Geotechnical and Geological Engineering **19:** 137–168, 2001.

A study of the ground control effects of mining longwall faces into open or backfilled entries

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(Received 16 October 2000; accepted 29 March 2001)

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. To help determine what factors contribute to such failures, a comprehensive international database of 131 case histories has been compiled. The cases include six failures where major rock falls occurred in front of the shields, and seven even more serious failures involving major overburden weighting. The case studies suggest two types of room failure mechanism. The first is a roof fall type failure caused by loading of the immediate roof at the face as the fender or remnant longwall panel narrows. The second is an overburden 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. Weighting failures were not greatly affected by the density of roof reinforcement. In one of the overburden weighting cases, in a Pittsburgh coalbed mine, stress cell, convergence, bolt load and extensometer data have been used to analyze the failure in detail.

Key words: coal mining, ground control, longwall, recovery room.

1. 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.
- To mine through entries that were driven mid-panel to facilitate ventilation and escape, ("super" longwall panels).
- To extract old barrier pillars that may include crosscuts or crossing entries.
- To mine through areas where geologic features, such as a dike or a fault have been removed prior to longwall mining.

Experience has shown, however, that there are serious ground control risks with this 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.

In order to help prevent such failures in the future, a comprehensive database of all known examples of longwalls mined into or through pre-driven rooms has been compiled. A total of 131 case histories have been collected from 18 mines in the U.S.A., Australia, and South Africa, covering the period from the mid-1980s through to 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 are provided in the paragraphs that follow.

One particular recovery room weighting failure (Pennsylvania Mine "B"), has been described and analyzed in detail. In that case, the room was instrumented with extensometers, instrumented roof bolts, convergence sensors and vibrating wire stress cells installed in both the longwall panel and in one of the front abutment pillars. The instrument data obtained from Pennsylvania Mine "B" are more detailed than are available from any of the other cases. The instrument data appear to confirm the weighting failure model derived both from individual anecdotal reports and from statistical analysis of the more limited data (both numerical and qualitative) available from the majority of the case histories.

2. U.S.A. 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:

- Eighteen crosscuts extracted with a 76 m (250 ft) wide longwall face.
- Two "probe entries" driven across a 122 m (400 ft) wide face.
- A number of 42 m (140 ft) crosscuts inside the same 122 m (400 ft) face.

In each of these cases, the face entered the pre-driven room at an angle, generally about seven 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 122 m (400 ft) face, a "massive roof fall" occurred at mid-face which required two 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 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 remnant longwall panel). The shield canopies were forced onto the face conveyor and one 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 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 cost considerations 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 fender was between 1–2 m (3–6 ft) wide, the face advance stopped for 6 hr 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 an 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).

