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A study of the efficiency of split-second delay electric blasting caps in underground limestone mining

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A STUDY OF THE EFFICIENCY OF SPLIT-SECOND DELAY ELECTRIC BLASTING CAPS IN UNDERGROUND LIMESTONE MINING

BY

JOHN B. H. FITZWILLIAM

A

THESIS

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Approved by J. D. Forrester
Professor of Mining Engineering

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PREFACE

The introduction of electric blasting caps having delay intervals of the order of one-half to one second proved of advantage in many aspects of underground mining, particularly development work. Their use spread, until they now supersede fuse-and-cap firing wherever possible. Split-second delay electric blasting caps are a comparatively recent development from conventional delay caps. They have been found of practicable use in quarrying operations, and have been applied in many phases of underground mining. While evidence, to show that short-delay firing in quarrying is more efficient than instantaneous firing, is becoming increasingly conclusive, it remains to be proved that split-second delays are more effective than conventional delays in underground operations. Being concerned with the lack of such evidence in favor of split-second delay caps, Mr. F. S. Elfred, Jr., General Manager, Western Cartridge Company, suggested that the testing of these caps be introduced into the research program of the Missouri School of Mines and Metallurgy. As one phase of this program, the author, under the guidance of Dr. J. D. Forrester, carried out a series of tests designed to compare the results of split-second and regular delay firing, at the Experimental Mine of the Missouri School of Mines and Metallurgy.

TABLE OF CONTENTS

Page

Acknowledgements ii

Preface iii

List of Illustrations v

List of Plates vi

List of Tables vii

Introduction 1

Review of Literature 2

The Experimental Mine and Equipment 13

Drilling and Blasting Techniques 22

Outline of Problem 23

Compilation of Data 24

Analysis of Data 30

Description of Tests 38

Conclusions 55

Summary 62

Bibliography 63

Vita 65

LIST OF ILLUSTRATIONS

Figure		Page
1	Cross-section of delay electric blasting cap. . . .	7
2	Comparison of raise round drill patterns used at Mount Weather Testing Adit	11
3	Plan of underground workings of the Experimental Mine of the Missouri School of Mines and Metallurgy	14
4	Experimental Drill Pattern No. 1	39
5	Experimental Drill Pattern No. 2	41
6	Experimental Drill Pattern No. 3	46
7	Experimental Drill Pattern No. 4	49
8	Experimental Drill Pattern No. 5	52
9	Experimental Drill Pattern No. 6	54
10	Diagram illustrating the way in which short-delay firing may give improved fragmentation . . .	60

LIST OF PLATES

Plate		Page
I	Western blasting caps	16
II	The author dumping a mine car on the grizzlies	26
III	View of the 4-inch and 12-inch grizzlies, and the weighing scales	27

LIST OF TABLES

TABLE Page

I Delay intervals of blasting caps of different manufacture 5

II Details of shaft station blasts at New Jersey Zinc 9

III Specifications on Minimax delay caps 17

IV Timing tests on Ventless Minimax Delay E. B. Caps 18

V Specifications for conventional Ventless Delay Caps 19

VI Timing tests on conventional Ventless Delay E. B. Caps 20

VII Timing tests on No. 6 Instantaneous E.B. Caps . . 21

VIII Loading of wedge-cut and modified wedge-cut drift rounds and the delays employed 33

IX Loading of Experimental Drill Pattern No. 4 and the delays employed 34

X Loading of Experimental Drill Pattern No. 5 and the delays employed 35

XI Loading of Experimental Drill Pattern No. 6 and the delays employed 36

XII Results and analyses of drift round tests 37

XIII Suggested delay series 58

INTRODUCTION

A comparatively recent development in the field of blasting detonators is the Split-second or Milli-second Delay Electric Blasting Cap. Although this type of blasting cap is reported to have been successfully applied to some underground mining operations, little evidence substantiating the claims of the various manufacturers has been published; and it is believed that these claims may have been derived more from theoretical considerations than from actual research.

The advantages of Split-second Delay E. B. Caps over Regular Delay E. B. Caps, as claimed by the manufacturers, may be summarized as follows:(1)

(1) improved fragmentation;

(2) marked reduction of "bootlegs";

(3) prevention of "cut-offs", and hence elimination of dynamite in the "muck-pile"; and,

(4) decreased concussion and vibration.

It has been the purpose, therefore, of the research herein described to assess the efficiency of Split-second Delay Caps as compared with that of Regular Delay Caps in the underground mining of limestone.

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(1) E. I. du Pont de Nemours & Company, Blasters' Handbook, p. 88 and pp. 1 - 7.

REVIEW OF LITERATURE

History of the Development of Blasting Caps (1)

One of the far-reaching discoveries of Alfred Nobel was the invention of a reasonably safe and efficient blasting cap, which was designed to detonate explosive with the safety fuse invented by the Englishman, William Bickford, in 1831. Nobel's blasting cap was a capsule, first of tin, but later of copper, containing mercury fulminate. The mercury fulminate was subsequently used in a mixture with potassium chlorate. However, it became desirable to produce a cheaper, more efficient, and safer cap without the use of mercury fulminate. Composition caps were a step towards this end. The first composition caps employed a primer of fulminate, and a base charge of tetryl. Tetryl explodes with high velocity, and will detonate many explosives of low sensitivity. Mercury fulminate was eventually eliminated by the use of lead azide in the ignition charge. The ignition mixture so obtained ignites easier and reduces the opportunity for misfires.

Blasting caps, as used with safety fuse, are still applied in many mining operations. However, in the initial stages of the development of blasting caps it was sought to fire them electrically. The earliest attempts had two bare wires inserted in the cap charge, and ignition was by means of a spark passed between these bare ends. This type of electric blasting cap was surplanted by low tension, or bridge-wire caps, such as that invented by H. J. Smith in 1876. Present day electric blasting caps, while embodying many improvements, still employ this principle.

The instantaneous electric blasting cap provides a means of firing simultaneously a number of charges of high explosive. An important development from the instantaneous E. B. cap is the delay electric blasting cap. Delay caps are generally used to fire explosives in sequence, and the advantages in their use, over that of fuse and caps, lies in the fact that timing is more accurate, and that a complete round can be fired without returning to the face between shots.

Regular Delay caps have a time interval of approximately from one to two seconds. Although the delay periods do not overlap, all caps of a given period do not detonate at precisely the same instant, and it is claimed that this fact is of advantage, since it reduces the violence of the blast for any given period of delay.(2) Such an advantage may be questioned on the grounds that some drill patterns, particularly the pyramid pattern, for optimum results, require that the cut holes fire as nearly in concert as is possible.

Split-second Delay Electric Blasting Caps

Split-second delay caps differ essentially from Regular delay caps in that the delay periods are very short. They contain a delay element of design different from that of Regular delays, so that the time intervals between the application of the current, and the firing of the successive delays are in the order of hundredths of a second. The actual delay intervals, as well as the

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(2) Ibid.

number of intervals available, vary with the products of the several manufacturers (Table I).

In Regular delay caps the delay interval is determined by the burning time of the explosive train contained in the cap. Hence, the delay element increases in length as the delay interval increases. In the split-second delay cap, however, the delay element is of constant length, the delay interval being obtained by regulation of the composition of the explosive train. An important improvement in the design of regular and split-second delays has been the introduction of the Ventless principle.(3) Whereas it was formerly necessary to provide a vent in the cap to allow the escape of gases evolved during the burning of the delay element, the use of an explosive train of such a composition that the small volume of gases evolved may be readily adsorbed, permits the caps to be completely sealed.

A cross-section of a typical delay electric blasting cap is shown in Figure 1. The shell is of nickel-plated gilding metal, sealed against water and moisture with a pitch water-proofing material, and a sulphur closure which is keyed to the metal shell. The passage of an electric current through the lead wires causes the bridge wire, a platinum alloy, to heat and ignite the igniter compound. This initiates the burning of the delay element, which is contained in a lead tube, detonation being complete on the igni-

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(3) U. S. Patents, Nos. 1,999,820 (basic patent), 1,989,729, 2,139,581, 1,924,324, 1,971,502, Re19,661 of 1,960,591.

TABLE I

Delay Intervals of Blasting Caps of Different Manufacture

WESTERN MINIMAX VENTLESS DELAY		DU PONT MS CAPS		ROCKMASTER CAPS		HERCULES NO-VENT SHORT-PERIOD CAPS	
Delay No.	Av. delay mil.-sec.	Delay No.	Av. delay mil.-sec.	Delay No.	Av. delay mil.-sec.	Delay No.	Av. delay mil.-sec.
0	10	MS-25	25	0	0	INST.	5
1	32	MS-50	50	1	8	A	25
2	60	MS-75	75	2	25	B	50
3	90	MS-100	100	3	50	C	100
4	130	MS-125	125	4	75		
5	170	MS-150	150	5	100		
6	210	MS-200	200	6	125		
7	250	MS-250	250	7	150		
8	300	MS-300	300	8	175		
9	350	MS-350	350	9	200		
10	400	MS-400	400	10	250		
		MS-450	450	11	300		
		MS-500	500	12	350		
				13	400		
				14	450		
				15	500		
				16	550		

tion of the cyclonite base charge. The total firing time, i.e. from the moment of enclosing the electric circuit to the bursting of the cap, is the sum of the pulse or excitation time, and the lag time. The pulse time is the time required for the bridge wire to ignite the heat-sensitive material, and the lag time is the time from ignition to detonation.(4) The pulse time may be varied between rather wide limits, comparatively, by the use of different combinations of igniter composition, and bridge-wire, composition, diameter, and length. For this reason it is not recommended that caps of differing series, strength, or manufacture be employed in the same circuit, lest failure of one or more caps occur. This normally occurs when instantaneous and split-second delay caps of differing series are used in the same circuit, since the total firing time of one may be in excess of the pulse time of another. The delay cap shown in Figure 1 is representative of both regular and split-second delays, for the latter differ only in composition of the delay element, which is of constant length.

Short-period Delay Firing in Surface Mining

In surface mining operations short-period delay firing may be obtained, not only pyrotechnically with detonators having the delay incorporated in them, but also by use of sequence switches in which the delay is obtained mechanically or electrically. There is ample evidence to show that the employment of short-period delay firing, either with split-second delay caps or sequence switches, results

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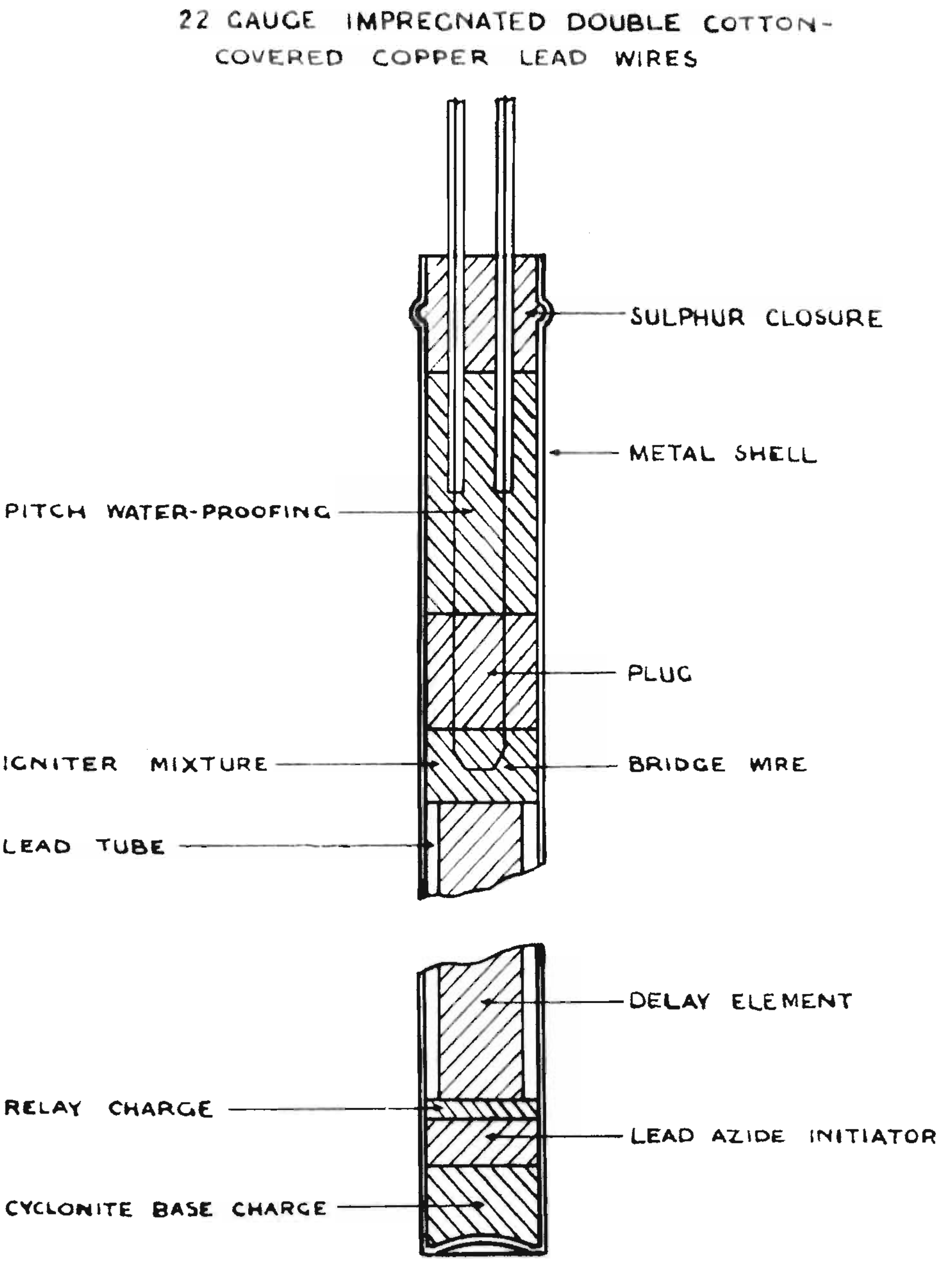
(4) Blake, T. G., Correspondence with author, May 3, 1950.



