International Experience with Longwall Mining into Pre-driven Rooms

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ABSTRACT

Unusual circumstances may require that a longwall retreat into or through a previously driven room. The operation can be completed successfully, but there have been a number of spectacular failures which exposed miners to serious roof fall hazards. To help determine what factors contribute to such failures, the National Institute for Occupational Safety and Health (NIOSH) compiled a comprehensive international database of 130 case histories. The cases include five failures where major rock falls occurred in front of the shields, and six even more serious failures involving major overburden weighting. This suggests two room failure mechanisms. The first is a roof fall type failure caused by loading of the immediate roof at the face as the fender narrows. The second is a weighting type failure caused by the inability of the roof to bridge the recovery room and face area, and affecting rock well above the immediate roof. The data indicate that the roof fall type of failure is less likely when intensive roof reinforcement (bolts, cables, and trusses) is employed together with higher-capacity shields. The overburden weighting failures, in contrast, occurred when the roof was weak and little standing support was used.

Acknowledgments

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INTRODUCTION

Although not standard industry practice, pre-driven longwall recovery rooms and cross panel entries have been used in a number of mines for various reasons, including:

- to speed up recovery of the longwall upon completion of a panel;
- with "super" longwall panels, to mine through entries that were driven mid-panel to facilitate ventilation and escape;
- to extract old barrier pillars that may include crosscuts or crossing entries, or;
- when a geologic feature, such as a dike or a fault, has been removed prior to longwall mining.

Experience has shown, however, that there are serious ground control risks with the procedure. Several spectacular failures have occurred, where rock falls or severe weighting pressures on the shields required weeks or even months to work through. During these incidents, miners were exposed to extremely hazardous conditions while working in very confined spaces.

To help prevent such failures in the future, NIOSH has compiled a comprehensive database of all known examples of longwalls mined into or through pre-driven rooms. A total of 130 case histories have been collected from 17 mines in the U.S., Australia, and South Africa, covering the period from the mid-1980's through 1997. The data were obtained primarily from the literature, supplemented by personal communications and experience where applicable. For each case history, every effort was made to obtain information on the geology, the dimensions of the pre-driven room, the support installed, and the results. Table 1 shows the complete database. Some further details on the mines and case histories is provided in the paragraphs that follow.

Table 1.-Data base of parameters used in analyzing the performance of longwall mine throughs of pre-driven rooms.

Country	State	Reference[1]	No. Of Rooms	Soft Floor[2]	Depth m	CMRR	Seam Ht, m	Panel Width, m	Room Length, m	Shield Capacity[3]	RDI[4] MPa·m	Standing Sup. MPa	Slow Mining[5]	Out come[6]
US	PA	1,2,3,4	1	N	150	40	2.4	244	61	454	0.37	5.6	N	1
US	PA	1,2,3,4	1	N	150	40	2.4	183	183	454	0.43	5.6	N	1
US	PA	1,2,3,4	1	N	150	40	2.4	183	183	454	0.37	4.1	N	1
US	PA	1,2,3,4	1	N	150	40	2.4	183	183	454	0.37	2.8	N	1
US	PA	12	3	N	168	40	2.9	270	270	794	0.22	1.5	N	1
US	PA	7	3	N	210	40	2.2	250	250	635	0.53	1.8	N	1
US	PA	7	3	N	210	40	2.2	305	305	635	0.29	4.8	N	1
US	PA		1	N	220	40	2.2	305	305	635	0.88	0.0	N	3
US	PA		1	N	220	40	2.2	305	305	635	0.72	1.8	Y	1
US	MD	5,6,19	16	N	190	40	2.6	229	229	599	0.33	1.2	Y	1
US	MD	5,6,19	1	N	190	40	2.6	229	229	599	0.33	1.2	Y	2
US	MD	5,6,19	6	N	190	40	2.6	229	229	599	0.66	4.6	N	1
US	CO	13,14	1	Y	140	35	2.1	168	168	590	0.62	0.3	Y	3
Aus	NSW	8	1	Y	90	60	3.1	200	200	590	0.64	0.1	N	1
Aus	NSW	8	6	Y	90	60	3.1	200	200	590	0.75	0.0	N	1
Aus	NSW	8	1	Y	50	82	3.4	200	200	590	0.75	0.0	N	1
Aus	NSW	8	4	N	290	50	3	200	200	590	1.83	0.4		1
Aus	NSW		1											
Aus	NSW		1	N	275	45	3	150	150	617	0.00		Y	3
Aus	NSW		3	N	275	45	3	150	150	617	0.93	0.1	N	1
Aus	QLD	15	1	N	190	50	2.4	200	200	726	0.76	0.1	N	3
Aus	NSW		2		400	70		200		907				1
Aus			several					50		363				1
S. Africa			1					200	150					1
S. Africa		9,10,11	1	N				200	200					2
S. Africa		9,10,11	4	N	125	50		200	200	327		3.5	N	1
S. Africa		10,11	1	Y	70	35	3	200	100	327	0.55	0.0	Y	3
US	WV	18	1	N	305	50	1.5	244	244	590	0.55	0.1	N	1
US	WV	18	1	N	305	50	1.5	244	244	590	0.42	0.1	N	1
US	WV	18	6	N	305	50	1.5	244	244	590	0.42	0.0	N	1
US	WV	18	6	N	305	50	1.5	244	244	590	0.42	0.0	N	1
US	AL	17	3	N	366	67	2.1	265	265	726	0.13	0.7	N	1
US	AL	17	3	N	366	67	2.1	265	265	726	0.41	0.3	N	1
US	AL	17	12	N	366	67	2.1	265	53	726	0.41	0.0	N	1
US	AL	16	1	Y	610	47	2.3	107	107	590	0.15	0.2	N	3
US	AL	16	3	Y	610	47	2.3	107	107	590	0.15	0.7	N	1
US	AL	16	1	N	610	57.5	2.5	76	76	590	0.15	0.0	N	2
US	AL	16	1	N	610	57.5	2.5	76	76	590	0.15	0.1	N	2
US	AL	16	16	N	610	57.5	3.0	76	76	590	0.29	0.1	N	1
US	AL	16	2	N	610	68	3.0	122	67	590	0.09	0.0	N	1
US	AL	16	6	N	610	68	3.0	122	67	590	0.32	0.0	N	1
US	AL	16	1	N	610	68	3.0	122	67	590	0.32	0.2	Y	2