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

Country	State	Mine	No. of Rooms	Soft Floor[1]	Depth, m	CMR, R[2]	Seam Height, m	Panel Width, m	Room Length, m	Room Width, m	Shield Capacity, tonnes	RDI[3], MPa·m	Standing Support, MPa	Slow Mining[4]	Out-come[5]
USA	PA	A	1	N	150	40	2.4	244	61	6.1	454	0.37	5.60	N	1
USA	PA	A	1	N	150	40	2.4	183	183	5.2	454	0.43	5.60	N	1
USA	PA	A	1	N	150	40	2.4	183	183	5.2	454	0.37	4.10	N	1
USA	PA	A	1	N	150	40	2.4	183	183	5.2	454	0.37	2.80	N	1
USA	PA	C	3	N	168	40	2.9	270	270	4.9	794	0.22	1.50	N	1
USA	PA	B	3	N	210	40	2.2	250	250	4.9	635	0.53	1.80	N	1
USA	PA	B	3	N	210	40	2.2	305	305	4.9	635	0.29	4.80	N	1
USA	PA	B	1	N	220	40	2.2	305	305	6.7	635	0.88	0.00	N	3
USA	PA	B	1	N	220	40	2.2	305	305	5.2	635	0.72	1.80	Y	1
USA	MD		16	N	190	40	2.6	229	229	4.9	599	0.33	1.20	Y	1
USA	MD		1	N	190	40	2.6	229	229	4.9	599	0.33	1.20	Y	2
USA	MD		6	N	190	40	2.6	229	229	11	599	0.66	4.60	N	1
USA	CO		1	Y	140	35	2.1	168	168	5.2	590	0.62	0.30	Y	3
Australia	NSW	A	1	Y	90	60	3.1	200	200	4.2	590	0.64	0.10	N	1
Australia	NSW	A	6	Y	90	60	3.1	200	200	4.8	590	0.75	0.00	N	1
Australia	NSW	A	1	Y	50	82	3.4	200	200	4.8	590	0.75	0.00	N	1
Australia	NSW	A	4	N	290	50	3	200	200	4.8	590	1.83	0.37		1
Australia	NSW	A	1	N				225	225						2
Australia	NSW	B	1	N	275	45	3	150	150	6.5	617	0.00		Y	3
Australia	NSW	B	3	N	275	45	3	150	150	3.5	617	0.93	0.14	N	1
Australia	NSW	D	2		400	70		200			907				1
Australia	NSW	E	several					50			363				1
Australia	QLD		1	N	190	50	2.4	200	200	5.2	726	0.76	0.14	N	3
South Africa		B	2		200	70	1.9	200	120	5		0.50	0.00	Y	1
South Africa		A	1	N	125	50		200	200	2.6	327	0.42	0.22	Y	2
South Africa		A	4	N	125	50		200	200	2.6	327		3.45	N	1
South Africa		A	1	Y	70	35	3	200	100	5	327	0.55	0.00	Y	3

[*continued*]

Table 1. Continued

Country	State	Mine	No. of Rooms	Soft Floor[1]	Depth, m	CMR, R[2]	Seam Height, m	Panel Width, m	Room Length, m	Room Width, m	Shield Capacity, tonnes	RDI[3], MPa·m	Standing Support, MPa	Slow Mining[4]	Out-come[5]
USA	WV		1	N	305	50	1.5	244	244		590	0.55	0.05	N	1
USA	WV		1	N	305	50	1.5	244	244		590	0.52	0.13	N	1
USA	WV		6	N	305	50	1.5	244	244		590	0.52	0.00	N	1
USA	WV		6	N	305	50	1.5	244	244		590	0.42	0.00	N	1
USA	AL	C	3	N	366	67	2.1	265	265		726	0.13	0.69	N	1
USA	AL	C	3	N	366	67	2.1	265	265		726	0.41	0.33	N	1
USA	AL	C	12	N	366	67	2.1	265	53		726	0.54	0.22	N	1
USA	AL	B	1	Y	610	47	2.3	107	107	6.1	590	0.15	0.24	N	3
USA	AL	B	3	Y	610	47	2.3	107	107	6.1	590	0.15	0.72	N	1
USA	AL	A	1	N	610	57.5	2.5	76	76	6.1	590	0.15	0.00	N	2
USA	AL	A	1	N	610	57.5	2.5	76	76	6.1	590	0.15	0.06	N	2
USA	AL	A	16	N	610	57.5	3.0	76	76	6.1	590	0.29	0.06	N	1
USA	AL	A	2	N	610	68	3.0	122	67	6.1	590	0.09	0.00	N	1
USA	AL	A	6	N	610	68	3.0	122	67	6.1	590	0.32	0.00	N	1
USA	AL	A	1	N	610	68	3.0	122	67	6.1	590	0.32	0.24	Y	2
USA	OH		1	Y	150	45	2.1	152	152	4.9–5.5	340	0.19	0.18	Y	3

