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Short-Delay Blasting in Underground Coal Mines

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot	pct	percent
in	inch	s	second
lb	pound	st	short ton
ms	millisecond		

SHORT-DELAY BLASTING IN UNDERGROUND COAL MINES

By Richard J. Mainiero [1] and Harry C. Verakis [2]

ABSTRACT

The Bureau of Mines has conducted research to determine whether the total elapsed delay time for blasting bituminous coal in underground mines could be safely expanded beyond the present 500-ms limitation without igniting a methane or methane-coal dust atmosphere. The results indicated that the increase of total delay from 500 to 1,000 ms had no detectable effect on safety relative to incendivity as long as permissible practices were observed in all other aspects.

Research was also conducted to evaluate the safety of 18-in hole spacing for delay blasting in coal relative to misfires. For a variety of permissible explosives, misfires were observed for about 50 pct of the holes at 18-in spacing. Based on this observation, the Bureau has recommended that the new regulations prohibit hole spacings of less than 24 inches in underground coal mines. Misfires were also observed for 24-in spacing, but the number of misfires and test shots was too small to support any firm conclusions.

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INTRODUCTION

For the purpose of improving regulations, the Mine Safety and Health Administration (MSHA), U.S. Department of Labor, has made a comprehensive review of the blasting and explosives standards for underground coal mines contained in Part 75, Title 30, Code of Federal Regulations. A concurrent review was also made of the approval requirements contained in Title 30, Parts 15 and 25, for permissible explosives, blasting machines, and related blasting items. From these reviews, MSHA completed development of preproposal safety standards for the use of explosives in underground coal mines and related requirements for the approval of permissible explosives and blasting items. The preproposals are the first stage in the MSHA rulemaking process, wherein public comments are solicited for consideration, review, and evaluation prior to an MSHA proposed rule.

The current approval standards, which contain use requirements for explosives, were reorganized, and the use requirements were consolidated into a Part 75 preproposal draft. The Part 75 preproposal draft contains sections on the use of explosives in bituminous, lignite, and anthracite mines and a section on compressed air blasting. The preproposed approval standards cover approval requirements for permissible explosives, including newly prepared requirements for sheathed explosives for use in unconfined applications, approval requirements for water stemming bags, new approval requirements for detonators, and also requirements for approval of blasting machines. These preproposed explosive use and approval requirements were announced in mid-1984 in the Federal Register with a request for public comments.

During development of the preproposed explosive use and approval standards, MSHA asked that the Bureau of Mines conduct research on multiple short-delay blasting of coal with permissible explosives. The type of research requested had not been performed since the work done in the Bureau's Experimental Coal Mine at Bruceton, PA, over 30 years ago. Accordingly, the Bureau, with the assistance of MSHA, sought a mine site at which to conduct experiments on the delay blasting of coal with permissible explosives. A site was found for the experimental work and officially acquired in early August 1984. The site, known as Consolidation Coal Co.'s Dark Hollow Mine, is located between St. Clairsville and Cadiz, OH. It is a surface coal mine site covering several acres of bituminous coal, from part of which the overburden has been removed, and a nearby 50-ft highwall. The exposed coal seam and the seam in the base of the highwall (both Pittsburgh No. 8) are about 5 ft thick (figs. 1-2).

A main objective of the Bureau's experiments at the acquired site was to study and determine if the total elapsed delay time for multiple short-delay blasting of bituminous coal could be safely expanded beyond 500 ms without igniting a methane or methane-coal dust atmosphere. MSHA presently limits the total elapsed time to 500 ms. Secondly, there have been many reports over the past few years of misfires of permissible explosives. These reports were not well documented, but sufficient reports of this type were received over a period of time to warrant study. The experimental arrangements, tests performed, and conclusions reached are described herein.

EXPERIMENTAL PROGRAM

DELAY TIME STUDY

The first series of shots at the Dark Hollow Mine was conducted in a pit in which the overburden had been stripped from the 5-ft-thick coal seam. The resulting exposed coal block was approximately 250 ft long by 100 ft wide. This test area provided ideal research conditions, since shooting could be conducted in an actual coal seam while avoiding many of the difficulties that would be encountered in an underground coal mine. For each shot, steel ingots