[1]References. Refers to the numbers of the references at the end of this paper.
[2]Soft Floor. Y=Soft. N=Normal or not noted as soft by the original source.
[3]Metric tons.
[4]RDI. Reinforcement Density Index. The product of the support capacity and the support length, divided by the tributary area affected by the support and summed for all support types. In the case of trusses the length of one anchor is used. The index does not apply to standing supports.
[5]Slow Mining. Y=Slow mining. N=Normal or rapid mining or rate unknown.
[6]Outcome. 1=Successful outcome. 2=Failure due to face break or roof fall. 3=Failure due to major overburden weighting

U.S. CASE HISTORIES

Alabama Mine "A": This mine has gained considerable experience with mining through pre-driven rooms in recent years (Hendon, 1998). Successful mine-throughs include:

- 18 crosscuts extracted with a 75 m (250 ft) wide longwall face;
- two "probe entries" driven across a 120 m (400 ft) wide face; and,
- a number of 42 m (140 ft) crosscuts inside the same 120 m (400 ft) face.

In each of these cases, the face entered the pre-driven room at an angle, generally about 7 degrees. Relatively little additional bolting was used to reinforce the roof, which was usually competent siltstone. Standing support consisted of, at most, a single row of fiber cribs on 6 m (20 ft) centers.

There was also one notable failure. At the "pull-out crosscut" of the same 120 m (400 ft) face, a "massive roof fall" occurred at mid-face which required 2 weeks to clean up. This was the most heavily supported of any of the mined through entries, with a double row of propsetters installed on 1.5 m (5 ft) centers. However, the other difference was that the wall approached the pull-out crosscut much more slowly to facilitate meshing. It was concluded that "substantial standing support was needed at the pull-out point where the face retreat rate was reduced significantly" (Hendon, 1998).

Alabama Mine "B": A longwall was used to extract a 110 m (350 ft) barrier pillar which was crossed at right angles by a set of four main entries (Hendon, 1998). The first entry was supported by double rows of propsetters, but a "massive squeeze" developed as the last coal was removed from the fender. The shield canopies were forced onto the face conveyor and 1 month was required to get the longwall moving again. The remaining three entries were reinforced with double rows of fiber cribs and propsetters, and were extracted without incident. The roof consisted of 1.5 m (5 ft) of mudstone and coal, overlain by competent siltstone.

Alabama Mine "C": Partial recovery rooms, 45-60 m (150-200 ft) long, have been used for many years at this mine (Stansbury, 1998). These have been located either in the middle or near the gate ends of the panels. Relatively light roof reinforcement, and no standing support, has been sufficient in the partial recovery rooms.

When a recent panel was extended through three pre-existing entries, the decision was made to fill them with a 0.7 MPa (100 psi) cellular concrete. There were no strata control incidents, but other complications made the experience unsatisfactory.

Most recently, cable trusses and concrete pilasters were employed in a full-face recovery room. The coal fender punched into the floor, there was significant shield convergence, and numerous pilasters crushed out, but the face was recovered on schedule. The pilasters were built of solid concrete blocks with approximately 15% wood.

Colorado: On one of the early longwall panels at this mine, a decision was made to recover the longwall from a sub-main entry. The room was supported by a single row of square fibercrete cribs topped with 0.15 m (6 in) wood blocks (Ropchan, 1990). Roof reinforcement included 2.4 m (8 ft) fully grouted rebar on 0.65 m (2 ft) centers with chain link fence. The immediate roof consisted of a weak, highly slickensided shale about 3-4 m (10-12 ft) thick, overlain by a series of weak siltstones, sandstones, and shales. The shale-siltstone floor was also weak.