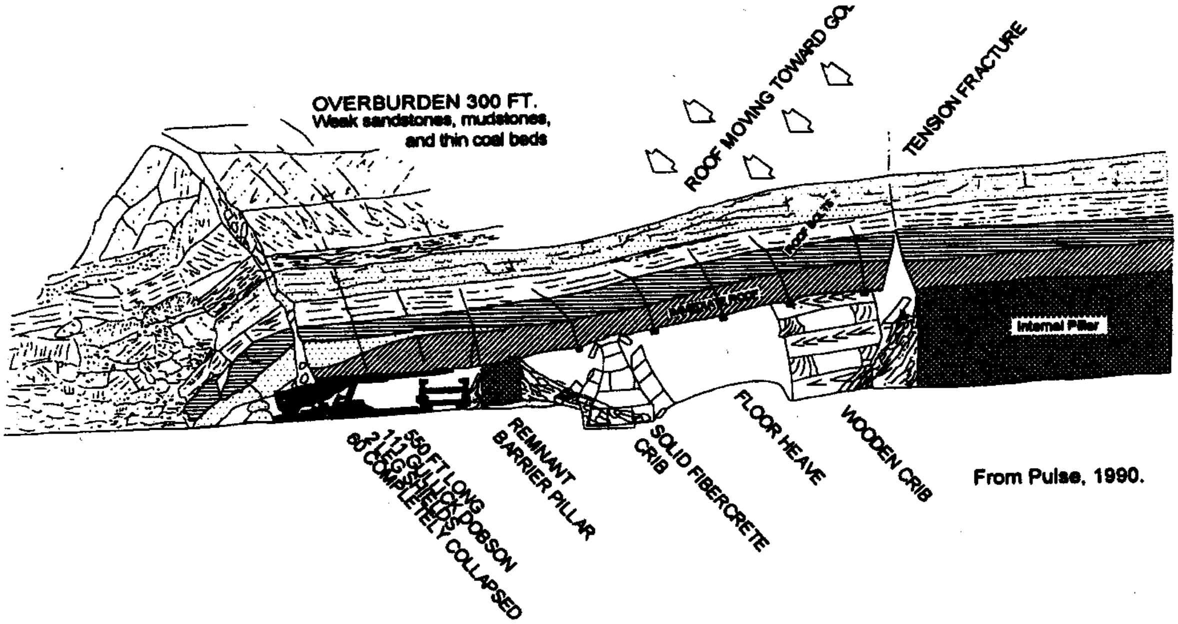
[1] Soft Floor. Y=Soft. N=Normal or not noted as soft by the original source.

[2] CMRR=Coal Mine Roof Rating.

[3] 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.

[4] Slow Mining. Y=Slow mining. N=Normal or rapid mining or rate unknown.

[5] Outcome. 1=Successful outcome. 2=Failure due to face break or face fall. 3=Failure due to major overburden weighting.



From Pulse, 1990.

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

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 portion of the abutment load appeared to have shifted onto the shields. Under such conditions the face could not move the last few feet into the room.

The longwall was eventually recovered from the location where the face was halted, just short of the recovery room. It was necessary to grout and heavily support the room to allow the fender to be mined out with a continuous miner and provide room for the recovery. The recovery operation took about two months.

Maryland: This mine has used 23 recovery rooms, typically 4.9 m (16 ft) wide; but six of the rooms were 11 m (36 ft) wide. The only failure was one of the standard rooms where roof falls necessitated two weeks of remedial action. The extra support in this case was a row of concrete cribs on the longwall panel side of the recovery room and a row of wooden cribs on the abutment pillar 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.*, 1993a, Wynne *et al.*, 1993b). 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).