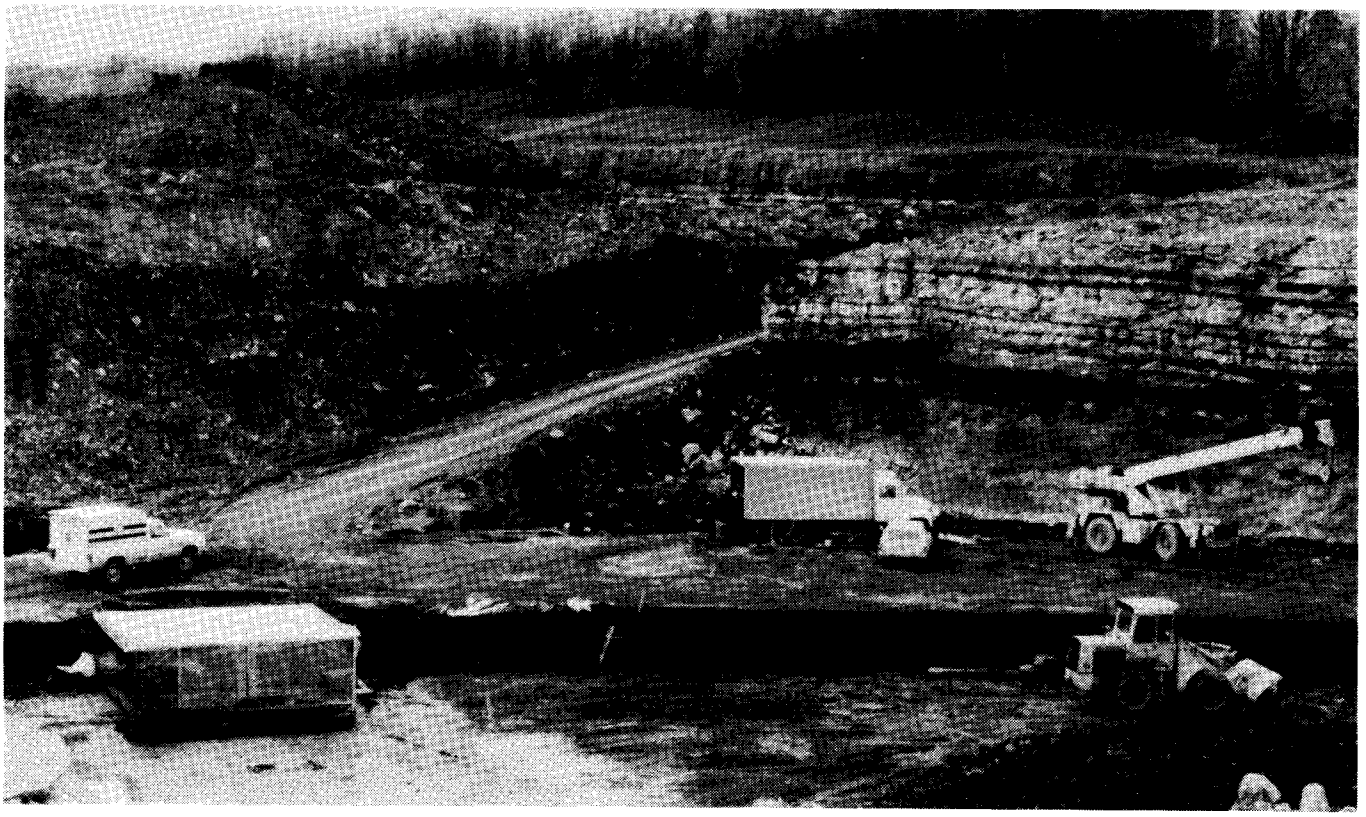

FIGURE 1. - Uncovered coal seam in which initial research was conducted.

FIGURE 2. - Pit in which highwall shots were fired.

top of the coal to provide burden and minimize the tendency of the coal to relieve in the upward direction. Preliminary shots indicated that 100 short tons (st) of steel ingots placed over an area measuring 20 by 10 ft was sufficient for this purpose.

The delay blasting tests began with a series of two- and three-hole shots to provide information necessary for the design of appropriate test-blast patterns. The initial shots showed that when two fully stemmed, 90-in-deep, 1.75-in-diam holes, each loaded with 3 lb of permissible explosive, were rear-primed and fired at a 24-in horizontal spacing with a 75-ms delay, partial misfires (failure to propagate detonation throughout the explosive column) were consistently observed. Examination of the muck pile showed the misfires to be the result of cutoff holes. The misfired cartridges of the second hole were no longer in a column but were shifted up to 12 in. to either side of the original column location. These misfires were avoided if the holes were placed 24 in. apart vertically or diagonally or 30 in. apart horizontally, or if the explosive load was lowered to 1.5 to 2 lb per hole.