When the panel fender was between 1-2 m (3-6 ft) wide, the face advance stopped for 6 hours because the pan line was stuck. The roof began to converge rapidly as the fender crushed, and many shields yielded with several becoming iron bound. The pillars in the recovery room punched into the roof with heavy rib spalling and cutter roof failure. All the fiber cribs failed either by splitting or crushing with many showing a hour glass failure configuration. The recovery room was then heavily reinforced with wood cribs, though convergence continued.

The subsequent investigation concluded that the roof had broken at the pillar line with the rock mass moving toward the face as shown in figure 1 (Pulse, 1990). Investigators noted a "tensile fracture" which resulted in the "roof moving toward the gob." With the roof beam apparently pivoting around the pillar rib, the largest roof movements were experienced at the face, and a significant amount of the abutment load had shifted onto the shields. Under such conditions the face could not move the last few feet into the room.

Recovery of the longwall was accomplished where the face had been halted short of the recovery room. The remnant fender was then mined out with a continuous miner after the roof was grouted and heavily supported. Approximately 2 months were required to recover the longwall face.

Maryland: This mine has used 23 recovery rooms, 6 of which were 11 m (36 ft) wide. The only failure was one of the standard rooms where roof falls necessitated 2 weeks of remedial action. The extra support in this case was a row of concrete cribs on the inby side of the recovery room and a row of wooden cribs on the outby side. The damage occurred when the face was 11 m (35 ft) from the room. Mining rates were slow because of wire meshing activity.

The wide recovery rooms were designed so that the face would not have to slow down for meshing (Wynne et al., 1993). The room was developed and supported in two passes. Supplemental support included eight rows of concrete donut cribs, three rows of truss bolts, and two rows of 5 m (16 ft), 25 mm (1 in) diameter roof bolts. All the wide rooms were reportedly mined without serious incident (Wynne, 1998).

Pennsylvania Mine "A": A total of four recovery rooms were successful at this Pittsburgh seam mine (Bauer et al., 1988; Bauer et al., 1989). Three different types of concrete supports

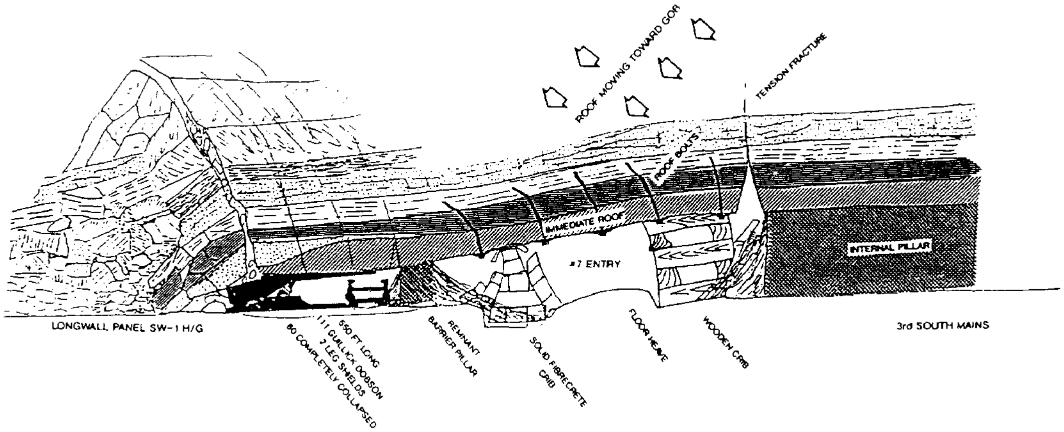

Figure 1, Typical physical behavior of a pre-driven room under weighting type roof failure. From underground observation of the Colorado recovery room failure. Note the fracture observed to develop at the front edge of the abutment pillar. (From Pulse, 1990)

were used. The first room employed 1.2 by 1.8m (4 by 6 ft) flyash concrete piers. The piers were designed to "replace the load-bearing capacity of the coal" by providing a support resistance of 5.5 MPa (800 psi). To reduce costs, fibercrete cribs with 0.3 m (1 ft) wood cap blocks were used on the next room. Again, the cribs were placed to give a support density of 5.5 MPa (800 psi). The concrete cribs were hard on the shearer and stageloader, however, and so the last two panels employed poured concrete cylinders. The concrete was pumped from the surface to fill 1 m (3 ft) diameter cardboard tubes. The top 0.2 to 0.3 m (8 to 12 in) above the concrete cylinders was wedged with wood. The support density was reduced on the fourth panel following good results from the third. No ground control problems were encountered in any of the recovery rooms.

Pennsylvania Mine "B": Three different techniques have been used at this Pittsburgh seam operation. Little information is available on the results from the first three 4.9 m (16 ft) wide recovery rooms. The mining company considered the rooms successful, but did not have full confidence in the technique because of floor heave and the failure of some of the donut cribs and several later panels were recovered short of prepared rooms, using conventional techniques.

More recently, a set of three entries were driven across a longwall panel so that the panel could be lengthened (Chen et al., 1997). The entries were filled with a low strength cement-flyash mixture. There were few ground control problems in mining through the entries, although the wood and steel left in the rooms caused equipment problems.