CROSS-SECTION OF

DELAY ELECTRIC BLASTING CAP

Scale: Four inches = One inch

FIGURE 1.

in a reduction in ground vibration.(5,6) Also there is evidence indicative of improved fragmentation and "back-break" with this technique, although long-term quantitative trials are essential before this evidence can become considered conclusive.(5,6) Many types of sequence switch, or "split-second timers" as they are sometimes called, have been invented and put to use. They are reported to be in successful use in Great Britain,(5) United States,(7) Australia,(6,8) and Sweden.(9) The principle of short-period firing has been widely introduced in many parts of the world. For example, in New Zealand split-second delays have been effectively employed in hydro-electric construction.(10)

Short-period Delay Firing in Underground Mining.

While it appears that the use of split-second delays in surface operations is, on the whole, advantageous, the same cannot necessarily be held true for underground mining. Although solid rock is the medium acted on in each case, on the one hand it is exposed on at least two sides, whereas in a drift it is exposed in only one plane.

Messrs Fish and Hancock state:(5)

> The early trials with short delay detonators took place in tunnels and colliery drifts, results being com-

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(5) Fish, B. G. and Hancock, J., Mine & Quarry Engineering, Vol. 15, No. 11, p. 339, Nov. 1949.
(6) Chemical Engineering and Mining Review, Vol. 42, No. 2, p. 41, Nov. 1949.
(7) Millar, L. F., Excavating Engineer, Vol. 43, pp. 13-19, Feb. 1949.
(8) Quarry Managers' Journal, Vol. 32, pp. 532-3, April, 1949.
(9) Langfors, U., Tekn. Tidskr., Vol. 79, pp. 141-8.
(10) Williams, Dr. G. J., Correspondence with author, April 4, 1950.

> comparable with those obtained from the use of orthodox one-second and half-second gasless delay detonators. There was evidence of improved fragmentation, but this advantage was largely offset by greater throw of debris.

There have been some reports of the successful application of split-second delay caps in undergound mining, nevertheless. It is to be understood that the use of any mechanical or electrical means of short-period delay firing underground is impracticable, because of the almost certain liklihood of leg wires being severed by the initial shots.

Split-second delays were used in enlarging two shaft stations of the New Jersey Zinc Company's mine at Ogdensburg, New Jersey, and good fragmentation, negligible vibration, and clean breaking were reported.(11) In these cases the delay caps were used in conjunction with diamond-drill blast-holes, 1-1/8 inch x 8-inch cartridges of 40 per cent special gelatin were used. Details of each blast are shown in Table II.

TABLE II

	Station 1	Station 2
Initial dimensions	7.3' x 27' x 52'	11' x 30' x 38'
Enlarged dimensions	3.6' x 27' x 52'	7' x 7' x 38'
Depth of holes	54'	39'
Number of holes	6	25
Tonnage/foot drilled	1.42	1.05
Lb. powder/ton broken	0.39	0.60

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(11) Sauerwein, F. W. and Hastings, W., Engineering and Mining Journal, Vol. 151, No. 5, p. 85, May, 1950.

This operation, being essentially stripping, is wholly comparable with surface mining conditions, and the results therefore, cannot be considered representative of those obtainable in underground blasting generally. Similarly, the use of split-second delays in stope blasts might be expected to give improved results over conventional delays and fuse-and-cap firing. In fact, Inland Steel Company has reported (12) an increase in blasting efficiency and a lowering of over-all stoping costs through the use of split-second delay caps. Prior to their use, the instantaneous firing of groups of stoping holes gave rise to dangerous vibration in pillars and the backs of stopes. Hence it appears that split-second delays may prove useful in improving dangerous stope conditions and over-all blasting efficiency in stoping.

While driving a ventilation raise at the Mount Weather Testing Adit of the Mining Division, U. S. Bureau of Mines, experiments have been carried out with various drill patterns. (13,14) Beginning with a conventional wedge-type drill pattern, the cut holes were gradually eliminated until a drill pattern having no cut holes was evolved. These drill patterns are compared in Figure 2. Not only were cut holes eliminated, but an unorthodox method of firing with split-second delays was devised and employed with complete success. In this

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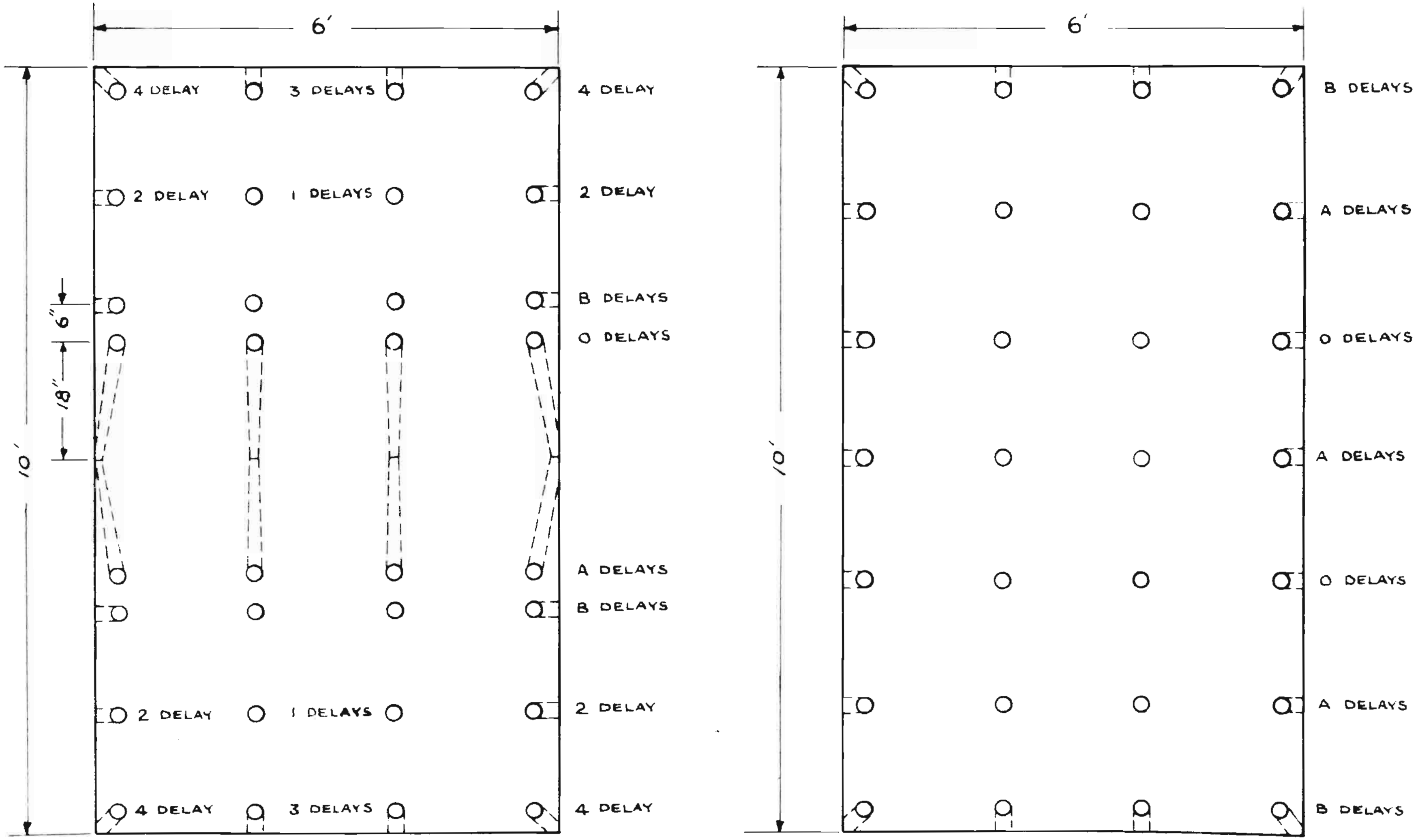
(12) Edwards, R. W., The Explosives Engineer, Vol. 27, No. 3, p. 82, May-June, 1949.
(13) Agnew, W. G., Mining Congress Journal, Vol. 35, No. 10, p. 30, October, 1949.
(14) Agnew, W. G., Mining Congress Journal, Vol. 35, No. 4, p. 70, April, 1949.



RAISE ROUND 1. ORIGINAL PATTERN

RAISE ROUND 5. "NO-CUT" PATTERN

FIGURE 2. COMPARISON OF RAISE ROUND DRILL PATTERNS USED AT MOUNT WEATHER TESTING ADIT.

firing order the middle row of holes is fired with a delay interval greater than that for outer rows. In the massive epidote and chloritic greenstone in which the raise is driven, the unorthodox firing order gave excellent results. The round broke clean without bootlegs, and the fragmentation was improved. Further experiments are being carried out at the Bureau of Mines Testing Station to augment the tests already made.

THE EXPERIMENTAL MINE AND EQUIPMENT

The research was conducted at the Experimental Mine of the Missouri School of Mines and Metallurgy, situated 1½ miles west of Rolla. The underground workings of this mine, shown in plan in Figure 3, have been driven from an adit entry in the School Ledge of the Jefferson City dolomite. This formation is a dolomitic limestone containing nodules of chert, and with well defined bedding planes. It is characterized by rather high resilience causing it to be difficult to break readily from the solid. It has the following general physical characteristics:(15)

Specific gravity	2.801
Porosity	13.00 %
Ratio of absorption	5.341
Weight per cu. ft.	152.2 lb.
Transverse strength	851.3 psi
Tensile strength	220.0 psi
Crushing strength	
On bed	486.7 psi
On edge	9161.0 psi

Equipment

Drilling was begun in Drift No. 2 west using a Cleveland pneumatic-feed drifter, Model FD24, mounted on a pneumatic column. This machine was later changed for an Ingersoll-Rand JB4 cradle-mounted Jackhammer, because it was easier to handle by a single operator. One inch hollow hexagonal drill steel was used with Ingersoll-Rand 1½-inch diameter Jackbits. The same size Jackbits were used on all steel changes to produce uniform hole diameter.