Considering this information, the blasting pattern illustrated in figures 3 and 4 was developed. This pattern, known as an "off-the-solid" slab round, is commonly used for conventional mining of coal in Appalachia. Two-inch-diameter holes made by a hand-held drill were used in this phase of the research. In some of the earlier work, 1.75-in holes made with a drilling rig were used. However, the drilling rig was not available throughout the test program. The slab-round pattern permitted the research work to be conducted with total elapsed delay times up to 5,500 ms. Emphasis in the test work was placed on experiments using the slab pattern with a total elapsed delay time of 1,000 ms. In the experimental work, the explosive columns were rear-primed and file-loaded, and clay was used for stemmed shots.

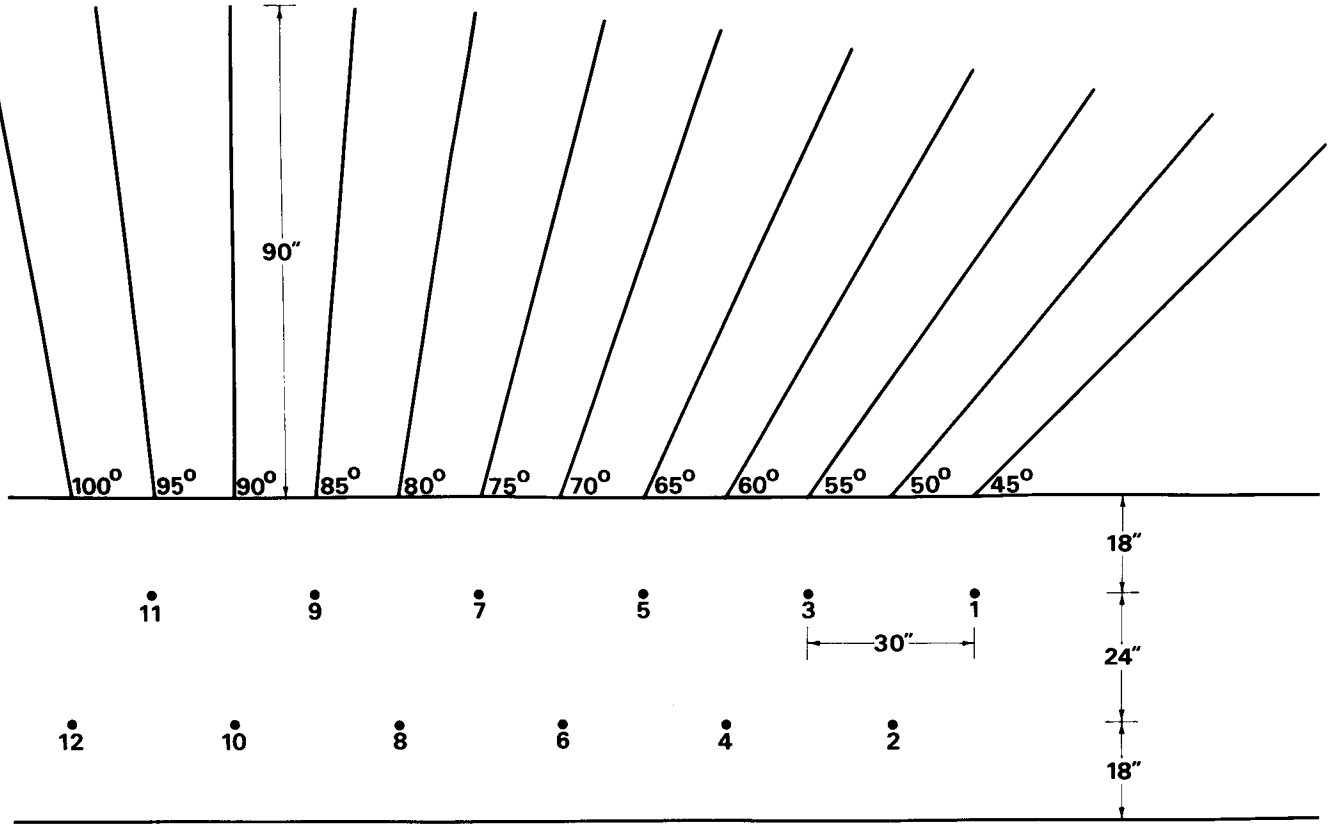

FIGURE 3. - Layout of the 12-hole, slab-round, shot pattern used in delay blasting research.