A full-face pre-driven recovery room was less fortunate. No standing support was used, though the roof was heavily reinforced with 2.4 m (8 ft) mechanically-anchored resin-assisted bolts, 3.7 m (12 ft) cable bolts, mesh, and channels. The mining rate averaged more than 15 m/d (50 ft/day) as the panel approached the room. When the face was 3 m (10 ft) away, the room began to deteriorate and a number of shields were constantly on yield. The face entered the recovery room at the headgate and tailgate areas, but the roof converged to the floor over much of the entire mid-panel section. It took several weeks to get through the collapsed roof, with remedial efforts including the use of polyurethane grout and the installation of cribs.

The face was then advanced to a second entry that had been mined at the same time as the original recovery room. This room was supported by two rows of donut cribs, a row of 0.76 m (30 in) wooden cribs, and cable bolts. The longwall recovery was successful, although the donut cribs were heavily damaged and a large amount of convergence took place.

Pennsylvania Mine "C": A three-entry system was driven across one panel to allow it to be extended beyond an adjacent, shorter panel. The entries were driven at a 30 degree angle to the panel, each supported by a single row of 1.2 m (4 ft) diameter poured cement cribs on approximately 2.4 m (8 ft) centers (Bookshar et al., 1998). The body of the cribs was made up of a stiff high strength concrete, and the cribs were then topped with a plastic bag approximately 0.3 m (1 ft) thick and filled with a yielding proprietary cement. The mine throughs were successful, with the largest measured deformations less than 80 mm (3 in) in the tailgate.

West Virginia: Eleven faces have been recovered using full-face recovery rooms at this mine (Smyth, 1998). The first two used some standing support, but most have used just roof bolts and cable bolts for reinforcement. The coal is quite thin, leaving little room for convergence. While some shields have been stuck, most face recoveries have been conducted without incident.

AUSTRALIAN CASE HISTORIES

New South Wales (NSW) Mine "A": Recovery rooms were used on 12 panels in 3 different coalbeds at this mine (Simpson et al., 1991). On the earlier panels in the Fassifern coalbed 1.8 or 2.1 m (6 or 7 ft) resin bolts, "w" straps and mesh were used for support. Standing support, consisting of two rows of timber props was used only on the first panel. The rooms were 4.8 m (16 ft) wide, except the first, which was only 4.2 m (14 ft) wide. A panel was also recovered in the shallower Great Northern coalbed using the same configuration. When the first recovery room was planned for the deeper Young Wallsend coalbed, three rows of 10 m (33 ft) fully grouted cable bolts were added, (at least near the headgate, the published report is unclear on whether cable bolts were used across the entire room) and a row of 1.8 m (6 ft) diameter standing supports known as Big Bags were installed on 5 m (16 ft) centers near the outby rib.

The mine management attributed the success of the recovery rooms to a large extent to the presence of a soft claystone floor which allowed the panel fenders to be slowly punched into the floor, with manageable floor heave, and avoiding fender yield. They reported that the fenders typically did not yield until the last few meters and in some cases did not yield at all. In the deeper Young Wallsend coalbed, this mechanism was not relied upon, the room was heavily supported by both secondary and standing support, even though the shale floor there was also soft. The sandstone or conglomerate immediate roof above the Fassifern, Great Northern and Young Wallsend probably also contributed to the success of the recovery rooms at this mine. The mine preferred to keep the tailgate back, as much as 8 m (26 ft) in the Young Wallsend coalbed, so that if ground control problems occurred, they would be less likely to affect the entire panel.

NSW Mine "B": Four rooms were mined into, the first being a full face recovery room 6.5 m (21 ft) wide and the next three being narrow (3.5 m or 12 ft) full face entries driven for ventilation. The recovery room failed, causing the shields to go on the solid and several months were required to recover them. The room was supported by a standard primary bolting pattern, with spot cable bolting only in areas considered critical, such as gate road and chute intersections. No standing support was used. The motor on the shearer ranging arm broke down when the face was just a few meters from the room and the face remained idle for an extended period. The fender failed when the face was 2 m (6 ft) from the room. High water flows from the gob and gas flows into the tailgate entry were noted in the course of the mine through and interpreted as the effect of the failure and subsequent weighting of an overlying sandstone aquifer and the opening of fractures in failed rock to allow gas flow.

The remaining mine throughs were supported by cable bolts, props and glue injection into the panel fender. Primary support consisted of 2.4 m (8 ft) bolts and "w" straps on a 0.8 m (2.5 ft) spacing, 10 m (33 ft) cable bolts on a density of 3 cables/2 m of entry and 3 rows of 150 mm (6 in) props on 0.8 m (2.5 ft)centers, over the entire length of the entry. These mine throughs were successful, although there was no necessity to remove the shields.

NSW Mine "C": A recovery room was used to successfully recover a single longwall at this mine. No specific information is available on the supports or on the panel geometry, but it is known that significant secondary support in the form of cable bolts and timber props was used.