Ohio: A single recovery room was attempted at this mine in the Pittsburgh coalbed sometime in the early 1980s. The recovery attempt resulted in a weighting type failure. Two 4.9–5.5 m (16–18 ft) entries were driven across the longwall face. The standing support consisted of large wooden posts and cribs in the recovery room and a large number of steel posts in the second room. The standing support density was estimated from examination of photographs of the room taken shortly after the failure. From a telephone conversation one of the authors (Oyler) had with an engineer who worked on the recovery project, the primary intrinsic support is believed to have consisted of 2.4 m and 3 m (8 and 10 ft), 16 mm (5/8 in) diameter mechanical bolts on 1.2 m (4 ft) centers. No secondary intrinsic support was used. Longwall census data give the mining height as 2–2.2 m (78–87 in) and the shield capacity as either 310 or 340 tonnes (two different shield types were used during the period in which the recovery attempt was believed to take place). In the telephone conversation the floor was noted as being soft with the shields digging into the bottom, possibly due to floor heave. National Institute for Occupational Safety and Health data on nearby Pittsburgh coalbed mines where thin competent sandstones are often present in the bolting horizon give estimates of the Coal Mine roof Rating (CMRR) (Molinda and Mark, 1994) between 35 and 55. The immediate roof at this mine was described as 1.8–2.4 m (6–8 ft) of drawrock and slickensided shale with a poor quality sandstone at 2.4–3 m (8–10 ft), suggesting a much lower roof strength. An estimate of 45 has been used for the CMRR in this report. The face was angled with the headgate about 14 m (46 ft) ahead of the tailgate. The angle is clearly apparent in photographs. Finally, mining was delayed at some point by as much as 1.5 shifts. At the time the weighting failure took place the shields had already advanced into the recovery room at the headgate. Because it is not possible to determine which portion of the face is shown in the photographs, it is not clear how far the face had advanced when the failure took place. It took several months to recover the face.

Pennsylvania Mine "A": A total of four recovery rooms were successful at this Pittsburgh seam mine (Bauer *et al.*, 1988; Bauer *et al.*, 1989; Bauer and Listak, 1989; Listak and Bauer, 1989). Three different types of concrete supports were used. The first room employed 1.2 m×1.8 m (4 ft×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 0.2–0.3 m (8–12 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 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×22 mm (8 ft×7/8 in) mechanically-anchored resin-assisted bolts, 3.7 m (12 ft) cable bolts, mesh over the entire roof, two rows of T-5 channels running parallel to the entry and 15 mm (0.6 in) cable trusses on 1.2 m (4 ft) centers. The room was driven 5 m (16 ft) wide and later widened to 6.5 m (22 ft). Supplemental bolting was performed to provide support of the additional mined width. During longwall operations the mining rate averaged more than 15 m/d (50 ft/d) as the panel approached the room. When the fender was 3 m (10 ft) wide, the room began to deteriorate and most shields went on yield immediately after being set. 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 advance the shields through the collapsed roof, with remedial efforts including the use of polyurethane grout and the installation of cribs.

This recovery room was extensively instrumented with roof extensometers, load cells on roof bolts, strain gauged roof bolts and cable trusses, and vibrating wire stress cells installed in an abutment pillar and in the panel. The data obtained from these instruments will be discussed in detail in a later section of this paper.

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 just over 127 mm (5 in) in the tailgate, and much smaller over most of the face.

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.

3. Australian Case Histories

New South Wales (NSW) Mine "A": Recovery rooms were used on 13 panels in four different coalbeds at this mine (Simpson *et al.*, 1991). All cases but one were successful. The unsuccessful case was the only mine through attempt in the West Borehole coalbed. The available information for the West Borehole case is limited to the panel width and the type of failure. 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 panel side 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 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 angle the face by keeping 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 first recovery room failed, causing the shields to go 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 it was 2 m (6 ft) wide. High water flows from the gob and gas flows into the tailgate entry were noted in the course of the mine through.These were 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 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 at 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 since mining continued after the longwall passed through the room.

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 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 and they were successful.

Queensland: A single 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 bolts closest to the ribs were angled over the panel 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 panel 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 fender was 5 m (16 ft) wide it 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.