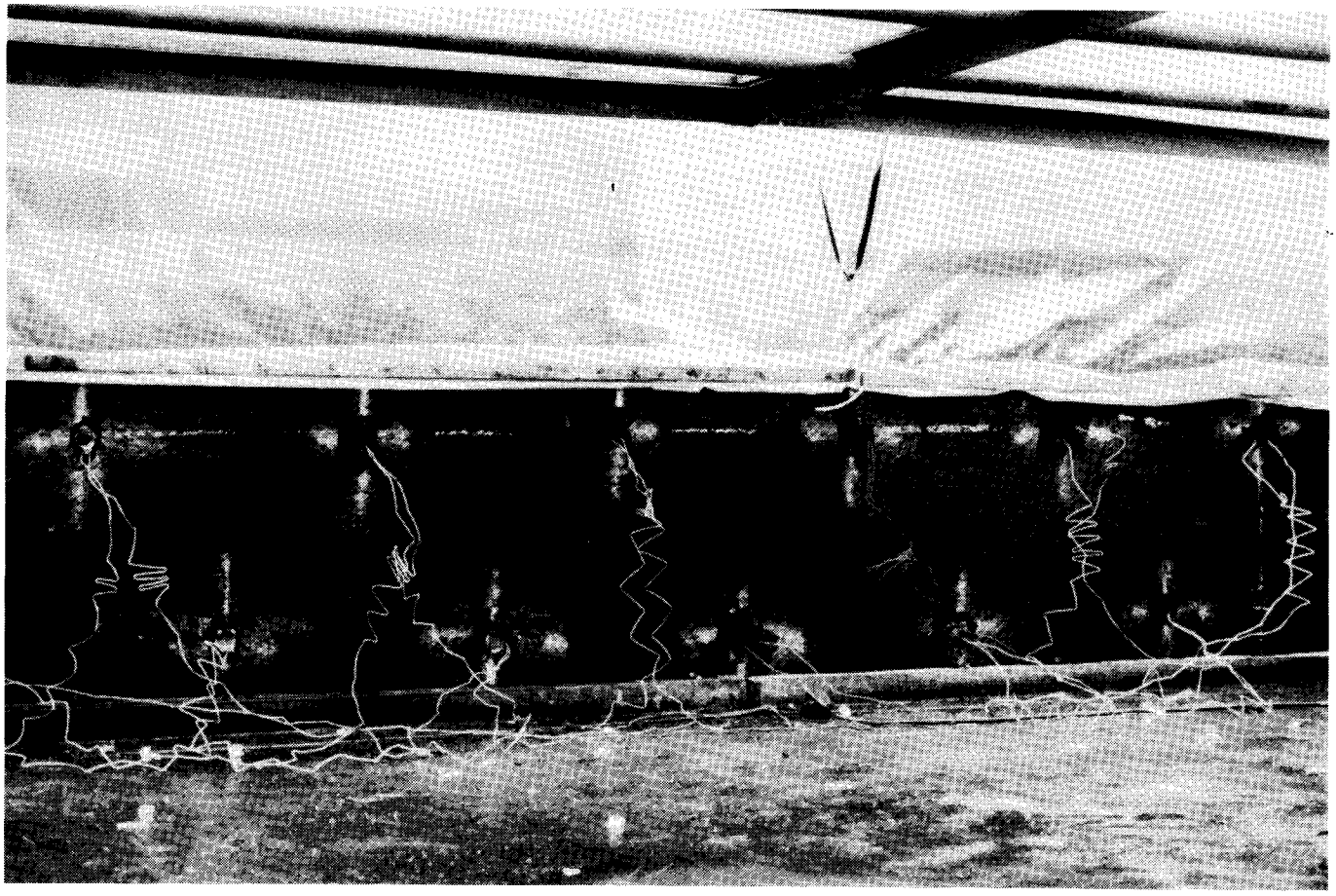

FIGURE 4. - Face loaded and ready for firing. Only 11 of the 12 holes are shown owing to the difficulty of taking photographs in the confined space of the gallery. The gas sampling tube can be seen in the center.

Later in the research, agreement was made with Consolidation Coal to use another pit, which had a 5-ft-high coal seam in a 50-ft highwall. At this location shot holes were loaded to 3 lb. The type of permissible explosive used, the explosive loading per hole, and delay timing were varied to determine the effect of these parameters on safety relative to incendivity. In the test work an attempt was made to use a sequential blasting machine to control the firing times for each of the holes in the shot pattern. This technique proved unsatisfactory because the multiple firing lines needed were frequently broken. Therefore, all but two of the shots were fired using commercial, electric, delay detonators connected in a single series to a 20-shot permissible blasting machine.