NSW Mine "D": Recovery rooms were used on two short, 200 m (660 ft) wide panels at this mine. The immediate roof in both cases is the massive, competent Coalcliff Sandstone. Both mine throughs were considered completely successful. No information is available on the type of support used in the rooms in either case. Recovery rooms were not used on subsequent panels because the roof lithology changed from competent sandstone to shale and because later panels were also significantly longer reducing the importance of rapid face moves.

NSW Mine "E": No information is available except that several panels were recovered, the panels were narrow, about 50 m (164 ft) and they were successful.

Queensland: A single 5.2 m (17 ft) wide recovery room was attempted at this mine (Klenowski et al., 1990). Primary roof support consisted of five rows of 2.1 m (7 ft) resin bolts on 1.5 m (5 ft) spacings with "w" straps. The inby and outby bolts were angled over the fender and barrier pillar. Two rows of 8 m (26 ft) cable bolts were also used on 4 m (13 ft) centers. Grouted 1.8 m (6 ft) fiberglass rib bolts were installed in the fender and in the barrier pillar. Standing support was only planned for use on an as required basis. The design was based upon the results of an instrumented 15 m (50 ft) stub entry.

Convergence was noted to begin to accelerate when the fender was 6 m (20 ft) wide. When the panel was 5 m (16 ft) from the room the fender failed and the shields began to continuously yield. Just prior to entering the room a maximum of 0.42 m (17 in) of convergence took place at one place on the face where the shearer was hung up under the canopy of a shield and typical convergence may have been 0.26 m (10 in). Less convergence took place in the recovery room. When the shields entered the room the mining height was greater and the available hydraulic fluid was insufficient to set them (due to fluid losses from continuous yielding of the shields). A delay took place until the hydraulic reservoir was refilled. The convergence continued after the room was entered and eventually it was necessary to set timber props, with a total of 392 props finally being used. Of the 440 shield legs on the face, 104 were found to have failed after the mine through due to malfunction of the gas yield valves. One conclusion arrived at by the mining company was that had the shields not failed, the roof convergence would not have been so large and fewer timber props would have been required. However, it is possible that the high rates of convergence caused the damage to the shields.

After-the-fact, back analysis indicated that a "tensile failure" extended upward to a rider seam located 16 m (50 ft) above the German Creek Seam (figure 2). Convergence at the face occurred much more rapidly at the face than in the recovery room, indicating that "the pivot point of the failing roof beam was over the barrier pillar" (Klenowski et al., 1990).

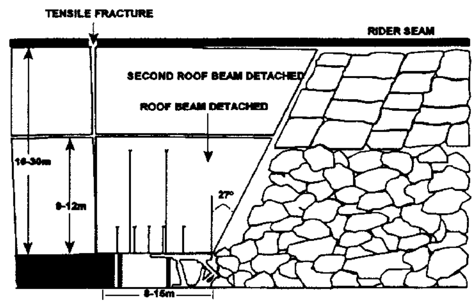

Figure 2.-Conceptual model of a weighting type room failure, based on observations and measurements at the Queensland recovery room failure (after Klenowski et al., 1990).

SOUTH AFRICAN CASE HISTORIES

South Africa Mine "A": Six mine throughs were attempted, five to mine through dikes and an experimental recovery of part of a face (van der Merwe, 1988; 1989). The dike mine throughs used either mat packs (rafts of timbers wired together and laid one on top of the other) or filled entries, except for the third mine through where only timber props were used. For the first and second mine throughs mat packs were used, for the third timber props, for the fourth a back fill material consisting of cement, plaster and sand, and sifted ash as well as timber props, and for the fifth a mix of coal fines and other unspecified materials used to improve the flow characteristics and strength of the mix.

All of the mine throughs except the third were successful. In that case, the room was entered 0.3 m (1 ft) too low and the recovery room eventually collapsed before the dike could be blasted away to allow advance into the room.

The sixth mine through was a recovery room test and only covered a portion of the panel. During the mine through the conveyor belt broke and the face sat idle for 8 hours when the face was 3 m (10 ft) from the room. Apparent water entry from a joint in the fender softened the floor rock and caused the fender to punch into the floor. The floor under the face conveyor heaved and left the face conveyor and shearer too high to allow the shields to be advanced. The recovery room roof also converged until it was impossible to enter, forcing shield recovery in place 3 m (10 ft) from the recovery room, a "lengthy process".

After the event, the conclusion was that "in longwalling, a deviation from standard practice should only be considered if the potential benefits outweigh the potential negative consequences of failure, longwalling is not a very tolerant mining method."

South Africa Mine "B": A room was mined across a longwall face to remove a dike. The roof rock included a 30 m (100 ft) sandstone approximately 30 m (100 ft) above the coalbed. In order to reduce the risks of the mine through the panel width was reduced some 50 m (160 ft) before reaching the room, from the normal 200 to 150 m (660 to 490 ft). No information is available on the support types used, except that mine management felt that if the technique was used in the future, standing support would be used. The reasons given were to give better resistance to abutment loading and to control the dike, pieces of which tended to fall out while entering the room.

