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EFFECTS OF TYPE OF CUT, DELAY, AND EXPLOSIVE ON UNDERGROUND BLASTING IN FROZEN GRAVEL

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

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By Richard A. Dick

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EFFECTS OF TYPE OF CUT, DELAY, AND EXPLOSIVE ON UNDERGROUND BLASTING IN FROZEN GRAVEL

by

Richard A. Dick[1]

ABSTRACT

Underground blasting in permanently frozen gravel was studied in a 7- by 12-ft drift by running a nonreplicated 2 x 2 x 2 factorial experiment on the effects of type of cut, delay, and explosive on the fragmentation subsystem. Comparisons were made between a V-cut round and a burn-cut round, millisecond delays and half-second delays, and 40 percent special gelatin and 60 percent high-density ammonia dynamite. The number of large blocks in the muck pile, loading time, shuttle car operating time lost because of cleanup needs, length of advance per round, and length of muck pile were recorded and statistically analyzed.

None of the blast parameters had a significant effect on the length of advance or length of muck pile, although the half-second delays tended to give a shorter muck pile than millisecond delays. The burn cut required less secondary breakage, less loading and cleanup time, and gave better overall fragmentation than the V-cut. The ammonia dynamite shots required less secondary breakage and less loading time than those using special gelatin. The half-second delays gave better overall fragmentation and required less cleanup time, but the millisecond delays gave a better loading rate. None of the differences between delays and explosives were notably significant.

INTRODUCTION

Under the Bureau of Mines Heavy Metals Program--an intensified search for new sources of heavy metals, including gold--the Twin Cities Mining Research Center is responsible for testing and evaluating rock disintegration systems to determine their feasibility in exploiting potential ore bodies. This particular research was directed toward determining the feasibility of exploiting a frozen placer gold deposit using drilling and blasting as the fragmentation subsystem. The data obtained were used as input in a Bureau study on the economics of mining frozen gravel. This report describes the 2 x 2 x 2 factorial experiment which was run in a 7- by 12-ft drift in permanently frozen gravel and schist bedrock at Fox, Alaska, to evaluate the effects of type of cut, type of delay, and type of explosive in a blasting system.

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The Bureau has used the factorial experiment extensively as a tool in both laboratory and small-scale field studies. Although the influence of factors outside the experimental design can usually be kept to a minimum in laboratory research, a field investigation presents many conditions over which the researcher has little or no control. In this experiment, change in gravel size and moisture content with increased depth, variations in atmospheric and gravel temperatures, and material differences between the gravel and decomposed bedrock were such factors. Although each blast round was designed to break the same volume of material, overbreak, bootlegging, and occasional imprecise hole alinement caused some variation. If the effects of the variables are to be significant, the differences in results obtained in the experiment must be large enough to override the error caused by these varying field conditions.

The U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), formerly known as the Terrestrial Sciences Center (USATSC), has done considerable research on methods of tunneling in permafrost and frozen glacial till (1, 3-6, 8).[2] CRREL's work in the "warm" (29° to 31° F) Fairbanks permafrost was confined to the soft upper silt strata, whereas the present investigation was done in the harder gravel and decomposed bedrock. Their work in harder material was confined to a "cold" (9° to 15° F) glacial till in Greenland and was not done as a designed experiment.

ACKNOWLEDGMENTS

The author wishes to express his appreciation to the personnel of the Fairbanks Field Station of the U.S. Army Cold Regions Research and Engineering Laboratory for their cooperation and assistance in this project. Special thanks are due to SP4 Charles Matherly, U.S. Army, for his time studies and technical assistance.

TEST SITE

The experiment was carried out at the CRREL experimental tunnel at Fox, Alaska, about 10 miles north of Fairbanks (fig. 1). Because of the remote location, careful and farsighted planning in the procurement of supplies and equipment was extremely important. Airfreight from regular points of supply was very expensive and surface delivery was very slow.

