale roof rock deterioration due to atmospheric moisture, explaining it seems to be a result of stresses from moisture-induced weakening and swelling strain, rather than slaking (*12, 13*). Finally, Merrill and Stateham (*14*) explained how loose roof and rib can be detected using infrared devices.

Although the above references dealt mostly with roof skin failure, rib skin failure has also received attention by the coal mining industry. The theory and practices regarding rib failure, especially in thick coal seams, was addressed by Smith (*15*) who suggested that fracturing begins at a stress level equivalent to one third to two thirds of the ultimate strength of the material. Peng (*16*), Dolinar and Tadolini (*17*), and Dolinar (*18*) discussed general coal rib stabilization and the effectiveness of wood dowels, resin bolts, and straps to provide pillar reinforcement. Martin, Carr and Hendon (*19*) provided information that demonstrated the superior performance of yieldable rib bolts to stabilize ribs when twin seam mining at Jim Walter Resources. Wykoff (*20*) and Horino, Duvall and Brady (*21*) investigated the use of wire rope to wrap pillars. Their research indicated that wire rope can significantly effect the compressive strength, and stability of pillars. In addition, many of the references on mine sealants mentioned the use of these for coating and sealing coal ribs.

Many advances have been made in dealing with roof and rib failures, but unfortunately, the problems have not been eliminated. Continued research by government, academia, labor, and the mining industry is needed to address roof and rib skin failures and minimize the associated mine worker injuries. Research at the National Institute for Occupational Safety and Health (NIOSH) is continuing this effort by investigating the causes of skin failure and evaluating control techniques.

DESCRIPTION OF SKIN FAILURE

For the purposes of this manuscript and analyses, skin failure is defined as "the progressive loosening of slabs, blocks, or layers of rock from the surface of the mine roof or the spalling of pieces or slabs of coal from the coal pillar." Skin failure involves smaller pieces of rock or coal, rather than massive roof failures (above anchorage) or coal pillar failures (bumps and bursts). Skin failures can occur in both supported and unsupported mine strata. Figure 1 illustrates skin failure of unsupported mine roof while figure 2 is an example of skin failure of supported (bolted) mine roof where the failure occurs between the supports. Rib skin failures are illustrated in figure 3 (unsupported rib) and figure 4 (supported rib).

Figure 1. Skin failure of unsupported roof.

Figure 2. Skin failure in supported roof.

Figure 3. Skin failure of unsupported rib.

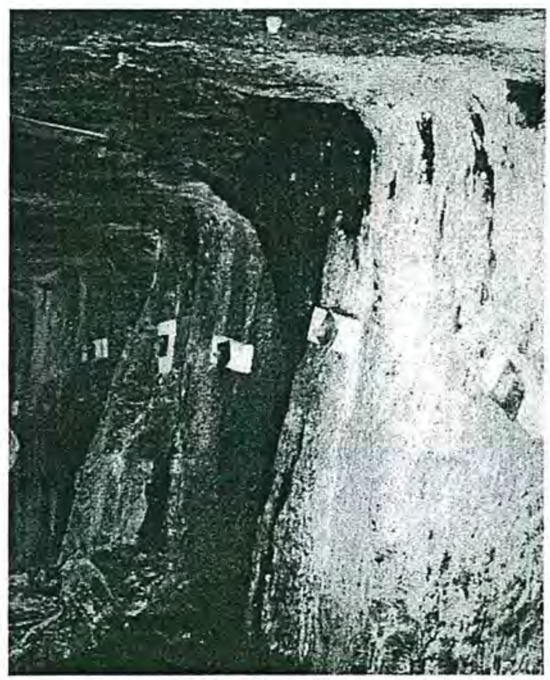

Figure 4. Skin failure of supported rib.