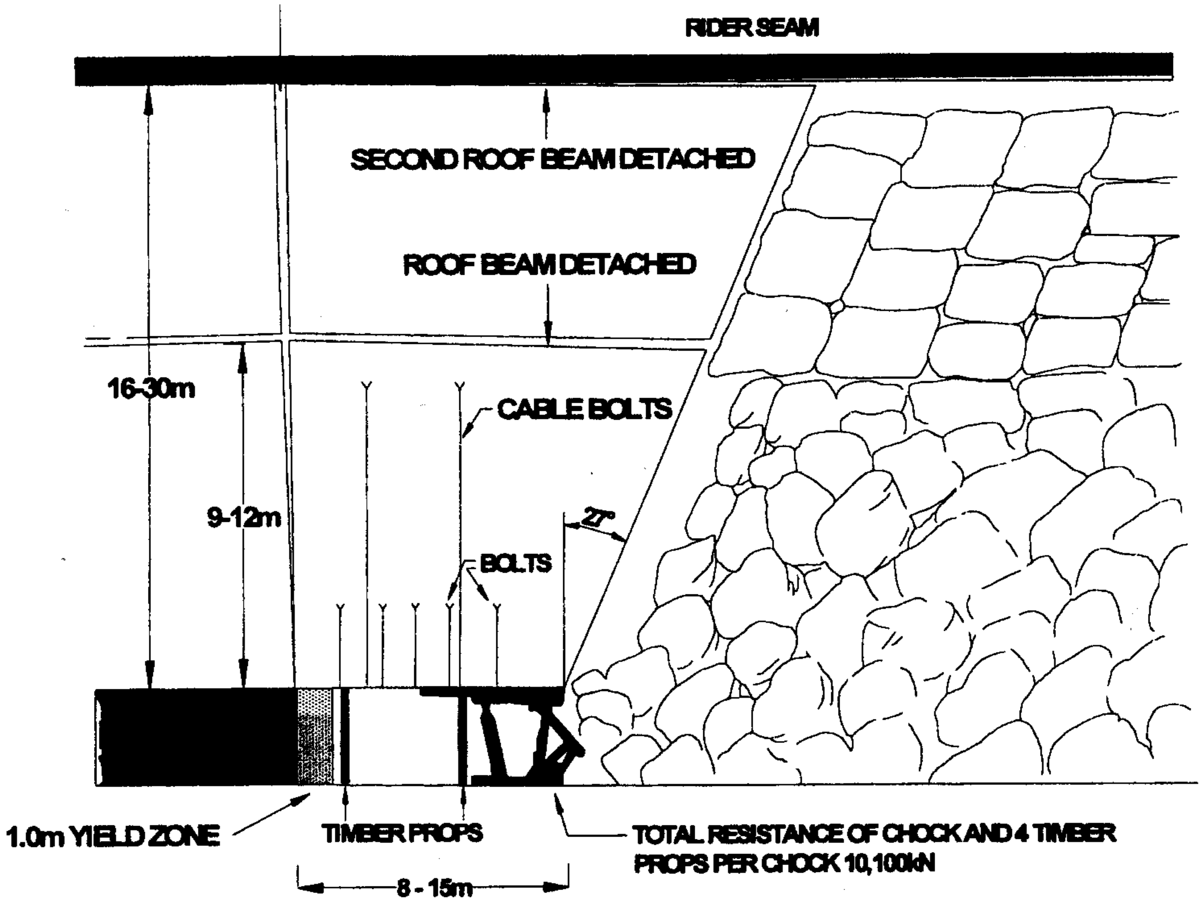


Figure 2. Conceptual model of a weighting type room failure. Based upon observations of an Australian weighting failure. From Klenowski, 1990.

An analysis made after the failure suggested that a "tensile failure" had extended upward to a rider seam located 16 m (50 ft) above the German Creek Seam (Figure 2). Convergence 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).

4. 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, 1998). 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 hrs when the fender was 3 m (10 ft) wide. Apparent water entry from a joint in the panel 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".

South Africa Mine "B": Two rooms were used successfully to remove a dike crossing both of them at roughly a 10° angle to the face orientation (Minney, 1999). The immediate roof rock was approximately 8 m (26 ft) of competent sandstone directly above the #4 coalbed. The main roof included nearly 50 m (160 ft) of competent siltstone/sandstone and sandstone. The rooms were driven by first mining an entry in the coal alongside the dike and then removing the dike, which was about 0.6 m (2 ft) wide. Primary support in the rooms consisted of three rows of 1.5 m (5 ft) fully grouted resin bolts on 2 m (6.6 ft) centers. Secondary support consisted of 1.8 m (6 ft) tensioned fully grouted resin bolts on 1.5×2.0 m (5×6.6 ft) centers and two rows of 6 m (20 ft) cable bolts. No significant standing support was used in either mine through. The second panel mine through experienced 5 shifts of down time, without significant detrimental effect on either the longwall face or the dike room.