For this research, a gassy mine atmosphere was simulated by the positioning of a 20- by 20- by 6-ft steel gallery against the coal face. Care had to be taken to provide a good seal between the open front of the gallery and the coal face. To accomplish this, a cutting machine was used to prepare a fairly smooth coal face prior to positioning of the gallery. The front opening of the gallery had pieces of rubber affixed to it in order to obtain a tight fit against the face. Once the face had been loaded, the open sides of the gallery were covered with 4-mil polyethylene. The gallery is shown in figures 5 and 6. In preparation for a shot, methane was introduced into the gallery through a 1-in plastic tube connected to compressed gas cylinders in an instrumentation truck

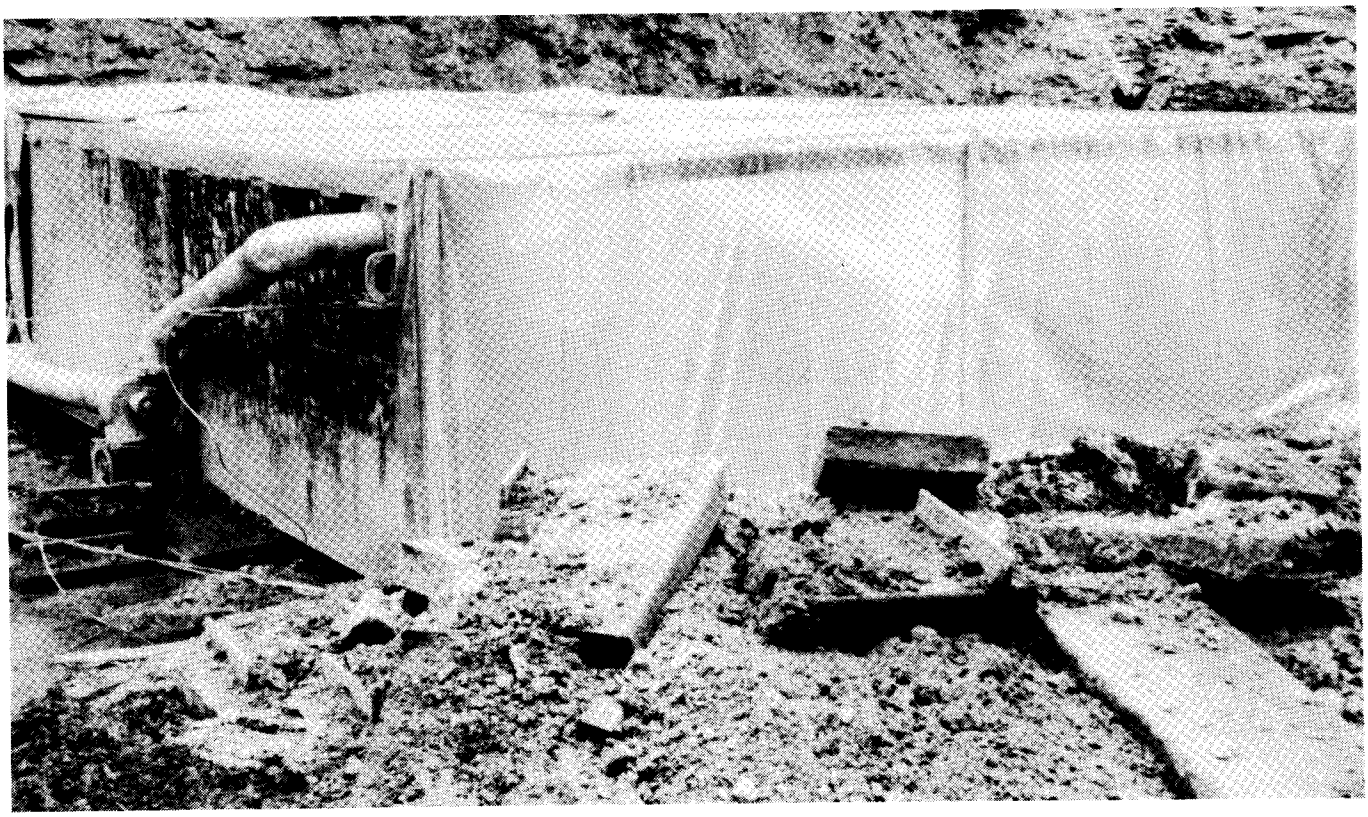

FIGURE 5. - The steel and plastic incendivity test gallery in place against the highwall face.

FIGURE 6. - Gallery in place against the highwall face. The instrumentation truck and connecting lines can be seen in the background.