The mechanisms responsible for skin failures can vary considerably, the most common factors being competence of the strata and presence of geologic discontinuities. In many mines the roof is composed of draw rock (slate and shale), coal, bony material, and other highly stratified, thinly laminated strata. This strata is susceptible to progressively failing in thin layers because of bedding plane weaknesses. Some of the causes of bedding plane failures which result in skin failures include sag of the strata under its own weight, overburden pressure as depth increases, horizontal stress, and moisture or temperature sensitivity. If geologic discontinuities are present, the likelihood of skin failure increases because the discontinuities weaken and compromise the structural integrity of the rock. It would seem logical that the potential for roof to experience skin failure can be estimated using the Coal Mine Roof Rating (CMRR). CMRR estimates the structural competence of coal mine roof and considers bedding most important. It includes the factors that weaken bedded coal-measure rocks such as discontinuities, moisture, and rock strength (*22*). The lower the CMRR, the less competent is the roof and the more susceptible to skin failure.

Coal ribs can experience skin failure for many of the same reasons. Primarily, rib skin failure is associated with the early stages of the failure of insufficiently sized pillars or the effects of depth. A general observation about rib skin failures is that rib spalling tends to increase as mining height increases. A plot of rib skin failure injuries and seam height for 1997 indicated that the injury rate increased as the seam height increased, up to 8-ft-thick (2.4-m-thick) (fig. 5). For seam heights above 8 ft (2.4 m), no specidific trend was eident, possibly because of insufficient data and the probability that more rib support is used in the thicker seams. Rib spalling may also increase as the depth increases, it can be affected by face cleat, and it can be self-perpetuating. As coal breaks from the solid pillar, pillar dimensions decrease and pillar pressures increase. The result is more fracturing and spalling, creating a cycle of spalling and loading that may continue unless control measures are implemented. Rib skin failure is also frequently associated with rock partings within the coal pillar or with draw rock located at the roof/rib interface. Rock partings or bands within the pillar create planes of weakness where differential movement (fig. 6) and failure can occur, leading to spalling (skin failure). When weak draw rock that is subject to failure during coal extraction is present, and is mined with the coal, the draw rock exposed in the coal pillars creates a zone of potential rib skin failure. This inherent weakness makes the draw rock susceptible to spalling from the rib as the coal pillars experience load.

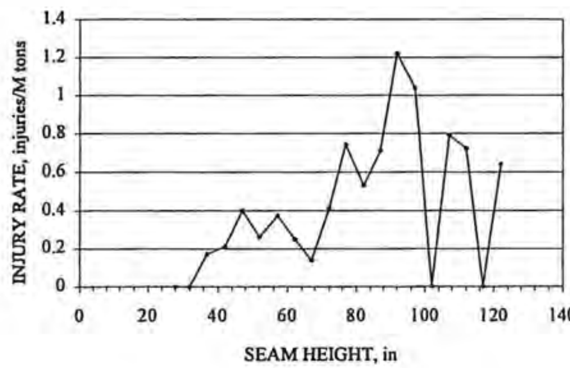

Figure 5. Seam height versus injury rate for rib skin failures, 1997.

Figure 6. Example of differential movement along parting in coal rib.

SKIN FAILURE INCIDENT ANALYSIS

Two separate incident analyses were conducted, one addressing roof and rib fall fatalities from 1993 through 1997, and another addressing all reported roof and rib fall incidents for 1997. These analyses were designed to identify the fatalities and injuries resulting from skin failures, both roof and rib, and the massive failures, then draw some statistically based conclusions.

Roof and Rib Fall Fatalities

The underground coal mine fatalities caused by falls of roof and rib for the years 1993 through 1997 were separated between skin and massive failures. The criteria for classifying a fall as massive or skin were the thickness and areal extent of the fallen material. In general, roof falls with a thickness less than the bolt length were classified as skin failures (nearly all roof skin failures were less than 2-ft-thick (0.6-m-thick) while the rib skin failures were all less than 3.5-ft-thick (1.1-m-thick)). The assumption is that these falls could possibly have been prevented if a more effective support system had been used, the Automated Temporary Roof Support (ATRS) system and bolting station canopy provided more surface control, and if scaling of the roof and rib were practiced more frequently. Nearly all rib failures were classified as skin failures except those listed in the Mine Safety and Health Administration (MSHA) Fatality Report as being an outburst or bump. Table 1 summarizes the initial classification and illustrates that slightly more fatalities resulted from massive failures. It should also be noted that the massive failures occurred nearly evenly between advance mining (15 fatalities) and retreat mining (12 fatalities).