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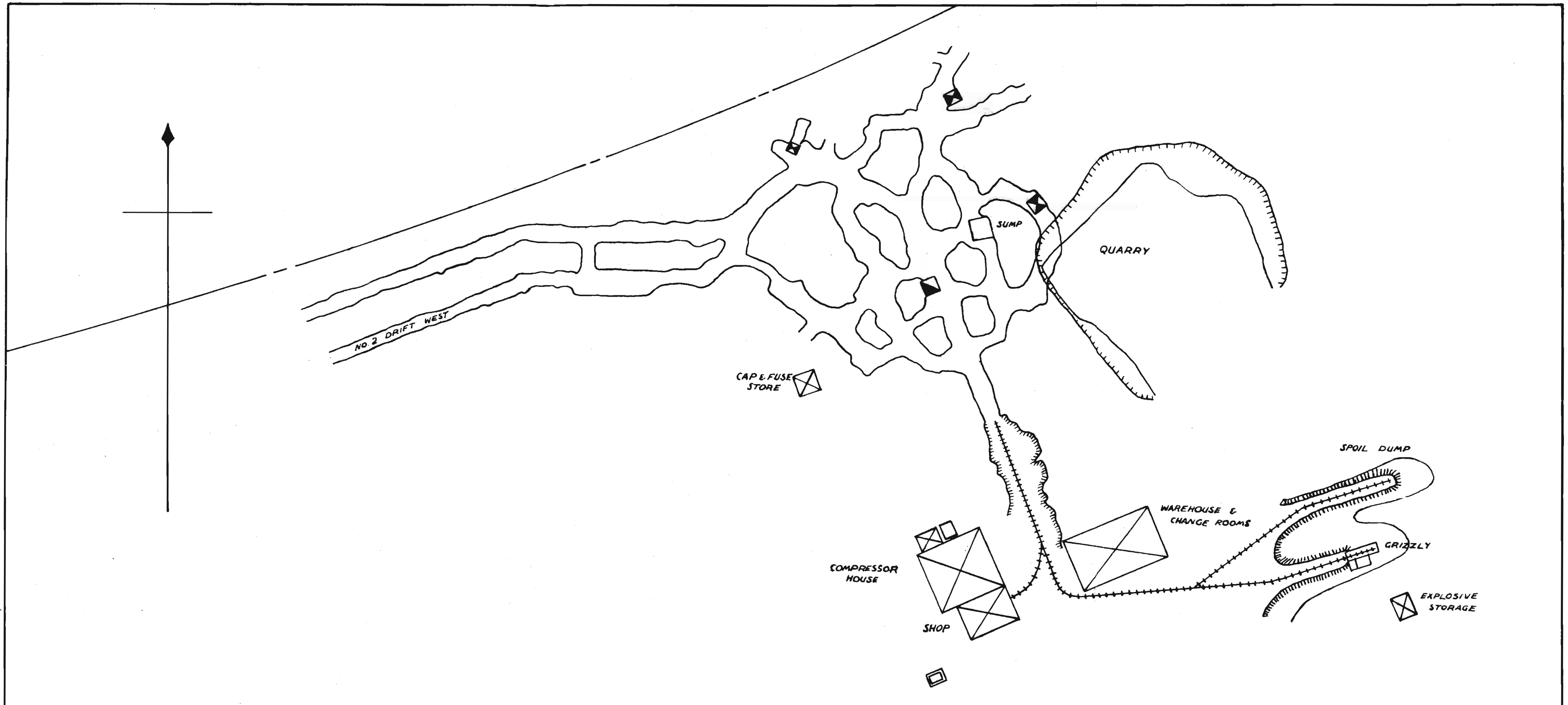
(15) Buckley, E. R. and Buehler, H. A., The Quarrying Industry, Missouri, Bureau of Geology and Mines, Ser. 2, Vol. 2, (1901), p. 102.



Plan of
MISSOURI SCHOOL OF MINES & METALLURGY
EXPERIMENTAL MINE
ROLLA, MISSOURI

SCALE : 1" = 40'

5 JULY 50

FIGURE 3.

The broken rock from blasting was loaded into one ton side-and-end dump cars with an Eimco 12-B RockerShovel. These cars were hand-trammed to the spoil dump, or the grizzlies for sizing. Compressed air for drilling and loading was furnished by an Ingersoll-Rand diesel-driven two-stage compressor.

Blasting Supplies

Because of the "springy" nature of the rock it was deemed advisable to use one of the slower explosives. 50 per cent Special Gelatin was chosen. This is not quite as water-resistant as other ammonia gelatins, but the fuming characteristics in the 30-80 per cent grades are excellent, and it is sufficiently water-resistant for general underground use. "Liberty" brand 50 per cent Special Gelatin in 1-inch x 8-inch cartridges was furnished free of charge by Olin Industries, Inc., through the courtesy of Mr. F. S. Elfred.

Western Ventless (regular) Delay E. B. caps and Western Ventless Minimax (split-second) Delay E. B. caps, both of No. 6 strength and with 8-foot leg wires were also furnished free of charge by Olin Industries, (Plate I). Table III shows the timing specifications on the Ventless Minimax Delay caps. Note that zero minimax delays may be used in the ventless delay series.

In the manufacture of these caps they are held in a metal plate while the igniter mix and other components are added. Production control tests are made on each plate of caps loaded. A "set-up" test is made on each lot of delay igniter mix prepared, and on the igniter mix at the beginning of each working shift in the production plant.

Plate I.

Western blasting caps.

Five caps are loaded and fired on each test, and the average of the five shots must be within the limits given in column I of Table III, with no individual shots outside the limits in column III. Five caps are removed from each plate of 200 caps loaded, and fired for timing. The average time must be within the limits given in column II of Table III, with no individual shots outside the limits given in column III. All tests are made with a current of 1.0 ampere. Table IV shows the results of timing tests made on caps representative of those used in the tests at the Experimental Mine. An additional 15 shots were fired with these caps, the results being labeled "Field" results and shown in Table IV.

TABLE III

Specifications on Minimax Delay Caps

Minimax Delay No.	I Set-up Average (milli-seconds)	II Control Average (milli-seconds)	III Individual Extremes (milli-seconds)
0	10 ± 5	5-15	4-30
1	32 ± 5	24-42	15-60
2	60 ± 5	49-72	30-90
3	90 ± 5	79-107	60-130
4	130 ± 10	114-147	90-170
5	170 ± 10	154-187	130-210
6	210 ± 10	194-227	170-250

TABLE IV

Timing Tests on Ventless Minimax Delay E. B. Caps

Minimax Delay No.	Set-up (milli-seconds)					Aver.	Control (milli-seconds)					Aver.	Field (milli-seconds)								Aver.
Zero	13	11	14	12	13	13	11	12	12	11	12	12	11 11	10 12	13 11	13 12	16 13	14 13	14 14	14	13
1	24	26	28	31	27	27	28	30	26	28	26	28	30 26	29 26	25 26	27 24	27 27	29 26	24 27	26	27
2	60	56	70	73*	66	65	56	70	49	58	66	60	66 56	53 54	56 46	63 60	60 56	53 56	53 49	70	57
3	90	85	96	72*	102*	89	96	100	95	86	106*	97	92 101	96 96	90 91	86 83	86 96	96 88	102* 96	96	93
4	114	120	130	140	138	128	129	132	138	126	141	134	120 120	116 114	124 120	130 126	125 111	143 124	118 102*	113	120
5	169	158	166	176*	161	166	162	174	163	180*	181*	172	161 166	168 170	166 172	169 174	166 170	171 159	176* 173	166	169
6	204	199	206	218	211	208	204	212	188	206	188	200	196 197	183 202	186 204	190 196	190 188	187 196	175* 181*	208	193

Similar tests were carried out on the conventional ventless delay caps used in the research, the specifications being shown in Table V.

TABLE V

Specifications for Conventional Ventless Delay Caps

Delay Period	Firing Time (Seconds)
0	0.2 (Max.)
1	0.5-1.0
2	1.2-2.5
3	1.9-2.5
4	2.7-3.2
5	3.4-4.0

> The set-up test for Ventless Delay Caps consists of 5 shots from each of 3 four foot delay tubes charged for each new batch of delay powder. These shots are made for No. 10 delay period which has a timing specification of 8.3 to 9.3 seconds. Individual shots must be within this range and the average of the 15 shots must be within the limits of 8.6 to 9.0 seconds. Delay tubes for the desired delay period are cut and assembled. Ten shots are then made and the timing must be within the specification limits. One cap, from each production plate of 200 caps, is fired, and the timing must be within limits for the particular delay period. All tests are made with a current of 1.0 ampere. (16)

From inspection of Table IV it will be noted that if certain caps (those marked with asterisks) were wired into the same circuit, the following would occur:

(a) One No. 3 delay would fire at 72 milli-seconds, and one

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(16) Blake, T. G., Correspondence with Dr. Forrester, Jan. 19, 1950

TABLE VI

Timing Tests on Conventional Ventless Delay E. B. Caps

Ventless Delay No.	Set-up (seconds)					Average	Field (seconds)								Average
1	0.56	0.63	0.59	0.61	0.57	0.59	0.60	0.63	0.57	0.56	0.56	0.56	0.52	0.60	0.58
	0.56	0.63	0.59	0.61	0.57		0.59	0.57	0.58	0.56	0.59	0.64	0.58		
2	1.61	1.48	1.50	1.47	1.52	1.50	1.33	1.47	1.38	1.39	1.50	1.49	1.52	1.44	1.47
	1.42	1.50	1.45	1.53	1.53		1.54	1.56	1.45	1.43	1.44	1.44	1.63		
3	2.25	2.27	2.18	2.15	2.23	2.26	2.30	2.35	2.37	2.33	2.33	2.30	2.35	2.34	2.35
	2.29	2.30	2.37	2.30	2.26		2.37	2.42	2.40	2.20	2.28	2.46	2.35		
4	3.04	3.03	3.02	3.10	3.14	3.11	3.18	3.05	3.20	3.18	3.12	3.00	3.14	3.22	3.10
	3.18	3.07	3.16	3.13	3.19		3.12	3.10	3.06	3.02	3.10	3.11	3.00		
5	3.64	3.80	3.73	3.70	3.80	3.80	3.76	3.75	3.79	3.79	3.82	3.90	3.81	3.83	3.80
	3.92	3.79	3.91	3.82	3.90		3.94	3.75	3.76	3.63	3.72	3.78	3.72		

No. 2 delay at 73 milli-seconds.

(b) Three No. 3 delays and one No. 4 delay would fire at 102 milli-seconds.

(c) Two No. 5 delays and one No. 6 delay would fire at 176 milli-seconds.

(d) One No. 5 delay and one No. 6 delay would fire at 181 milli-seconds, while one No. 5 delay would fire at 180 milli-seconds.

This occurrence has been termed "overlapping of the delay periods", or merely "overlap", and is believed responsible for anomalous failures in some of the drift tests.

Table VI shows the set up tests and field tests respectively, for Ventless Delay caps.

Some No. 6 Instantaneous E. B. caps were used in the tests. Twenty-five random samples of these caps were tested at the production plant for total time at a current of 1.0 ampere. These timing tests are shown in Table VII.

TABLE VII

Total Firing Time in Milli-seconds

12.19	14.89	13.35	13.80	12.51
13.96	17.94	13.67	11.50	13.58
14.35	11.81	11.49	12.26	13.02
11.93	11.97	12.59	12.93	14.20
11.33	13.09	11.70	12.62	14.48
	Average	-		13.05

DRILLING AND BLASTING TECHNIQUES

Attempts were made to drill all holes of such a length that they would end in the same plane, so that the round on blasting, if "pulled" completely, would leave a straight face. Hence all the holes of any one round, particularly if the face were irregular, were not necessarily of the same length.

The 1" x 8" cartridges were effectively tamped without slitting, and no stemming was employed in the tests. Caps were primed according to standard practice, and the primer cartridge placed midway in the string of cartridges in each hole. This position for the primer cartridge was arrived at by trials in the initial tests. It was found that if the primer cartridge were placed at or near the back of the hole, there was a tendency for the leg wires to be broken during subsequent loading and tamping. Moreover, one or more cartridges could be ejected from the drill-hole without exploding, under these circumstances. Such an occurrence would be due to inadequate tamping, but this possibility could not be overlooked. For reasons of safety it is undesirable to place the primer cartridge in first or second place from the collar of the hole, since explosive may be left in the bootleg, and thus prove hazardous when drilling.

All caps were tested individually with a galvanometer before being wired into the circuit, and the entire circuit was tested after wiring. 500 feet of enameled, rubber-and-composition-covered, 14-gauge copper wire was used as lead wire for firing, with a 100-cap push-down type blasting machine.

OUTLINE OF PROBLEM

The work evaluating split-second delay caps was initiated at the suggestion of Mr. F. S. Elfred, Jr., General Manager, Explosives Division of Olin Industries, Inc., with the view that such research should be of interest, not only to the manufacturers of blasting caps, but to the mining industry as a whole. It was decided that experiments be conducted to determine any difference in gradation and volume of the broken rock resulting from any given blast, by using different types of blasting cap.(17)

Hence, it was planned to use regular delay and split-second delay caps in a number of drift rounds using several standard types of drill pattern. For proper analysis of the results it was considered essential that the only variable in the tests should be the blasting caps. To this end comparative tests were conducted at the Experimental Mine, using four drill patterns. In addition, a number of additional tests were carried out to determine the effectiveness of split-second delays used in different combinations.

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(17) Elfred, F. S., Correspondence with Dr. J. D. Forrester, August 25, 1949.

COMPILATION OF DATA

The data collected for analysis of the effectiveness of the several drift rounds included the following:

(1) Explosive consumption and distribution.

(2) Number, type and distribution of blasting caps.

(3) Distance advanced.

