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The influence of cartridge diameter on the effectiveness of dynamite

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THE INFLUENCE OF
CARTRIDGE DIAMETER
ON THE EFFECTIVENESS OF DYNAMITE

BY

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A

THESIS

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The field work was carried out under the direction of Mr. L. E. Shaffer, Associate Professor, Department of Mining Engineering. Special thanks are due him for his counsel and sincere interest throughout the work, and for his assistance in the preparation of this thesis.

The problem was suggested and made possible through the cooperation of E. I. du Pont de Nemours and Company, Wilmington, Delaware. Acknowledgement of this aid is hereby made. Suggestions of Mr. H. A. Lewis, Manager, Technical Service Section, Explosives Division are appreciated.

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INTRODUCTION

For many years the manufacturers of explosives have attempted to show the advantages of using dynamite of a cartridge diameter of at least 1-1/8 inches. Tests by the manufacturers and by the United States Bureau of Mines have definitely shown that the dynamites prepared in larger diameter cartridges have several advantages: They are more sensitive to detonation; they detonate at a higher velocity; they are more resistant to water; they are safer to use; and they are more stable than dynamites made in smaller diameter cartridges. In spite of these advantages listed, several large consumers still insist on smaller diameter cartridges.

Dynamite is sold by weight and the cost to the consumer for a box of 50 pounds is the same regardless of the cartridge size. The manufacturing cost, however, increases with the smaller diameter cartridges because it takes more cartridges to fill a 50-pound box.

The study described in this thesis was suggested to the Mining Department of Missouri School of Mines and Metallurgy by officials of the Explosives Division of E. I. du Pont de Nemours & Company, of Wilmington, Delaware. With their cooperation an attempt has been made to determine the effectiveness of different sized cartridges of dynamite when used under actual mining conditions.

REVIEW OF LITERATURE

According to the Du Pont Company[1], "Commercial explosives are mixtures

1. E. I. du Pont de Nemours & Company, Blasters Handbook, 11th Ed., 1942, Introduction.

of solids and liquids......the ingredients of which break up from their initial solid or liquid state and recombine to form other materials which are mostly gaseous and which occupy a great deal more volume than the explosive did originally".

Peele[2] states that dynamite composed of 40 percent nitroglycerin, 46

2. Peele, R. and Church, A. Mining Engineer's Handbook. 3d ed. N.Y., Wiley, 1941. Sec. 4, p. 2.

percent sodium nitrate, and 14 percent wood meal will have the following explosion reaction when detonated:

$$2\ C_3H_5\ (NO_3)_3 + 6\ NaNO_3 + C_6H_{10}O_5 = 9CO_2 + 6N_2\ 10H_2O + 2O_2 + 3\ Na_2CO_3$$

When nitroglycerin[3] is detonated, the resultant gases, at the high

3. Peele, R. and Church, A. Ibid. p. 2

temperature of the explosion and at atmospheric pressure, would occupy about 1,000 times the volume of the original, solid, nitroglycerin. Such a tremendous increase in volume exerts a pressure on anything that confines the gas, and consequently, the confining material usually is broken and fragmented. In a drill hole, however, if the resistance of the confining material is greater than the explosive force of the dynamite, the gases will seek an exit through the drill hole. When this happens the confining material is not broken, and the result is what is commonly known as a "bootlegged hole".

Thus, the dimaster of the drill hole, the amount and type of dynamite in the drill hole, and the spacing between the drill holes, are all important factors to be considered when determining the effectiveness of dynamite.

For many years the manufacturers of explosives have stated that the larger diameter dynamites are more effective, safer, and more stable. Tests[4] by the Eastern Laboratory of the Du Pont Company have shown con-

4. Hurter, C. S. The effect of cartridge diameter on the strength and quickness of high explosives. Am. Min. Cong. 24th Ann. Conv. 1921, pp. 770-774.

clusively that the following statements are true:

1. Larger diameter dynamites are more sensitive to detonation.

2. The velocity of detonation increases with increased cartridge size.

3. Larger cartridges are more resistant to water.

Similar tests[5] by the U. S. Bureau of Mines have shown that:

5. Howell, S. P. and Crawshaw, J. E. The effect of cartridge diameter on the strength and sensitiveness of certain high explosives. Reports of Invest. Serial 2436, Bureau of Mines, 1923, p. 7.

1. Both the rate of detonation and sensitiveness to explosion by propagation increases with an increase in cartridge diameter.

2. When gelatin dynamite ages, its sensitiveness to detonation and explosion by propagation decrease rapidly, but ammonia dynamite is little affected.

3. Insensitiveness of gelatin dynamite due to age proceeds more rapidly as cartridge diameter decreases.

4. Insensitiveness due to age proceeds more rapidly in 60 percent gelatin dynamite than in 40 percent gelatin dynamite.

On the basis of such conclusions, the Bureau of Mines recommends that drill holes be used that are large enough to accommodate cartridges of at least 1-1/4 inch diameter.

Van Winkle[6] makes the following statement:

6. Van Winkle, R. N. Pit and Quarry Handbook, Drilling and blasting practice. 6th ed. Complete Service Publ. Co., 1928, p. 37.

"In selecting size of cartridges to be used, it is good practice to buy as large a cartridge as can possibly be used; first, because the manufacturer makes a dense packing and with the large cartridges there will be fewer voids in the bore hole; second, because you have fewer cartridges to handle when loading a drill hole; and third, because you are buying less paper and more explosive when using large, instead of small cartridges, as dynamite is sold by the case of 50 pounds, paper weighed in".

Greensfelder[7] gives additional disadvantages of small cartridges. He

7. Greensfelder, N. S. Eliminating waste in blasting, Hercules Powder Co., 1922, p. 32.

states that they are less efficient, less sensitive to detonation, more conducive to chilling and freezing, and less effective because rock and dirt can lodge between the cartridges.

In hard rock at the North Star Mine[8] in California the drill hole

8. Foote, A. B. American Mining Congress, 24th Annual Con., 1921, p.766.

diameter was reduced to decrease the drilling cost. However, 7/8 inch diameter dynamite was used and did not break the ground.

The Anaconda Copper Mining Company[9] has found that in drifts and

9. Daly, W. B. American Mining Congress, 24th Annual Con., 1921, p. 765.

crosscuts the 1-1/4 inch dynamite gives the best results, although in stopes where there are two free faces to break to the Company uses 7/8 inch dynamite.

Bayles[10] makes the following statement:

10. Bayles, L. C. American Mining Congress, 24th Annual Con., 1921,p.765

> "The cost of a hole advances about as the square of the diameter, and the point is soon reached when the increased cost becomes more than the increased efficiency of the explosive."

It is easy to see from the literature cited that a given weight of larger diameter cartridges should be more effective than the same weight of smaller diameter cartridges. Other factors however, must be considered. Some of these are: The effect of drill hole diameter; the relative cost of drilling and loading small holes and large holes; and the effect of the distribution of the dynamite in the drill hole.

MATERIALS AND EQUIPMENT

The tests described in this paper were made at the Experimental Mine of Missouri School of Mines and Metallurgy. This mine, which is about 1-1/2 miles southwest of the town of Rolla, is used for laboratory studies and research work in mining practice. Underground workings of the mine consist of about 600 feet of drifts and crosscuts driven from a side-hill entry. Figure 1 shows the underground openings. The west drift shown in red on Figure 1 was driven during this study. All of the mine openings have been driven in a soft, gray, well-bedded, dolomitic limestone known locally as the Jefferson City dolomite. The rock has the following physical characteristics[11]:

11. Buckley, E. R. and Buehler, H. A. The quarrying indistry. Missouri Bureau of Geology and Mines. Ser. 2, Vol. II, (1901), p. 102.

Specific Gravity	2.801	
Porosity	13.00	percent
Ratio of Absorption	5.341	
Weight per Cubic Foot	152.2	pounds
Transverse Strength	851.3	psi
Tensile Strength	220.0	psi
Crushing Strength	8486.7	psi (on bed)
	9161.0	psi (on edge)

The rock contained occasional layers of hard cherty material. The dolomite is comparatively easy to drill; the chert, however, is difficult to drill and was a problem in drilling the lifter holes.

Because the rock is relatively soft and well-bedded, it is "springy", and therefore does not break readily from the solid.

DRILLING EQUIPMENT

A Clevelnd H-10 jackhammer was used to drill the holes. All holes except the lifters were drilled with the jackhammer mounted on an Ingersoll-Rand Jackleg. The lifter holes were drilled with the jackhammer removed

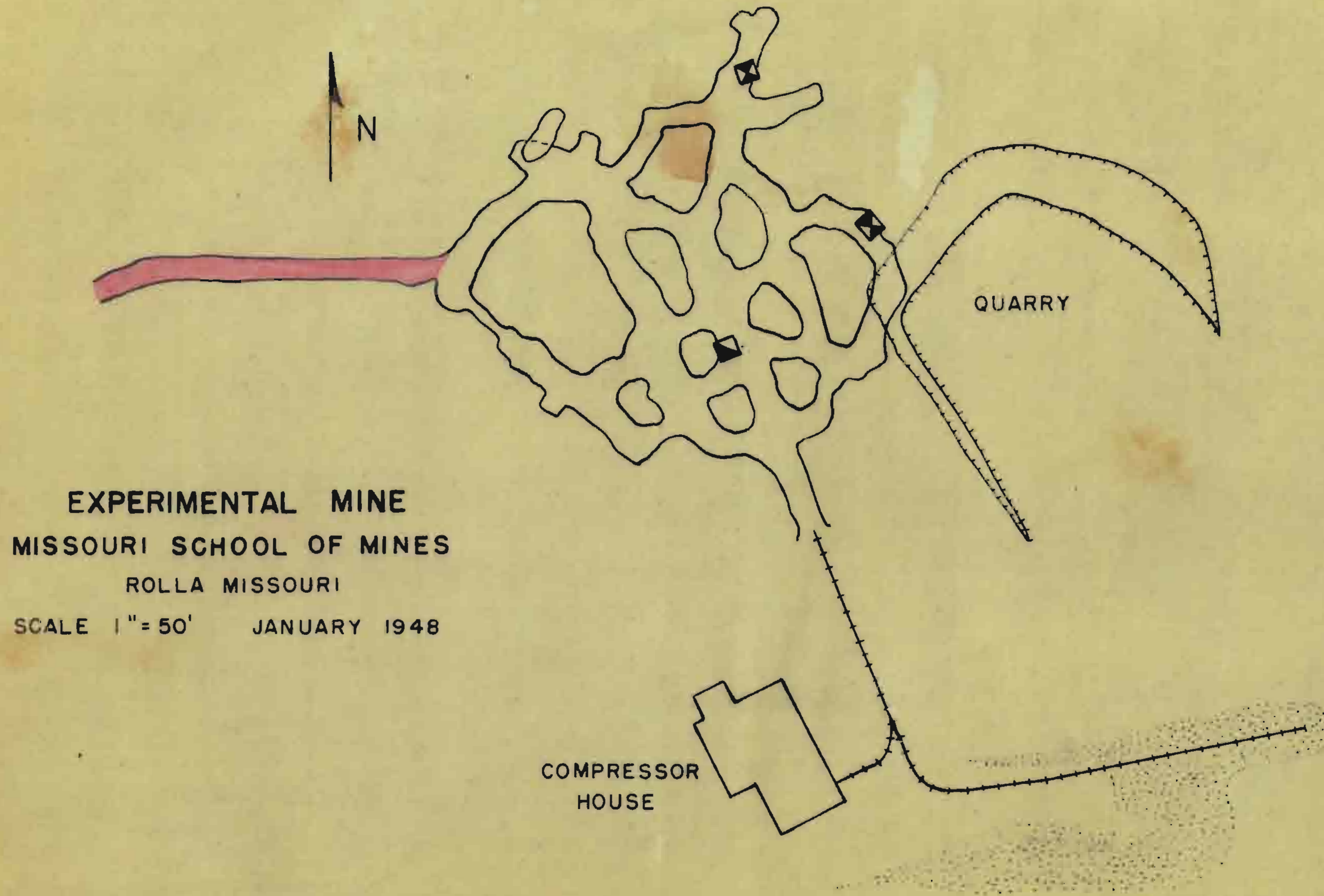


Figure 1. The Experimental Mine

from the mounting. The steel was 1-inch hollow hexagonal steel. Ingersoll-Rand 4 point bits were used to drill all holes.

Air for the drilling machine and for the loading equipment described below was furnished by an Ingersoll-Rand diesel driven 2-stage compressor. The capacity of this compressor is 215 cubic feet of air a minute. Air pressure ranged from 85 to 105 psi, at the compressor.

Broken rock was loaded into 1-ton mine cars by an Eimco 12-B Rocker Shovel. The mine cars were hand trammed to the dump where a scale was set up to weigh the broken rock.

DYNAMITE AND CAPS

Most commercial dynamites are graded according to their strength as compared to straight dynamite. The grade-strength of straight dynamite corresponds to the actual percentage of nitroglycerin in the dynamite. Thus, a 40 percent gelatin dynamite does not contain 40 percent nitroglycerin, but rather its strength is equivalent to a straight dynamite containing 40 percent nitroglycerin.

The dynamite used in the experimental rounds was furnished without charge by the du Pont de Nemours & Company through the cooperation of Mr. H. A. Lewis, Manager, Technical Service Section, of the Explosive Division.

Two types of dynamite were used; 40 percent Special Gelatin, and Gelex No. 2. The composition[12] of each type is given below:

12. Lewis, H. A. Correspondence with L. E. Shaffer. Nov. 7, 1947.

Ingredient	Gelex No. 2	40% Special Gelatin
Nitroglycerin	20.0	22.50
Nitrocotton	0.4	0.55
Ammonium Nitrate	63.0	13.50
Sodium Nitrate	9.6	49.00
Carbonaceous Combustibles	5.7	7.65
Sulphur	1.0	6.50
Calcium Carbonate	0.3	0.30

The prices[13] for 100 pounds of these dynamites when delivered to the

13. Lewis, H. A. Ibid.

consumer are given below:

	Car Loads	2000 Pounds	Less than 2000 Pounds
Du Pont Special Gelatin 40 Percent	$15.50	$18.00	$20.00
Du Pont Gelex No. 2	$14.75	$17.25	$19.25

The number of cartridges in a 50 pound box of Special Gelatin and in a box of Gelex No. 2 was determined during the tests by counting the cartridges in several boxes and averaging the figures. These cartridge counts are tabulated below:

Dynamite	Cartridge Size	Av. No. of Cart. per 50 Lb.
40 Percent Special Gelatin	1 inch	139
Gelex No. 2	1 inch	182
40 Percent Special Gelatin	1-1/4 inch	97
Gelex No. 2	1-1/4 inch	120

Both types of dynamite were detonated by Du Pont electric delay caps with 8-feet leg wires. Electric current to fire the caps was supplied by a hand-operated blasting box that has a capacity of 30 caps in series.

EXPERIMENTAL TESTS

In January 1947, officials from the Du Pont Company met with Dr. J.D. Forrester and Professor L. E. Shaffer to discuss the general outline of the problem. It was decided at this meeting that the drift to be driven would be about 6 feet by 7 feet, and the drill round would be designed to pull at least 5 feet. Further, as the burn cut round is one of the most common drill rounds used in mining practice today, it was decided that the drill round to be used would be a burn cut type.

In August 1947, Mr. Robt. Girdler and Mr. Wilbur Tipton, Du Pont representatives from the Eastern Laboratory, came to Rolla to run a series of tests on the velocities of dynamites at the experimental mine. This work is described in Appendix D.

Some preliminary work was necessary before the drift could be started to carry on the experiments. It was to be driven due west on the west side of the mine and some preliminary slabbing had to be done and a suitable turnout had to be constructed.