The existing CRREL tunnel was driven in the silt zone, partly by drilling and blasting and partly by mechanical mining machine. It varies from 6 to 12 ft high and is about 400 ft long.

The Bureau of Mines experimental drift was started at a point within the CRREL tunnel 110 ft from the portal and was driven on an average grade of minus 12 percent, as indicated in figure 2. The three strata encountered were silt, gravel, and bedrock.

The silt is a dark gray, very fine-grained material containing 30 percent or more moisture. Frequent ice lenses and occasional sand and gravel lenses

[2] Underlined numbers in parentheses refer to items in the list of references at the end of this report.

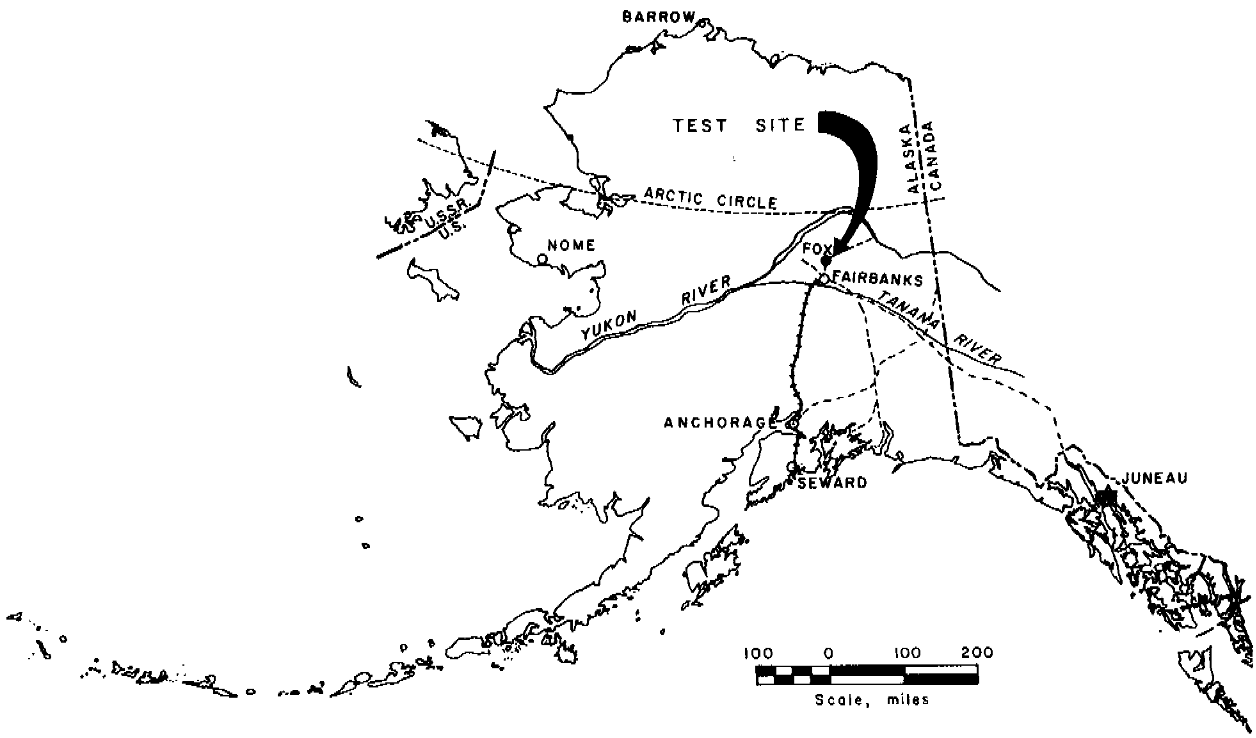


FIGURE 1. - Location Map of Test Site.