In order to reduce the risks associated with the mine throughs, the panel widths were reduced to some 120 m (394 ft) on the first panel, and to an estimated 140 m (460 ft) on the second. On both panels a 30 m (100 ft) long entry was mined from the room, parallel to the gateroads, toward the advancing longwall face to serve as a tailgate entry and facilitate the removal of the shields from the portion of the panel that would not be mined until the dike was reached and the face could be widened back to 200 m (650 ft).

5. Failure Mechanisms

In the vast majority of cases, longwalls have been successfully mined into pre-driven rooms. Of the 131 cases, only 13 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 six cases where the problems were due to roof falls occurring in front of the shields. The second group consists of seven cases involving severe shield weightings accompanied by major convergence.

Roof falls occurred in two situations as the longwalls approached the pre-driven rooms. Some failures developed in the unsupported roof span between the shield tips and the fender (the portion of the longwall panel between the shields and the room), because of the increased span that resulted from extensive coal yielding in the fender. Other roof failures developed because of the large span between the shield tips and the abutment pillar once the fender crushed or was mined out. In both cases a substantial portion of the room could be involved. Additional secondary support was typically required to prevent or control roof fall failures.

The weighting type failures resulted in the most severe ground conditions. In the weighting failures, the shields were loaded to the yield point, allowing large roof-to-floor convergences that could be severe enough to cause the shields to become iron-bound. The heavy loading apparently resulted when a new caving break line developed at the abutment pillar rib of the pre-mined room. In the seven cases where the weighting type failures occurred, accelerated rates of convergence were initiated when the fenders were 3 m (10 ft) or less in width. Up until then, the fenders apparently provided enough support to the main roof to prevent the formation of a new caving break line.

Where the standing support density in a room is insufficient, when the new cave line develops, the shields may be called upon to control most of the weight of a cantilever of roof that extends across the pre-mined room. The additional span can double the load that the shields previously supported. As shown in Figure 2, the height of the broken rock requiring support is also greater than normal because of the wider span between the shield tips and the abutment pillar. Further, because the shields are not directly under the main rock mass, they are not in a good position to handle this new load distribution. As the detached block moves down, the main roof is affected. If the main roof is not strong enough to bridge over the detached block, it will subside and add additional load to the face area. Once a weighting failure begins, intrinsic supports (roof bolts) are of little use, because the new caving zone goes above them. On the other hand, where the main roof is strong, it can help the overburden to bridge across the room and face, resulting in manageable face and room conditions, even with minimal standing support.

6. Qualitative Analysis of Factors Affecting 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 authors in past visits to the mines.