(4) Tonnage of rock broken.

(5) Size analysis of the broken rock.

(6) Throw of the rock from the face.

(7) Drift face dimensions.

Explosive consumption

The cartridge count of 50 per cent special gelatin in 1-inch by 8-inch sticks is listed as 145 per 50-pound case.(18) However, it was found that the number actually varied from 145 to 153, and so an average figure of 150 cartridges per case was employed in the calculations. Any cartridges found in the "muck-pile" were deducted from the total number loaded to obtain the values listed in Table XII for pounds of explosive effective.

Measurement of advance

The simplest and most obvious means of determining this value is by a direct measurement of the distance advanced, by the center of the face. However, because of the greater amount of "bootleg"

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(18) Olin Industries, Inc., Handbook of Explosives Products, pp. 12 and 50.

in trim, back, and lifter holes, than in the cut, burn and relief holes, this method invariably gave a figure somewhat higher than was actually the case. Although this measurement was taken in all cases to afford a check, the figure actually used was that obtained by difference between the average depth drilled and the average depth of resulting "bootlegs." In many individual cases, particularly of cut, burn, or relief holes, "bootleg" depth was unobtainable because of the shearing of the face along bedding-planes. Nevertheless sufficient measurements were obtainable in every test to afford an accurate value for advance.

Determination of tons broken

Since facilities were not available for the weighing of individual cars, each car was loaded to a uniformly heaped capacity, which was then taken as 2000 pounds, this figure having been arrived at by previous experiment.(19)

Sizing of the broken rock.

Since it was not feasible to size all the broken rock from a round, cars were selected periodically for dumping on the grizzlies, (Plates II and III) which sized to plus 12 inches and plus 4 inches. At first every third car was run over the grizzlies, but as facilities for handling the undersize became less adequate, the interval between sized cars was increased to five. The second or third car loaded was arbitrarily taken as the first car to be

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(19) Nelson, H. P., Explosives Research Project, Missouri School of Mines.

Plate II.

The author dumping a mine car on the grizzlies. The weighing scales appear on the left.

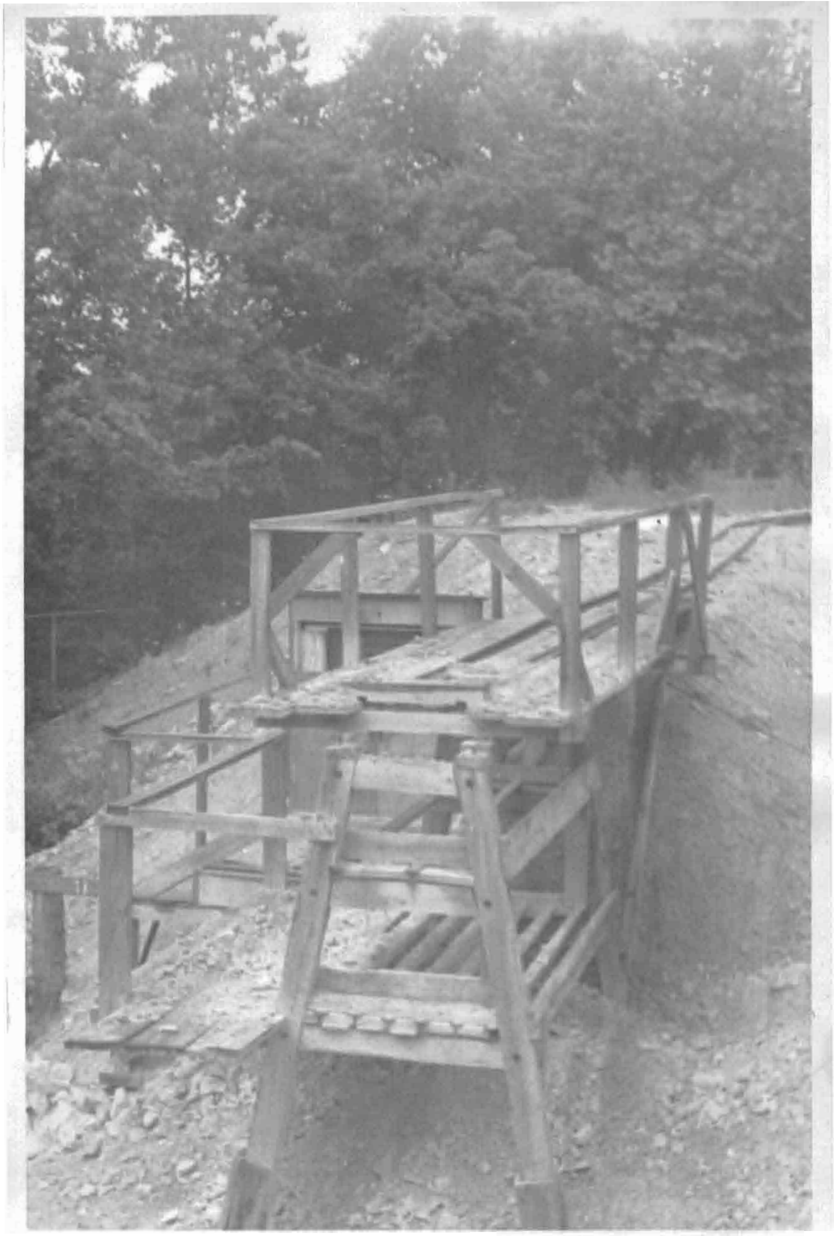

Plate III.

View of the 4-inch and 12-inch grizzlies, and the weighing scales (partly concealed).

sized, in order to avoid the material at and beyond the "toe" of the "muck-pile", which was not considered truly representative of subsequent cars. Thus it was usual to size a minimum of three cars per round, and as might be expected the percentage of oversize increased as the face was approached.

Because of the bedded character of the rock, fragments were almost always of a "slabby" nature. This presented difficulties in sizing, in that all slabs, less than 4 inches thick, could conceibably pass through the 4-inch grizzly. However, it was reasoned that since the "muck" had to fall through a distance of 5 or 6 feet before reaching the 4-inch grizzly, thus obviating cushioning by fines, the opportunity of oversize fragments for passage through the grizzly bars by presenting themselves at the right angle was very nearly the same in all cases.

Many of the customary criticisms of sizing and sampling techniques may be levelled at this particular operation, and it is admitted that errors have been introduced which affect the quantitative accuracy of the size analyses. Nevertheless it is believed that these errors are sufficiently constant, in each case, for comparative purposes, and that the method used closely simulates operating practice.

Measurement of throw.

This was a simple, direct measurement taken from the fresh drift face to the "toe" of the "muck-pile." The "toe" was usually well-defined, being the point at which the track began being covered with debris. Although fragments were normally scattered beyond this point, their distribution was too haphazard for accurate measurement, and they represented only a negligible percentage of the bulk of the broken rock.

Drift face dimensions.

Measurements of the average width and average height of the drift face were taken to check on the variation from the standard dimensions of 7 feet by 6 feet, and thus detect any possible anomalies in tonnage.

ANALYSIS OF DATA

The loading of the various rounds, and the type, number, and distribution of the delays are listed in Tables VIII, IX, X, and XI; while results and analyses are shown in Table XII. The assessment of the effectiveness of any round must be made from the following four factors:

(1) Advance.

(2) Fragmentation, or size analysis of the broken rock.

(3) Breakage, or tons of rock broken per pound of explosive.

(4) Throw.

It is obvious that advance is a function of breakage, and so breakage, fragmentation, and throw, taken together represent the effective energy available in any given blast.

Although it was desirable to have no variables in the comparative tests, other than the caps themselves, limitations of time, experience, and equipment resulted in some variation in drift dimensions, as may be noted in Table XII. For the tonnage values this resulted in anomalies, which were reflected in the figures for breakage. To overcome the lack of utility in the actual breakage figures, as far as their use for the judging of the effectiveness of the rounds is concerned, a figure termed "effective breakage" was determined for each test. This figure was obtained by the use of a tonnage value calculated by empirical means, i.e.,

$$\text{Effective tonnage broken} = \frac{\text{advance (ft)} \times 6' \times 7' \times 152.2\ \text{lb/c.ft.}}{2000\ \text{lb.}}$$

Hence "effective breakage" is "effective tons broken" per pound of explosive. The extent to which variation in the burden placed on trim, back, and lifter holes may affect the footage advanced, is possibly a matter for conjecture. It is considered by the author, however, that the advance is dependent primarily on the effectiveness of the cut and relief holes. In cases of wide variation in the height and width of the drift, overall advance may conceivably be affected by the increased "bootlegs" on trim, back, and lifter holes due to too much burden being placed on them, since these "bootleg" depths are included in the average used to obtain a value for advance. It is thought that the only such instance which may have occurred in the tests is in Round No. 7, where the average width was only five feet.

The effective breakage is visualized, therefore, as being ideal, in that its calculation employs only one variable, viz. advance. The value of the effectiveness of any round may now be judged by the three factors: effective breakage, fragmentation, and throw. The use of three indices is rather undesirable, for it is difficult to estimate the degree of importance which should be allotted to each. However, fragmentation and breakage might well be combined, not only because each is defined by gravimetric units, but also since it may reasonably be postulated that a high proportion of the energy not employed in advancing the face, is used in comminution of the rock already severed from the face. The index of effectiveness, therefore, combining effective breakage and fragmentation, is termed "effective fine breakage," and may be defined as the effective tonnage of minus four-inch material broken per pound of explosive.

Each round has been judged on the basis of its effective fine breakage, and throw. It may be seen from Table XII that the figures for throw, particularly for tests in which split-second caps were employed, increase as the tests proceed. As the work progressed it became more and more apparent, from inspection of the "muck-pile," that this was a result of the curvature in the drift. For the "muck", in its throw away from the drift face, hit the north wall of the drift and was thereby impeded in its flight. Therefore the values of throw listed, are by no means absolute in many cases. They are, however, sufficient for comparing the results of regular and split-second delay firing.

The importance of throw will vary according to circumstances, and will undoubtedly be reflected in costs. The disadvantages of a long throw are:

(1) Increased time of loading broken rock.

(2) Possible damage to timbers.

(3) Possible prolongation of exposure of workmen to hazardous conditions.

TABLE VIII

Loading of Wedge-cut and Modified Wedge-cut Drift Rounds and the Delays Employed

	DRILL-HOLE Type	No.	Posn.	ROUND NUMBER 1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Cut	1	left	9	14	12	11	12	12	11	9	12	12	12	11	11	11
		1	right	9	14	12	12	12	12	11	9	12	12	12	11	11	11
L	1st Relief	1	upper	-	-	12	12	12	11	11	9	6	9	9	9	9	9
O		1	lower	-	-	12	12	12	11	11	9	8	9	9	9	9	9
A	2nd Relief	2	upper	7	12	10	10	10	9	9	7	8	10	10	9	9	9
D		2	lower	7	12/13	10	10	10	9	9	7	9	10	10	9	9	9
I	Helpers	4		-	-	-	-	-	-	-	-	-	-	-	7	7	7
N	Trim	4		-	8	8	8	8	8	8	8	8	8	8	6	6	6
G	Back	1	mid.	-	8	8	8	8	8	8	8	8	8	8	6	6	6
		2	side	-	6	6	6	6	6	6	6	6	6/7	7/6	4	4	4
	Lifters	1	mid.	-	10	12	12	12	11	11	11	11	12	12	10	10	10
		2	side	-	8	10	10	10	9	9	9	7/8	12	12	9	9	9
Total No. of cartridges				46	155	172	171	172	163	161	145	153	171	171	170	171	170
Lbs. of explos. effective				10.3	51.7	57.3	57.0	57.3	54.3	53.7	48.3	51.0	57.0	55.7	55.7	57.0	56.7
Type of cap used*				S	S	S	R	S	S	S	S	S	S	R	S	R	R
D	Cut			0	0	0	0	0	0	1	1	0	0	0	0	inst	0
E	1st Relief			-	-	1	1	1	1	1	1	0	1	1	1	inst	1
L	2nd Relief			0	1	2	2	2	2	2	2	1	3	2	2	1	2
A	Helpers			-	-	-	-	-	-	-	-	-	-	-	3	2	3
Y	Trim		upper	-	2	3	3	3	3	4	4	2	5	4	5	4	5
S			lower	-	3	4	4	4	4	3	3	3	4	3	4	3	4
	Back		mid.	-	3	4	4	4	4	3	3	3	4	3	4	3	4
			side	-	4	5	5	5	5	5	5	4	6	5	6	5	6
	Lifters		mid.	-	2	3	3	3	3	4	4	2	5	4	5	4	5
			side	-	4	5	5	5	5	5	5	4	6	5	6	5	6

(* S = split-second; R = regular)