Next, a comparison of the skin failures was conducted. Table 2 illustrates that nearly twice the number of fatalities resulted from roof skin failures than rib skin failures. In addition, most of the roof skin failures occurred under unsupported roof while the victim was inby permanent supports. The fatalities resulted from improper worker behavior (going inby supports). Additionally, the average thickness of the roof skin failures and rib skin failures was calculated. The rib skin failures were thicker (mean = 2.55 ft (0.78 m), std. dev. = 1.03 ft (0.31 m)) than the roof skin failures (mean = 0.88 ft (0.27 m), std. dev. = 0.70 ft (0.21 m)). For comparison, the massive failures on average were thicker (mean = 9.1 ft (2.8 m), std. dev. = 7.5 ft (2.3 m)).

Table 1. Roof and rib fatalities, 1993-1997.

Year	Total fatalities	Massive failures	Skin failures
1993	12	7	5
1994	8	4	4
1995	8	6	2
1996	13	4	9
1997	9	6	3
Total	50	27	23

Table 2. Comparison of fatalities from roof and rib skin failures.

Year	Rib skin fatalities	Roof skin fatalities	
		Supported roof	Unsupported roof
1993	1	0	4
1994	1	0	3
1995	0	0	2
1996	3	1	5
1997	3	0	0
Total	8	1	14

Finally, an attempt was made to correlate the tendencies for skin failures to occur within specific states or MSHA Districts. As shown in tables 3 and 4, the only trend is that the states and districts with the most underground mines experienced the most roof and rib fatalities.

Table 3. Roof and rib fatalities by state, 1993-1997.

State	Total fatalities	Massive failures	Skin failures	
			Roof	Rib
AL	1	0	0	1
CO	1	1	0	0
IL	2	1	0	1
KY	15	7	6	2
PA	7	4	1	2
TN	3	3	0	0
UT	1	1	0	0
VA	8	5	3	0
WV	11	5	4	2
WY	1	0	1	0
Total	50	27	15	8

Table 4. Roof and rib fatalities by MSHA District, 1993-1997.

MSHA District	Total fatalities	Massive failures	Skin failures	
			Roof	Rib
1	4	3	1	0
2	3	1	0	2
3	1	0	0	1
4	10	5	4	1
5	8	5	3	0
6	6	2	4	0
7	10	6	2	2
8	2	1	0	1
9	3	2	1	0
10	2	2	0	0
11	1	0	0	1
Total	50	27	15	8

Reported Roof and Rib Fall Injuries

To delineate the extent of the worker injuries resulting from skin failures, the MSHA Health and Safety Analysis Center (HSAC) Accident Database was examined for 1997. All injuries occurring in underground coal mines resulting from roof and rib failures were extracted and analyzed. This included degree of injury classes from one to six which were injuries ranging from no lost time or restricted activity to those that resulted in a fatality, but did not include reportable roof falls that occurred when no workers were present. In addition, the accident injury illness types extracted were fall of face, rib, or side, fall of roof, and machinery. The machinery incidents were included because some of these occurrences were actually the result of falling roof or rib. These misclassified incidents were sorted out by using the source of injury code with a criteria of caving of rock, coal, ore, and waste. This query eliminated the correctly classified machinery incidents. Table 5 lists a summary of the roof and rib injuries for 1997. It reveals that most of the injuries resulted from roof skin failures, but that the severity of the rib skin injuries was greater because the average days lost was higher. Finally, the table reveals that 570 mines did not report any roof or rib injuries in 1997.

Table 5. Number of injuries from roof and rib failures, 1997.