FAILURE MECHANISMS

In the vast majority of cases, longwalls have been successfully mined into pre-driven rooms. Of the 130 cases, only 11 were apparently complete failures. However, the costs associated with these failures, and the hazards they created, were very substantial.

The failures can be divided into two categories. The first includes five cases where the problems were due to roof falls occurring in front of the shields. The second group consists of cases involving severe shield weightings accompanied by major convergence.

Roof falls occurred in two situations as the longwalls approached the pre-driven rooms. At the face, failures developed in the unsupported roof span between the shield tips and the remnant fender (the portion of the longwall panel between the shields and the room) because of an increased span resulting from extensive coal yielding in the fender. In this type of failure, there was insufficient secondary support in position to prevent the roof fall. Roof failures in the recovery room developed because of the high stress and deformation environment and the large span from the shield tips to the abutment pillar once the fender was mined out. Often a substantial portion of the room was involved with this type of failure.

Weighting type failures resulting in the most severe ground conditions were due to main roof action caused by the failure of a weak roof. These types of failures were accompanied by significant room and face convergence where shields were loaded to yield, often becoming iron bound. The development of a new cave break at the edge of the abutment pillar resulted in the loss of the immediate roof cantilever as a supporting element (figures 1 and 2). In the six cases where the weighting failure occurred, accelerated rates of convergence leading to failure initiated when the fenders were 3 m (10 ft) or less in width. Up until then, the remnant panel was providing substantial support to the main roof.

Where insufficient standing support is present in the room, the shields may be called upon to control most of the weight of the new caving block that extends across the recovery room, doubling the roof span they previously supported. As shown in figure 2, the failure may extend up higher into the main roof because of a wider pressure arch causing a further increase in the shield load. Further, the shields are not in good position to handle this new load distribution. As the detached block moves, the main roof is affected. If the main roof is not strong enough to bridge over the detached block it will subside, progressively adding to the loads on the face area. With this type of failure, intrinsic support will not resist the failure because the support is internal to the detached block. A strong main roof can help the overburden to bridge across the room and face resulting in more favorable face and room conditions.

CHARACTERISTICS OF PRE-DRIVEN ROOMS

In this study, every effort was made to obtain information on a variety of descriptive characteristics of all the case histories. The results are summarized in Table 1. The goal was to identify those characteristics which correlated with the failed case histories. Statistical techniques, including Pearson correlation and logistic regression, aided the analysis.

Immediate Roof: Descriptions of the roof geology were usually contained in the literature, and were quantified using the Coal Mine Roof Rating (CMRR). In almost every instance, the published description was supplemented by CMRR data collected by the fourth author in past visits to the mines.

A very strong correlation between the CMRR and weighting failure was found. All of the six weighting failures occurred where the roof was relatively weak (CMRR<50). The correlation is less evident for roof falls (figure 3).

Main Roof: Insufficient data were available on main roof

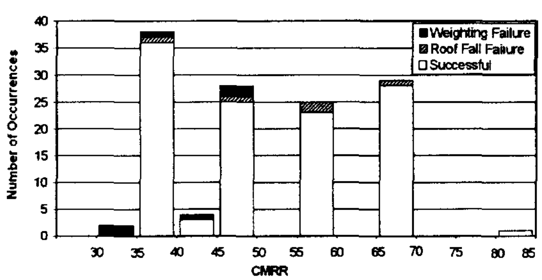

Figure 3.-Histogram of CMRR versus mine through occurrences. All weighting type failures took place with CMRR<50, while roof fall failures took place over a wide CMRR range

geology for analysis. The authors believe, however, that the main roof geology should be very important to weighting failures. It seems likely that the CMRR is substituting for a characterization of the main roof in many instances.

Floor: Soft floor was reported in 14 of the mine throughs, but these included three of the weighting failures. Under some conditions where the thin, heavily loaded fender is likely to punch into the floor, the potential for failure could be increased, although there were also successful cases where soft floor was credited with delaying fender yield and contributing to the success of the recovery rooms.

Overburden Depth: The case histories cover a very wide range of cover depths. Roof falls were somewhat more likely to occur at greater depth, but not weighting failures (figure 4).

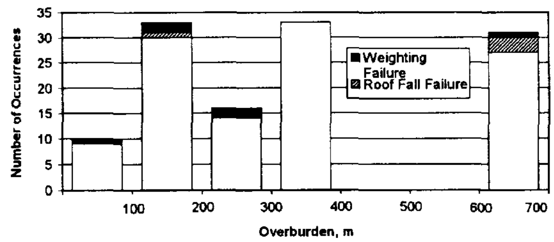

Figure 4. Histogram of overburden versus mine through occurrence. Weighting failures were not strongly correlated to room depth

Seam Thickness: No correlation was found between seam thickness and either type of failure. It is worth noting that while there is less potential for roof weighting when the seam is thin, the tolerance for convergence is also usually much less.

Mining Rate: A slow mining rate seems to be a strong predictor of both types of failures. Twenty mine throughs were associated with reports of slower than normal mining, either because they were meshing, or because a breakdown occurred near the recovery room. Four of the weighting incidents, and two of the roof falls, were in this group. However, it may be that slow mining rates are more likely to be reported when a failure occurred. The rate may actually have been slow in many of the reported successes.