TABLE IX

Loading of Experimental Drift Pattern No. 4 and the Delays Employed

	DRILL-HOLE			ROUND	
	Type	No.	Position	15	16
	Shock	4		6	5
L	Inner Relief	4		6	3
O	Outer Relief	4		6	8
A	Helpers	4		7	9
D	Trim	2	Upper	8	9
I		2	Lower	8	9
N	Back	2	Middle	2	2
G		2	Side	4	5
	Lifters	2	Middle	7	7
		2	Side	7	8
	Total number of cartridges			172	176
	Lbs. of explosive effective			58.3	57.3
	Type of E. B. cap used*			S	S
D	Shock			0	0
E	Inner Relief			1	1
L	Outer Relief			1	2
A	Helpers			2	3
Y	Trim		Upper	4	5
S			Lower	3	4
	Back		Middle	3	4
			Side	5	6
	Lifters		Middle	4	5
			Side	5	6

(* S = split-second)

TABLE X

Loading of Experimental Drill Pattern No. 5

and the Delays Employed

	DRILL-HOLE			ROUND NO.	
	Type	No.	Position	17	18
	Centre Burn	1		14	14
	Side Burn	2		10	10
	Vertical Burn	2		10	10
L	Relief	2	Upper top	7	7
O		2	Upper bottom	8	8
A		2	Lower	9	9
D	Helpers	2		8	8
I	Trim	2	Upper	7	7
N		2	Lower	8	8
G	Back	1	Middle	5	5
		2	Side	5	5
	Lifters	1	Middle	10	10
		2	Side	9	9
	Total number of cartridges.			191	191
	Lbs. of explosive			63.7	63.7
	Type of delay cap used*			S	R
	Centre Burn			0	0
D	Side Burn			1	1
E	Vertical Burn			2	2
L	Relief			3	3
A	Helpers			4	4
Y	Trim		Upper	5	5
S			Lower	4	4
	Back		Middle	4	4
			Side	6	6
	Lifters		Middle	5	5
			Side	6	6

(*S = split-second; R = regular)

TABLE XI

Loading of Experimental Drill Pattern No. 6

and the Delays Employed

	DRILL-HOLE			ROUND NO.	
	Type	No.	Position	19	20
	Burn	1	Upper	14	14
		1	Side	14	14
		1	Lower	14	14
L	Relief	2	Upper top	9	9
O		2	Upper Bottom	9	9
A		2	Lower	10	10
D	Helpers	2		8	8
I	Trim	2	Upper	8	8
N		2	Lower	8	8
G	Back	1	Middle	6	6
		2	Side	6	6
	Lifters	1	Middle	10	10
		2	Side	10	10
	Total no. of cartridges			193	193
	Lbs. of explosive			64.3	64.3
	Type of delay cap used*			S	R
	Burn		Upper	0	0
			Side	1	1
D			Lower	2	2
E	Relief			3	3
L	Helpers			4	4
A	Trim		Upper	5	5
Y			Lower	4	4
S	Back		Middle	4	4
			Side	6	6
	Lifters		Middle	5	5
			Side	6	6

(* S = split-second; R = regular)

ROUND NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Type delay cap used *	S	S	S	R	S	S	S	S	S	S	R	S	R	R	S	S	S	R	S	R
Average depth drilled (ft)	6.0	6.0	5.0	4.7	5.0	5.1	5.2	5.3	5.3	5.4	5.2	5.2	5.2	5.0	5.1	5.2	5.5	5.5	5.6	5.4
Average advance (ft)	2.0	3.0	4.3	3.9	3.8	3.8	4.1	3.5	3.3	4.0	3.9	4.6	4.0	4.5	4.2	3.8	4.6	4.8	4.1	4.8
Average height of face (ft)	7.5	7.5	7.0	7.0	6.8	7.0	7.0	7.3	7.2	7.3	7.4	7.4	7.4	7.2	7.0	7.1	6.8	7.1	7.3	7.5
Average width of face (ft)	7.3	7.3	6.5	6.7	6.4	5.5	5.0	5.5	5.3	6.0	6.0	6.0	6.0	6.6	6.0	5.5	5.5	6.3	6.5	7.0
Tonnage broken (short tons)	–	12	14	15	12½	11½	11	11	9	13	13	15½	12	17½	13½	11½	13	16	15	16½
Lb. of explosive effective	10.3	51.7	57.3	57.0	57.3	54.3	53.7	48.3	51.0	57.0	55.7	55.7	57.0	56.7	58.3	57.3	63.7	63.7	64.3	64.3
Fragmentation (per cent) +12"	–	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0
+4" -12"	–	5.0	2.9	8.1	5.1	11.2	4.6	5.6	8.1	14.0	6.4	5.2	3.8	6.4	8.0	10.6	1.7	17.3	9.7	13.3
-4"	–	95.0	97.1	91.9	94.9	87.6	95.4	94.4	91.9	86.0	93.6	94.8	96.2	93.6	92.0	89.4	98.3	82.7	87.3	86.7
Actual breakage (Tons/lb.)	–	.232	.244	.263	.218	.212	.205	.228	.176	.228	.233	.278	.211	.308	.232	.201	.207	.251	.234	.261
Effective breakage	–	.186	.241	.220	.213	.225	.245	.233	.208	.225	.225	.265	.225	.255	.232	.213	.236	.242	.204	.239
Effective fine breakage	–	.177	.234	.202	.203	.197	.232	.220	.191	.194	.210	.251	.217	.238	.213	.190	.231	.200	.177	.207
Throw (ft)	–	55	58	29	59	65	72	80	81	82	37	90	43	41	105	70	81	48	78	38

Table 12. Results and analyses of drift round tests.

(* S = Split-second delays; R = Regular delays)

DESCRIPTION OF TESTS

Drift Rounds of Wedge or Modified Wedge Drill Pattern

The wedge-cut type of round (Figure 4) is a 17-hole drill pattern substantially similar to those previously employed in research at the Experimental Mine.(20) The two converging cut holes are designed to break a slice normal to the drift face. The relief holes may then break to this free face. The center hole is not loaded, its function being to aid the breaking of the cut.

Rounds 1 and 2 were drilled to an average depth of 6 feet, and loaded as shown in Table VIII. The purpose of the initial round was primarily to determine the amount of explosive needed to break the cut. Hence cut and relief holes were fired separately. The former failed to break at the first firing, and so were reloaded and fired with the relief holes. The final results were still unsatisfactory (Table XII), and the round was abandoned as far as the test program was concerned. However, it was established that 9 cartridges per hole were insufficient to draw a cut 6 feet deep, and that the relief holes were of little aid in breaking the cut.

The amount of explosive used was increased considerably in Round 2, the cut being loaded to the collars of the holes and 5 cartridges added to each of the relief holes. It is to be noted

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(20) Shaffer, L. E. and Noren, C. H., The influence of cartridge diameter on the effectiveness of dynamite, Missouri School of Mines Bulletin, Vol. 19, No. 1.