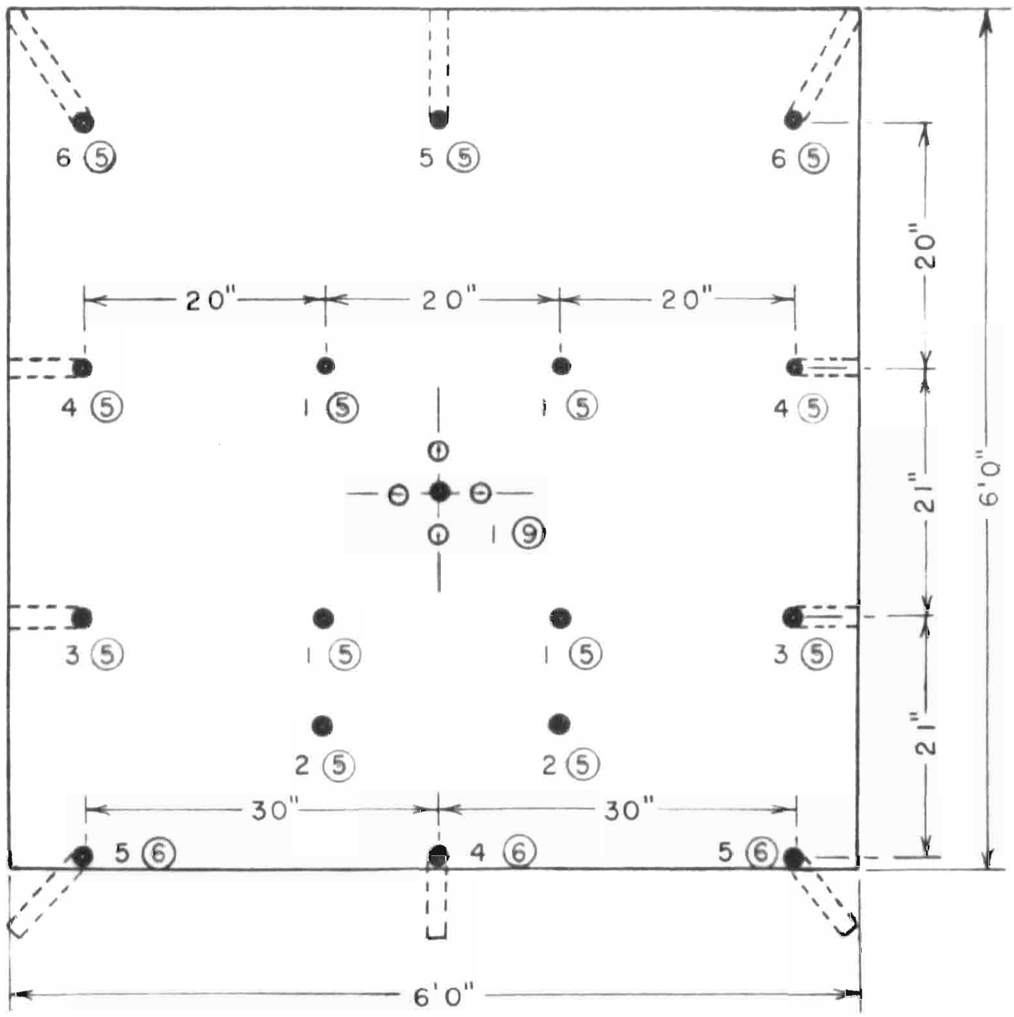
As the round was to be a burn cut round, the first major problem was to determine a burn cut that would break well with a minimum number of holes. The second step was to determine a round that would break with little or no bootleg with a minimum amount of dynamite consumption.

In each experimental round the burn hole was fired first. If the cut did not break with the initial loading, the hole or holes were reloaded and shot until the burn broke out. Thus, in the experimental rounds, the round always had a suitable cut to break to. The failure of any round would not, therefore, be dependent upon the success or failure of the burn cut.

The following work gives a description of the characteristics of each round, and of the results obtained during the experimental tests.

Experimental Round No. 1

The first experimental round drilled was comprised of 21-holes and included a 5-hole diamond-shaped burn cut. This round is shown in Figure 2. The center hole of the burn cut was loaded with nine sticks of 40 percent gelatin dynamite. With the exception of the primer cartridge, all of the sticks were slit and tamped. As the center hole, when fired, did not break to the collar, two of the remaining four holes then were loaded and were fired. This broke out the cut. After the cut was broken, the rest of the holes were wired in series and were shot. The round did not



● Loaded hole
○ Unloaded hole
3 ⑤ Shows No. 3 delay electric cap; 5 sticks of dynamite
1-5/8 to 1-1/2 " holes
1-1/4 " gelatin dynamite 92 sticks 47.4 pounds
Scale 3/4" = 1'

Figure 2. Experimental round no. 1

pull; most of the holes bootlegged for a distance of from 18 to 24 inches, and the lower right lifter failed entirely.

Several factors became apparent after this first round had been fired. First, more holes would be needed to break the round, and second, the back holes and trimmer holes would have to be angled less to reduce the burden on these holes at the bottom of the holes. In addition, it was evident that a more efficient and more easily drilled burn cut should be designed and that the number of cartridges of dynamite used in the center hole of the burn cut would have to be increased to break the cut to the collar.

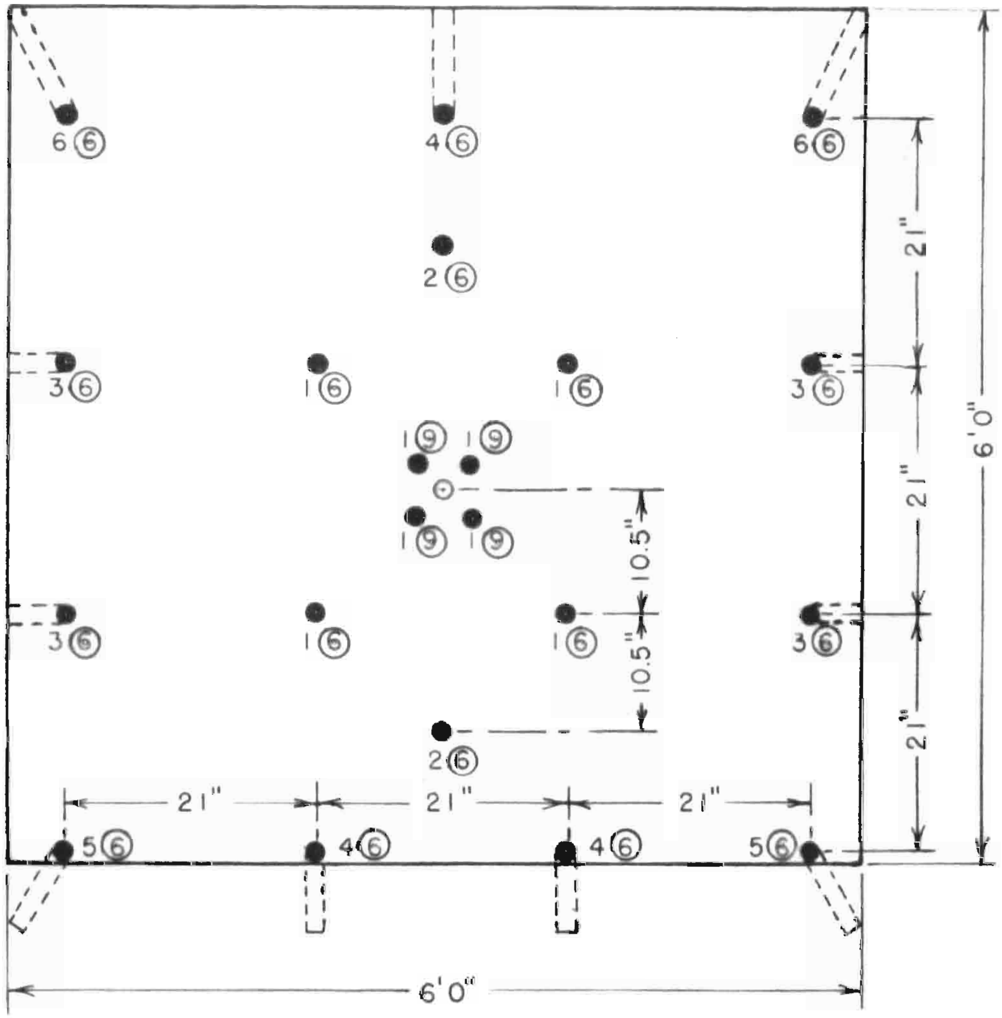
Experimental Round No. 2

In an attempt to relieve the difficulty of aligning the burn holes, the second experimental round was drilled with a square-pattern burn cut as shown in Figure 3. This arrangement of holes was not any easier to drill than that used in the first round. All of the four corner holes were loaded with nine sticks of 40 percent straight gelatin dynamite and were fired simultaneously. The cut did not break; two holes bootlegged and two holes filled with crushed rock. When the two bootlegged holes were loaded and shot, the burn cut broke out.

The other holes in the round then were loaded and were fired. The round broke better than the previous one, but all of the holes bootlegged from 10 to 24 inches. It was evident that more holes were needed to pull the round.

Burn Cut Experiments

Several conclusions were reached concerning the burn cuts used in the first two rounds: The drill holes were difficult to keep in alignment; the drill holes did not provide sufficient relief for the rock broken in



1-5/8 " to 1-1/2 " holes
1-1/4 " gelatin dynamite 138 sticks 71 pounds
Scale 3/4" = 1'

Figure 3. Experimental round no. 2

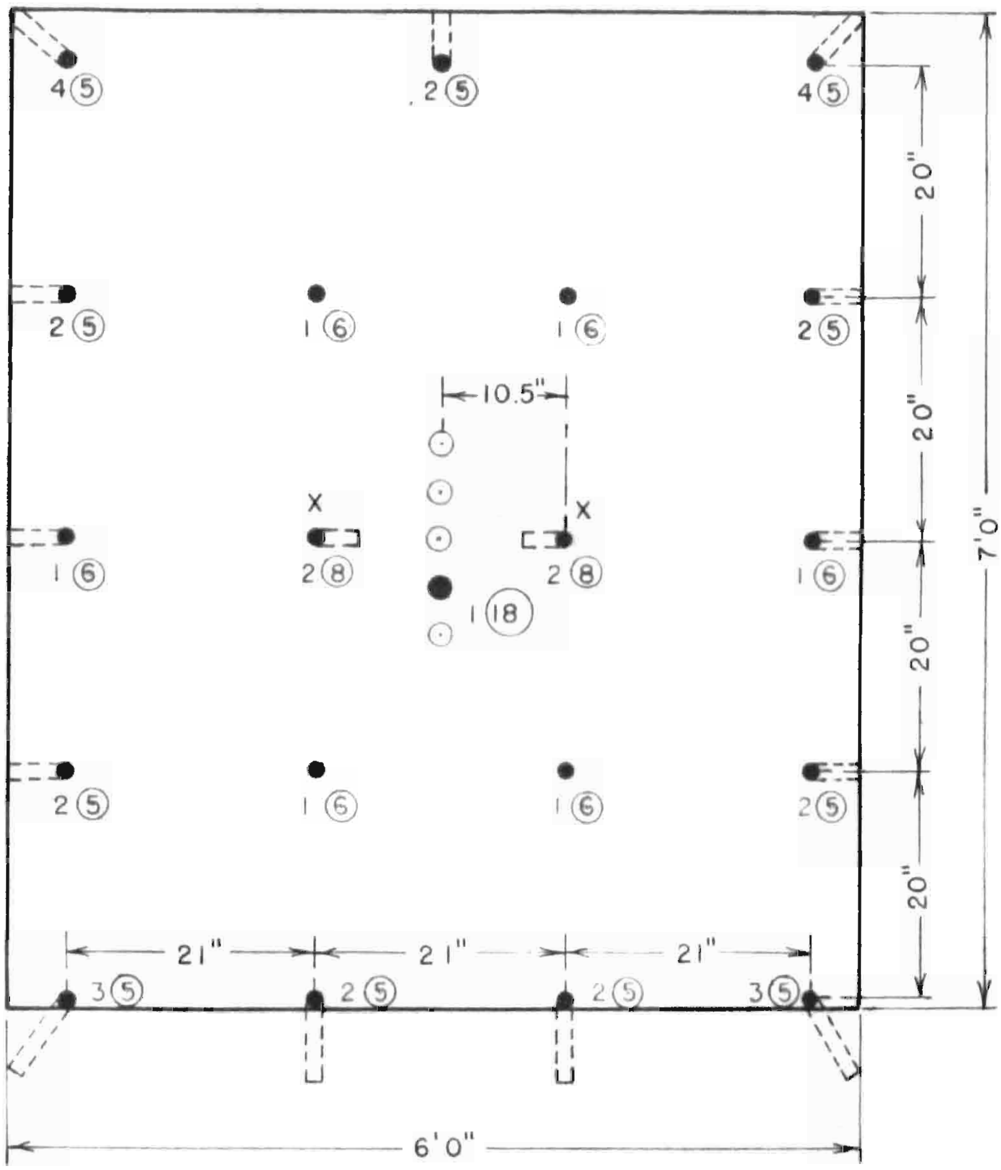
the burn; and there was too much burden on the relief holes around the burn cut. To remedy these undesirable features, a vertically arranged 5-hole burn cut was drilled with 2-inch holes on 4-inch centers. The center hole was loaded with 16 sticks of 40 percent straight gelatin dynamite. Although some crushing took place in the holes, the cut brokeon firing. It tapered from about 15 by 5 inches at the face to about 9 by 3 inches at the bottom.

To increase the size of the center cut and thus provide more relief for the relief holes around the burn holes, another 5-hole burn cut was tried with two relief-holes angled to meet the center burn hole. Although the two relief holes were primed with delay caps to shoot after the burn hole, the explosion of the burn hole detonated the caps in the relief holes and all holes went off at the same time. The two relief holes bootlegged about 3 feet. It was evident that the relief holes should not be angled to meet the burn hole.

Experimental Round No. 3

This round was designed to correct the faults of the two preceding rounds. The 5-hole vertically arranged burn cut was drilled with two relief-holes angled only slightly toward the center hole, as shown in Figure 4. When drilling the burn cut, the center hole deflected and, at about four feet from the collar, ran into the hole immediately above. Because of this, the hole below the center hole was loaded and fired. The burn cut did not break satisfactorily. The top burn hole then was loaded and shot and the burn cut broke out. It was evident that extreme care would have to be taken to line up the burn cut holes.

Though this round broke better than the previous ones, the lower trim holes on each side bootlegged 12 to 18 inches. The broken rock was very



1-1/2 to 1-3/8" holes
1" 40 percent Special Gelatin dynamite 125 sticks 45 pounds
Scale 3/4" = 1'

2" Burn holes with 2" spacing between holes.
The loaded burn hole and the two relief holes (X) are shot first. The rest of the holes are then loaded and fired.

Figure 4. Experimental round no. 3

fine; most of it was less than 6 inches in diameter.

When this round was drilled the height of the drift was increased to 7 feet for two reasons: The loading machine required at least $6\frac{1}{2}$ feet clearance for good operation, and a strong parting plane about 7 feet above the floor served as a good back to break to.

