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Effects of a reverse order of firing using millisecond delay electric blasting caps in a quarry operation

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EFFECTS OF A REVERSE ORDER OF FIRING USING MILLISECOND DELAY ELECTRIC BLASTING CAPS IN A QUARRY OPERATION

BY

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THESIS

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Professor of Mining Engineering

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I desire to express my appreciation to Dr. J. D. Forrester, Chairman, Department of Mining Engineering, for his guidance and valuable assistance in making possible the completion of this work.

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INTRODUCTION

Evidence of the steady increase in the production of quarries is a reflection of the improved blasting practices that are being used. New explosives, the new millisecond electrical blasting caps and the endless experimentation carried on by both manufacturer and operator continue to aid or better the old methods of quarry blasting. In many instances the better results were obtained from practices hitherto unknown or at least unused.

This report describes the results obtained from comparing quarry rounds shot in the accepted firing order and those shot in the reverse order of firing. The purpose of the report is to determine if the reverse order of firing is in any way superior to that of the regular order.

REVIEW OF LITERATURE

A search for literature dealing with reverse order of firing in quarries failed to reveal any published material.

However, Wing G. Agnew of the Bureau of Mines, has published two articles in the Mining Congress Journal describing experiments in raise rounds using millisecond delay blasting caps and a variation of detonating the round by a reverse firing order.[1]

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(1) Agnew, W. G., Mining Congress Journal, April and October 1949, pp. 80, pp. 30.

PROCEDURE

The following is a discussion of a method whereby an "index" system is used to compare the relative overall character of the results of the individual test rounds. The method was developed by Assistant Professor R. F. Bruzewski of the Department of Mining Engineering of the University of Missouri School of Mines and Metallurgy.

The index is based on the functions: (1) fragmentation (size of rock after blasting), (2) yield (tons of rock broken per pound of explosive used), (3) throw (area over which the broken rock is scattered after blasting.

An arbitrary figure of "10," as a total of these functions, is considered a perfect index. Each of the functions was assigned a value in respect to their importance to the "perfect" value. These functional values are as follows:

Fragmentation	=	6.5
Yield	=	3.0
Throw	=	0.5
Index	=	10.0

With this index any individual round can be compared with respect to its success to any and all other rounds. For example, a round producing fragmentation that is 60% of perfect; a yield 70% of perfect and throw 65% of perfect, has a computed "index" as follows:

Fragmentation	6.5 x .60	=	3.90
Yield	3.0 x .70	=	2.1
Throw	.5 x .65	=	.325
Total test index			6.325

Because this method of evaluation produces an index of "relative" desirability for each round, it was decided to assume arbitrary conditions to represent a perfect or optimum round. Therefore, fragmentation is considered to be "perfect" when all rock has been broken to minus 10 inches (-10"); yield is realized when 4.38 tons of rock are broken per pound of explosive used, this figure is given by Young (2) as being an average for open pit work in comparison to other various mining work. Perfect "throw" is represented by the distance, perpendicular to the original quarry face, that will accommodate all the broken rock in a pile four feet deep in the front of the blasted section.

If a test-round produces rock particles larger than 10 inches (-10"), the index function for fragmentation will fall below the perfect value assigned. A blast producing particles that fall within the plus 10 inches and minus 16 inches (+10" and -16") category will produce a fragmentation index of 50 per cent of the perfect index (-10") classification. The extremely large particles (plus 26 inches), are assigned negative values. A summary of the values for the various sizes of fragments are as follows:

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(2) Young, George J., Elements of Mining, 4th ed., McGraw-Hill Book Company, 1946, p. 161.

- 10" size bears a + 100% influence

+ 10" - 16" size bears a + 50% influence

+ 16" - 26" size bears a + 0% influence

+ 26" size bears a - 100% influence

To illustrate the actual calculation of a fragmentation index, Preliminary Round 3 is taken as an example

Fragmentation	Test Round 3
- 10"	67.0%
+ 10" - 16"	18.5%
+ 16" - 26"	14.5%
+ 26"	None

Calculation:

- 10"	67.0 x (+) 1.00	=	+67.0%
+ 10" - 16"	18.5 x (+) .50	=	+ 9.25%
+ 16" - 26"	14.5 x (+) .00	=	+ .00%
+ 26"	0.0 x (-) 1.00	=	.00%
			76.25%

The fragmentation of Preliminary Round 3 is 76.25 percent of perfect. As the index function for perfect fragmentation is 6.5, this fragmentation index for Round 3 is equal to 0.7625 x 6.5 or 4.95.

Perfect yield has been assigned an influence factor of 3.0 and is realized when each pound of powder breaks 4.38 tons of rock. Thus, if a round breaks anything less than 4.38 tons of rock per pound of explosive used, the factor is decreased in direct proportion. Using Preliminary Round 3 as an example, the "yield" is:

$$\frac{1.65}{4.38} \times 100 = 37.7\%$$

of being perfect. The "yield" index for this round is then .377 x 3.0 or 1.131.