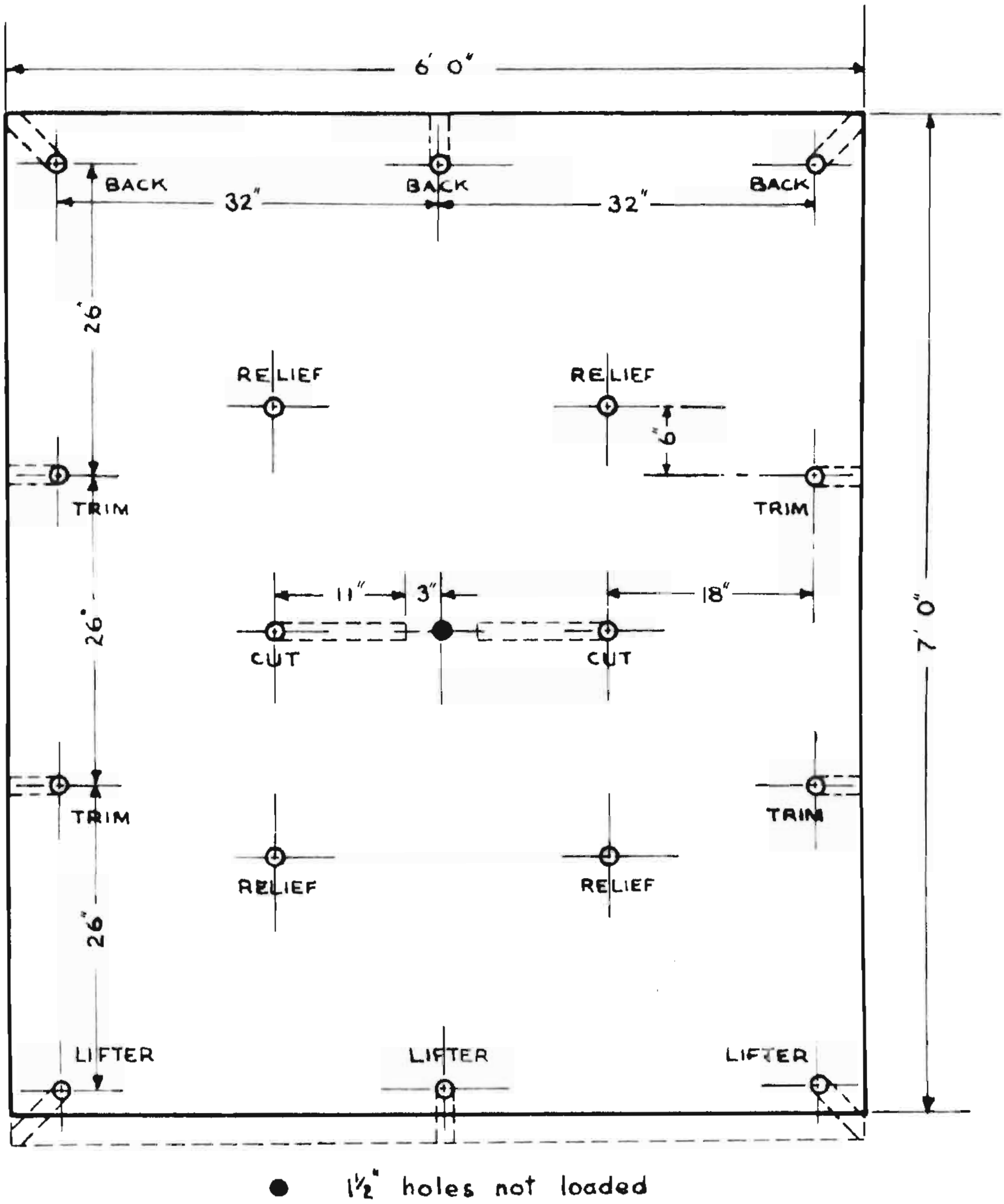


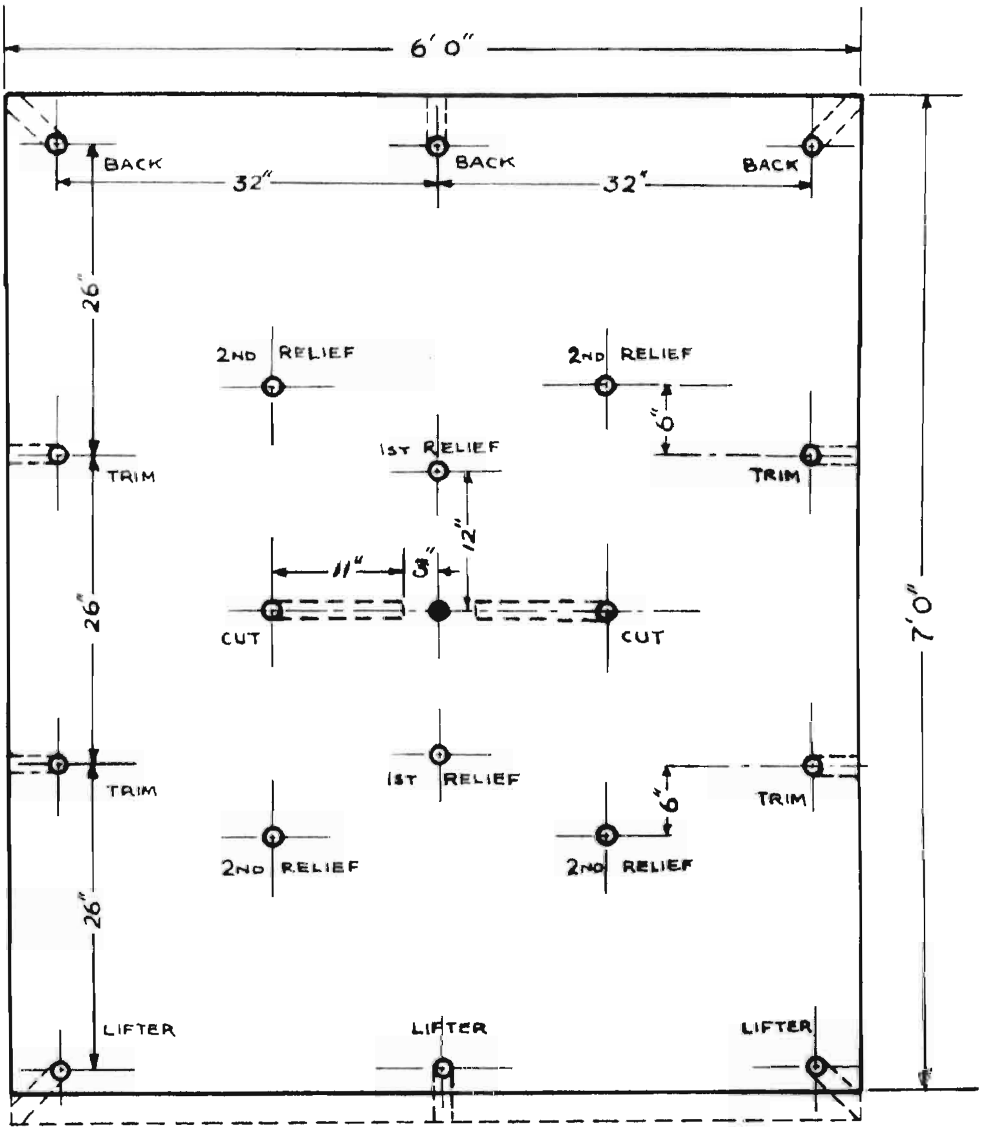
FIGURE 4. EXPERIMENTAL DRILL PATTERN NO. 1

(Table VIII) that the loading of trim, back, and lifter holes is substantially the same as in all subsequent rounds. The effective fine breakage was low, and so it was decided to modify the drill pattern by including two additional relief holes, and reducing the average depth drilled to 5 feet (Figure 5).

The results obtained by using this modified pattern in Round 3 were more satisfactory. Although the advance was not complete, it was high, and the size analysis of the broken rock shows a very small percentage of material greater than four inches. Hence to provide a comparison with the results obtainable with Regular Delay caps, Round 4 was loaded and fired under identical conditions.

The resulting comparison, which may be drawn between split-second and regular delays, used under like conditions, shows a value for effective fine fragmentation to the advantage of split-second delays, but a throw to their disadvantage. In detail, split-second delays gave a greater advance, 3 per cent less oversize, but 100 per cent more throw (Table XII).

Round 5 was a duplication of Round 3, to check the results of the latter, particularly the throw. Comparison of the results of these two rounds shows, for Round 5, a sharp decrease in the advance, a 2 per cent increase in oversize, while the throw has increased slightly (Table XII). The most likely explanation for this difference is that "overlap" occurred. That such an "overlap" can be obtained in the shorter delay periods has already been noted (p. 21). Nevertheless the index of effectiveness for Round 5 in which split-second delays were used, is still somewhat higher than that for



● 1½" hole not loaded

FIGURE 5 EXPERIMENTAL DRILL PATTERN NO. 2.

Round 4, where Regular delays were used.

The six tests following Round 5, viz. Rounds 6 - 11, all represent attempts to reduce throw and improve advance by adjustments to the loading, and the use of different split-second delay combinations. Since the limitations of time did not permit the changing of only one variable per round, several variables were altered at the same time where it was thought to be expedient.

The reduction in the loading of cut and relief holes in Round 6 (Table VIII) gave no increase in advance, whereas there was a 7 per cent increase in oversize as compared with Round 5, or almost 10 per cent as compared with Round 3. Moreover the throw was still high.

In Round 7 the loading of the cut holes was reduced to 11 cartridges each, while the first relief holes were fired with the same delay as the cut. It was hoped by this means to increase the depth broken in the cut, and so improve the overall advance. The use of No. 1 delays in place of zero delays gave a longer delay period between the firing of the cut and second relief holes, thus providing more time for the cut to clear of broken material. The results of this blast (Table XII) were a decrease in the oversize material to approximately 5 per cent, and an advance of 4.1 feet which was somewhat higher than in the previous three rounds, but nevertheless still unsatisfactory. It should be noted that although the value of actual breakage is the lowest obtained to this point, the effective fine breakage value is almost as high as that of Round

3. This arises almost wholly from the reduction in the drift dimensions. The marked reduction in the "bootleg" of lifter holes in Round 7 may be attributed to the changing of the delays in the trim, middle back, and middle lifter holes. In all previous rounds the upper trims and middle lifter had been fired with No. 3 delays, and the lower trims and middle back with No. 4 delays. In Round 7 the former were fired with No. 4 delays and the latter with No. 3 delays. The firing of the lower trims before the middle lifter gives a greater free face to which this lifter can break.

As the throw in Round 7 had increased by 8 feet, to the high figure of 72 feet, (it was not yet apparent that the increasing throw was due more to the conformation of the drift than to any changes in the tests) Rounds 8 and 9 were attempts to reduce throw by reducing the amount of explosive used, even though this might well mean a reduction in advance. To this end a total of 12 cartridges were removed from the cut and relief holes, since it was assumed that these holes contribute more to the throw than any others. However the throw rose to 80 feet in Round 8, and the footage advanced dropped to 3.5 feet. The distribution of explosive in the cut and relief holes was changed in Round 9, giving 12 cartridges to each of the cut holes, and 6 and 8 cartridges to the upper and lower relief holes, respectively. The greater number of "sticks" placed in the lower 1st and 2nd relief were provided since these holes had to break against gravity. Although the cut and 1st relief were given the same delay as in the previous two rounds, zero delays were employed instead of No. 1 delays. The results of Round

9 were a slight increase in throw, and a reduction in advance to 3.3 feet. It was therefore established that the large amount of throw obtained by using split-second delays was not a consequence of the amount of explosive being used. It was found from examination of the "bootlegs," that gravitational forces played a negligible part in hindering or aiding the breaking of relief holes, and so the differential loading of relief holes was discontinued.

As it was likely that overlap may have occurred in the tests already carried out, Round 10 was fired with the No. 2 delay omitted. Because there were insufficient delays available to omit every second delay in the series, the No. 2 delay was chosen for omission, since firing of the second relief before or simultaneously with the first relief holes was considered the most serious overlap which could occur. It will be noted from Table VIII that the loading of first and second relief holes was increased to 9 and 10 cartridges each, respectively.

The results of Round 10 may be compared with those of Round 6, the total amount of explosive in the cut and relief holes being the same. The advance in Round 10 was 5 per cent greater than in Round 6, although the fragmentation was substantially the same. Although this round was designed to avoid overlap there was evidence that the No. 6 delay in the left-hand lifter fired earlier than the No. 5 delay in the middle lifter. This was deduced from the presence of a remnant in the lower left-hand corner of the face. This remnant was drilled and blasted, the overall results of the round being adjusted to those which would have been obtained had no overlap occurred.

Round 11 was fired using regular delays under the same conditions as in Round 10. However no delays were omitted from the sequence since the opportunity for overlap in regular delays is negligible, by the very nature of the delay periods inherent in them. The comparison shows (Table XII), to the advantage of the split-second caps, an advance greater by one-tenth of a foot, whereas the use of regular delays gave an increase in -4-inch material of about $4\frac{1}{2}$ per cent, and 52 per cent decrease in the distance the "muck" was thrown.

At this point it was decided to again modify the drill pattern by spacing the cut, 1st relief, and 2nd relief holes closer together, and by the addition of four "helper" holes, as shown in Figure 6. Rounds 12, 13 and 14 were drilled to this pattern, No. 12 being fired with split-second delays, and Nos. 13 and 14 with Regular delays. The total amount of explosive used did not exceed the maximum used in any preceeding round, but it was re-distributed to give an adequate number of sticks to the helpers. Since only seven delays were available (including the zero delay), none could be omitted to avoid possible overlap.

Round 13 was fired using No. 6 Instantaneous caps in the cut and 1st relief, in place of zero delays. Only five other delays were available at this time necessitating the firing of cut and 1st relief holes together. The use of the Instantaneous caps resulted in the misfiring of the upper 1st relief, the leg wires probably having been cut off by the firing of one or other of the cut or relief holes. The inadvisability of using caps of different series has already been pointed out (p. 6). The results of Round No. 13 were

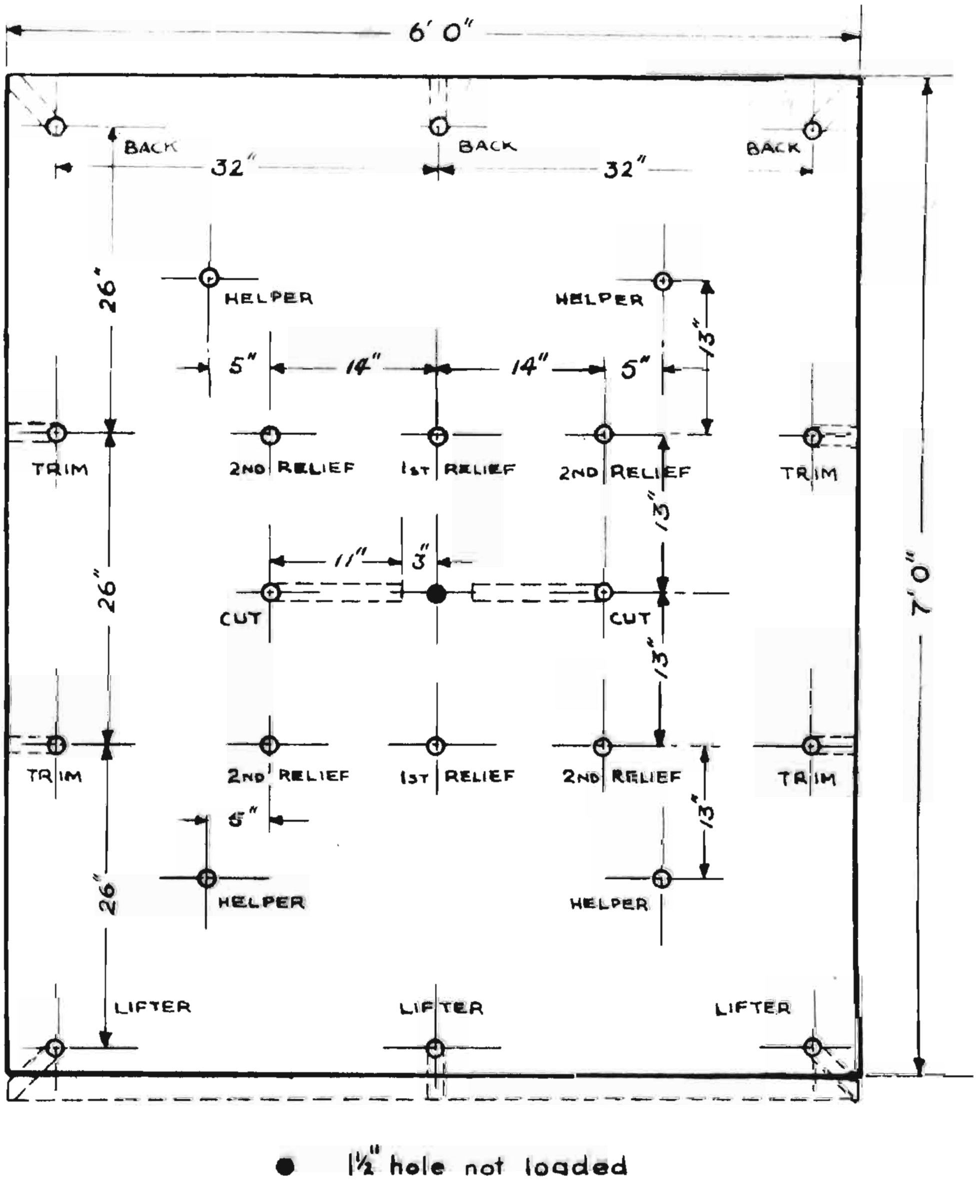


FIGURE 6. EXPERIMENTAL DRILL PATTERN NO. 3.

not used for comparative purposes.

The comparison of Rounds 12 and 14 shows that the effective fine breakage of the former is well in excess of the latter, although the throw in the case of the split-second delay round is more than twice that for the Regular delay round. The results to this point show that when no overlap in the delay periods of the split-second caps occurs, the results obtained with their use, are superior to those with Regular delay caps, except insofar as throw is concerned. However, when overlap does occur their efficiency may drop below that of Regular delays. (cf. Rounds 3, 4, and 5 and 12 and 14). Moreover, if it is sought to eliminate overlap by the omission of one or more delays from the series, their effectiveness may be less than that of Regular delays (cf. Rounds 10 and 11).