Experimental Round No. 4

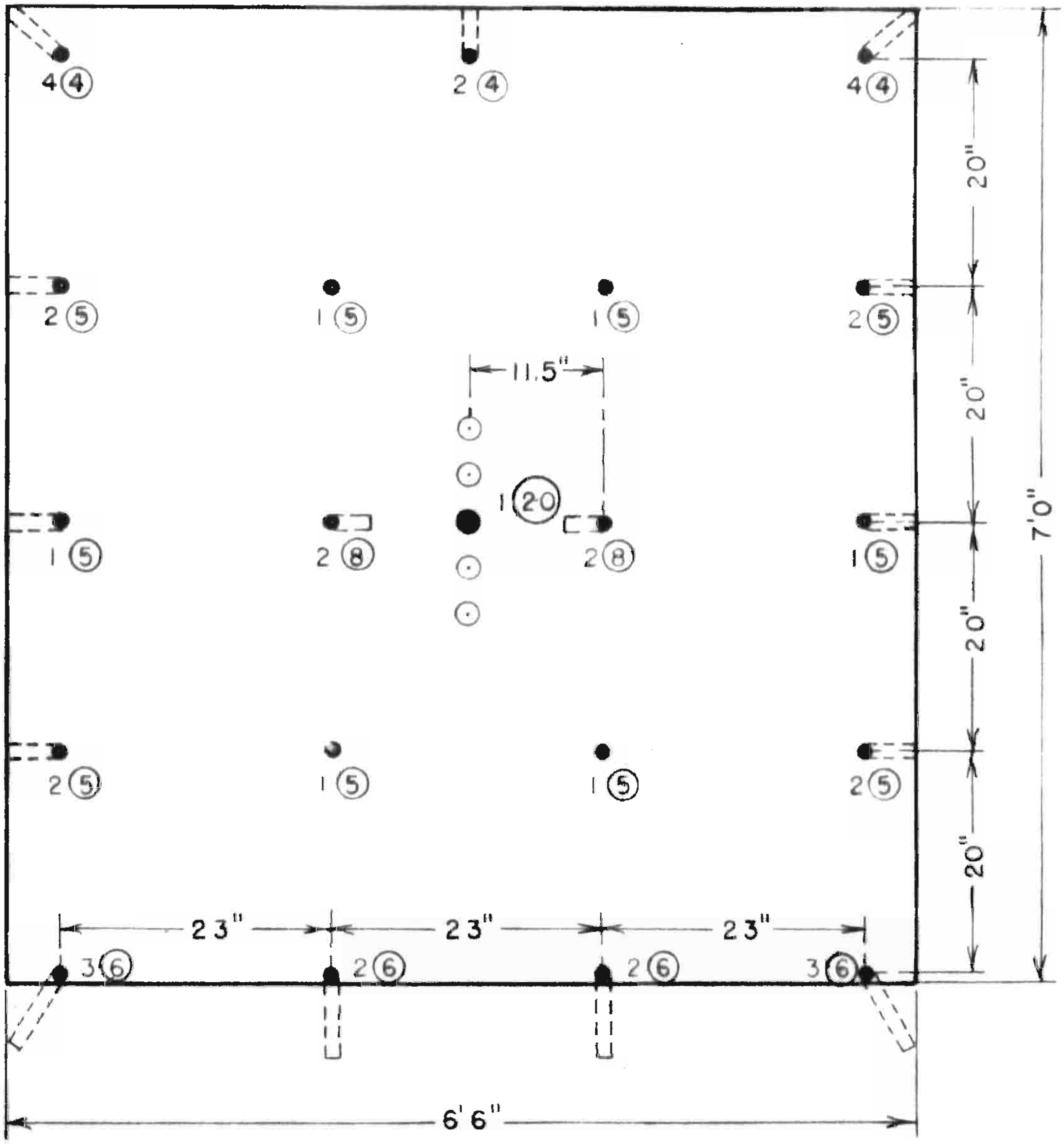
With two alterations, Round No. 4 was the same as Round No. 3. The burn cut holes were increased from 5 feet in length to 5 feet 6 inches to insure a break of at least 5 feet in the burn. The number of sticks of dynamite used in the relief holes was reduced from six to five sticks. This round is shown in Figure 5.

To help keep the burn holes parallel a tamping stick large enough to form a tight fit in a 2-inch hole was put in the first burn cut hole that was drilled. The rest of the holes were drilled with this stick as a guide. This proved to be an effective means of aligning the burn holes.

The burn cut broke well, but the round was a failure because all of the remaining holes bootlegged for distances of from 2 feet 6 inches to 4 feet. An examination of the face revealed that there was too much burden on the relief holes around the burn cut. It was felt that the design of the round must be improved to give better relief to the initial burn cut.

Experimental Round No. 5

Round No. 5 was drilled with the burn holes S $10\frac{1}{2}$ inches off center. This was done for two reasons: First, by alternating the burn holes from one side to the other, the succeeding burn was started in fresh unbroken rock; and second, the burn cut was thus brought closer to the relief holes immediately above and below. This reduced the burden on the holes to be fired following the burn cut. One additional hole had to be added to the



1-1/2 " to 1-3/8 " holes
1" 40 percent Special Gelatin dynamite 122 sticks 44 pounds
Scale 3/4" = 1'

Figure 5. Experimental round no. 4

pattern used in the previous round.

Round No. 5 was loaded as shown in Figure 6. When blasted, the round broke well, but the broken rock was rather fine. The average advance of the heading was 4 feet 10 inches.

The data from this round are shown below. The source of these data is explained in the section that follows this tabulation.

DRILLING DATA

Round No.	Drilling Time	Advance	Loading Time
5	5 hr. 14 min.	4' 10"	1 hr. 10 min.

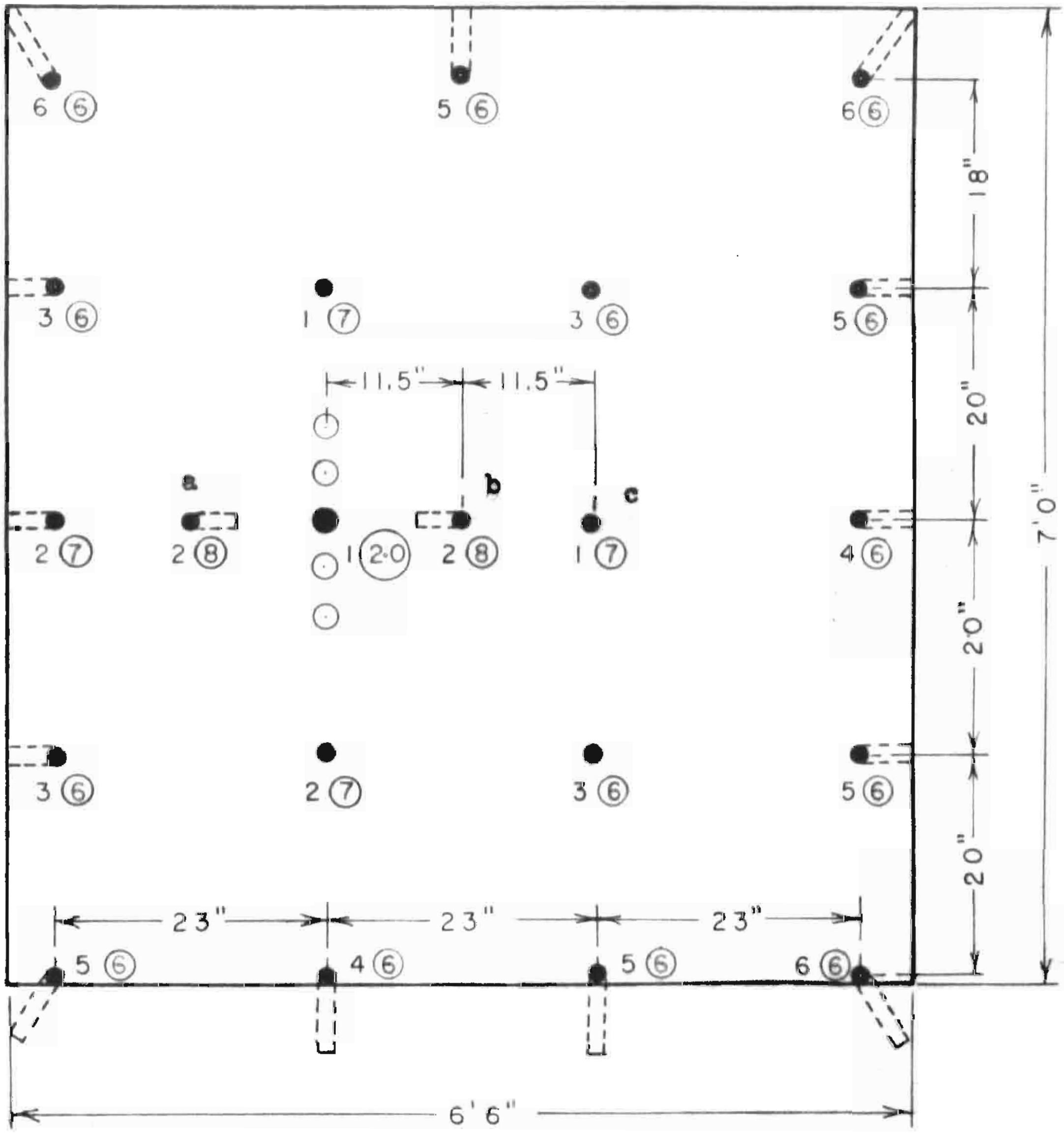
SIZING DATA

Round No.	Total Cars	Car No.	Rock Wt. Pounds	+4"-12" Pounds	+12" Pounds
5	16	3	2115	—	220
		8	2060	90	0
		13	2102	180	0

In conjunction with Round No. 5, a definite procedure was established to be followed in the succeeding rounds. This was necessary in order to standardize the round and to provide data for comparative tests both on fragmentation and on drilling time.

DRILLING

Drilling Time: Experimental data were recorded when drilling holes marked a, b, and c on Figure 6. The average time required to drill a 5-foot hole was about 5 minutes and 30 seconds. This is a drilling rate of about one foot a minute. It should be noted that when holes are being drilled with a jackhammer mounted on a Jackleg, the drilling speed is not constant for all holes but is dependent on the height of the hole above the floor of the drift. Hence, back holes require much more time to drill than the other holes. The lifters also require more time because they are drilled with an unmounted jackhammer.



1-1/2 " to 1-3/8 " holes
1" 40 percent Special Gelatin dynamite 148 sticks 53.4 pounds
Scale 3/4" = 1'

Figure 6. Experimental round no. 5

The time required to drill the five burn cut holes is not included in the total drilling time because the drilling time for these holes should be constant for all rounds as long as the burn cut holes are the same size.

Where the term "drilling time" is used in this paper, it includes the time required to drill all holes other than the burn cut holes; it does not include time spent on mining activities that are not directly connected with drilling. Drilling time, then, includes the time needed for: Drilling the holes, blowing the holes, changing steel, and changing set-ups.

Drilling Procedure: The experimental drift was driven due west, and the center burn hole, was therefore, drilled in a due west direction. The rest of the holes were then drilled, using the first one as a guide. The position of all holes was determined by measuring from the center burn hole. All angled holes were pointed by aligning the drill steel with respect to the center burn hole. All holes, other than the burn cut holes, were drilled to a depth of 5 feet from the collar of the center burn hole. These holes were started with a 2-foot steel and finished with a 6-foot steel with a reduction in gauge of 1/8 inch on the drill bit. Thus, a hole which started with a diameter of 1-1/2 inch bottomed with a diameter of about 1-3/8 inches and a 1-3/4 inch hole bottomed with a diameter of about 1-5/8 inches.

Loading Time: Loading time is the time required to clean out the holes, make up the primers, slit the cartridges, and load the holes.

FRAGMENTATION

To compare the effectiveness of the different types of dynamite, some means was necessary for measuring the amount and degree of fragmentation of the broken rock.

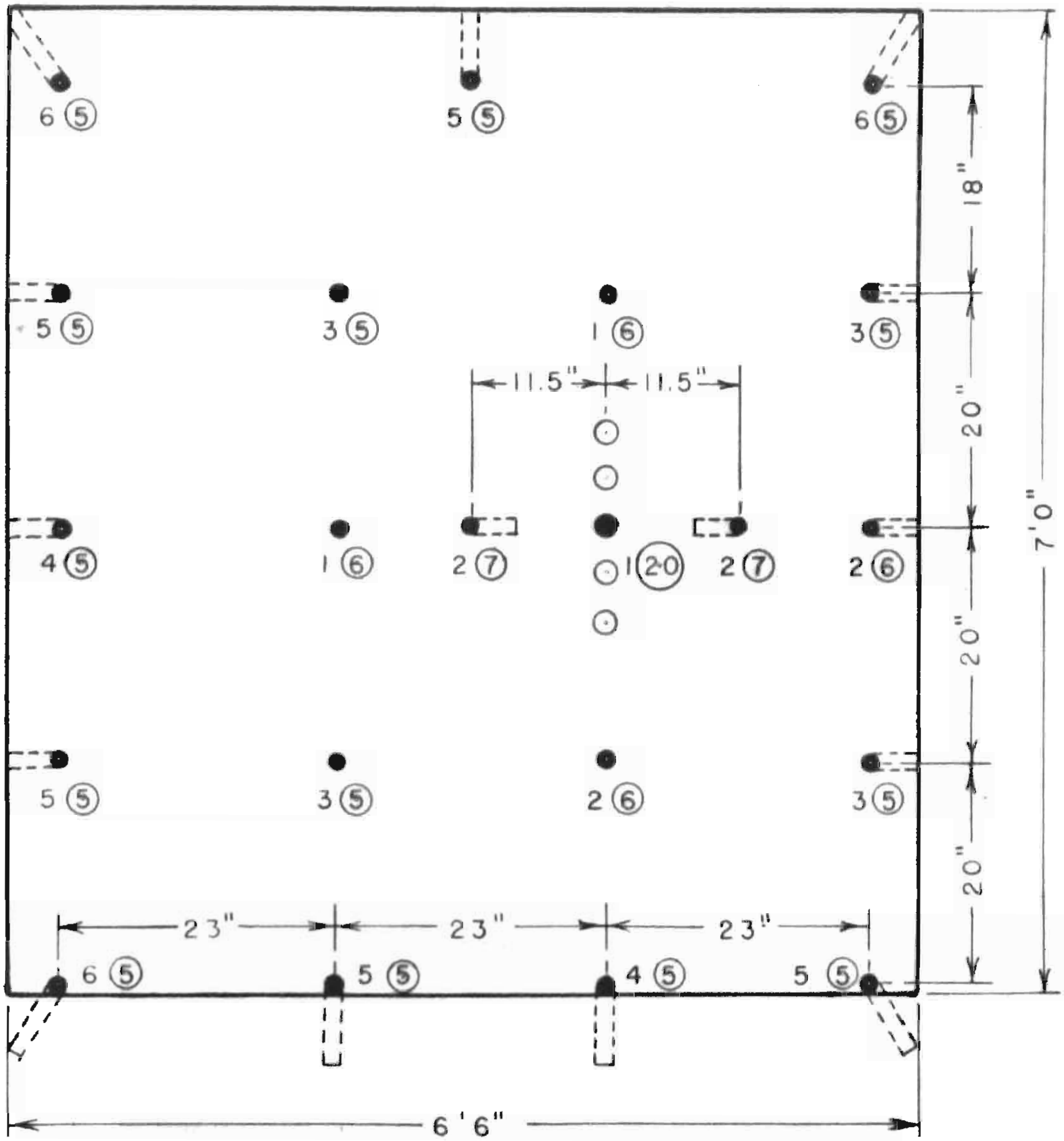
During the test of Round No. 5, the broken rock from cars no. 2 and 7 was screened through an 8-1/4 inch grizzly and a 12 inch hoop. The grizzly was made by placing a section of 20-pound rail lengthwise between the rails of the 18-1/2 inch gauge track on the dumping trestle. The rail was put in with the flange up. A heavy wire hoop 12 inches in diameter was used to measure all material over 8-1/4 inches in diameter but less than 12 inches in diameter. The 8-1/4 inch grizzly opening was too large to catch much material. The dolomite rock is closely bedded and shows a marked tendency to break into slabby pieces, most of which range from 4 to 6 inches in thickness. Another rail was added to the grizzly, and the spacing was thus reduced to 4-1/8 inches. The rock from cars 8, 9, and 12 was put through this grizzly. From the results of this screening, it was decided that Round No. 5 had broken too fine, and a reduction in the amount of dynamite was necessary.

Sizing Procedure: To provide a uniform basis for comparison, the material from three cars was screened from each round blasted; One car of muck was taken from near the edge of the pile of broken rock; one from the center; and one from near the face. Assuming that each round would break about 16 cars, it was decided that the cars 3, 8, and 13 of each round should be weighed and screened. The car was weighed when full and then dumped on the grizzly. Material coarser than 4-1/8 inches that remained on the grizzly was then weighed. Of this material, all rock larger than 12 inches then again was weighed. Because of the bedding in the rock, it was decided that any piece larger than 12 inches in two dimensions and more than 4-1/8 inches thick would be considered as plus 12 inch material.

Experimental Rounds No. 6,7, and 8

Round No. 6 was drilled the same as No. 5. The number of sticks of dynamite loaded in the holes was reduced by one stick a hole as shown in Figure 7.

The round broke well and the broken rock was considerably coarser than



1-1/2 " to 1-3/8 " holes
1" 40 percent Special Gelatin dynamite 128 sticks 46.1 pounds
Scale 3/4" = 1'

Figure 7. Standard round for 1" 40 percent Special Gelatin dynamite.

that of the preceding round. The average advance of the heading was 4 feet 10 inches. Because the advance was good and because the broken rock was relatively coarse, Round No. 6 was chosen as the standard round to be shot with 1-inch Special Gelatin.

Rounds No. 7 and 8 then were drilled and blasted, using the same drilling pattern and the same amount of dynamite as in Round No. 6, illustrated in Figure 7.

The data from Rounds 6, 7 and 8 are as follows:

DRILLING DATA

Round No.	Drilling Time	Advance	Loading Time
6	5 hr. 5 min.	4'10"	1 hr. 0 min.
7	4 hr. 50 min.	4'11"	1 hr. 10 min.
8	4 hr. 20 min.	4'10"	1 hr. 0 min.