Failure type	No. of injuries	Pct. of injuries	Avg. days lost per injury	No. of mines[1]
None	0	0	0	570
Roof skin	669	83	27	266
Rib skin	128	15	190[2]	83
Massive	13	2	2,783[3]	6
Total	810	100	---	925

[1]No. of mines reporting at least one injury of the failure type listed.
[2]Avg. includes 3 fatalities (18,000 days away), avg. without fatals is 43.
[3]Avg. includes 6 fatalities (36,000 days away), avg. without fatals is 25.

Next, another analysis determined the mining situations in which roof and rib skin injuries occurred. Table 6 indicates that 84 pct of the skin failure injuries occurred during development or retreat mining, the remaining 16 pct divided among longwall and other. An attempt was made to determine the location of skin failure injuries with respect to the state of roof support. The best estimate is that 383 of the 669 roof skin injuries occurred under permanent support, or 57 pct. It is possible that many of the roof skin failure injuries occurring where the roof was permanently supported could have been prevented through modified support designs. Another 233 (35 pct) roof skin injuries occurred under temporarily or unsupported roof. In addition, increasing the skin coverage of the ATRS and drill station canopies could help reduce the roof skin failure injuries occurring under temporarily supported roof. For the remaining 53 roof skin injuries, the state of support was unknown. Approximately 85 of the 128 rib skin injuries occurred where the roof was permanently supported, or 66 pct. The rib skin failure injuries occurring under permanently supported roof may be minimized by securing the ribs if necessary, or through scaling and increased awareness of rib conditions. Another 19 (15 pct) rib skin injuries occurred under temporarily or unsupported roof, while the remaining 24 (19 pct) occurred where the state of the support was unknown.

Table 6. Roof and rib skin failure injuries classified by mining situation, 1997.

Mining situation	Roof skin failures		Rib skin failures	
	Injuries	Percent	Injuries	Percent
Development[1]	560	84	108	84
Longwall[2]	38	6	11	9
Other[3]	71	10	9	7
Total	669	100	128	100

[1]Includes advance and retreat mining.
[2]Includes injuries occurring in the headgate and tailgate during panel mining.
[3]Includes injuries outby face and unknown origin.

Finally, the mine worker activities during roof and rib skin injuries was extracted from the database. The most common activities of workers injured by roof skin failures were drilling or bolting of the roof (44 pct), operating the continuous mining machine (CM) (10 pct), and general inside labor (8 pct). These three activities accounted for 62 pct of the injuries. No other worker activity was involved in more than 7 pct of the injuries. For injuries resulting from rib skin failures, the most common worker activities were drilling or bolting the roof (19 pct), operating the CM (17 pct), walking (12 pct), moving power cables (11 pct), general inside labor (11 pct), and maintenance and repair (9 pct), which in total accounted for 79 pct of the injuries. All other activities were involved in 7 pct or less of the rib skin injuries. Surprisingly, scaling of the roof or rib, which deals directly with skin failure and is thought to be a dangerous activity, comprised only 1 pct of the roof and rib skin failure injuries.

SKIN CONTROL METHODS

The review of skin control methods includes both a historical look at what has been done in the past as well as a description of current control techniques. The investigation reveals that many of the same methods are in use today as in the past.

Early Skin Control Efforts

Referring back to the literature review presented in the introduction, past control methods were directed primarily at preventing skin failures resulting from changes in temperature and humidity. These included various coating materials designed simply to seal the surface without providing additional strength or reinforcement, and attempts at conditioning the mine air prior to introduction into the mine workings. The air conditioning involved regulating the temperature and humidity to near ambient mine conditions to prevent failures due to expansion and contraction, and moisture variations. In the face area, past attempts at controlling roof and rib skin failure using artificial means were reflective of the support materials available. Mechanical bolts in combination with wood headers and planks, oversized plates, wire mesh, old hoist rope, wood dowels, and other simple support methods were commonly employed.