Drift Rounds of Unorthodox Drill Pattern

At this point in the research it was decided that although split-second delays had a slight advantage over Regular delays under favorable circumstances, it might be possible to use a drill pattern similar to that used in raise rounds at the Mount Weather Testing Station, by the Bureau of Mines,(13) and thereby take advantage of the milli-second timing.

The total energy available in underground blasting is the sum of that which goes to advance the heading, fragmentation of the rock, throw of the rock from the face, and the wasted energy expended into the air, which might loosely be termed "concussion." Throw, too, very largely represents wasted energy. The fact that such high throw had been encountered with split-second delays was one of the main reasons why it was thought that a drill pattern should be designed for split-second delays themselves.

Under conditions of 100 per cent efficiency in blasting, it would be expected that the face of the heading not only be advanced the whole distance drilled, but that the rock be broken uniformly fine, and be thrown not further than, say 15-20 feet. These would be perfect results and thus probably unattainable. As an approach to this end Experimental Drill Pattern No. 4 (Figure 7) was evolved. It was hoped that a pressure would be built up in the rock by placing and loading holes so that the pressure could be relieved by the subsequent firing of other holes, before the rock was fractured or the pressure dissipated. By this means throw might be vastly reduced and the overall results improved. Having no cut holes it would seem that the rock would collapse rather than be thrown some distance down the drift.

Experimental Drill Pattern No. 4 was a 28-hole pattern with 12 holes in the center of the face. The so-called "shock" holes, which were spaced far enough apart to avoid their acting as burn holes, were those which were fired with zero delays, and which were designed to stress the rock. The function of the inner relief, fired with No. 1 delays, was to relieve the stress area, while the outer relief with No. 1 or No. 2 delays actually forced the rock from the solid. The remaining trim, back, and lifter holes were designed to act in the orthodox manner.

In Round 15 the inner and outer relief were both primed with

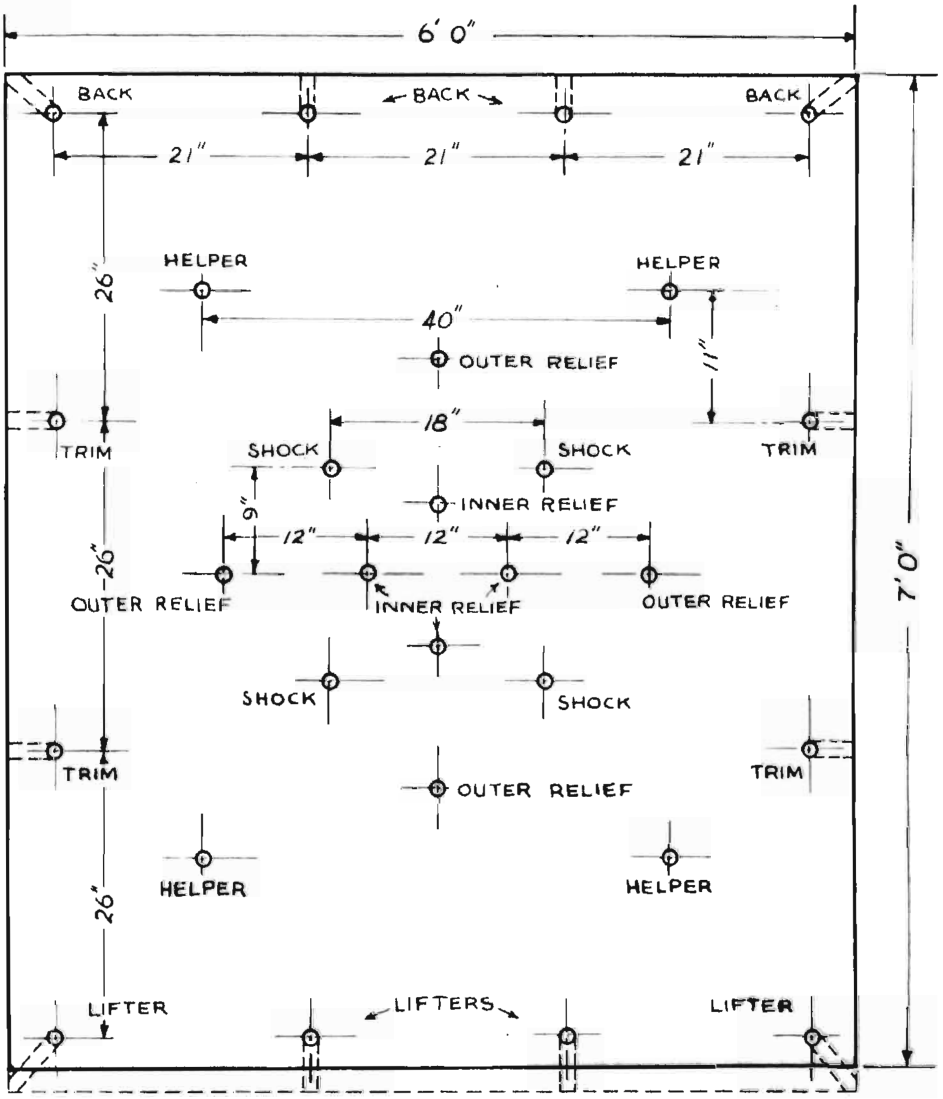


FIGURE 7. EXPERIMENTAL DRILL PATTERN NO. 4.

No. 1 delays. This was done to thoroughly ensure that the stress be relieved before dissipitation, in the event this period of dissipitation was not exceeded by the time interval elapsing between the firing of the zero and No. 1 delays. Although an advance of 4.2 feet, and a fragmentation of 92 per cent were attained, the record throw of 105 feet did not accord with the theory. It is likely that the inner relief holes acted as burn holes, and that the large number of holes fired in such close sequence served to project the broken rock well away from the face.

Hence in Round 16 the outer relief holes were fired with No. 2 delays, and the loading of the inner relief reduced by 50 per cent. This reduction allowed more cartridges to be loaded in the outer relief. It might be added that the theory advanced required that the inner relief merely fracture the rock, while the outer relief remove it from the face. The results for Round 16 were poor, effective fine fragmentation being only .190, and throw 90 feet, although the latter represents some reduction over Round 15.

It was decided to abandon tests with this drill pattern, for taking the number of holes needed into account, its efficiency was even lower than that shown by the figures for effective fine fragmentation and throw. The author believes that the failure of this type of drill pattern and firing order is a consequence of the physical properties of the limestone, and that it would probably be more successful in a more brittle, less resilient rock. It cannot be overlooked that the tests were inadequate in number to prove beyond doubt that the pattern is inapplicable to limestone mining, although the tests pointed that way.

Drift Rounds of Burn Drill Pattern

To conclude the research two sets of comparative tests were planned, using two substantially different burn patterns. The choice of suitable patterns from the large variety available was governed by the fact that only three delay periods were available for the burn itself, and that it was desirable to use only the most efficient designs. Experimental Drill Pattern No. 5 was a 27-hole pattern with a 9-hole burn (Figure 8). Four 2-inch holes were placed on 8-inch centers around the center and initial burn hole, and their function was to aid in the breaking of the burn. This symmetrical multiple-hole burn type is recommended as being suitable for rock very difficult to break, and for low powder consumption.(21)

Rounds 17 and 18 were drilled to this pattern, No. 17 being fired with split-second delays and No. 18 with regular delays. The total amount of explosive used in each of these rounds was a trifle higher than that previously employed, but it was deemed necessary to ensure their success. Both were blasted under identical conditions. The results are somewhat difficult to assess, since Round 18 gave a greater advance than No. 17, but a much greater amount of oversize. Judging by effective fine breakage No. 17 had a much higher efficiency than No. 18, although the reverse is true

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(21) Jenkins, R. W., Cycle Planning for Rock Headings, Engineering and Mining Journal, Vol. 151, No. 5, May 1950.

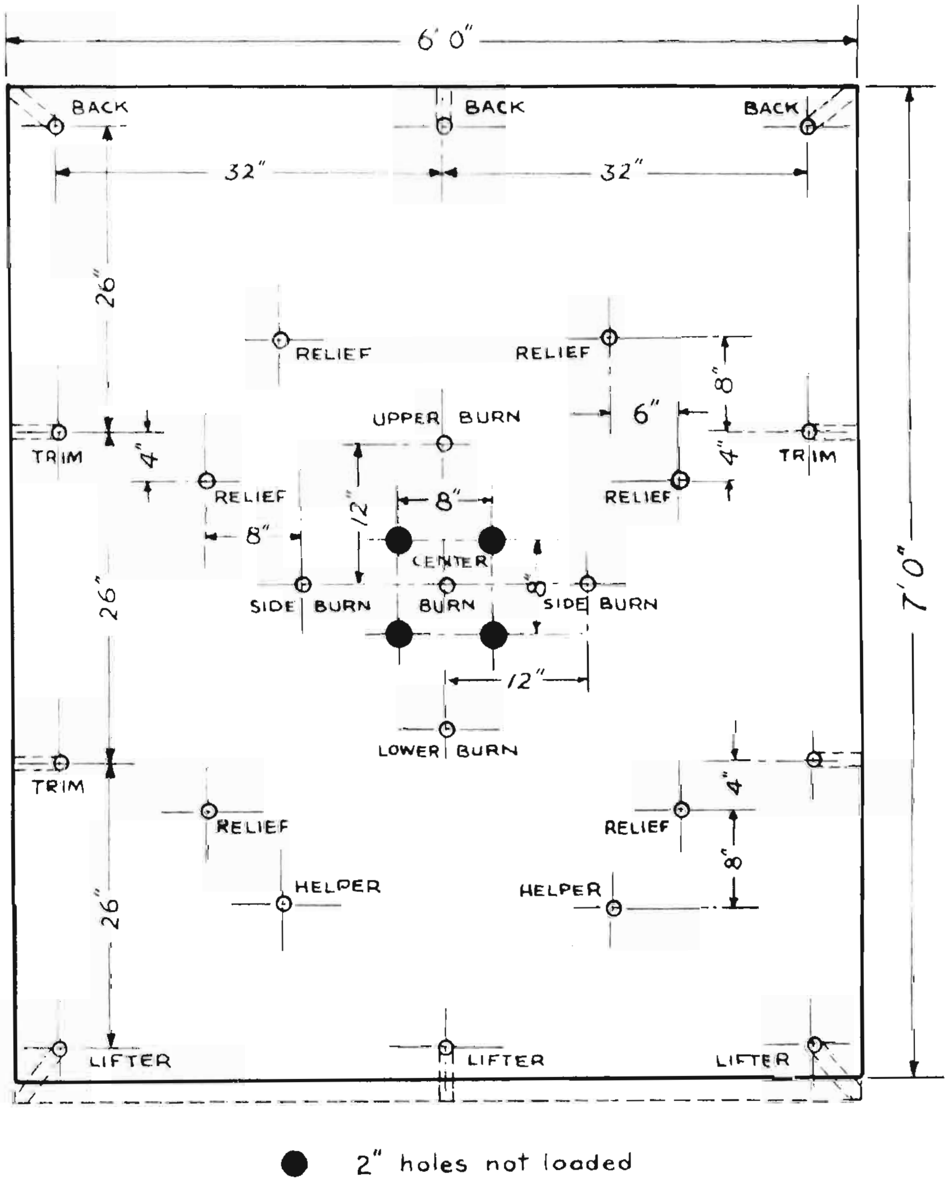
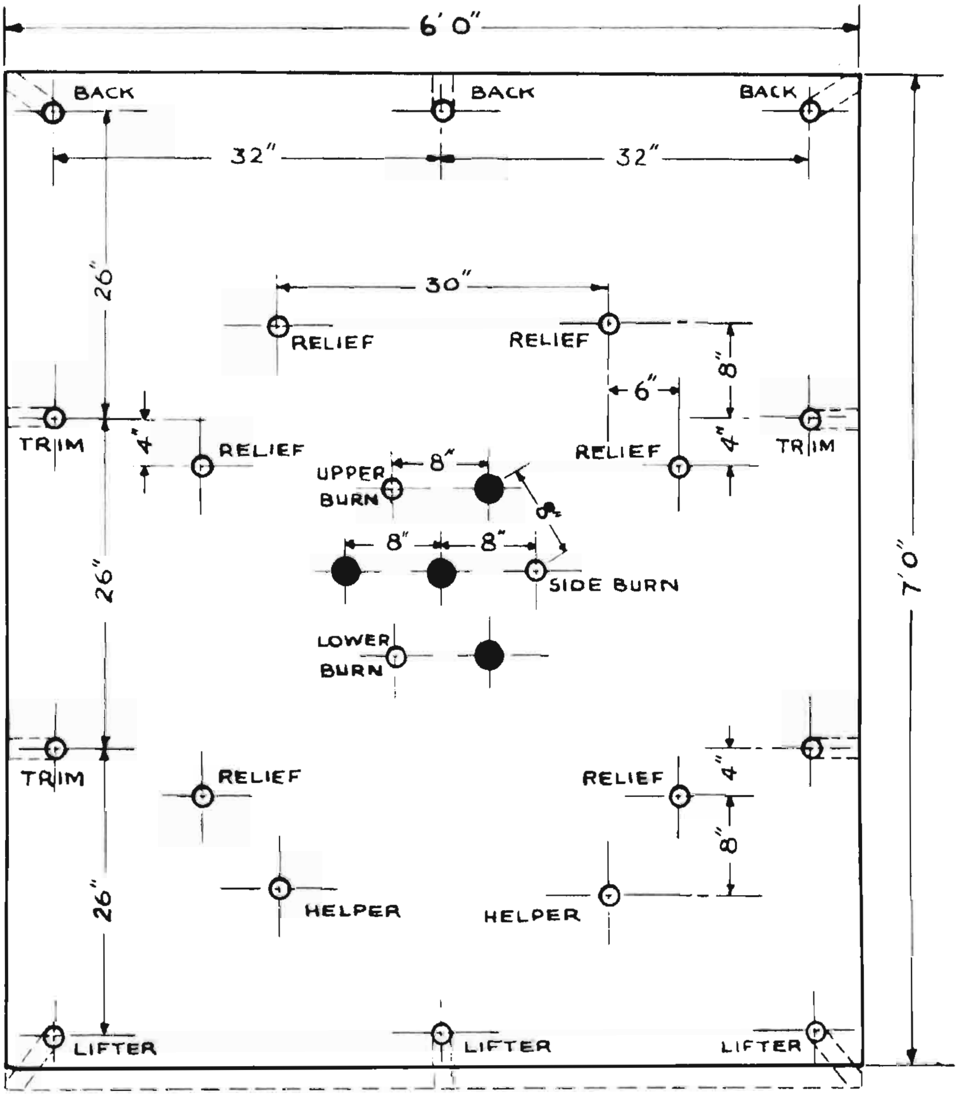