SIZING DATA

Round No.	Total Cars	Car No.	Rock Wt. Pounds	+4"-12" Pounds	+12" Pounds
6	16	3	2186	149	326
		8	2108	67	266
		13	2114	156	124
7	16	3	2123	157	258
		8	2221	251	66
		13	2124	170	164
8	16-2/3	3	2162	160	225
		8	2126	198	0
		13	2257	9	275

Experimental Round No. 9

Round No. 9 was the first one blasted with Gelex No. 2 dynamite. The same drill hole pattern was used as in Rounds No. 6, 7, and 8. The same amount, by weight, of dynamite was used as in the Special Gelatin rounds. It must be noted that Gelex No. 2 is a low density dynamite. A 50-pound box of 1 inch by 8 inch Gelex No. 2 dynamite contains an average of 182 cartridges, and a 50-pound box of Special Gelatin contains only 139 cartridges of the same size. Thus, it was determined that 168 sticks of Gelex No. 2 would be equivalent by weight to the 128 sticks of Special Gelatin used in each of Rounds No. 6, 7, and 8. Round No. 9 was loaded with 168 sticks and fired as shown in Figure 8.

The round broke well when blasted but the broken rock was considerably finer than that obtained from the previous tests. Apparently, Gelex No. 2 dynamite fractured the rock better than an equivalent amount of Special Gelatin.

The data of Round No. 9 are as follows:

DRILLING DATA

Round No.	Drilling Time	Advance	Loading Time
9	4 hr. 35 min.	4'10"	1 hr. 15 min.

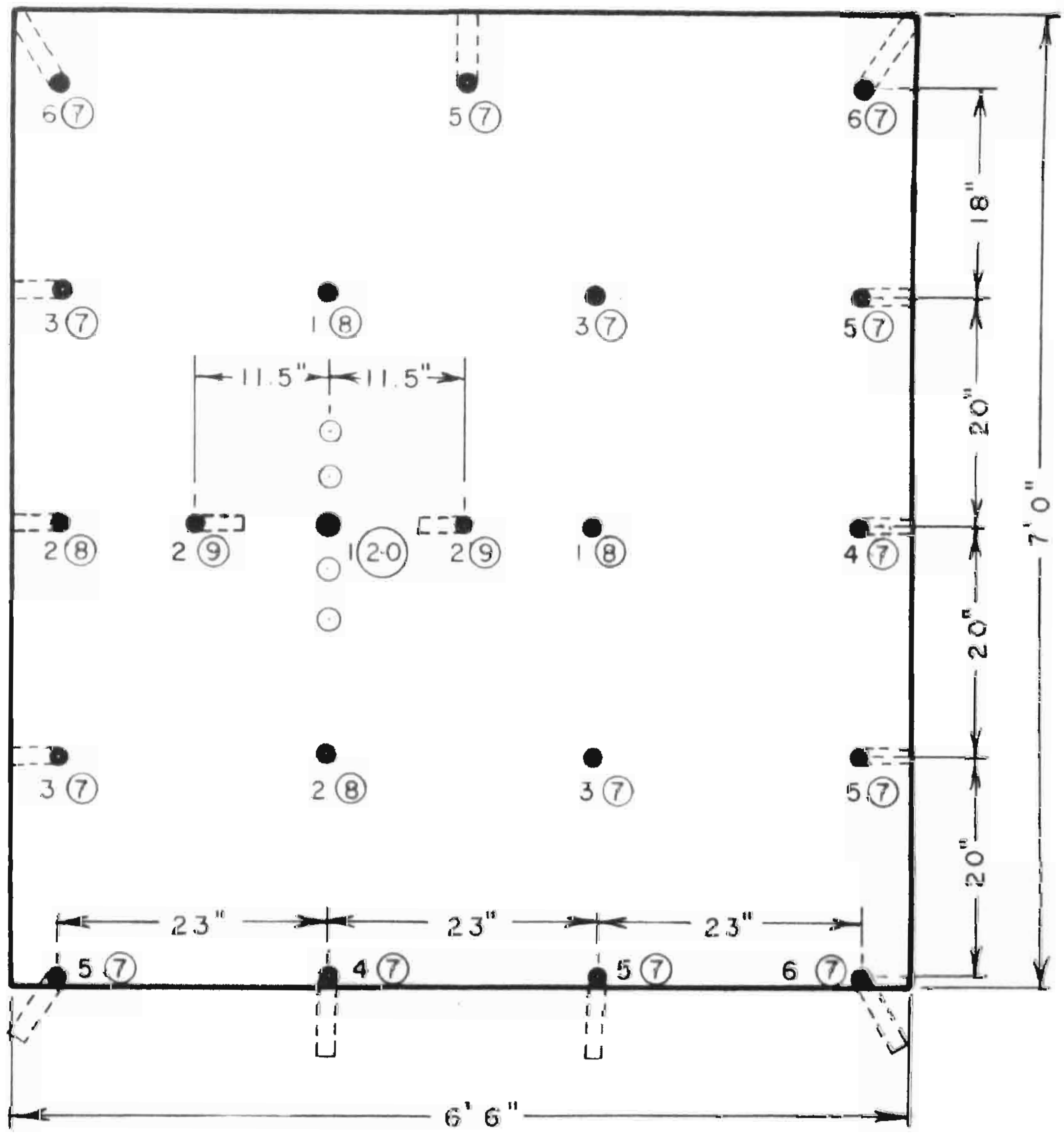
SIZING DATA

Round No.	Total Cars	Car No.	Rock Wt. Pounds	+4"-12" Pounds	+12" Pounds
9	16-2/3	3	2198	120	34
		8	2226	56	152
		13	2261	114	54

Experimental Rounds No. 10, 11, and 12

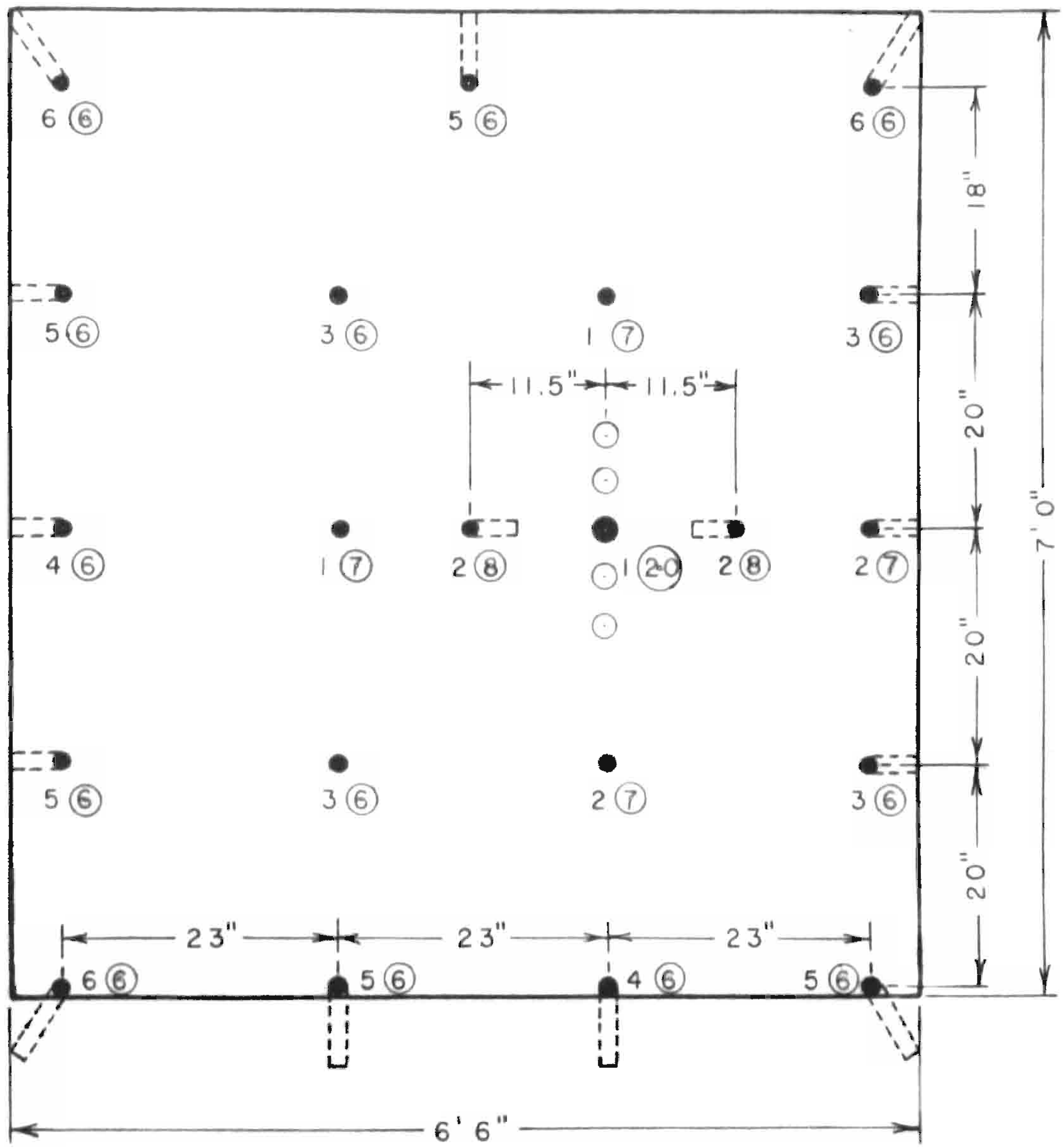
Because the previous round had broken rather fine, Round No. 10 was blasted with only 148 sticks of Gelex No. 2. The round broke well and, although the broken rock was somewhat finer than that of the Special Gelatin rounds, a further reduction in the amount of dynamite did not seem feasible. This was confirmed later, when Round No. 14 failed on being loaded and fired with only 130 sticks.

Round No. 10 was taken as the standard round for 1 inch Gelex No. 2 dynamite. Rounds No. 11 and 12 were drilled and blasted with the same loading as in Figure 9.



1-1/2" to 1-3/8" holes
1" Gelex No. 2 dynamite   168 sticks   46.2 pounds
Scale 3/4" = 1'

Figure 8. Experimental round no. 9



1-1/2" to 1-3/8" holes
1" Gelex No. 2 dynamite 148 sticks 40.6 pounds
Scale 3/4" = 1'

Figure 9. Standard round for 1 inch Gelex No. 2 dynamite

The data from these rounds are shown as follows:

DRILLING DATA

Round No.	Drilling Time	Advance	Loading Time
10	4 hr. 20 min.	4'9"	1 hr. 25 min.
11	4 hr. 25 min.	4'8"	1 hr. 20 min.
12	4 hr. 15 min.	4'8"	----

SIZING DATA

Round No.	Total Cars	Car No.	Rock Wt. Pounds	⁄4"-12" Pounds	⁄12" Pounds
10	16-3/4	3	2240	189	183
		8	2160	147	151
		13	2105	116	56
11	16-3/4	3	2234	108	177
		8	2270	100	48
		13	2213	122	0
12	16-1/3	3	2198	173	188
		8	2145	103	124
		13	2184	161	0

Experimental Round No. 13

Round No. 13 was drilled and loaded exactly as Rounds 10, 11, and 12. Before blasting, however, two sticks of 12-inch stemming, composed of soft moist clay, were tamped into each hole.

When blasted, the round broke well. Most of the broken rock was relatively fine, but there were a few boulders, larger than those found in any of the previous rounds. Car No. 3 contained one boulder 24 by 14 by 14 inches and Car No. 4 contained one boulder 20 by 14 by 12 inches; however, the broken rock loaded after Car No. 4 was relatively fine.

DRILLING DATA

Round No.	Drilling Time	Advance	Loading Time
13	4 hr. 25 min.	4'10"	1 hr. 30 min.

SIZING DATA

Round No.	Total Cars	Car No.	Rock Wt. Pounds	⁄4"-12" Pounds	⁄12" Pounds
13	16-3/4	3	2202	154	364
		8	2214	123	55
		13	2207	101	0

Experimental Round No. 14

Inasmuch as most of the broken rock of Round No. 13 was rather fine, Round No. 14 was loaded with about 12 percent less dynamite. Two sticks of stemming were used in each hole, as in the previous round.

This round was a failure. The average advance was only 3 feet 9 inches and, apparently, 130 sticks of Gelex No. 2 was not sufficient to break the round properly.

It was decided that further tests on stemming would be omitted. Although the data from Rounds No. 13 and 14 are not conclusive, they seem to indicate that there is relatively little saving in dynamite when stemming is used in drill holes in soft rock.

DRILLING DATA

Round No.	Drilling Time	Advance	Loading Time
14	4 hr. 10 min.	3'9"	1 hr. 35 min.

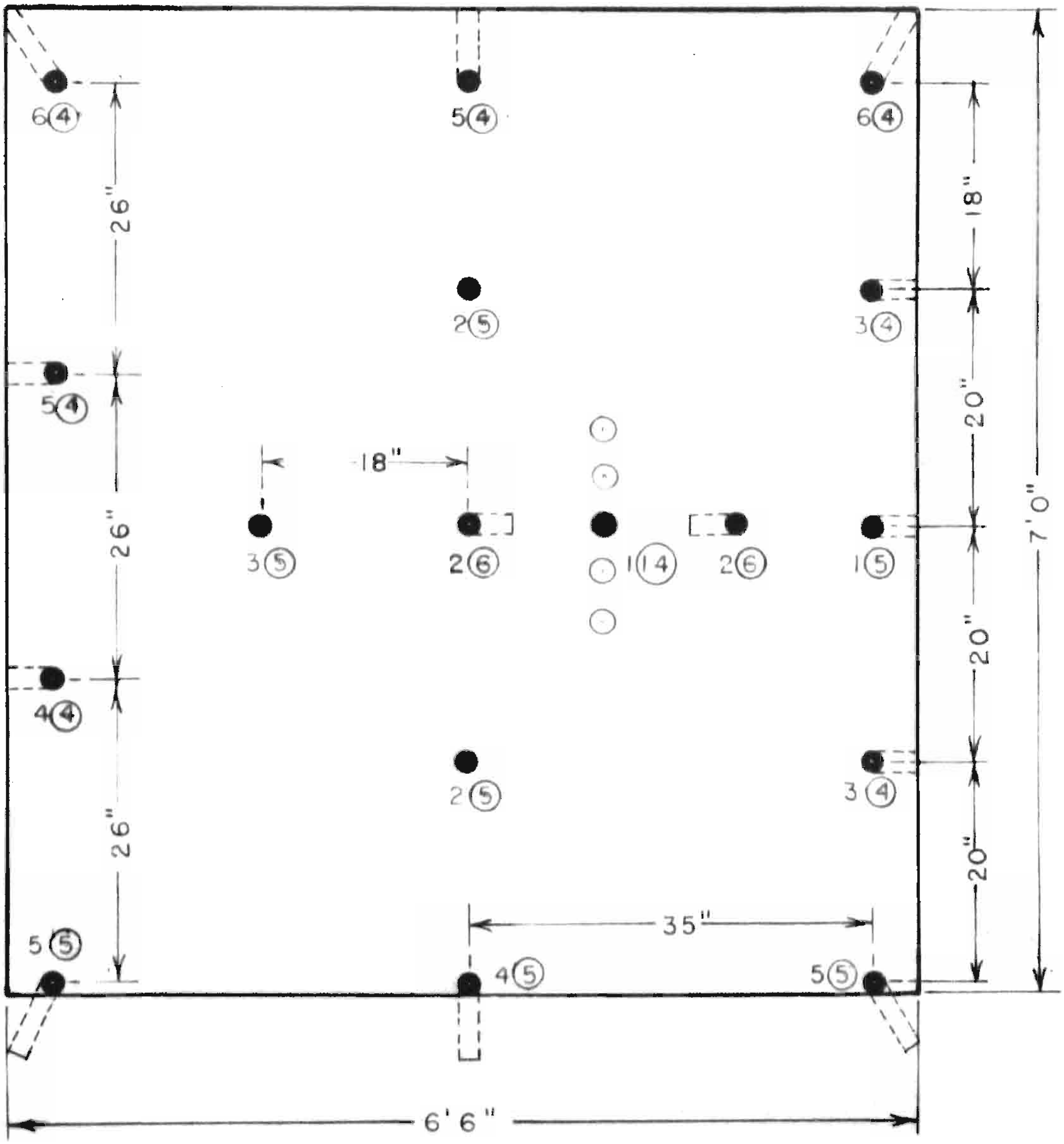
SIZING DATA

Round No.	Total Cars	Car No.	Rock Wt. Pounds	/4"-12" Pounds	/12" Pounds
14	13-1/3	3	2210	158	49
		8	2132	95	0
		13	2202	78	0

Experimental Round No. 15

Round No. 15 as shown in Figure 10 was the first round drilled with larger diameter drill holes for the use of larger diameter dynamite. The diameter of the holes was increased from 1-1/2 inches to 1-3/4 inches, and the cartridge diameter was increased from 1 inch to 1-1/4 inches.