Current Skin Control Methods

Current control methods have built on the successes of the past techniques, employing the more sophisticated support materials currently in use. In addition, more thought has been given to matching the type of control to the failure mode. For instance because the mining industry has an improved understanding of the mechanism of strata failure, cement coatings utilizing steel or glass fibers are available to not only seal the strata, but also to add strength to resist failure. For control of roof skin failure, wood planks, steel straps and channel, and various meshes such as welded wire, chain link, or synthetic grid material are being used.

Rib support methods have changed as well, primarily in the use, type, and location of bolts. The emphasis is to match the deformability of the rib supports to that of the rib. Yieldable bolts as used at Jim Walters Resources *(19)*, can stabilize the coal seam and ribs effectively by controlling displacements to reduce stress buildup.

A recent information request from MSHA District 3 revealed the following examples of roof skin control methods: (1) A mine using screens in one intake, one return, and the track entry, plus using a lot of gunite; (2) Another mine using 8 gauge steel, 5 by 16 ft (1.5 by 4.9 m) sections of "monster mats" installed on cycle; (3) A longwall mine required to use screening or spray where they have trouble holding up head coal in their gate roads; and (4) A mine that has a history of falls due to deteriorating top has miles of gunited track entry. Information obtained from MSHA District 4 revealed some additional skin control methods. These included using oversized bearing plates on pattern bolts, installing 2-ft-long (0.6-m-long) "bacon skins" (straps) with 3-ft-long (0.9-m-long) mechanical anchor bolts in between the pattern bolts, or covering the roof with synthetic grid material when roof skin failure is a problem. For rib skin failures at the face, some mines install 4- to 6-ft-long (1.2- to 1.8-m-long) planks with 18 or 36 in (45.7 or 91.4 cm)bolts. When sporadic rib failures occur outby the face area, mines mainly use timbers set close to the ribs to minimize the dangers to mine workers traveling nearby.

Typical rib skin control methods, taken from a roof control plan from a mine in Pennsylvania, includes the following: "Loose ribs are to be blocked, bolted, or taken down. Steel straps, planks, or header blocks with 4- to 6-ft-long (1.2- to 1.8-m-long) bolts may be used. Bolts are not to exceed 8-ft (2.4-m) intervals. In lieu of the above, such ribs may be supported by posts or cribs installed tightly near the rib."

SUMMARY AND CONCLUSIONS

Skin failure of roof and ribs injures many workers in underground coal mines. Statistics from 1997 indicate 98 pct of the injuries from roof and rib falls are due to skin failures, resulting in over 800 injuries, or approximately 15 pct of all underground coal mine injuries.

Skin failures, defined as the failure of small pieces of rock and coal, rather than massive roof falls or coal pillar failures, occur in both supported and unsupported roof and rib. It is possible that many of the injuries can be avoided by using improved methods of support and by limiting the need for mine workers to travel inby permanent supports to set temporary supports prior to installing permanent supports.

An analysis of roof and rib skin failure injuries revealed that far more injuries resulted from roof skin failures, but the rib skin failures caused more severe injuries. The analysis also revealed that roof and rib skin failures were three times more likely to result in an injury when they occurred on the working section than outby in other mine areas, simply because of greater worker activity in the face area.

The methods for support of roof and ribs to prevent skin failure are merely extensions of standard roof support methods. As dictated by the extent of skin failure problems, the on-cycle supporting methods are modified to provide additional surface coverage. Common skin control methods include oversized plates, header boards, wood planks, steel straps, meshing, and in rare instances, spray coatings. These control methods can control skin failures, unfortunately they are implemented reactively to control problems that are occurring rather than proactively to prevent future skin failure occurrences. The success of these controls can be enhanced by matching the characteristics of the support to the expected strata reactions to mining and modes of failure.

NIOSH research is continuing to address the causes and control of skin failure in underground coal mines. Emphasis will be to determine the mine, roof, and rib conditions most likely to result in skin failures then verify the most effective control techniques.

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