FIGURE 8. EXPERIMENTAL DRILL PATTERN NO. 5.

in the case of effective breakage. However, taking throw into account, Round 18 must be accorded the more efficient.

Experimental Drill Pattern No. 6 (Figure 9) was used for Rounds 19 and 20. This is 25-hole pattern with a 7-hole burn, only three holes of which are loaded. The remaining four holes in the burn are 2-inch holes and are provided as space for the burn holes to break to. Round 19, fired with split-second delays, was a pronounced failure, yielding only 4.1 feet of advance, 86.3 per cent of undersize and a throw of 78 feet. The effective fine breakage was as low as in Round 2, being .177. There was considerable "bootleg" on all the back holes and on the lower left-hand lifter. This was no doubt a result of "overlap" in the primers contained in the middle back hole and either the lower left-hand lifter or the middle lifter.

Round 20, fired with regular delays, did not give outstanding results, but the advance was satisfactory, even though the percentage of oversize was high. The throw was close to the ideal, and it is doubtful if it could be improved upon.



● 2" holes not loaded

FIGURE 9. EXPERIMENTAL DRILL PATTERN NO. 6.

CONCLUSIONS

The extent to which throw is disadvantageous to any underground mining operation will depend upon the importance attached to it in each case. Each case must be dealt with on its own merits, and the assessment of the importance of throw must ultimately come from a cost analysis or a safety viewpoint.

If the weight attached to throw in the final index of efficiency be equivalent to that for fragmentation and advance, then split-second caps must be judged less efficient than regular delays, for it has been shown beyond reasonable doubt that split-second delays throw debris much further than do regular delays.

If throw is not considered, then the results of the foregoing tests may be analysed to reasonably show the following tendencies on the part of split-second delays:

(1) In rounds drilled in a V-cut pattern split-second delays will prove a little more efficient than regular delays, if none of the delay periods overlap.

(2) If overlapping does occur in such rounds split-second delays will, at best, be only slightly more effective than regular delays, while in many cases they will be less effective, depending on the position and number of overlaps.

(3) When delays are dropped from the normal sequence to avoid overlap, efficiency may decrease to the same level as with regular delays, or even below that of regular delays.

(4) In rounds of burn pattern split-second delays will be more

effective only in certain types of burn round, and then only as a consequence of the fragmentation.

(5) The use of split-second delays in unorthodox firing orders in underground limestone mining reduces their effectiveness.

The above conclusions must be viewed with as much caution as they have been drawn, for it would not be prudent to infer that the application of split-second delays to underground mining in general causes a lowering of blasting efficiency. From purely theoretical speculation it would seem that their use would be as advantageous as it has been demonstrated to be in surface mining.

Although we know very little about the way or the degree to which rock is stressed in blasting it would appear almost certain that split-second delays would take advantage of stresses set up in the rock during firing. This is apparently true in quarry blasting, but an entirely different set of circumstances is prevalent in underground blasting.

7 Blasting in an underground development heading is always tight. There is only one free face to which the ground can be broken and this is usually of limited size. ...Rounds consist of (1) the cut or burn holes, (2) the relief holes, and (3) the trim holes. These three types of holes are fired in rotation, the cut holes to make the initial opening, the relievers to make the enlarged opening, and the trimmers to square up the face to its full desired dimensions.... The first and most difficult step in blasting any heading is to make an opening into the solid ground, usually in the center of the face and as deep as practical to advance the face at any one time. This opening is called the "cut" or "burn" and although cuts may be "pulled" by a number of methods of drilling and blasting, they all serve the same purpose, namely, to form a second free face to which the remainder of the holes in a round can break. It is therefore obvious that the cut is the most essential part of the round as the rest of the

holes cannot possibly "pull", unless the cut comes out completely.(22)

The author believes that split-second delays fail to fulfill their theoretical purpose because the cut or burn has insufficient time to clear of broken debris before the remaining holes fire. Evidence in the tests which points to the truth of this statement is the fact that split-second delays performed better in V-cut rounds than they did in burn rounds. Unlike the V-cut which is designed to break out a wedge or cone of rock, the burn cut is intended to shatter and pulverize the rock, breaking it into small fragments which are expelled by the blast leaving a roughly cylindrical opening.(23) Hence if the relief holes in a burn round fire before the burn is clear of broken rock there must be some loss of advance. In V-cut rounds, on the other hand, most of the debris is separated from the face at the moment of severance. This would be more pronounced in drill patterns having more than one pair of cut holes, or in pyramid type patterns. In the tests carried out, evidence to support this view was the presence of "bootlegs" in the burn which were filled with rock sheared along bedding planes, often to the extent that they were not even visible. This was also the case in the wedge-cut rounds, but to a lesser degree.

Therefore the author considers that split-second delay caps should be provided in two series, with an interval of a half to one

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(22) E. I. du Pont de Nemours and Company Inc., op. cit., p. 223.
(23) E. I. du Pont de Nemours and Company Inc., op. cit., p. 225.

second between the two, such as that shown in Table XIII. The first series could be used in the cut or burn, and the other in the relief and trims.

TABLE XIII

Suggested Delay Series

Delay No.	Series	Delay Period (seconds)
0	A	.000
1		.025
2		.050
3		.075
4		.100
5	B	.600
6		.625
7		.650
8		.675
9		.700
10		.725

In the research described vibration and concussion were not determined quantitatively, but the concussion from split-second delay blasts seemed much greater than that from regular delay blasts. This is probably true since the final shots from the regular delay blasts are so muffled by the "muck" as to be barely audible.

In tests using split-second delays the concussion was quite violent at the portal of the mine -- about 300 feet from the seat of the blast. The effects then, in a timbered drift, would be rather undesirable.

It is readily apparent why the throw should be greater with split-second delays than with regular delays, for the "muck" which becomes airborne with the initial shots is likely to be kept in suspension, and given more impetus by subsequent shots. It is difficult to see how it can be reduced in the narrow confines of a drift, without resorting to radically different drilling patterns or firing orders.

Much of the advantage gained by split-second firing in the tests was a result of superior fragmentation. Although this was not always the case, it has been found true by other workers.(24) Fish and Hancock have advanced a theory applicable to quarry blasting which may hold true for underground blasting:(24)

> Figure 10 suggests diagrammatically the way in which short delay blasting could give better fragmentation. When a shot is fired in rock, breakage of the ground occurs in two ways, first, by the original shock of the detonation and, second, by the subsequent movement of the ground under gas pressure in which the pieces of rock part along cleavage planes or are shattered by hitting other fragments and the ground. It is therefore reasonable to assume that the more jostling that can occur among the pieces of rock, the more chances there are of further breakage. In an instantaneous blast, where a number of holes are fired simultaneously, the fragments of rock broken by adjacent holes tend to move parallel with one another with a minimum of transverse relative movement. On the other hand, where short delay blasting is used in a row of holes starting, for instance, from the middle and working outwards in series, the instantaneous holes form a cavity across which the next pair of holes in sequence tend to blast towards each other. Hence, there is a tendency for increased relative transverse movement and greater jostling of the fragments of rock. Such a theory is supported by the fact that short delay blasting in tunnel rounds has resulted in definitely improved fragmentation. In such cases the instantaneous shots form a cavity into which the next shots in sequence fire, and so on.

Whatever the precise mechanism of rock breakage with split-second delay E. B. caps may be, it is not advisable to predict that they

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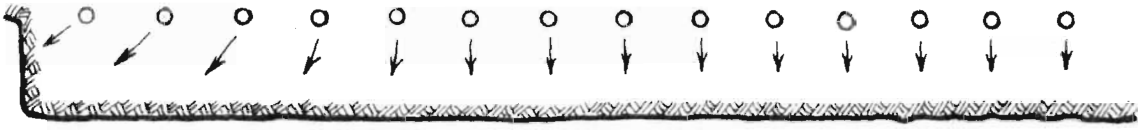
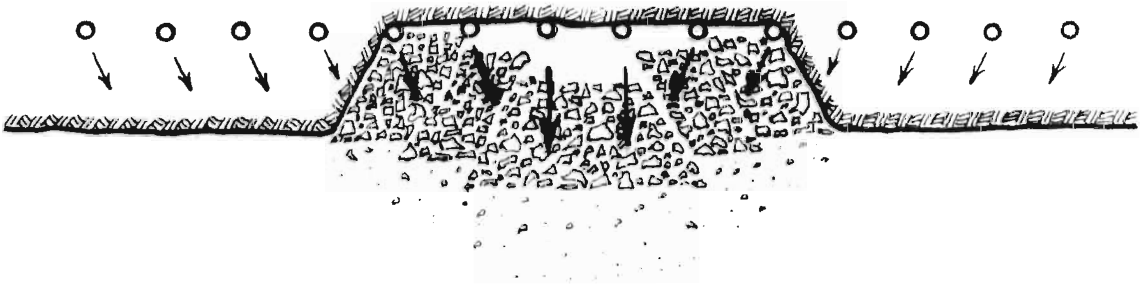
(24) Fish, B. G. and Hancock, J., *op. cit.*, p. 334-335.



instantaneous blast



short delay blast

Figure 10. Diagram illustrating the way in which short delay firing may give improved fragmentation.

will be superior to conventional delay caps, without more conclusive evidence, which is of necessity, of a long-term nature. Also it must be emphasized that the results of the research carried out by the author and described herein, may only be applied where the same or similar conditions of mining hold, and the same blasting methods used. In particular the results obtainable with a different size, strength or speed of explosive may be quite different.

SUMMARY

To assess the effectiveness of split-second delay E. B. caps as compared with that of regular delay E. B. caps, 20 rounds were drilled and blasted at the Experimental Mine of the Missouri School of Mines and Metallurgy. To make the comparison pairs of rounds were drilled and fired under similar conditions, one with split-second delays and the other with regular delays. Three standard types of drill pattern were employed, and one unorthodox drill pattern.

It was found that split-second delays produced greater throw than did regular delays, but if throw was not taken into consideration they generally proved more effective than regular delays, when no overlapping of the delay periods occurred. An exception was in the case of one burn round, which "pulled" better with regular delays.

The tests advanced the drift 95 feet, consuming approximately 1200 pounds of "liberty" 1-inch 50 per cent special gelatin, 280 Western Ventless Minimax Delay caps, 122 Western Ventless Delay caps, and 60 1½-inch Jackbits.

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