It is a common belief that fewer holes will be requred to break a drill round if larger diameter holes and larger diameter dynamite are used. This belief is based on several reasons. Inasmuch as the holes are larger, more dynamite can be placed toward the bottom of the hole. A better loading density is possible because fewer cartridges are needed, which results



1-3/4" to 1-5/8" holes
1-1/4" 40 percent Special Gelatin dynamite 89 sticks 46. pounds
Scale 3/4" = 1'

Figure 10. Experimental round no. 15

in less paper and more explosive, as well as fewer voids. In addition, tests[14] by a manufacturer of explosives have indicated that the strength

14. Hurter, C. S. Op.cit. p. 771

of dynamite increases with increased cartridge diameter.

Round No. 15 was therefore, designed as shown in Figure 10 with four less holes than the standard round used for tests with 1 inch dynamite. The total amount by weight of dynamite used was about the same as the amount used in the standard rounds with 1 inch dynamite. This was done to compare the fragmentation of the rock broken by the 1 inch dynamite with the fragmentation of rock broken by the 1-1/4 inch dynamite. This round failed when it was blasted. The right trim holes bootlegged about 2 feet. The heading advance, after these bootlegged holes were reloaded and blasted, was about 4 feet 1 inch. The broken rock was relatively fine. This round had been drilled into the bootlegged face of the previous round, and therefore, this may have been the reason for the lack of +12 inch material.

It should be noted that the amount of dynamite shown in the figures illustrating the experimental drift rounds is the amount used in the initial loading. When a round did not pull well, the bootlegged holes were reloaded with enough dynamite to break the ground. The "advance" and "total cars" as tabulated for each round represent the results of the initial blast, plus any secondary blast.

DRILLING DATA

Round No.	Drilling Time	Advance	Loading Time
15	3 hr. 40 min.	4'1"	--

SIZING DATA

Round No.	Total Cars	Car No.	Rock Wt. Pounds	+4"-12" Pounds	+12" Pounds
15	14-1/2	3	2145	202	0
		8	2132	102	0
		13	2234	78	0

Experimental Round No. 16

Round No. 16 was drilled as shown in Figure 11. The first relief holes to be fired, after the burn hole, were moved to positions directly above and below the burn cut hole. This was done to relieve the burden on these holes. The round did not break well as the left trim holes and all back holes bootlegged from 2 to 3 feet. These holes were reloaded and blasted, and the average advance of the heading then was 4 feet 2 inches. It was evident that there was too much burden on the trim holes opposite the burn.

DRILLING DATA

Round No.	Drilling Time	Advance	Loading Time
16	3 hr. 35 min.	4'2"	50 min.

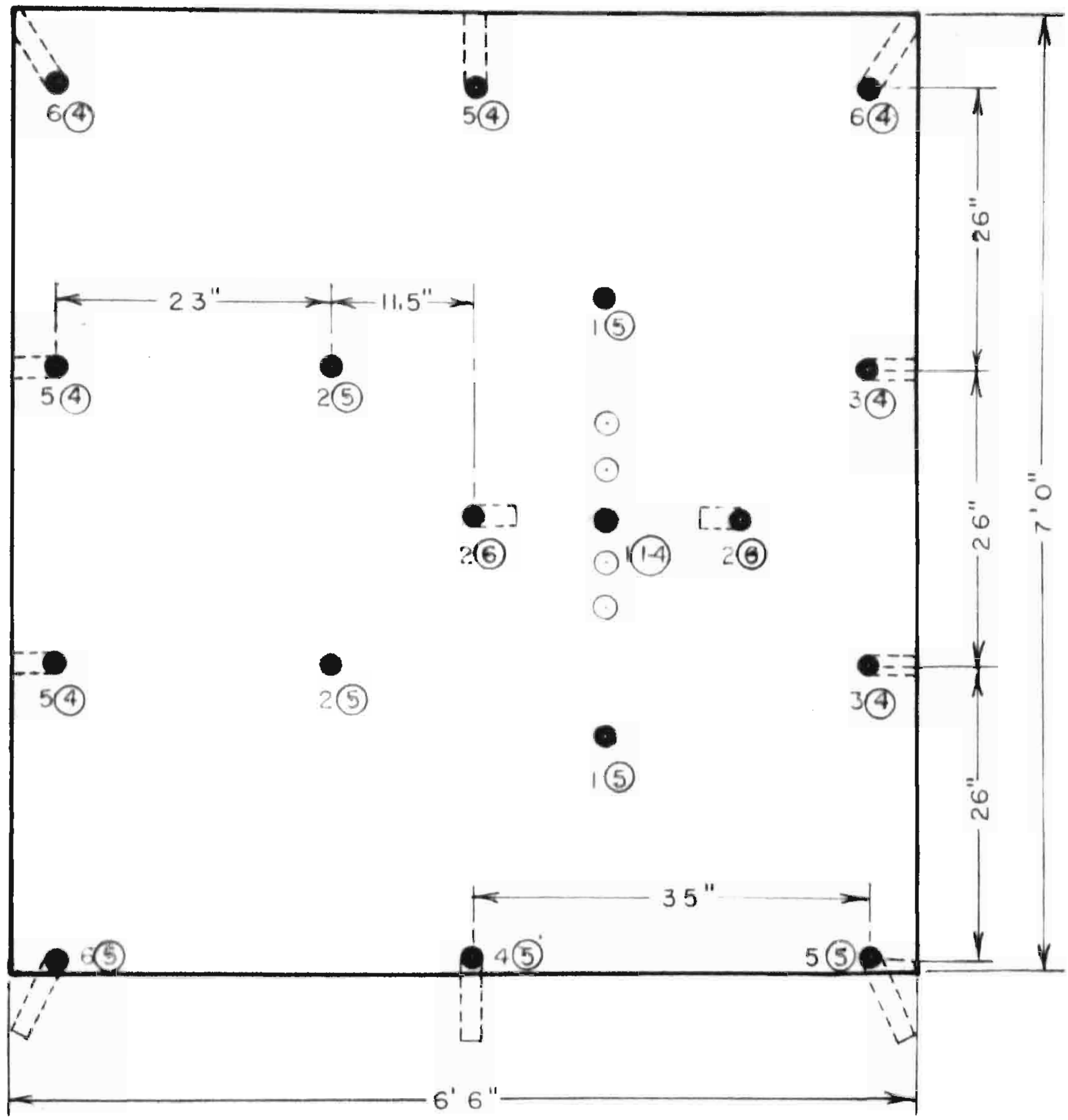
SIZING DATA

Round No.	Total Cars	Car No.	Rock Wt. Pounds	+4"-12" Pounds	+12" Pounds
16	15	3	2130	240	140
		8	2190	152	0
		13	2235	220	90

Experimental Round No. 17

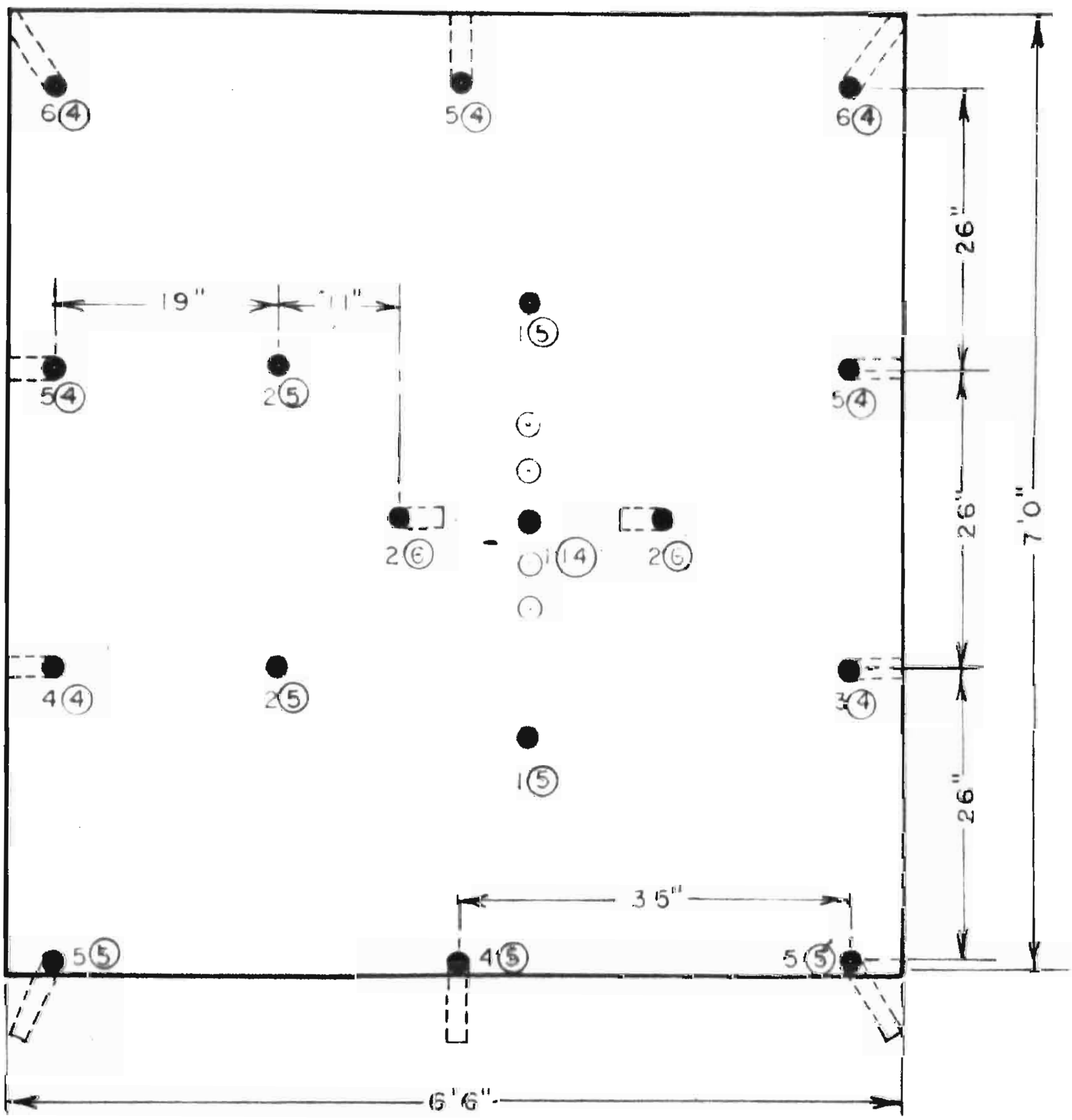
Round No. 17 was drilled with the burn holes only 6 inches off center as shown in Figure 12. This was done to decrease the burden on the left trim holes.

When fired, this round did not break well, as all trim holes bootlegged from 1 to 2 feet, and the top holes bootlegged from 2 to 3 feet. The broken rock was coarse. Several boulders were found that were very large; one piece was 40 by 16 by 8 inches, one was 40 by 28 by 5 inches, and one piece was 30 by 20 by 16 inches. In general the rock was coarser than that yielded from any previous round.



1-3/4" to 1-5/8" holes
1-1/4" 40 percent Special Gelatin dynamite 89 sticks 46 pounds
Scale 3/4" = 1'

Figure 11. Experimental round no. 16



1-3/4" to 1-5/8" holes
1-1/4" Special Gelatin dynamite, 40 percent 89 sticks 46 pounds
Scale 3/4" = 1'

Figure 12. Experimental round no. 17

DRILLING DATA

Round No.	Drilling Time	Advance	Loading Time
17	3 hr. 35 min.	4'3"	45 min.

SIZING DATA

Round No.	Total Cars	Car No.	Rock Wt. Pounds	+4"-12" Pounds	+12" Pounds
17	15-1/2	3	2220	292	288
		8	2138	253	116
		13	2120	320	280

Experimental Round No. 18

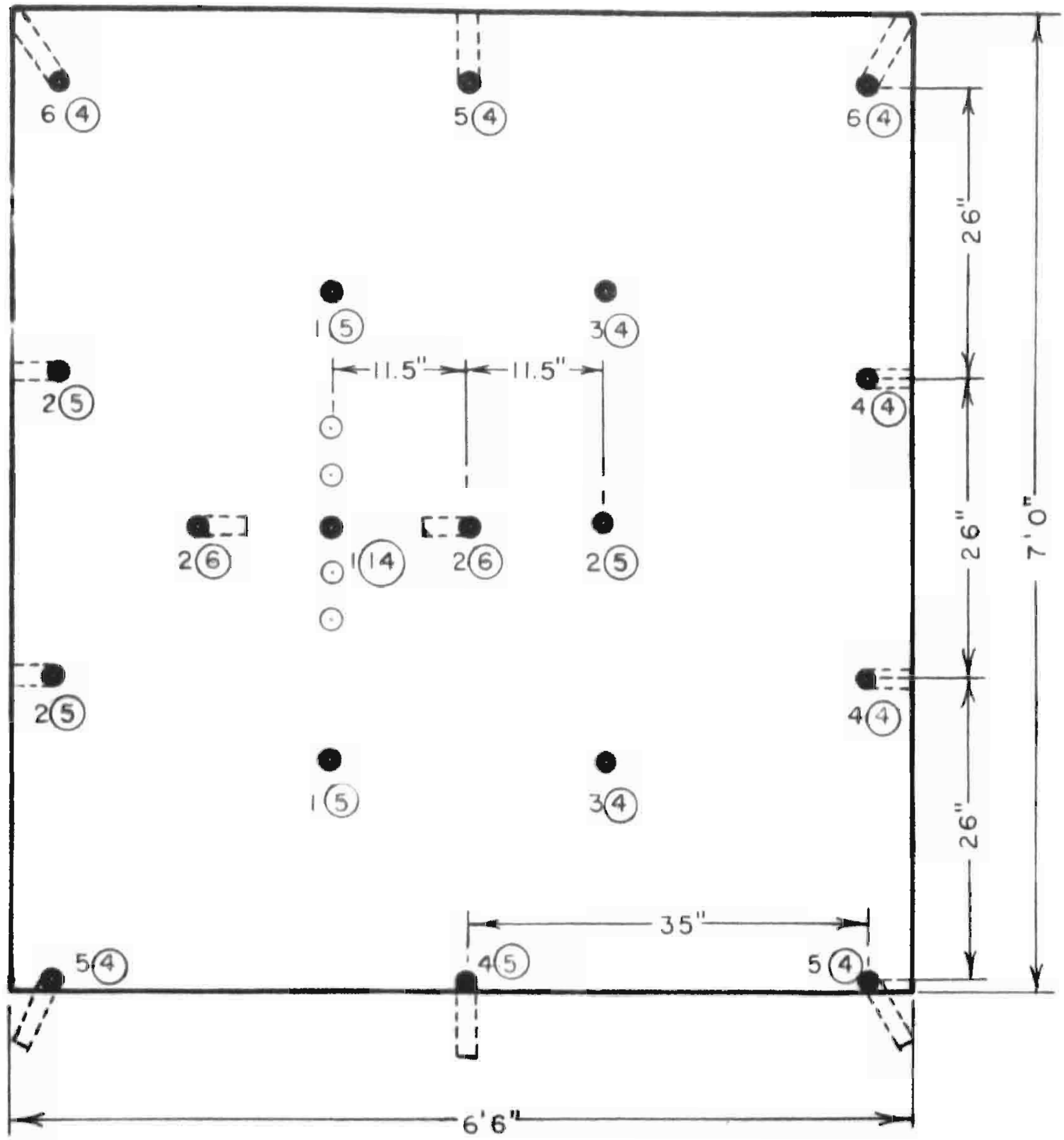
Round No. 18 was drilled as shown in Figure 13. One additional hole was added to the number of holes used in Round No. 17. This was done to reduce the burden on the trim holes and to decrease the burden on the relief holes around the burn cut. The round failed when it was blasted. The upper trim holes and the back holes bootlegged from 2 to 4 feet. These holes were reloaded and blasted. It was apparent at this stage that 2 trim holes on each side would not break the round properly. Rounds No. 1, 2, 15, 16, 17 and 18 were all drilled with 2 trim holes on each side, and in all of these rounds the trim holes bootlegged. This was particularly true of the trim holes opposite the burn cut when it was off center.