To determine the distance of perfect "throw" it is necessary to select a representative cross-section of the burden perpendicular to the quarry face. The area of this cross-section is multiplied by 1.3 to allow for a 30 percent swell, and is then divided by four to determine the length over which the area would be distributed at a height of four feet. This represents the distance, from the quarry face, within which all rock must fall to obtain a perfect "throw" -- and any rock falling beyond this calculated distance will cause the "throw" to fall below perfection. Should the "throw" surpass the distance by 500 feet, the "throw" index will receive a negative value in proportion to the distance it exceeds the limits. Again Preliminary Round 3 will be used as an example in which the throw was 52 feet. The cross section consists of 4 feet of quarry face, 3 feet of burden, and holes 4.2 feet deep, presenting an area of 12 square feet. This, multiplied by 1.3 and divided by 4, gives a maximum perfect throw distance of 3.9 feet. When rock is scattered 500 feet beyond this limit the index is 0.0% of perfect. Throw for Preliminary Round 3 is 52 feet or 52 - 3.9 = 48.1 feet beyond the "calculated" limit, therefore, it is said to be

$$\frac{500 - 48.1}{500} \times 100 = 90.4\%$$

of perfect. After correction, the throw index for this round is equal to 0.5 x .904 = .4520

All of the individual functions are added to determine an index for the test round.

Fragmentation	4.495
Yield	1.131
Throw	.452
Test Index	6.078

The ease with which this round can be compared to succeeding rounds is readily appreciated. It should, however, be kept in mind that all values were arbitrarily selected and were used for comparative purposes only. No attempt was made to apply the values to specific conditions or specifications.

Problem Procedure.

Three series of test rounds were decided upon, consisting of 5 rounds per series. Each series utilized two rounds detonated in the ordinary firing order, two rounds detonated by a reverse firing order and one round fired simultaneously. The individual series were charged in a different manner. The drill pattern used for all tests is shown in Figure 1. The holes were 1-3/8 inches in diameter and were drilled 4.2 feet in depth.

Comparative rounds for each series were charged and shot under identical conditions. The results obtained from these rounds gave comparisons as to the relative effectiveness of the firing orders detonating the charges.

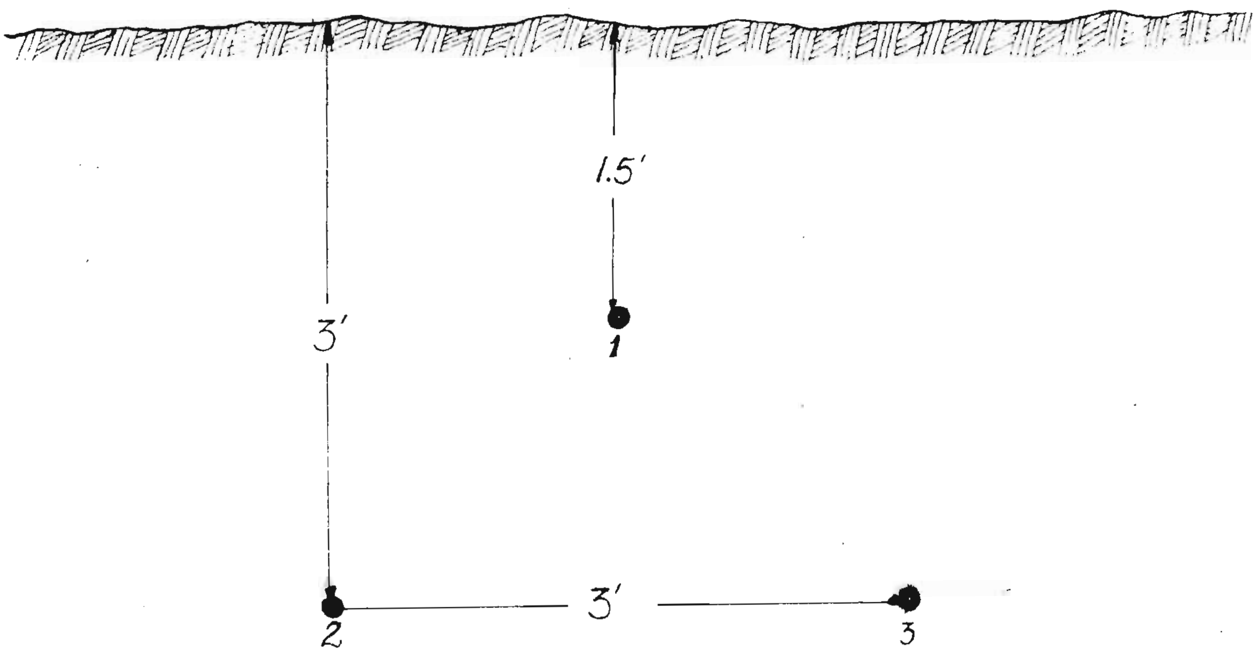

Figure 1

MATERIALS AND EQUIPMENT

Experimental work described in this paper was carried on at the Experimental Quarry of Missouri School of Mines and Metallurgy. This quarry, which is about 1½ miles southwest of Rolla, is used for laboratory studies and research work in mining. The quarry rock is a soft, gray, well bedded, dolomitic limestone known locally as the Jefferson City dolomite.

Drilling Equipment

All holes were drilled dry with an Ingersoll-Rand JB-5 Jackhammer using 1-inch hollow hexagonal drill steel, and Ingersoll-Rand 4-point, 1-3/8 inch Jack-bits.

Dynamite, Caps and Prima Cord

The dynamite used in the test rounds was 50 per cent Special Gelatin, manufactured by the Olin Industries, and was detonated with Atlas Rockmaster No. 6 electrical blasting caps and Bickford prima cord.

BLASTING

Preliminary Round 1

The purpose of the first preliminary round was to obtain an idea of the amount of powder needed to break the rock.

All holes, 1, 2 and 3, were solidly charged with four sticks of powder per hole. The primers were placed in the next to the top cartridge and arranged so as to effect a reverse firing order. Atlas Rockmaster No. 6, 0 delays were in the back holes and a No. 1 delay in the front hole.