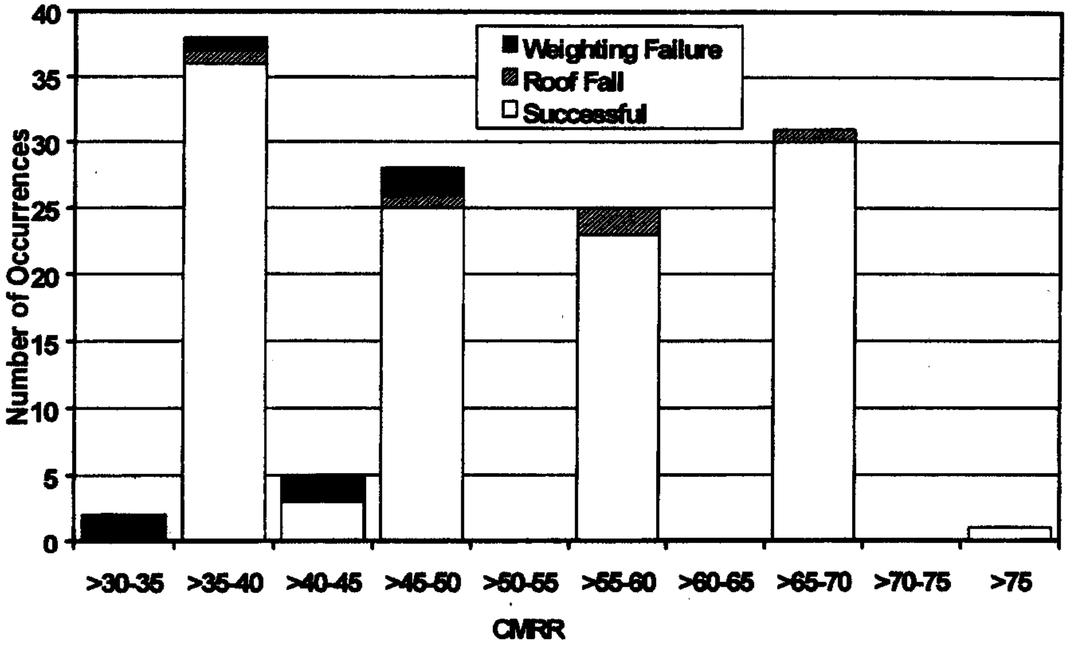


Figure 3. Histogram of CMRR versus mine through occurrences, and indicating results of the mine through.

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

Main Roof: Insufficient data were available on main roof 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: Case histories were available for a wide range of depths. Roof fall type failures were more likely to occur at greater depth, but not weighting failures (Figure 4).

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.

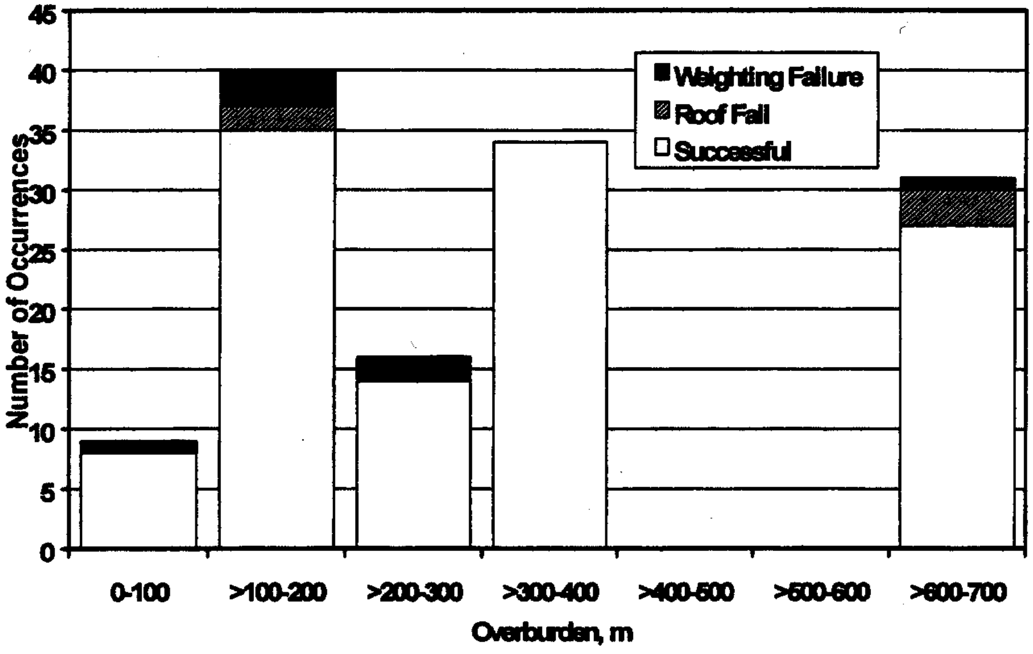


Figure 4. Histogram of Overburden versus mine through occurrence.