DRILLING DATA

Round No.	Drilling Time	Advance	Loading Time
18	3 hr. 50 min.	4'3"	55 min.

SIZING DATA

Round No.	Total Cars	Car No.	Rock Wt. Pounds	+4"-12" Pounds	+12" Pounds
18	16	3	2146	151	88
		8	2225	81	254
		13	2166	252	0



1-3/4" to 1-5/8" holes
1-1/4" 40 percent Special Gelatin dynamite 92 sticks 47.5 pounds
Scale 3/4" = 1'

Figure 13. Experimental round no. 18

Experimental Round No. 19

Round No. 19 was drilled with three trim holes on the side opposite the burn cut as shown in Figure 14. The total number of holes was one more than in Round No. 18 and two less than the number used in the standard round for the smaller diameter holes.

When blasted, the round broke well except the left back hole bootlegged about 18 inches.

DRILLING DATA

Round No.	Drilling Time	Advance	Loading Time
19	3 hr. 35 min.	4'10"	55 min.

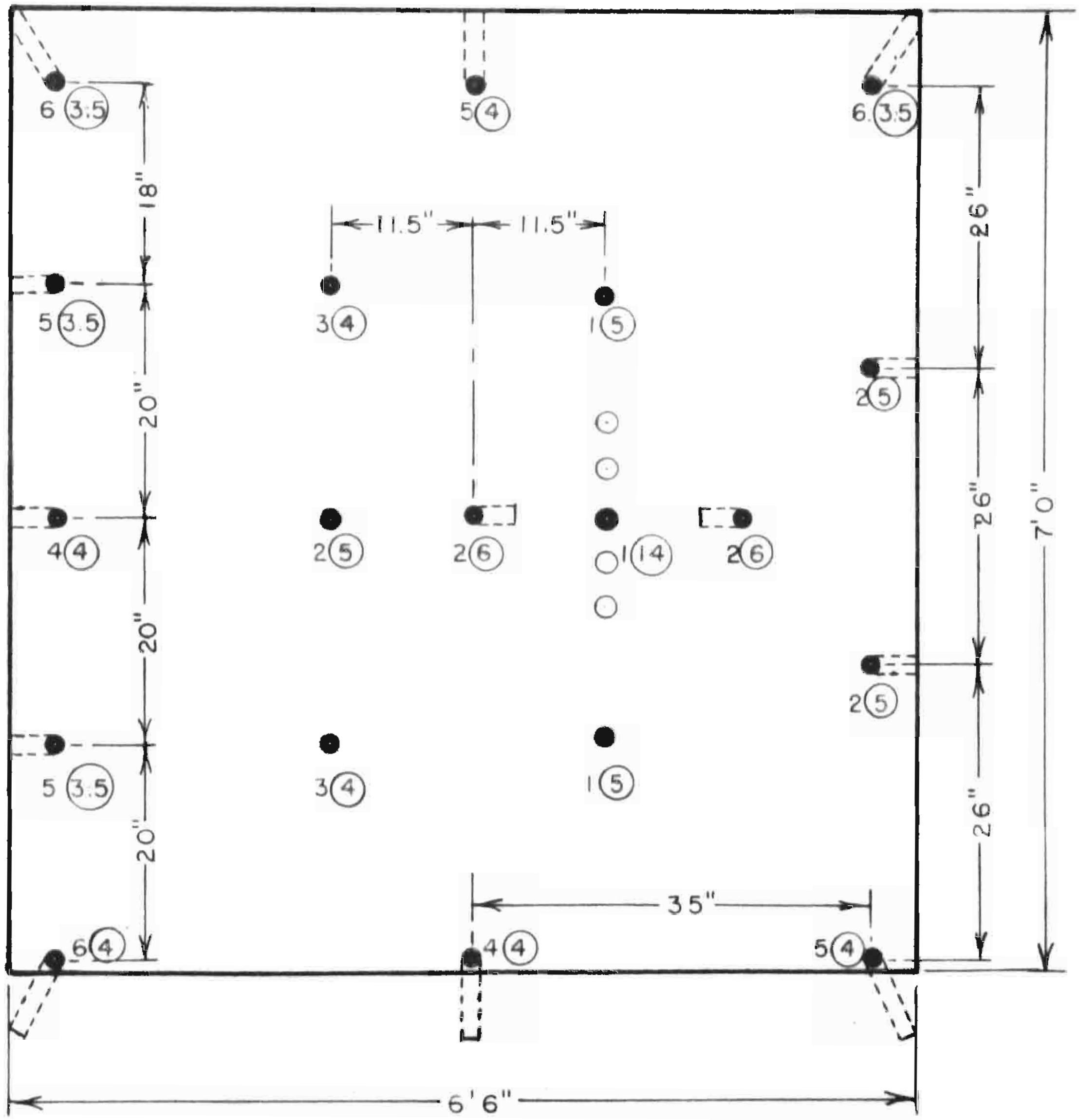
SIZING DATA

Round No.	Total Cars	Car No.	Rock Wt. Pounds	+4"-12" Pounds	+12" Pounds
19	17	3	2200	140	255
		8	2125	238	42
		13	2100	228	92

Experimental Round No. 20

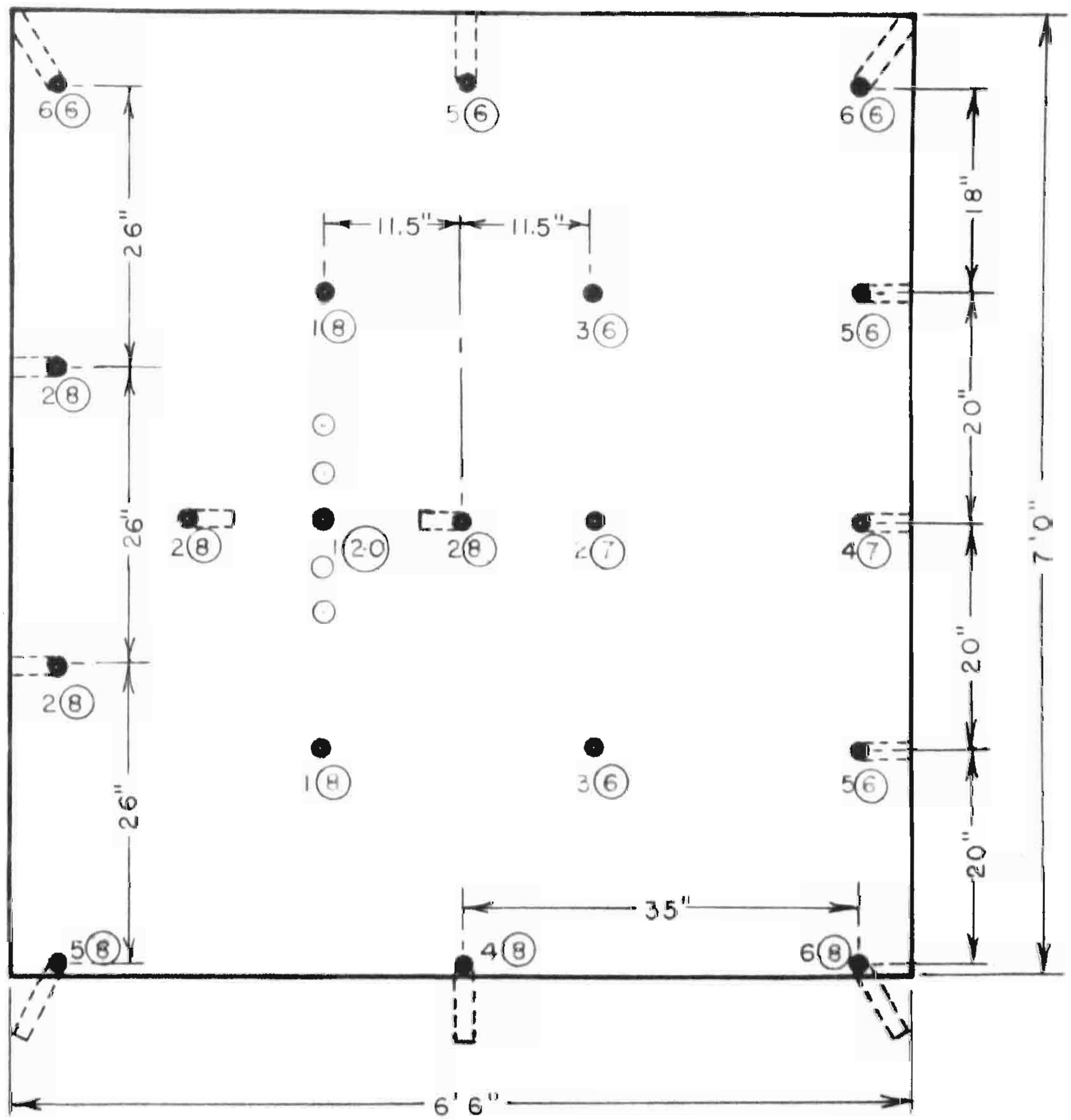
Data obtained while breaking Rounds No. 15, 16, 17, 18, and 19 seemed to indicate that the total number of holes used in the 1-inch dynamite tests could be reduced by 2 holes when using larger diameter dynamite. Before accepting that conclusion, it was felt Round No. 20 should be drilled with 1-1/2 inch bits and loaded with 1 inch dynamite to determine if this reduced number of holes would break the round if loaded with 1-inch dynamite.

Therefore, Round No. 20, as shown in Figure 15, was drilled the same as Round 19 except smaller diameter bits were employed. The holes were loaded with 1-inch Gelex No. 2 . The same amount of dynamite was used as in Standard 1 inch Gelex rounds No. 10, 11 and 12. Gelex No. 2 dynamite was used in this round because all available 1-inch Special Gelatin had



1-3/4" to 1-5/8" holes
1-1/4" 40 percent Special Gelatin dynamite 93 sticks 48 pounds
Scale 3/4" = 1'

Figure 14. Experimental round no. 19



1-1/2" to 1-3/8" holes
1" Gelex No. 2 dynamite 148 sticks 40.6 pounds
Scale 3/4" = 1'

Figure 15. Experimental round no. 20

been consumed. It should be noted that the Gelex dynamite available for this round was extremely hard and was difficult to use in making the primers. When blasted, the round broke well except for the back holes. However, when the face was examined, it was evident that the back holes had not been drilled properly as there was almost 3 feet of burden on the bottom of these holes. The average height of the drift was about 6 inches more than for most of the other rounds. It was evident, therefore, that the back holes failed because of improper drilling.

As the lifters and the rest of the holes had broken well, it was concluded that the same number 1-1/2 inch holes would break the same round as that drilled with 1-3/4 inch holes.

The broken rock from this round was comparatively fine.

DRILLING DATA

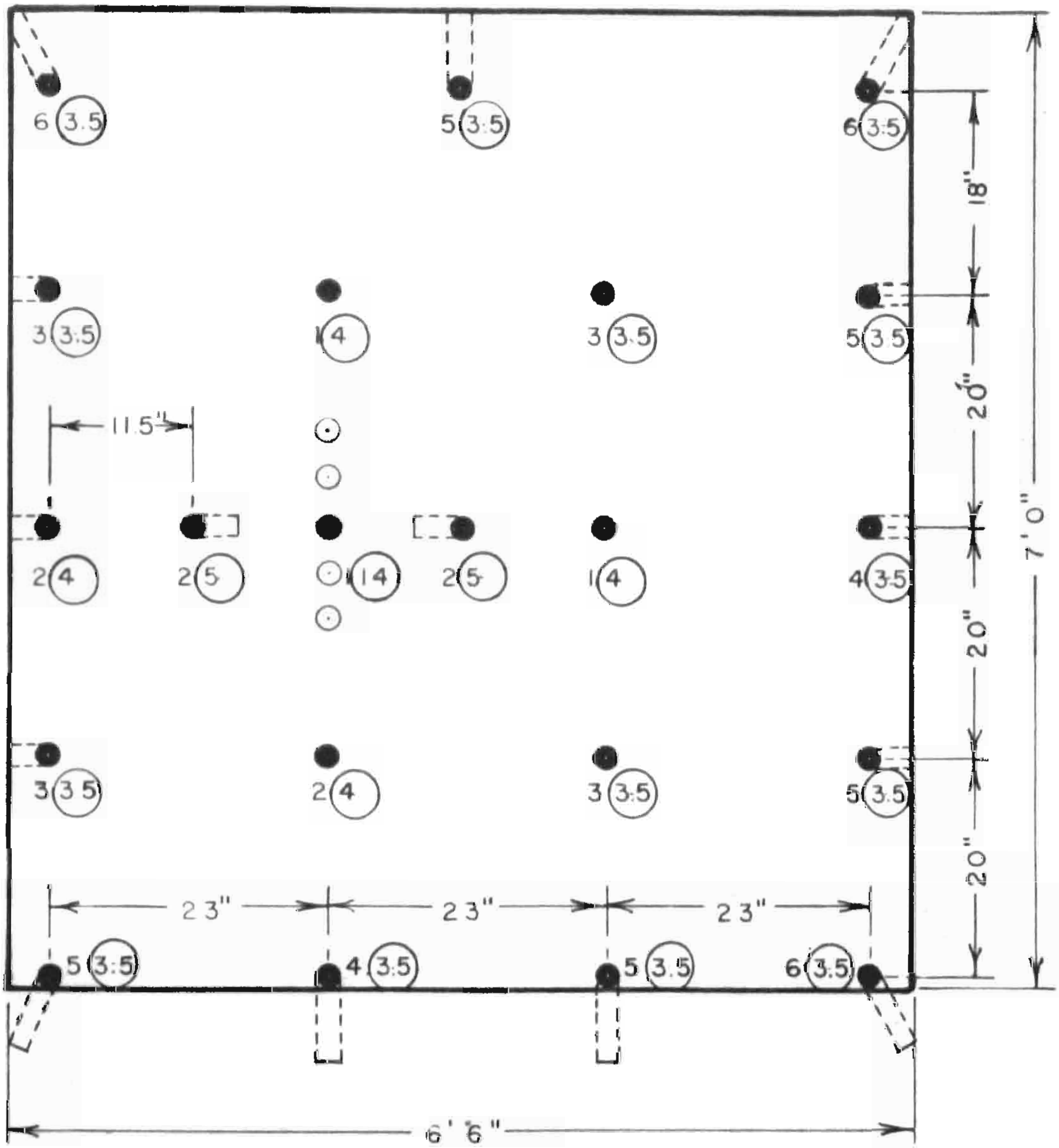
Round No.	Drilling Time	Advance	Loading Time
20	3 hr. 20 min.	4'9"	1 hr. 15 min.

SIZING DATA

Round No.	Total Cars	Car No.	Rock Wt. Pounds	+4"-12" Pounds	+12" Pounds
20	17	3	2225	88	121
		8	2120	15	0
		13	2166	92	0

Experimental Round No. 21

The previous rounds indicated that a reduction in the number of drill holes was not practicable when using larger diameter holes. Apparently any round that can be broken with larger diameter holes can be broken equally well with smaller diameter holes. Thus, Round No. 21 was drilled with 1-3/4 inch holes in the pattern followed in the earlier tests with 1-1/2 inch holes and 1 inch dynamite, illustrated in Figure 16.



1-3/4" to 1-5/8" holes
1-1/4" Special Gelatin dynamite, 40 percent 89 sticks 46 pounds
Scale 3/4" = 1'

Figure 16. Experimental round no. 21

This pattern was used with 1-3/4 inch holes so that drilling time, loading time, and weight of explosive could be compared to the data obtained in the tests using 1-1/2 inch holes and 1 inch dynamite. The holes were loaded with an amount of 1-1/4 inch Special Gelatin dynamite, equivalent by weight, to the amount of 1 inch dynamite used in Rounds 6, 7, and 8. The round failed when blasted. The average advance of the heading was about 3 feet. Most of the holes were reloaded and shot.