The round was considered a failure as it failed to produce any satisfactory information. The volume of rock from the top of the charge to the collar of the hole broke into excessively large boulders.

Preliminary Round 2

This round was fired under the identical conditions of Preliminary Round 1 with the exception of the firing order. In this round a 0 delay was located in the front hole and 1 delays in the back holes. This method of priming produced the ordinary firing order.

This round was also a failure and the results were comparable to Preliminary Round 1.

The results observed from Preliminary Rounds 1 and 2 indicated that more powder was needed to break the rock and that the charges needed to be lengthened in the hole to effect a greater area.

It was decided to use five sticks of powder per back hole and six sticks in the front hole.

Preliminary Round 3

This round was charged and primed for a reverse firing order with 0 delays in the back holes and a 1 delay in the front hole. The results were considerably better than those of Preliminary Rounds 1 and 2.

Primer-detonator	Atlas Rockmaster No. 6, #0, 1 delays
Hole diameter	1-3/8"
Depth of hole	4.2'
Type of charge	Solid
Distance from top of charges to hole collar	2.04', 2.4', 2.4'
Tons of rock broken	17.8
Tons per pound of explosive	3.38
Rock throw	52'

Fragmentation:

- 10"	64%
+ 10" - 16"	8.36%
+ 16" - 26"	22.14%
+ 26"	5.5%
Depth of break	5.6'
Index of effectiveness	6.078

Preliminary Round 4

This round was an exact copy of Preliminary Round 3 with the exception of the firing order. In this round a 0 delay was placed in the front hole and 1 delays placed in the back holes.

The results were favorable. Fragmentation was improved over Preliminary Round 3, but a big difference was seen in the tonnage broken and the distance of the throw which is superior for Preliminary Round 3.

Primer-detonator	Atlas Rockmaster No. 6, # 0, 1 delays
Hole diameter	1-3/8"
Depth of hole	4.2'
Type of charge	Solid
Distance from top of charge to hole collar	2.04', 2.4', 2.4'
Tons of rock broken	8.65
Tons per pound of powder	1.65
Rock throw	100'
Fragmentation:	
- 10"	67.0%
+ 10" - 16"	18.5%
+ 16" - 26"	14.5%
+ 26"	0.0%
Average depth of break	4.2
Index of effectiveness	6.48

The results obtained from Tests 3 and 4 indicated that the powder charge needed to be raised nearer the collar of the hole and a reduction in the amount of powder could be utilized. To accomplish these simultaneously, it was decided to use deck loading.

Figure 2 illustrates a cross section, front view, of the holes

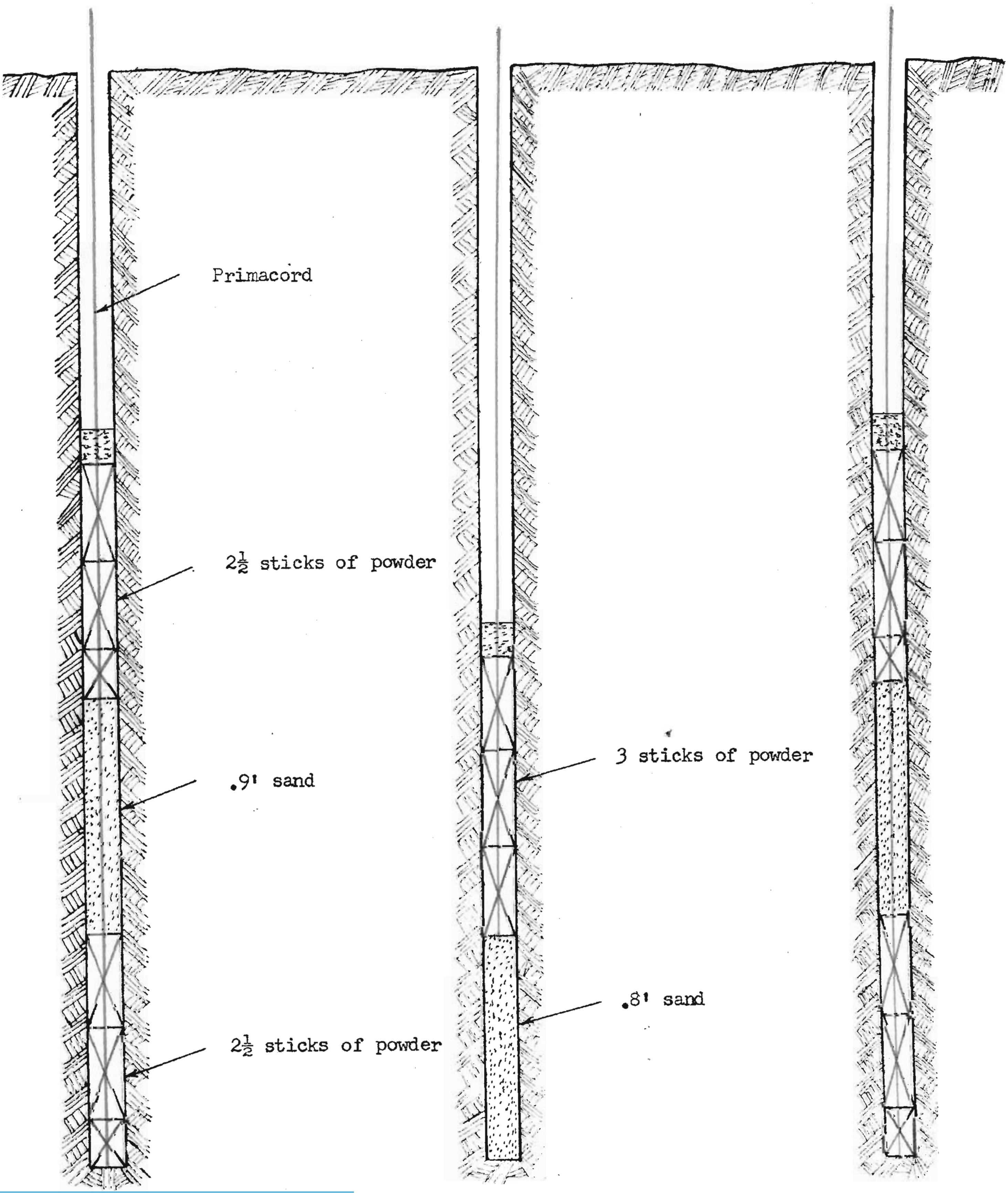
Primacord
2½ sticks of powder
.9' sand
2½ sticks of powder
3 sticks of powder
.8' sand