200 ft away. The gallery atmosphere was constantly mixed by a squirrel-cage fan connected to two corners of the gallery by 8-in reinforced-plastic flexible duct. The composition of the gas mixture was continuously monitored by an infrared analyzer. Gas samples were also taken for laboratory analysis to verify the analyzer's calibration. When the gallery atmosphere had stabilized at 9 pct methane, the mixing fan and analyzer were shut down and the test shot was fired. All of the shots were recorded on video tape by cameras located in an area overlooking the pit. An ignition in the gallery could be identified by the associated bright orange fireball, which was totally absent for nonignitions. The area of the face with the broken coal resulting from the firing of a slab round is shown in figure 7. Figures 8 and 9 illustrate the fireball produced by a planned ignition of the gallery. Test results are summarized in table 1. Table 2 provides information on the permissible explosives used.

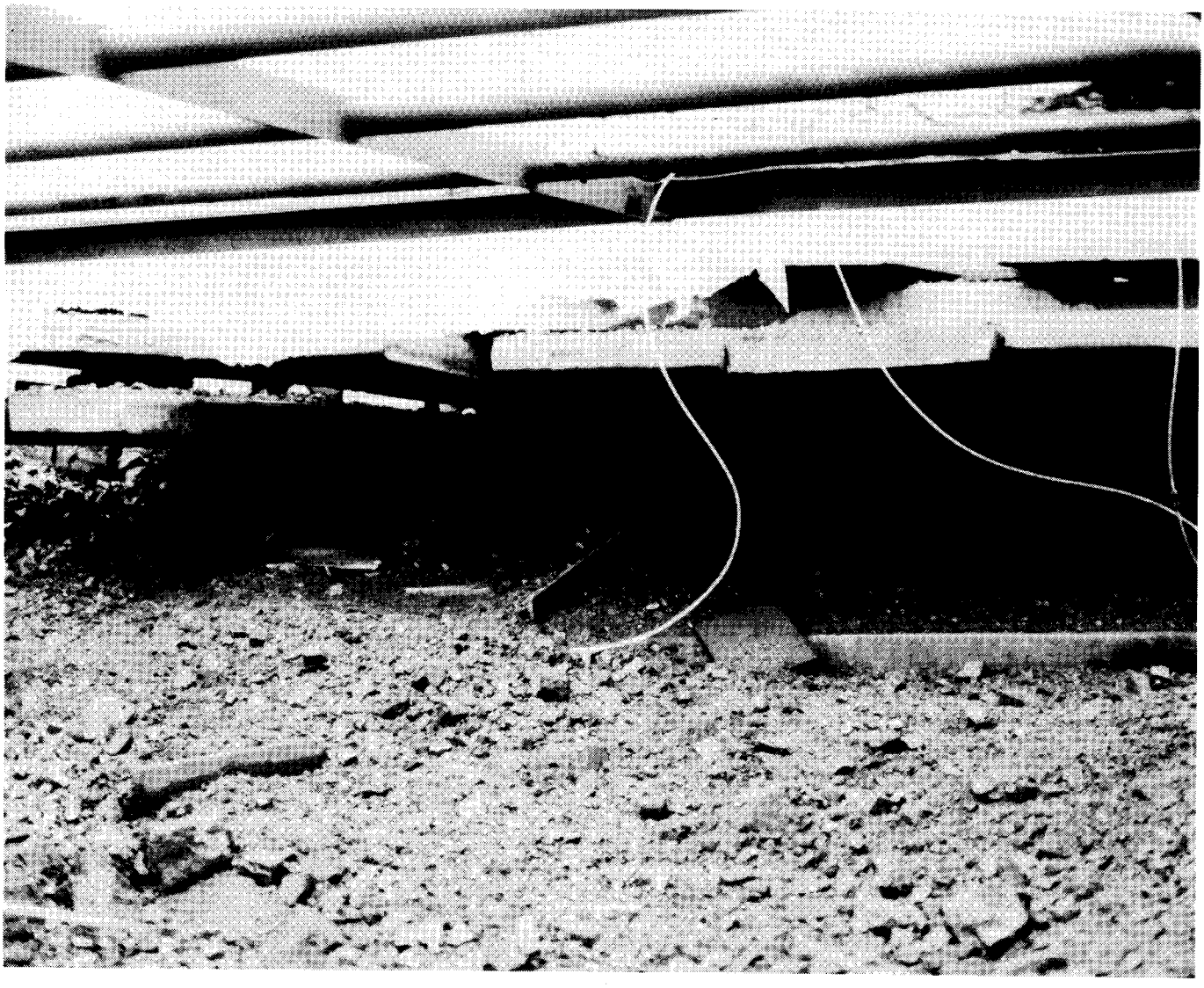

FIGURE 7. - Coal broken by a typical shot in the uncovered coal seam.