DRILLING DATA

Round No.	Drilling Time	Advance	Loading Time
21	4 hr. 45 min.	4'2"	1 hour

SIZING DATA

Round No.	Total Cars	Car No.	Rock Wt. Pounds	+4"-12" Pounds	+12" Pounds
21	15-1/4	3	2160	258	190
		8	2272	202	0
		13	2192	102	0

Experimental Round No. 22

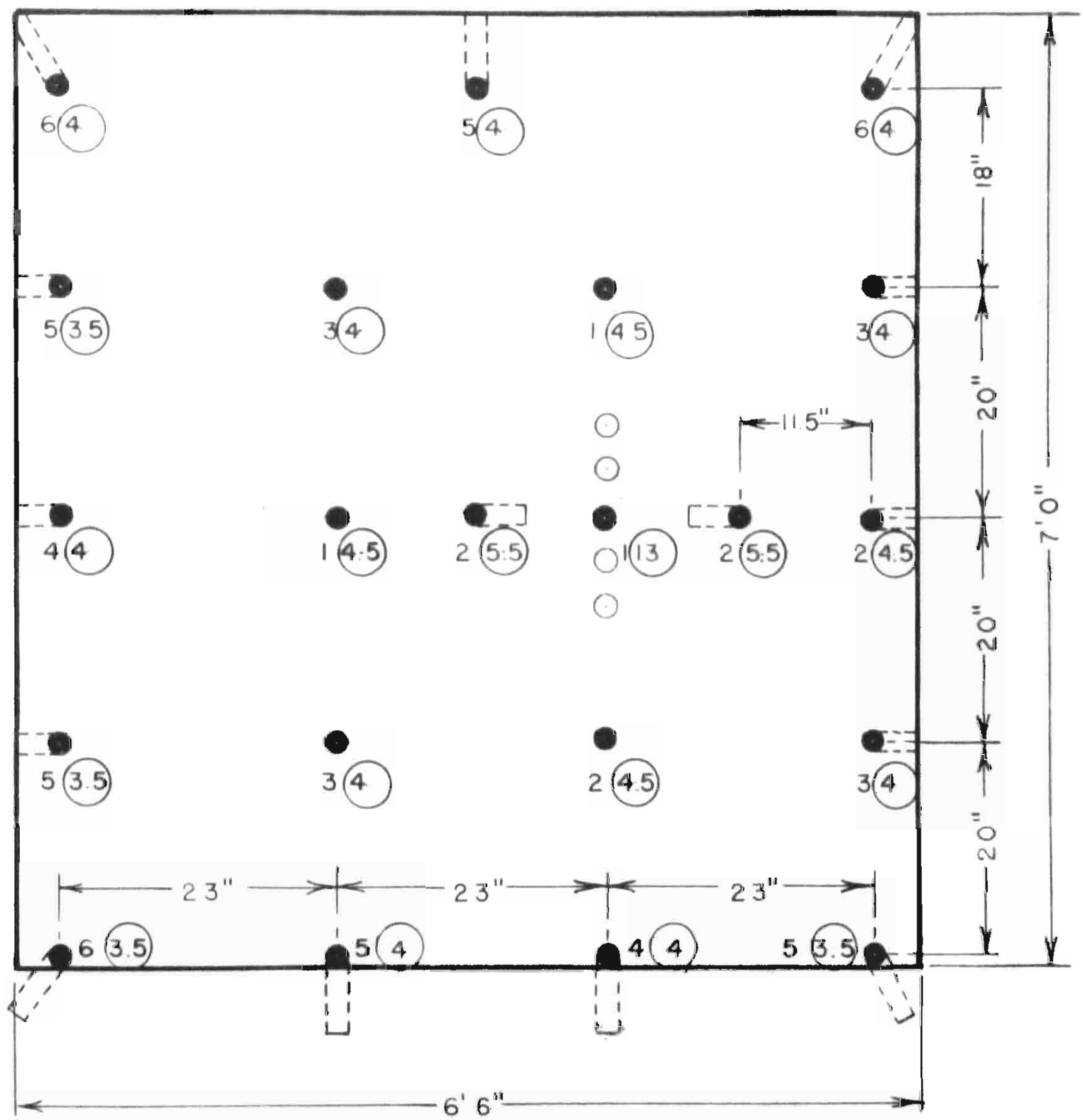
Round No. 22 was drilled as shown in Figure 17 with the same pattern used in Round No. 21. The holes were loaded with an amount of 1-1/4 inch Gelex No. 2 dynamite, equivalent by weight, to the amount of 1 inch dynamite used in Rounds No. 10, 11, and 12. The round was a failure. The average advance was about 2 feet; most of the holes were reloaded and blasted.

DRILLING DATA

Round No.	Drilling Time	Advance	Loading Time
22	4 hr. 50 min.	4'10"	55 min.

SIZING DATA

Round No.	Total Cars	Car No.	Rock Wt. Pounds	+4"-12" Pounds	+12" Pounds
22	17	3	2098	248	114
		8	2132	102	0
		13	2092	42	0



1-3/4" to 1-5/8" holes
1-1/4" Gelex No. 2 dynamite 96 sticks 40.0 pounds
3/4" = 1'

Figure 17. Experimental round no. 22

Experimental Round No. 23

Rounds No. 21 and 22 had been drilled using the standard round employed in the 1 inch diameter dynamite tests. The rounds had been loaded with an equivalent amount, by weight, of dynamite as used in the 1-inch dynamite tests. Both rounds failed to break. This indicated that an equal amount, by weight, of 1-1/4 inch dynamite is not as effective as the same amount, by weight, of 1-inch dynamite. For that reason Round No. 23 was drilled as shown by Figure 18 in the same pattern as that of the 1-inch dynamite tests. The total amount, by weight, of 1-1/4 inch Gelex No. 2 was increased about 12 percent over that used in Round No. 22. The round broke well when it was blasted.

The data obtained from Round No. 23 are as follows:

DRILLING DATA

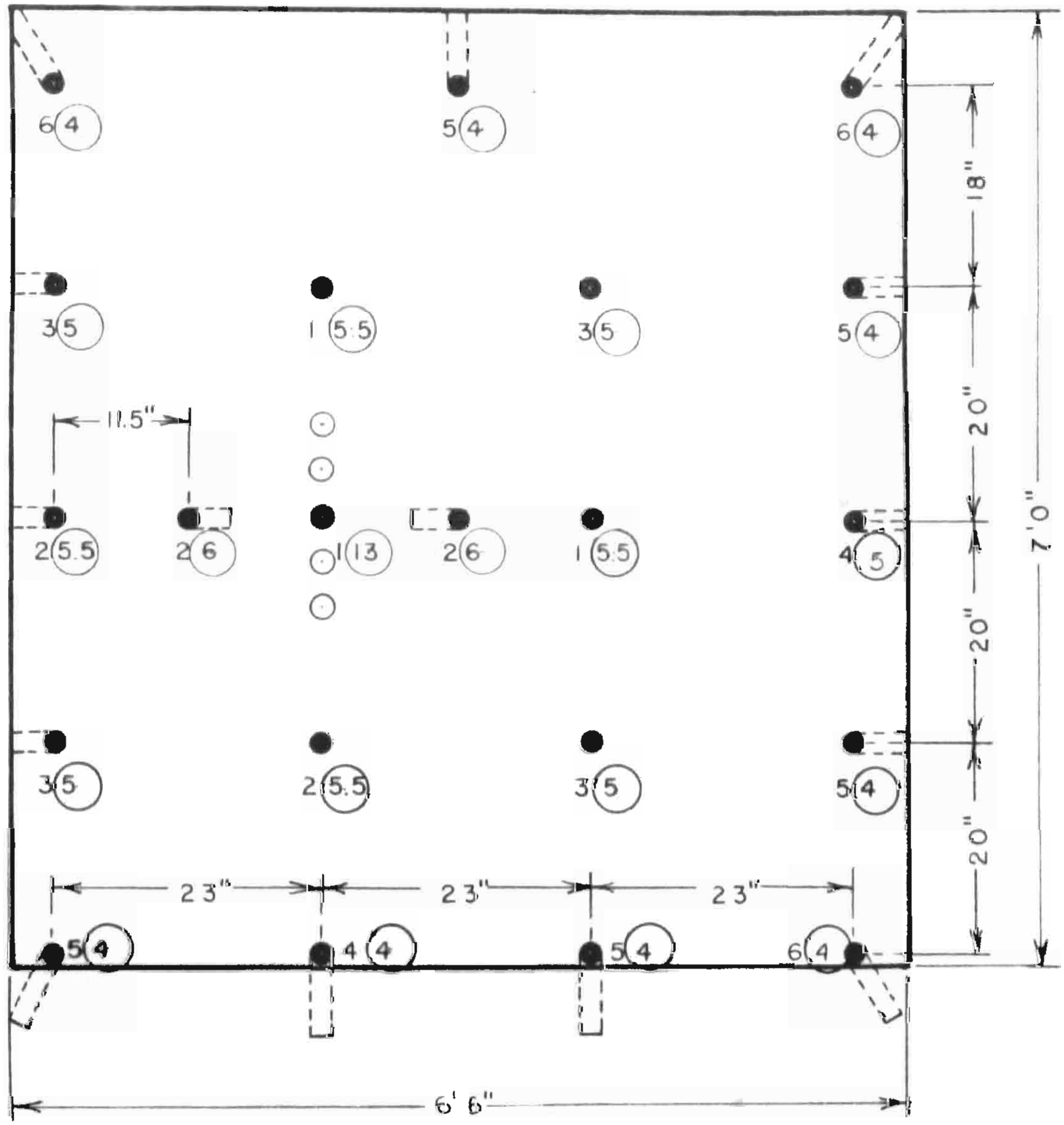
Round No.	Drilling Time	Advance	Loading Time
23	4 hr. 55 min.	4'9"	1 hr. 5 min.

SIZING DATA

Round No.	Total Cars	Car No.	Rock Wt. Pounds	+4"-12" Pounds	+12" Pounds
23	16-3/4	3	2155	282	0
		8	2220	168	224
		13	2175	244	32

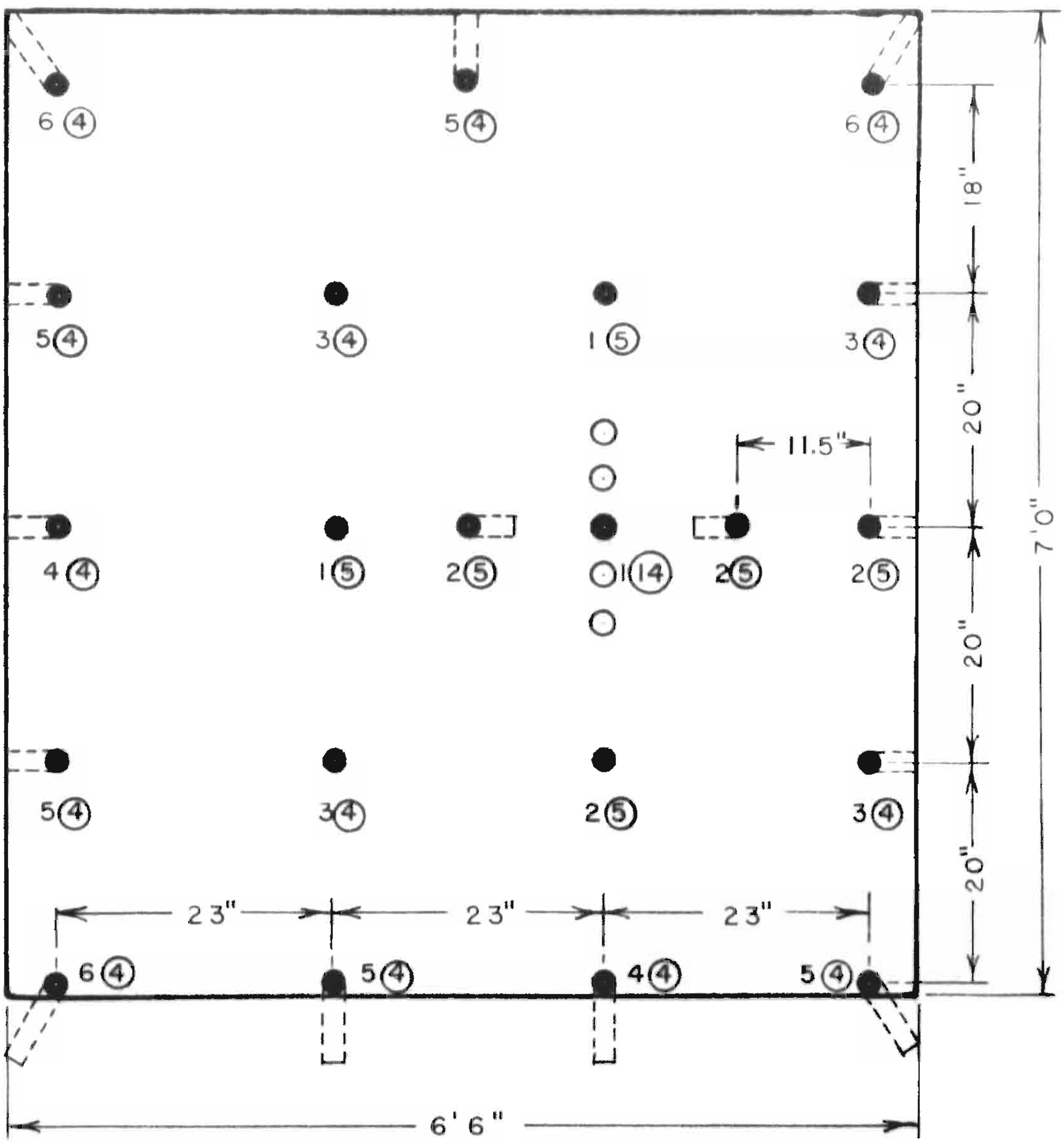
Experimental Round No. 24

The data from Round No. 23 indicated that if the standard drill hole pattern is employed with 1-3/4 inch holes, and loaded with 1-1/4 inch Gelex No. 2 dynamite, the round will break if an additional 12 percent of dynamite is used over that in the 1 inch Gelex No.2 tests. Thus, Round No. 24, see Figure 19, was drilled in the same standard drill hole pattern as that of Round No. 23. The round was loaded with 1-1/4 inch Special Gelatin. The total weight of dynamite was increased about 12 percent over the amount used in the 1 inch Special Gelatin test rounds No. 6, 7, and 8.



1-3/4" to 1-5/8" holes
1-1/4" Gelex No. 2 dynamite 108 sticks 45 pounds
Scale 3/4" = 1'

Figure 18. Experimental round no. 23



1-3/4" to 1-5/8" holes
1-1/4" 40 percent Special Gelatin dynamite 100 sticks 51.5 pounds
Scale 3/4" = 1'

Figure 19. Experimental round no. 24

The round broke well. The broken rock was relatively fine, very little of it being plus 12 inch material.

DRILLING DATA

Round No.	Drilling Time	Advance	Loading Time
24	4 hr. 35 min.	4'9"	55 min.

SIZING DATA

Round No.	Total Cars	Car No.	Rock Wt. Pounds	+4"-12" Pounds	+12" Pounds
24	17	3	2104	228	0
		8	2236	182	0
		13	2120	158	0

CONCLUSIONS

1. Gelex No. 2 dynamite is about 12 percent more effective than 40 percent Special Gelatin.
2. The rock will be broken finer when Gelex No. 2 dynamite is used.
3. The cost of Gelex No. 2 dynamite per round is about 15 percent less than the cost when using 40 percent Special Gelatin dynamite.
4. A given weight of 1-inch dynamite is more effective than the same amount of 1-1/4 inch dynamite.
5. The over-all cost of mining is reduced when using 1 inch dynamite and 1-1/2 inch holes as compared to the cost when using 1-1/4 inch dynamite and 1-3/4 inch holes.

These conclusions were derived from work in dolomitic rock and may not be wholly applicable to other types of rock.

SUMMARY

A series of experimental rounds was drilled and blasted to determine a given round that would break when using 1-1/2 inch holes and 1 inch dynamite. This round then was used as a standard round for 1 inch dynamite tests. Both 40 percent Special Gelatin dynamite and Gelex No. 2 dynamite were tested with this standard round. It was found that about 12 percent less Gelex No. 2 dynamite will break the round, and break it finer than 40 percent Special Gelatin.

Another series of experimental rounds was drilled with 1-3/4 inch holes and blasted with 1-1/4 inch dynamite. It was determined that any round that can be broken with 1-3/4 inch holes and 1-1/4 inch dynamite, can be broken equally as well with 1-1/2 inch holes and 1 inch dynamite.