Figure 2

as charged for tests 1, 2, 3, 4 and 5.

The prima cord was strung through the center of each cartridge as it entered the hole. This procedure was followed for the next fifteen test rounds.

Test Round 1

The round was primed so as to obtain a reversed order of firing. 0 delays were used in the back holes and a 1 delay in the front hole.

The round broke a large tonnage but fragmentation was very poor. The depth of break extended 1.4 feet below the bottom of the hole, accounting for a portion of the tonnage. In addition there was a great amount of wing breakage that also supported the large tonnage but at the same time hindered the fragmentation.

Primer-detonator	Atlas Rockmaster No. 6, #0, 1 delays
Hole diameter	1-3/8"
Depth of holes	4.2'
Type of charge	Deck
Distance from top charges to hole collars	2.3', 1.5', 1.5'
Tons of broken rock	14.15
Tons per pound of explosive	3.27
Rock throw	40'
Fragmentation:	
- 10"	40.7%
+ 10" - 16"	5.3%
+ 16" - 26"	42.6%

+ 26"	11.4%
Average depth of break	5.6
Index of effectiveness	4.782

Test Round 2

Test Round 2 was similar in all respects to Test Round 1 with the exception of the order of firing. In this round the 0 delay was located in the front hole and the 1 delays in the back holes.

The results gave a direct comparison of the two types of firing order and indicated that the fragmentation for this round was better than that for Test Round 1, but amount of rock broken was less.

Primer-detonator	Atlas Rockmaster No. 6, #0, 1 delays
Depth of hole	4.2'
Type of charge	Deck
Distance from top of charge to hole collar	2.3', 1.5', 1.5'
Tons of rock broken	8.5
Tons per pound of explosive	1.95
Rock throw	85'
Fragmentation:	
- 10"	82.1%
+ 10" - 16"	3.53%
+ 16" - 26"	14.37%
+ 26"	0.0%
Average depth of break	4.2'
Index of effectiveness	7.194

Because of the poor results obtained from Test Round 1 it was concluded that a shorter delay interval was needed for the reverse order of firing to compensate for the close spacing of the holes. The procedure used to obtain the shorter delay was the use of prima cord as the timing interval.

It was calculated that 2.2 feet of prima cord would compensate for the anticipated plus or minus fluctuation time of detonation in the 0 delays and still give a shorter interval than could be obtained from any available delay caps.

Test Round 3

The round was charged in the exact manner as Rounds 1 and 2. The back holes were primed with 0 delays and the front hole used 0 delays plus the 2.2 feet of prima cord as per the procedure explained above to obtain a reverse order of firing.

The results were favorable and indicated that the shorter delay period with this particular charging gave better fragmentation and yield. When compared with Test Round 1 the effective index shows this round to be considerably better and surpassed any round shot with this method of charging.

The outstanding result of the round again was the large tonnage due to the large wing breakage and the breakage below the depth of the hole by 1.4'.

Primer detonator	Atlas Rockmaster No. 6, #0 delay and Primacord.
Hole diameter	1-3/8"
Depth of hole	4.2'

Type of charge	Deck
Distance from top of charge to hole collar	2.3', 1.5', 1.5'
Tons of rock broken	15.9
Tons per pound of explosive	3.68
Rock throw	35'
Fragmentation:	
- 10"	65.0%
+ 10" - 16"	11.3%
+ 16" - 26"	18.9%
+ 26"	4.8%
Average depth of break	5.6
Index of effectiveness	7.426

Test Round 4

Again the round was charged as shown in Figure 2. The holes were timed with primacord as explained for Test Round 3. This round was shot in the ordinary firing order using the plus 2.2 feet of primacord in the back holes and all holes primed with 0 delays.

The results indicated that, with this method of charging, the shorter delay was of no benefit to the ordinary firing order.

Primer-detonator	Atlas Rockmaster No. 6, #0 delay and primacord
Hole diameter	1-3/8"
Depth of hole	4.2'
Type of charge	Deck

Distance from top of charge to hole collar	2.3', 1.5', 1.5'
Tons of rock broken	9.9
Tons per pound of explosive	2.29
Rock throw	60'
Fragmentation:	
-10"	70.5%
+ 10" - 16"	3.34%
+ 16" - 26"	26.16%
+ 26"	0.0 %
Average depth of break	4.2'
Index of Effectiveness	7.019

Test Round 5

This round was shot to ascertain if Rounds 3 or 4 were using such a short interval as to be approaching the results of the holes being fired simultaneously.

The holes for Test Round 5 were charged in the identical manner as the four previous rounds. All holes were primed with 0 delays so as to detonate the charges simultaneously.