FIGURE 8. - Planned ignition of incendivity test gallery in a shot against the highwall face. Ignition was caused by loading the first hole beyond the collar without stemming.

FIGURE 9. - A later stage of the ignition shown in figure 8.

TABLE 1. - Summary of 12-hole gallery shots stemmed with 2 ft of clay and rear primed

(Shots 18-22 were fired in the highwall. Shots 1-17 were fired in the uncovered coal. All shots were off the solid slab rounds using 2-in-diam holes, rear priming, and 2 ft of clay stemming. No ignitions were observed.)

Shot	Permissible explosive	Explosive, lb per hole	Hole depth, in	Delay, s	Misfire
1	Emulsion	1.74	60	1	No.
2	...do	1.74	60	2	Yes.
3	...do	1.74	60	1	No.
4	...do	1.74	60	1	No.
5	Gelatinous A	2.0	60	1	No.
6	Granular A	1.6	60	1	No.
7	...do	1.4	60	1	No.
8	Granular B	1.65	60	1	No.
9	...do	1.65	60	1	No.
10	...do	1.65	60	1	No.
11	Granular B	1.65	60	2	Yes.
12	Water gel A	1.54	60	1	No.
13	...do	1.5	56	1	No.
14	...do	1.5	60	1	No.
15	...do	3.0	88	1	No.
16	...do	1.5	60	5.5	Yes.
17	...do	3.0	84	5.5	No.
18	Emulsion	3.0	96	5.5	No.
19	...do	2.9	84	1	No.
20	Gelatinous A	3.0	72	1	No.
21	Water gel A	3.0	84	1	No.
22	...do	3.0	84	1	No.

TABLE 2. - Permissible explosives used in delay blasting research

(All cartridges were 1.25-in diam)

Permissible explosive	Cartridge length, in	Cartridge weight, g	Average detonation rate, ft/s
Emulsion	12	264	16,540
Gelatinous A	8	226	18,440
Gelatinous B	8	212	16,010
Granular A	8	187	8,200
Granular B	8	189	9,840
Water gel A	15	350	11,650
Water gel B	15	361	12,630

HOLE SPACING STUDY

In-mine and field research into the misfire problem was conducted in two parts: in the Bureau of Mines Experimental Coal Mine during February 1984 and at Dark Hollow Mine during April 1985. The research conducted in the Bruceton Experimental Coal Mine is shown in table 3. This work was not intended or expected to solve the entire misfire problem, but merely to determine whether there was a misfire problem as had been proposed. At the time, 18-in spacing and 15-ms delay time between holes were considered the conditions that would most likely lead to misfires. The delays reported in table 3 were obtained using a combination of instantaneous and coal mine type delay detonators. Each shot consisted of a pattern of three parallel holes, each 1.75-in diam by 7.5 ft deep, laid out in a horizontal row. The spacing between the holes and the delay time between the center hole and the two outer holes were varied to determine the conditions that would lead to misfires. Two types of misfires were observed for the 18-in spacing. In some cases the explosive failed to fire and the column was found intact in the borehole following the shot. In other cases an inspection of the face following the shot revealed that the explosive was gone but the borehole was still intact, indicating a lack of detonation; it is suspected that the explosive may have burned in these cases. The first type of misfire is indicated in table 3 as "did not fire," and the second is indicated by "empty." As indicated in table 3, misfires were observed for all of the shots at 18-in spacing, and no misfires were observed for the holes at 27-in spacing. The delay time seemed to have no effect on the occurrence of misfires.

Additional research was conducted at Dark Hollow Mine to verify the occurrence of misfires at 18-in hole spacing. The hole diameters and depths employed in this part of the work were the same as those used in the mine, but the layout was changed in that some of the shots were in a vertical row rather than a horizontal row. No attempt was made to vary the delay time between boreholes. A coal mine type period 1 delay detonator was used to prime the center hole and coal mine type period 2 delay detonators were used in the two outer holes. Hole spacings of 18 and 24 in were used. As may be seen in table 4, the 18-in spacing led to misfires for most of the explosives. (In the table, the terminology "2/4 M" means that two out of a total of four cartridges in the hole misfired.) A few misfires were also observed at the 24-in spacing, but the frequency was much lower than that observed for the 18-in spacing.