Room Width: There seems to be a little correlation between room width and difficulties. The very widest recovery rooms, the 11 m (36 ft) rooms at the Maryland mine, were trouble free. However, it seems reasonable that overall stability will improve as the room width decreases, all other factors being equal.

Room Length: It might be expected that overburden weightings would occur more often in longer rooms. No such correlation is apparent in these data, however (figure 5). Two of the severe weightings (one in South Africa and the other in Alabama) occurred on faces that were less than 110 m (350 ft) wide.

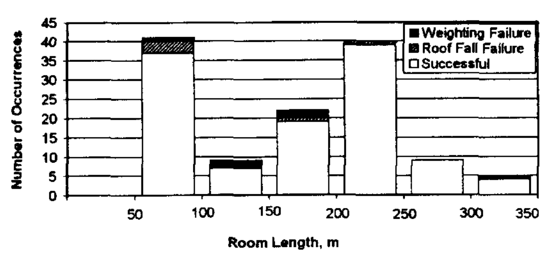

Figure 5.- Histogram of room length versus mine through occurrence

Shield Capacity: Some correlation was observed between shield capacity and roof falls, but heavier shields apparently have not helped prevent weighting failures (figure 6).

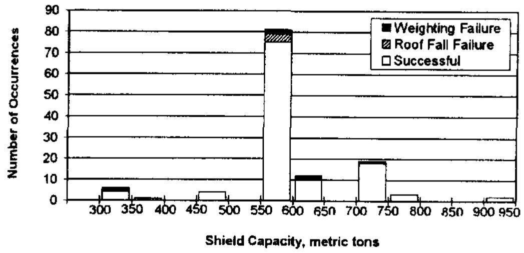

Figure 6.-Histogram of shield capacity versus mine through occurrence

Roof Reinforcement: Roof reinforcement includes all intrinsic supports elements, such as roof bolts, cable bolts, and trusses. The quantitative rating is obtained by determining the load capacity of each element per unit area of roof supported by the element and multiplied by the length of the element. This Reinforcement Density Index (RDI) has the units of MPa·m. Where several types of support were used, the ratings for individual supports are summed.

Heavy roof reinforcement was apparently successful in reducing the incidence of roof fall type failures. Roof reinforcement was apparently not effective in preventing weightings (figure 7).

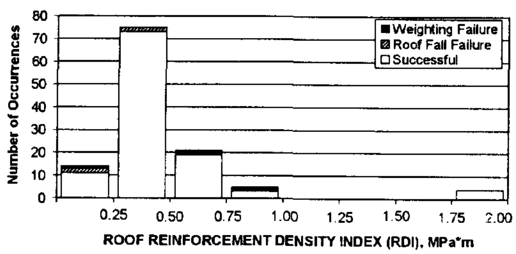

Figure 7, Histogram of Roof Reinforcement Density Index (RDI) versus mine through occurrence

Standing Support: A characteristic of every one of the weighting failures is the lack of standing support (figure 8). In two mines, after a severe weighting failure developed in a room without standing support, adjacent rooms were mined successfully with standing support. These two cases indicate that standing support can be the difference between success and failure. The importance of standing support also lends credence to the proposed mechanism of weighting failure.

Face-Room Angle: Because of the limited data on cases where the room was at an angle to the face, no detailed analysis was conducted on this parameter. However, the mine throughs in the documented cases were successful. As noted earlier, some mines have entered the pre-driven rooms at small angles with the tailgate lagging 6-10 m (20-30 ft) behind the headgate to limit the extent of ground control problems. The evidence that a narrow fender still provides significant support suggests that this approach may be valid.

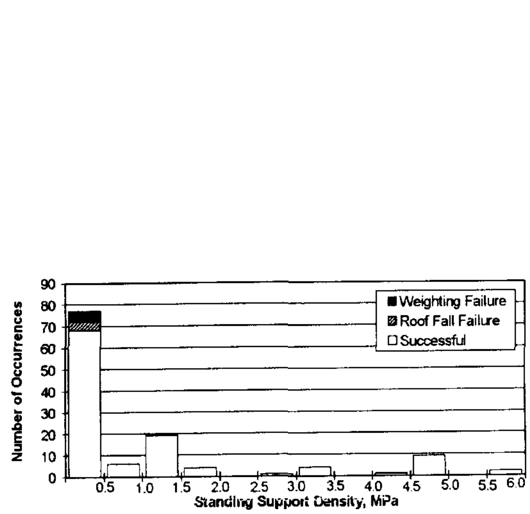

Figure 8.-Histogram of standing support versus mine through occurrence. No occurrences of weighting failures were observed when the standing support density was greater than 0.5 MPa

MULTIVARIATE ANALYSES

Logistic regression was employed to obtain insight into possible design guidelines. Three analyses were performed, analyzing the roof falls, the weightings, and the combined set of failures. Mining rate and weak floor were not included in the analysis because the data were judged incomplete.