The results show fragmentation to be very poor, throw excessive and also that the short delay used in Rounds 3 and 4 was effective.

Primer-detonator	Atlas Rockmaster No. 6, #0 delay
Hole diameter	1-3/8"
Depth of hole	4.2'
Type of charge	Deck

Distances from top of charge to hole collars	2.3', 1.5', 1.5'
Tons of rock broken	13.3
Tons per pound of explosive	3.06
Rock throw	105'
Fragmentation:	
- 10"	53.0%
+ 10" - 16"	9.3%
+ 16" - 26"	23.4%
+ 26"	14.3%
Average depth of break	4.2'
Index of effectiveness	5.309

Test Rounds 1, 2, 3, 4 and 5 utilized one method of charging and three different delay intervals. The effective indices indicate that Round 3 was superior to any others of this series. The tabulated results show fragmentation for the ordinary firing order surpassed those for the reverse order of firing while tonnage broke was a great deal less and the rock throw considerably greater.

A new method charging the holes was decided upon to again obtain comparative results of the firing orders. The system adopted to charge Test Rounds 6, 7, 8, 9 and 10 is shown in Figure 3.

Test Round 6

The round was charged as shown in Figure 3, primed as Test Round 1 with 0 delays in the back holes and a 1 delay in the front to effect the reverse firing order.

The results were similar to those of Round 1. The tonnage broken was large but fragmentation was again poor.

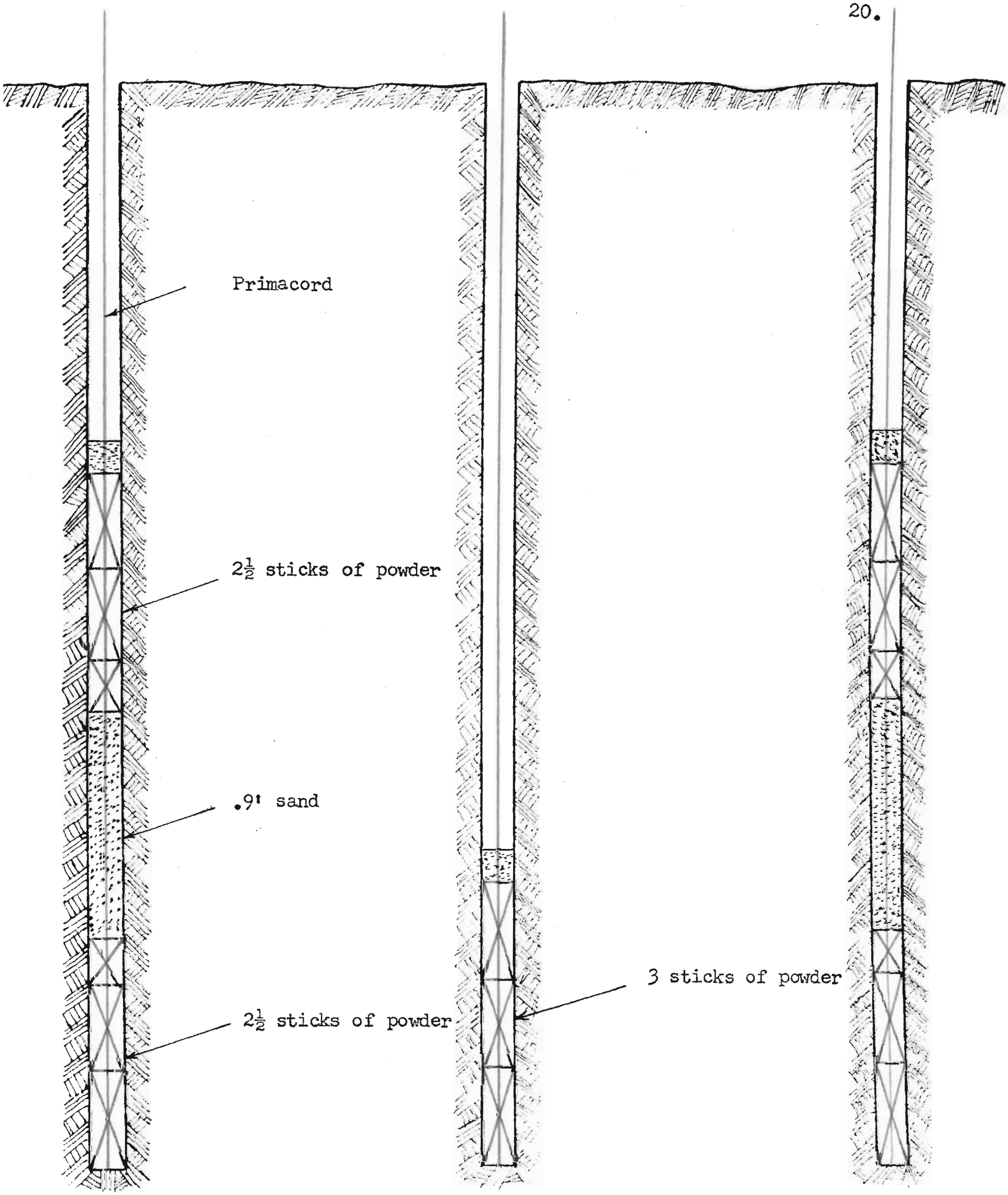
Primacord
2½ sticks of powder
.9' sand
2½ sticks of powder
3 sticks of powder

Figure 3

Primer-detonator	Atlas Rockmaster No. 6 #0, 1 delays taped to end of primacord.
Depth of hole	4.2'
Distance from top of charge to hole collar	3.1', 1.5', 1.5'
Tons of rock broken	14.45
Tons per pound of explosive	3.34
Rock throw	52'
Fragmentation:	
-10"	49.0%
+ 10" -16"	7.35%
+ 16" -26"	28.4 %
+ 26"	15.25%
Average depth of break	4.2'
Index of effectiveness	5.034

Test Round 7

Round 7 was set up for the ordinary firing with 1 delays in the back holes and a 0 delay in the front.