Several tests were made using 1-3/4 inch holes and 1-1/4 inch dynamite with the same drill pattern as used in the 1 inch dynamite tests. It was found that when using 1-3/4 inch holes and 1-1/4 inch dynamite, about 12 percent more dynamite is required than when 1-1/2 inch holes and 1 inch dynamite are employed. Thus, it is concluded that a given weight of larger diameter cartridges is not as effective in blasting as the same weight of smaller diameter cartridges.

Appendix A

Part I

DYNAMITE CALCULATIONS

Dynamite	Diameter	Cartridges per 50 lbs.
40 Percent Special Gelatin	1"	139
Gelex No. 2	1"	182
40 Percent Special Gelatin	1-1/4"	97
Gelex No. 2	1-1/4"	120

Cartridges	Diameter	Type	Calculation	Pounds
92	1-1/4"	Gel. Dynamite	$\frac{92 \times 50}{97}$	47.4
138	1-1/4"	Gel. Dynamite	$\frac{138 \times 50}{97}$	71
125	1"	40% Spec. Gel.	$\frac{125 \times 50}{139}$	45
122	1"	40% Spec. Gel.	$\frac{122 \times 50}{139}$	44
148	1"	40% Spec. Gel.	$\frac{148 \times 50}{139}$	53.4
128	1"	40% Spec. Gel.	$\frac{128 \times 50}{139}$	46.1
168	1"	Gelex No. 2	$\frac{168 \times 50}{182}$	46.2
148	1"	Gelex No. 2	$\frac{148 \times 50}{182}$	40.6
89	1-1/4"	40% Spec. Gel.	$\frac{89 \times 50}{97}$	46
92	1-1/4"	40% Spec. Gel.	$\frac{92 \times 50}{97}$	47.5
93	1-1/4"	40% Spec. Gel.	$\frac{93 \times 50}{97}$	48
96	1-1/4"	Gelex No. 2	$\frac{96 \times 50}{120}$	40.0
108	1-1/4"	Gelex No. 2	$\frac{108 \times 50}{120}$	45
100	1-1/4"	40% Spec. Gel.	$\frac{100 \times 50}{97}$	51.5

Appendix A

Part 2

EQUIVALENT CARTRIDGE CALCULATIONS

No. of 1" Cartridges	Type	Calculation	No. of 1-1/4" Cartridges Used
5	40% Sp. Gel.	$\frac{5 \times 97}{139} = 3.5$	3.5
6	40% Sp. Gel.	$\frac{6 \times 97}{139} = 4.2$	4.0
7	40% Sp. Gel.	$\frac{7 \times 97}{139} = 4.9$	5.0
20	40% Sp. Gel.	$\frac{20 \times 97}{139} = 14$	14.0
6	Gelex No. 2	$\frac{6 \times 120}{182} = 3.9$	4.0 and 3.5
7	Gelex No. 2	$\frac{7 \times 120}{182} = 4.6$	4.5
8	Gelex No. 2	$\frac{8 \times 120}{182} = 5.3$	5.5
20	Gelex No. 2	$\frac{20 \times 120}{182} = 13.1$	13.0

Appendix B

Part 1

CUMULATIVE SIZING DATA OF 4 INCH DYNAMITE TESTS

Round Number	Dynamite Type	Dynamite Amount	Total Cars	Car No.	Rock Weight	Sizing +4" -12"	Sizing +12"	Sizing Total +4"	Sizing % +4"
5	Sp.Gel.	53.3	16	3	2115	-	220	-	-
				8	2060	90	0	90	-
				13	2102	180	0	180	-
6	Sp.Gel.	46.2	16	3	2186	149	326	575	26.2
				8	2108	67	266	333	15.3
				13	2114	156	124	280	13.3
7	Sp.Gel.	46.2	16	3	2123	157	258	415	19.5
				8	2221	251	66	317	14.3
				13	2124	170	164	334	15.7
8	Sp.Gel.	46.2	16	3	2162	160	225	385	17.8
				8	2126	198	0	198	9.3
				13	2257	9	275	284	12.6
9	Gel.No.2	46.3	16-2/3	3	2198	120	34	154	7.0
				8	2226	56	152	208	9.3
				13	2261	114	54	168	7.4
10	Gel.No.2	40.8	16-3/4	3	2240	189	183	372	16.6
				8	2160	147	151	298	13.8
				13	2105	116	56	172	8.2
11	Gel.No.2	40.8	16-3/4	3	2234	108	177	285	10.5
				8	2270	100	48	148	6.5
				13	2213	122	0	122	5.5

Appendix B

Part 1 (continued)

Round Number	Dynamite Type	Dynamite Amount	Total Cars	Car No.	Rock Weight	Sizing +4" -12"	Sizing +12"	Sizing Total +4"	Sizing % +4"
12	Gel.No.2	40.8	16-1/3	3	2198	173	188	361	16.5
				8	2145	103	124	227	10.5
				13	2184	161	0	161	7.4
13	Gel.No.2	40.8	16-3/4	3	2202	154	364	528	24.0
				8	2214	123	55	178	8.0
				13	2207	101	0	101	2.5
14	Gel.No.2	35.9	13-1/3	3	2210	158	49	207	9.4
				8	2132	95	0	95	4.5
				13	2202	78	0	78	3.5

Appendix B

Part 2

CUMULATIVE SIZING DATA OF $1\frac{1}{4}$ INCH DYNAMITE TESTS

Round Number	Dynamite Type	Dynamite Amount	Total Cars	Car No.	Rock Weight	Sizing +4" -12"	Sizing +12"	Sizing Total +4"	Sizing % +4"
15*	Sp.Gel.	46	14-1/2	3	2145	202	0	202	9.4
				8	2132	102	0	102	4.9
				13	2234	78	0	78	3.5
16*	Sp.Gel.	46	15	3	2130	240	140	380	17.8
				8	2190	152	0	152	7.0
				13	2235	220	90	310	13.9
17*	Sp.Gel.	46	15-1/2	3	2220	292	288	580	26.1
				8	2138	253	116	369	17.3
				13	2120	320	280	600	28.2
18*	Sp.Gel.	47.5	16	3	2146	151	88	239	11.1
				8	2225	81	254	335	15.1
				13	2166	252	0	252	11.6
19	Sp.Gel.	48	17	3	2200	140	255	395	18.0
				8	2125	238	42	280	13.2
				13	2100	228	92	320	15.3
20	Gel.No.2	40.6	17	3	2225	88	121	209	9.4
				8	2120	15	0	15	0.7
				13	2166	92	0	92	4.2

Appendix B

Part 2 (continued)

Round Number	Dynamite Type	Dynamite Amount	Total Cars	Car No.	Rock Weight	Sizing +4" -12"	Sizing +12"	Sizing Total +4"	Sizing % +4"
21*	Sp.Gel.	46	15-1/4	3	2160	258	190	448	20.8
				8	2272	202	0	202	8.9
				13	2192	102	0	102	4.7
22*	Gel.No.2	40	17	3	2098	248	114	362	17.2
				8	2132	102	9	102	4.8
				13	2092	42	0	42	2.0
23	Gel.No.2	45	16-3/4	3	2155	282	0	282	13.1
				8	2220	168	224	392	17.7
				13	2175	244	32	276	12.7
24	Sp.Gel.	51.5	17	3	2104	228	0	228	10.7
				8	2236	182	0	182	8.2
				13	2120	158	0	158	7.5

* Round failed, reblasted

Appendix B

Part 2

CUMULATIVE DRILLING DATA OF 1 INCH DYNAMITE TESTS

Round Number	Drilling Time	Loading Time	Advance	Dynamite Type	Dynamite Pounds
5	5 hr. 14 min.	1 hr. 10 min.	4'10"	Sp.Gel.	53.3
6	5 hr. 05 min.	1 hr. 0 min.	4'10"	Sp.Gel.	46.2
7	4 hr. 50 min.	1 hr. 10 min.	4'11"	Sp.Gel.	46.2
8	4 hr. 20 min.	1 hr. 0 min.	4'10"	Sp.Gel.	46.2
9	4 hr. 35 min.	1 hr. 15 min.	4'9"	Gel.No.2	46.3
10	4 hr. 20 min.	1 hr. 25 min.	4'9"	Gel.No.2	40.8
11	4 hr. 25 min.	1 hr. 20 min.	4'8"	Gel.No.2	40.8
12	4 hr. 15 min.	----	4'8"	Gel.No.2	40.8
13	4 hr. 25 min.	1 hr. 30 min.	4'10"	Gel.No.2	40.8
14	4 hr. 10 min.	1 hr. 35 min.	3'9"	Gel.No.2	35.9

CUMULATIVE DRILLING DATA OF 1¼ INCH DYNAMITE TESTS

Round Number	Drilling Time	Loading Time	Advance	Dynamite Type	Dynamite Pounds
15*	3 hr. 40 min.	----	4'1"	Sp.Gel.	46.
16*	3 hr. 35 min.	50 min.	4'2"	Sp.Gel.	46.
17*	3 hr. 35 min.	45 min.	4'3"	Sp.Gel.	46.
18*	3 hr. 50 min.	55 min.	4'3"	Sp.Gel.	47.5
19	3 hr. 35 min.	55 min.	4'10"	Sp.Gel.	48.
20**	3 hr. 20 min.	1 hr. 15 min.	4'9"	Gel.No.2	40.6
21*	4 hr. 45 min.	1 hr. 0 min.	4'2"	Sp.Gel.	46.
22*	4 hr. 50 min.	55 min.	4'10"	Sp.Gel.	40.0
23	4 hr. 55 min.	1 hr. 5 min.	4'9"	Gel.No.2	45.
24	4 hr. 35 min.	55 min.	4'9"	Sp.Gel.	51.5

* Round failed and was reblasted
** 1 inch dynamite used

Appendix C

COMPARATIVE COST DATA

The costs listed below do not represent the total cost, but merely represent the cost of the items that will vary depending upon the drill hole diameter and cartridge diameter.

1 Inch Special Gelatin

Item	Amount	Cost per Unit	Total Cost per Round	Cost per Ft. of Advance
Drilling	4 hr. 20 min.	$1.35 per hr.	$5.85	
Loading	1 hr. 15 min.	1.35 per hr.	1.69	
Dynamite	46.2 lbs.	18.00 per 100 lbs.	16.75	
Bits	.8	.40 per bit	.32	
			$24.61	$4.95

1 Inch Gelex No. 2

Drilling	4 hr. 20 min.	$1.35 per hr.	$5.85	
Loading	1 hr. 15 min.	1.35 per hr.	1.69	
Dynamite	40.8 lbs.	17.25 per 100 lbs.	14.10	
Bits	.8	.40 per bit	.32	
			$21.96	$4.39

1-1/4 Inch Special Gelatin

Drilling	4 hr. 40 min.	$1.35 per hr.	$6.20	
Loading	1 hr.	1.35 per hr.	1.35	
Dynamite	51.5 lbs.	18.00 per 100 lbs.	18.50	
Bits	.55	.40 per bit	.22	
			$26.27	$5.25

1-1/4 Inch Gelex No. 2

Drilling	4 hr. 40 min.	$1.35 per hr.	$6.20	
Loading	1 hr.	1.35 per hr.	1.35	
Dynamite	45.0 lbs.	17.25 per 100 lbs.	15.52	
Bits	.55	.40 per bits	.22	
			$23.39	$4.67

These costs are based on the following data:

Bits - 8 bits were used in 10 rounds of 1-1/2"-1-3/8" holes
5 bits were used in 9 rounds of 1-3/4"-1-5/8" holes
(All bits failed by fatigue)

Average Drilling Time - 1-1/2"-1-3/8" holes - 4 hr. 20 min.
(Taken from Rounds No. 8, 9, 10, 11, 12, 13, 14)

1-3/4"-1-5/8" holes - 4 hr. 40 min.
(Taken from Rounds No. 21, 22, 23, 24)

Average Loading Time - 1" dynamite - 1 hr. 15 min.
(From Rounds 5, 6, 7, 8, 9, 10, 11)

1-1/4" dynamite - 1 hr.
(From Rounds No. 21, 22, 23, 24)

Dynamite - 1" Special Gelatin - 46.2 lb.
(Rounds No. 6, 7, 8)

1" Gelex No. 2 - 40.8 lb.
(Rounds 10, 11, 12)

1-1/4" Special Gelatin - 51.5 lb.
(Round No. 24)

1-1/4" Gelex No. 2 - 45.0 lb.
(Round No. 23)

Appendix D

VELOCITY TESTS

Mr. Robert Girdler and Mr. Wilbur Tipton, representatives of the Eastern Laboratory, Explosive Division, of the Du Pont Company came to Rolla, Missouri in August 1947, to conduct a series of tests on velocities of dynamites.

About 30 holes were drilled in preparation for the tests. Most of them were drilled as slabbing holes on various pillars in the mine; however, some holes were drilled in the solid where the rock could not be broken freely.

The tests were made by inserting a "start" and a "stop" target in each drill hole. These targets are similar in appearance to a blasting cap and are inserted in a cartridge of dynamite. The "start" target is put next to the primer cartridge, and the "stop" target is put near the opposite end of the drill hole. The space between is filled with the explosive to be tested. The distance between the targets is that over which the velocity of detonation is measured.

The "stop" and "start" targets were connected by rubber-coated wire to a counter chronograph located outside the mine. This instrument measures the time in micro seconds that the wave of detonation takes in passing from the "start" target to the "stop" target.

Before these tests were made, no drill hole experiments on the velocity of dynamite had been conducted. All prior tests were made on dynamite either in the open or in steel pipe. Drill hole experiments revealed the following interesting facts:

1. The velocity of detonation of dynamite in a drill hole is about the same as the velocity of dynamite exploded in a steel pipe.

2. Special Gelatin, 40 percent, detonates at a "low" velocity when exploded in a drill hole.

The results of these tests are shown on the following page.

Appendix D

VELOCITY TESTS*

Grade	Hole Diameter	Slit and Tamped	Burden	Distance be-tween targets	Velocity Meters/Sec.	Velocity in Open	Remarks
Gelex No. 2	1-3/4"-1-1/2"	Yes	Solid	8'-0"	4340	3862	
	1-3/4"-1-1/2"	Yes	Solid	7'-7"	4250		
	2"	Yes	Solid	4'-7"	4000		
	2"	No	Solid	4'-4"	3390		
	1-3/4"-1-1/2"	Yes	---	9'-4"	3800		1" Cartridges
	1-3/4"-1-1/2"	No	---	8'-8"	3000		1" Cartridges
40% Gelatin	1-3/4"-1-1/2"	Yes	Solid	9'-0"	2350	2287	
	1-3/4"-1-1/2"	Yes	Solid	6'-0"	2730		
	1-3/4"-1-5/8"	No	Slab.	6'-0"	2260		2' Air Space
	1-3/4"-1-5/8"	No.	Slab.	4'-5"	1730		
	2"	No.	Slab.	3'-10"	1260		
	1-3/4"-1-5/8"	Yes	--	5'-5"	2180		1" Cartridges
Red Cross Extra 40%	1-3/4"-1-5/8"	Yes	Slab.	5'-4"	3190	3302	
	1-3/4"-1-5/8"	No	Slab.	6'-4"	3300		Ends cut off
Monobel "AA"	1-3/4"-1-1/2"	No	Slab.	7'-3"	2540	2885	
	1-3/4"-1-5/8"	No	Slab.	6'-6"	2500		
Lump Coal "C"	1-3/4"-1-5/8"	No	Slab.	6'-6"	1910	1595	
	1-3/4"-1-5/8"	No	Slab.	9'-0"	1705		
	1-3/4"-1-5/8"	No	Slab.	7'-5"	1840		

* The author is indebted to Mr. Robt. Girdler for these data.

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VITA

Charles Harding Noren, born January 25, 1922 in Chicago, Illinois, attended primary schools in Villa Park, Illinois and was graduated from the high school of that community in 1939. On graduation, Mr. Noren entered the University of North Dakota and obtained a Bachelor of Science degree in Mining Engineering in May 1943. Immediately upon graduation he entered active duty with the United States Army Air Force and was honorably discharged as an officer in November 1945.

Shortly after his discharge from the Army, Mr. Noren accepted a position as a junior engineer and geologist with the Chino Division of the Kennecott Copper Corporation. In August 1946 he left that company to take graduate work in Mining at the Missouri School of Mines and Metallurgy. From September 1946 to January 1948 he served as a graduate assistant in the Mining Engineering Department.