Looking at roof falls alone, the two most important variables were shield capacity and the total intrinsic support (RDI or reinforcement density index). It appears that as the shield capacity increases, the required standing support decreases, and vice versa (figure 9). However, the relationship explains only half of the roof failures.

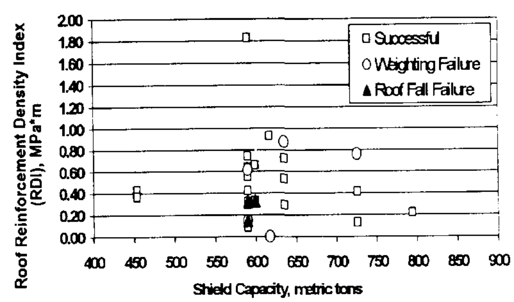

Figure 9.-Shield capacity versus Roof Reinforcement Density Index, for successful mine throughs and cases of roof fall and weighting type failures

For weighting failures, the CMRR and standing support are the two important variables (figure 10). A highly significant relationship indicates that when the CMRR was greater than 50, little standing support was necessary. For CMRR=40, the successful cases used a standing support density of at least 1.0 MPa (145 psi). For CMRR values in the range of 45 to 50, standing support densities as low as 0.5 MPa (73 psi) appeared sufficient to prevent or control weighting failures. However, the cost of standing support is small compared to the cost of a weighting room failure, and the observations made from figure 10 should not be taken as a recommendation to eliminate standing support.

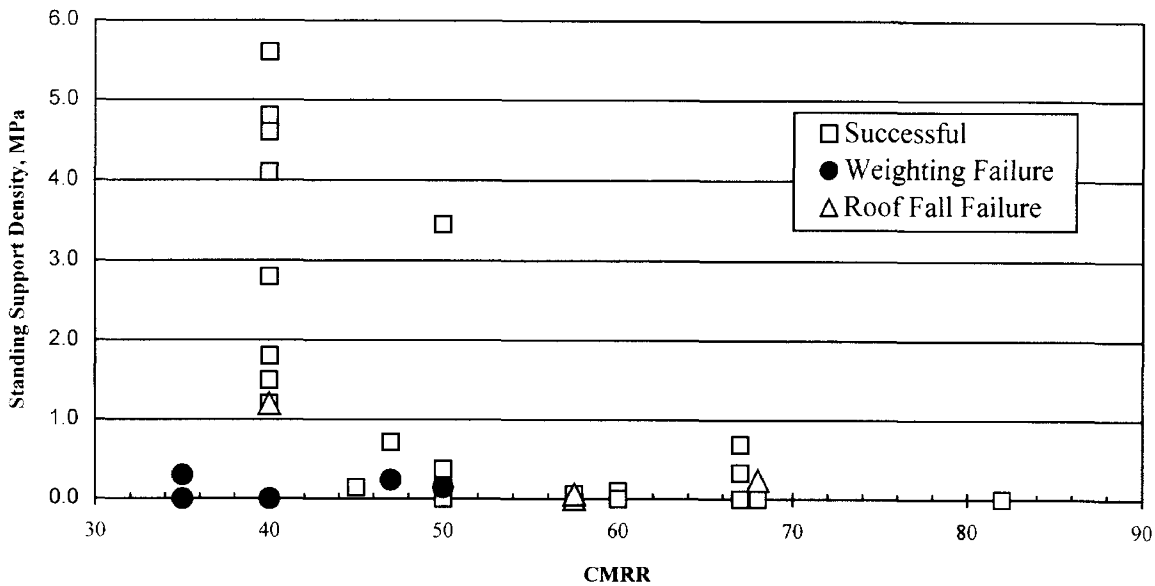

Figure 10.-CMRR versus Standing Support Density, for successful mine throughs and cases of weighting and roof fall type failures. All weighting failures took place with CMRR<50 and standing support density <0.5 MPa.

CONCLUSIONS

As the vast majority of cases attest (92%), longwall mining into pre-driven rooms can be safely accomplished with adequate support for the conditions. However, severe ground control problems from weighting can be encountered where there is weak roof and little or no standing support. Although it appears of little value in preventing weighting failures, intrinsic roof support is of significant value in preventing roof falls. In the cases of weighting failures, the failure involves the main roof and the establishment of a new caving break ahead of the face along the abutment pillar. The costs associated with these failures and the hazards created are substantial. However, even with a weak roof, (CMRR=40), a standing support density of 1.0 MPa (145 psi) appeared sufficient to prevent or control failure and allow the longwall to enter or pass through the rooms. With stronger roof (higher CMRR values) the standing support density required appeared to decrease. This is an observation and should not be considered a recommendation to eliminate standing support solely on the basis of measured CMRR values. Other factors that contribute to this type of failure include soft floors that can result in pillar punching and slow mining rates.

With a stronger roof, where the weighting type failure does not occur, much less standing support or intrinsic roof reinforcement alone have been successful. However, even under these conditions roof falls occur either in the unsupported area between the shields and the fender or in the room itself. In the cases where the falls occur in the rooms, they can be controlled by increased roof reinforcement or by the addition of standing support.

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