TABLE 3. - Results of misfire research in Bruceton Experimental Coal Mine

(All holes were 1.75-in diam and 7.5 ft deep and were file loaded.
DNF means "did not fire." SP means "shot properly."
Empty means hole was empty.)

Permissible explosive	Spacing, in		Timing, ms		Result	
	Right	Left	Right	Left	Left	Right
Emulsion.....	18	18	15	15	DNF	DNF
Granular B.....	18	18	15	15	SP	DNF
Water gel A.....	18	18	15	15	Empty	Empty
Water gel B.....	18	18	15	15	DNF	SP
Do.....	18	18	70	70	DNF	Empty
Do.....	27	27	70	70	SP	SP
Do.....	27	27	85	15	SP	SP

TABLE 4. - Results of misfire research at Dark Hollow Mine

Permissible explosive	Result[1]	
	1st hole[2]	2d hole[3]
18-in-SPACING		
Horizontal orientation:		
Emulsion	4/5 M	4/5 M.
Do	4/5 M	4/5 M.
Gelatinous A	2/6 M	Shot properly.
Do	Shot properly	Do.
Gelatinous B	...do	Do.
Do	...do	Do.
Granular A	...do	Do.
Granular B	4/7 M	6/7 M.
Do	Shot properly	Shot properly.
Water gel A	3/4 M	1/4 M.
Do	Shot properly	Shot properly.
Vertical orientation:		
Emulsion	4/5 M	4/5 M.
Gelatinous A	2/6 M	Shot properly.
Gelatinous B	5/6 M	2/6 M.
Granular A	Shot properly	Shot properly.
Granular B	...do	1/7 M.
Water gel A	2/4 M	1/4 M.
24-in-SPACING		
Horizontal orientation:		
Emulsion	1/5 M	2/5 M.
Gelatinous A	Shot properly	Shot properly.
Gelatinous B	...do	Do.
Granular A	...do	Do.
Granular B	...do	Do.
Water gel A	...do	Do.
Vertical orientation:		
Emulsion	...do	4/5 M.
Gelatinous A	...do	Shot properly.
Gelatinous B	4/6 M	Do.
Granular A	Shot properly	Do.
Granular B	...do	Do.
Water gel A	...do	1/4 M.

[1] 4/5 M indicates 4 of 5 cartridges misfired (etc.).

[2] 1st hole is left hole for horizontal orientation, top hole for vertical orientation.

[3] 2d hole is right hole for horizontal, bottom hole for vertical orientation.

DISCUSSION AND CONCLUSION

As shown in table 1, no ignitions were obtained for any of the shots of 12-hole patterns of stemmed holes fired as off-the-solid slab rounds with total delays of 1.0, 2.0, and 5.5 s. The research indicates that increasing the total delay from 0.5 to 1.0 s has no detectable effect on safety relative to incendivity so long as permissible practices are utilized for all other aspects of the shot. Although a few shots were performed with total elapsed delay times of 2.0 and 5.5 s, the data were too limited to suggest trends or conclusions relative to these long delays.

Three misfires were observed--in test shots 2, 11, and 16. The misfire in shot 11 is not significant because the shot was fired using a sequential blasting machine and involved the failure of holes 10, 11, and 12 to fire due to the cutting of the firing line connected to these holes. Blasted-out coal from holes 1-9 apparently cut this firing line before the sequential blaster could deliver a firing pulse to holes 10-12. This is a serious problem where multiple firing lines are run close to the face. Three firing lines had been used in both shots 2 and 11: one connected to holes 1-6, one to holes 7-9, and one to holes 10-12.

The cause of the misfire in shot 2 is not known. While a sequential blasting machine was used to fire this shot as well, the misfire was different from that in shot 11, in that the explosive column and intact detonator appeared to have been ejected from a single hole. The two other holes connected in series with the misfired hole, as well as all the other holes in the pattern, fired properly; thus the misfire could not be attributed to a broken firing line, as for shot 11.

The misfire in shot 16 consisted of half a cartridge of permissible water gel explosive being found in the muckpile; this could possibly be attributed to the cutoff of an explosive column.

The use of 18-in hole spacing led to misfires in 50 pct of the holes for the variety of permissible explosives studied. This indicates that the use of 18-in hole spacings in delay blasting in underground coal mines is unsafe and should be prohibited. A few misfires were also observed at the 24-in spacing, but the frequency was much lower than that observed for the 18-in spacing and the significance of these misfires is uncertain at this point.

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