Fragmentation for the round was very good, but, as in the previous rounds, the tonnage was considerably less than the tonnage for the reverse order of firing.

The effective index indicates the round to be much better than Test Round 6. This is due mostly to the good fragmentation of the round.

Primer-detonator	Atlas Rockmaster No. 6, #0, 1 delays
Depth of hole	4.2'
Distance from top of charge to hole collar	3.1', 1.5', 1.5'
Tons of rock broken	8.1
Tons per pound of explosive	1.87
Rock throw	54'
Fragmentation:	
- 10"	86.3 %
+ 10" - 16"	5.67%
+ 16" - 26"	8.03%
+ 26"	0.0 %
Average depth of break	4.2'
Index of effectiveness	7.535

Test Round 8

Round 8 was primed for a reverse order of firing using the additional 2.2 feet of primacord, as explained in Round 3, for the delay interval.

The round produced poor fragmentation but again the large tonnage broken was very noticeable.

Primer-detonator	Atlas Rockmaster No 6, # 0, + 2.2 primacord
Depth of hole	4.2'
Distance from top of charge to hole collar	3.1', 1.5', 1.5'
Tons of rock broken	15.9

Tons per pound of explosive	3.68
Rock throw	66'
Fragmentation:	
- 10"	62.0 %
+ 10" - 16"	1.57%
+ 16" - 26"	8.36%
+ 26"	28.07%
Average depth of break	5.6'
Index of effectiveness	5.218

Test Round 9

Round 9 was another direct comparison of firing orders. The round was the same as Round 8 except that the 2.2 feet of primacord was located in the back holes.

Again with this particular charging, the ordinary firing order was superior to the reverse order. Fragmentation was much better for the ordinary order while the reverse order maintained the greater tonnage.

Primer-detonator	Atlas Rockmaster No. 6, #0, 0 + 2.2' primacord
Depth of hole	4.2'
Distance from top of charge to hole collar	3.1', 1.5', 1.5'
Tons of rock broken	10.65
Tons per pound of explosive	2.46
Rock throw	80'
Fragmentation:	
- 10"	74.5%

+ 10" - 16"	10.2%
+ 16" - 26"	9.2%
+ 26"	6.1%
Average depth of break	4.2'
Index of effectiveness	6.879

Test Round 10

Round 10 was shot simultaneously with 0 delays and was used as a check on Round 8 and Round 9 to determine if the short delay was too nearly simultaneous to effect any appreciable differences in the results.

The results of the round were very poor, and this type of round again indicated that the short delay did improve results.

Primer-detonator	Atlas Rockmaster No. 6, #0 delays.
Depth of hole	4.2'
Distance from top of charge to hole collar	3.1', 1.5', 1.5'
Tons of rock broken	10.8
Tons per pound of explosive	2.47
Rock throw	80'
Fragmentation:	
-10"	38.9%
+ 10" - 16"	1.7%
+ 16" - 26"	15.6%
+ 26"	43.8%
Average depth of break	4.2'
Index of effectiveness	1.863

The Test Rounds 6, 7, 8, 9 and 10 were comparisons of firing orders for holes charged as shown in Figure 3. The results indicated that the ordinary firing order was superior due to its better fragmentation. It is evident again as in the first method of charging, Figure 2, that the reverse firing order produced a considerably larger tonnage because of its excessive wing breakage and the ability to break below the hole depth.

It was thought that by increasing the amount of powder in the front hole, better fragmentation would be realized in the reverse order of firing. The method of charging that was used for Test Rounds 11, 12, 13, 14 and 15 is shown in Figure 4.

Test Round 11

Round 11 was charged as in Figure 4 and primed for the reverse firing orders with 0 delays in the back holes and a 1 delay in the front.

The results were as anticipated. That is, fragmentation was greatly improved and the tonnage broken was still large. The effective index number surpasses that of any other round.

Primer-detonator	Atlas Rockmaster No. 6, #0, 1 delay taped to primacord.
Depth of hole	4.2
Distance from top of charge to hole collar	.6', 1.5', 1.5'
Tons of rock broken	14.75
Tons per pound of explosive	2.95
Rock throw	42'

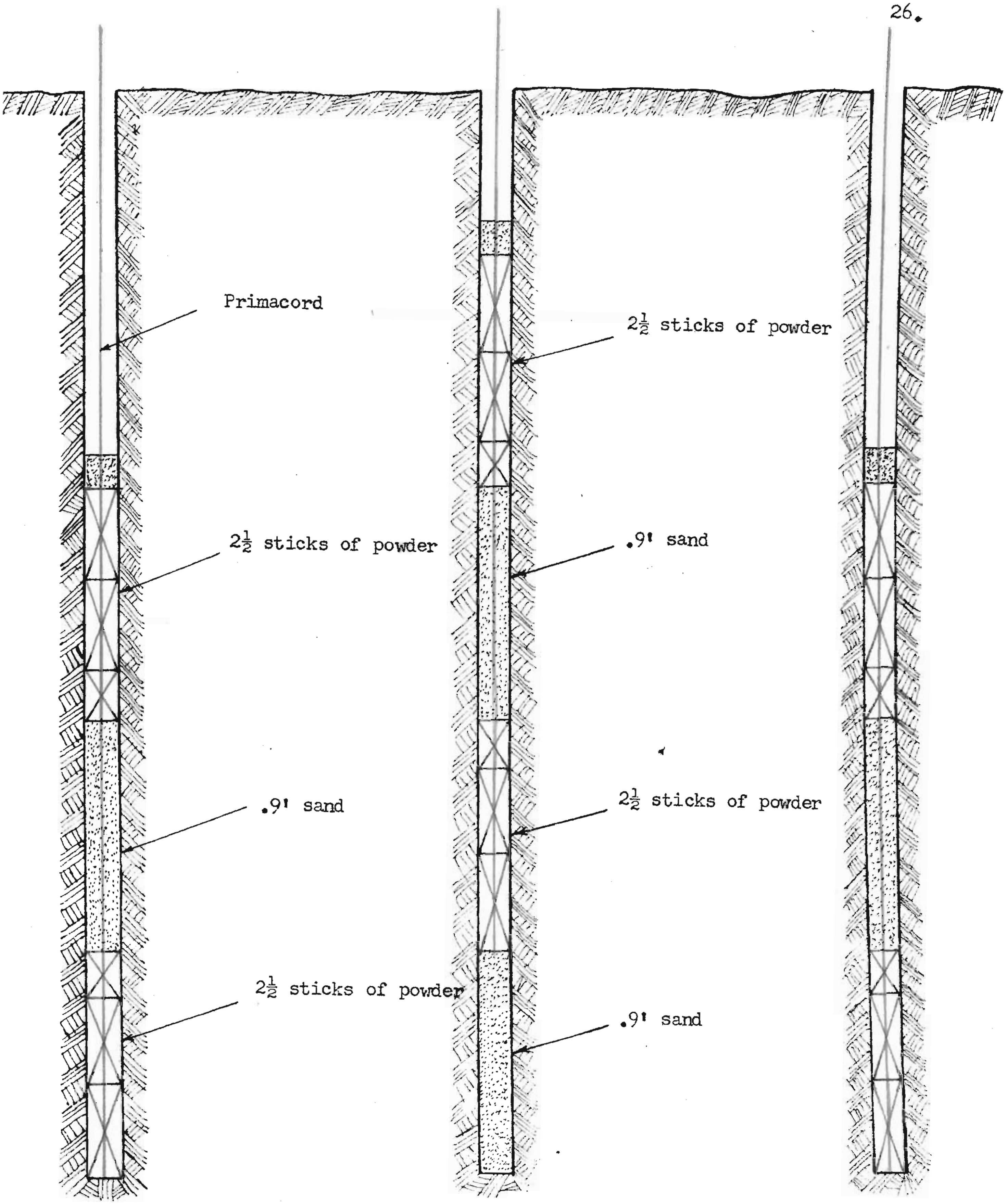
Primacord
2½ sticks of powder
.9' sand
2½ sticks of powder
2½ sticks of powder
.9' sand
2½ sticks of powder
.9' sand

Figure 4

Fragmentation:

- 10"	81.7 %
+ 10" - 16"	8.15%
+ 16" - 26"	10.15%
+ 26"	0.0 %
Average depth of break	5.2'
Index of effectiveness	8.045

Test Round 12

Test Round 12 was an ordinary firing order round with all conditions the same as for Test Round 11. A 0 delay was placed in the front hole and 1 delays placed in the back holes. The results of the round as compared to Round 11 show it to be inferior in all respects. Although the tonnage for this ordinary firing order did increase for Round 12, it was still less than that for the reverse firing order Round 11.

Primer-detonator	Atlas Rockmaster No. 6, #0, 1 delay taped to primacord.
Depth of hole	4.2'
Distance from top of charge to hole collar	.6', 1.5', 1.5'
Tons of rock broken	12.15
Tons per pound of explosive	2.43
Rock throw	63'

Fragmentation:

- 10"	69.6 %
+ 10" - 16"	4.75%

+ 16" - 26"	15.25%
+ 26"	10.4 %
Average depth of break	4.2'
Index of effectiveness	6.105

Test Round 13

Round 13 was another reverse order of firing using 0 delays plus 2.2 feet of primacord to give the delay interval. The plus 2.2 feet of primacord was located in the front hole with a 0 delay and the back holes were timed with 0 delays. This is the system explained for Test Round 3.

The results were satisfactory but not as good as those for Round 11. The amount of tonnage was again high and fragmentation was better than the other reverse order rounds with the exception of Test Round 11. This is also evidenced by the effective index.

Primer-detonator	Atlas Rockmaster No. 6, #0, 0 delay + 2.2' of primacord.
Depth of hole	4.2'
Distance from top of charge to hole collar	.6', 1.5', 1.5'
Tons of rock broken	16.5
Tons per pound of explosive	3.3
Rock throw	40'
Fragmentation:	
- 10"	75.5%
+ 10" - 16"	4.4%
+ 16" - 26"	15.0%
+ 26"	5.1%

Average depth of break	5.6'
Index of effectiveness	7.456

Test Round 14

The round was an ordinary firing order using the plus 2.2 feet of primacord with 0 delays in the back holes and a 0 delay in the front hole.

The results were greatly inferior to its comparative results of Round 13. Fragmentation was very poor but tonnage was again larger than the tonnages obtained from the ordinary firing order rounds of the previous methods of charging.

Primer-detonator	Atlas Rockmaster No. 6, #0, 0 delays, 0 delays + 2.2' of primacord
Depth of hole	4.2'
Distance from top of charge to hole collar	.6', 1.5', 1.5'
Tons of rock broken	13.4
Tons per pound of explosive	2.78
Rock throw	72'
Fragmentation:	
- 10"	35.5%
+ 10" - 16"	14.01%
+ 16" - 26"	30.07%
+ 26"	20.43%
Average depth of break	5.0'
Index of Effectiveness	3.773

Test Round 15

Round 15 was again a comparative round to determine if the short delay of Rounds 13 and 14 was effective or if it was approaching simultaneous firing so closely as to be similar in its results. All holes were fired simultaneously.

The results of the round were good. However, the short delay indicated it was, for this particular charging method, a benefit to the reverse order of firing as Round 13 is superior to this round.

Primer-detonator	Atlas Rockmater No. 6, #0 delays
Depth of hole	4.2'
Distance from top of charge to hole collar	.6', 1.5', 1.5'
Tons of rock broken	12.15
Tons per pound of explosive	2.43
Rock throw	57'
Fragmentation:	
− 10"	75.3%
+ 10" − 16"	4.2 %
+ 16" − 26"	20.5%
+ 26"	0.0 %
Average depth of break	4.6'
Index of effectiveness	7.142

CONCLUSIONS

1. Total tonnage of rock broken in the quarry by employing a reverse firing order when detonating the explosive charge exceeded that tonnage obtained from using the ordinary firing order.

2. The time interval or delay period elapsing between the detonation of the charges is an important factor in the results of the blast. However small, this interval of delay is an aid to both firing orders.

3. Fragmentation resulting from the use of the ordinary firing order in detonating the charges bettered that of the reverse firing order of detonation in all but the last series of test rounds. This series used 13.3 per cent more powder than the two previous series and resulted in superior fragmentation for the reverse firing order of detonation.

4. The throw of material realized by detonating the charges in reverse order was considerably less than that by detonating the charges in an ordinary manner.

SUMMARY

In three series of test rounds, consisting of 5 rounds per series, two firing orders for detonating the charges were compared as to their overall effectiveness. Each series used a different method of charging. The five rounds constituting a series consisted of 2 rounds detonated in the ordinary firing, 2 rounds detonated in a reverse firing order and 1 round detonated simultaneously. Conditions for comparative rounds were identical.

The results indicated that by detonating the charges with the reverse firing order a larger tonnage of rock would be broken with all the charging methods used. The amount of throw resulting from detonating with the reverse firing order was less than for ordinary firing order. However, fragmentation for the reverse order of detonation was better than the ordinary order of detonation only when an increase in the amount of powder was used.

In all rounds using a delay interval between the charges detonating, regardless of how short, results were better than for those rounds fired simultaneously.

TABLE I

Cumulative Round Data

TEST NUMBER	POUNDS OF EXPLOSIVE	PRIMER	STEMMING	TONS OF ROCK BROKEN	FRAGMENTATION (PERCENT) -10"	NO. OF BOULDERS	+10",-16"	NO. OF BOULDERS	+16",-26"	NO. OF BOULDERS	+26"	TONS OF ROCK PER POUND OF EXPLOSIVE	ROCK THROW
1	4.33	0, 1 delays, primacord	sand	14.15	40.7	6	5.3	9	42.6	1	11.4	3.27	40'
2	4.33	0,1 delays, primacord	sand	8.5	82.1	2	3.53	6	14.37	0	0.0	1.95	85'
3	4.33	primacord	sand	15.9	65.0	8	11.3	7	18.9	1	4.8	3.68	35'
4	4.33	primacord	sand	9.9	70.5	2	3.34	8	26.16	0	0.0	2.29	60'
5	4.33	0 delays	sand	13.3	53.0	9	9.3	10	23.4	2	14.3	3.06	106'
6	4.33	0,1 delays, primacord	sand	14.45	49.0	10	7.35	8	28.4	1	15.25	3.34	52'
7	4.33	0,1 delays, primacord	sand	8.1	86.4	3	5.67	3	8.05	0	0.0	1.87	54'
8	4.33	primacord	sand	15.9	62.0	2	1.57	4	8.36	3	28.47	3.68	66'
9	4.33	primacord	sand	10.65	74.5	6	10.2	3	9.2	1	6.1	2.46	80'
10	4.33	0 delays	sand	10.8	38.9	1	1.7	4	15.6	3	43.8	2.47	80'
11	5	0,1 delays, primacord	sand	14.75	81.7	8	8.15	6	10.15	0	0.0	2.95	42'
12	5	0,1 delays, primacord	sand	12.15	69.6	4	4.75	6	15.25	2	10.4	2.43	63'
13	5	primacord	sand	16.5	75.5	5	4.4	6	15.0	1	5.1	3.3	40'
14	5	primacord	sand	13.4	35.5	8	14.01	12	30.07	2	20.43	2.78	72'
15	5	0 delays	sand	12.15	75.3	3	4.2	6	20.5	0	0,0	2.43	57'

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VITA

The author was born in Platteville, Wisconsin, June 7, 1924. He received his elementary and high school training in this town. In September 1942 he enrolled at the Wisconsin Institute of Technology. From March 1943 until February 1946 he served with the Army Air Force. After discharge he again enrolled at the Wisconsin Institute of Technology from which he graduated in June 1948. In September 1948 the author enrolled at the University of Missouri School of Mines and Metallurgy and graduated with a B. S. in Mining Engineering in May 1949.