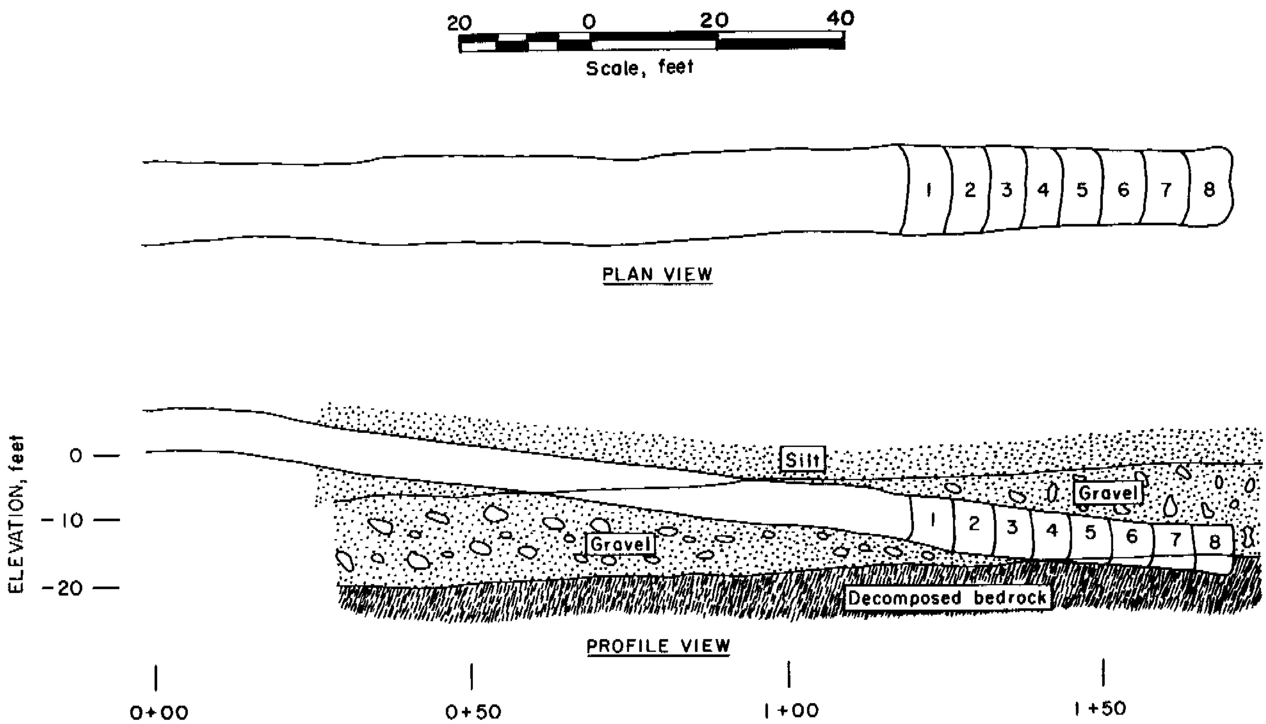


FIGURE 2. - Location of Test Shots in Tunnel. Station 0+00 is 110 feet from portal.

are present. Because of its high organic content, the silt gives off a fetid odor upon exposure. Exposed surfaces eventually become covered with a layer of fine dust as the moisture from the silt sublimates.

The gravel is a mixture of mica schist, chlorite schist, phyllite, gneiss, and quartz cobbles in a matrix of poorly stratified sand. The moisture content decreases with increased depth and varies from 7 to 11 percent. Both the gravel and silt are permanently frozen at about 30° F.

Although the Birch Creek Schist is called bedrock, the schist encountered in the experiment was not highly competent. A Precambrian formation underlying the gravel, the Birch Creek Schist is composed largely of quartz, biotite, and sericite. The upper few feet of schist is highly weathered and, when thawed, has the consistency of a silty, gritty clay.

The stability of openings in the silt and gravel depends entirely on the material's frozen condition. Because the temperature of the permafrost in the Fox area is so high (29° to 31° F), it was extremely important to minimize the heat introduced into the drift. For this reason, the tunneling was not started until late October, when outside temperatures remained below freezing. This precaution eliminated the need to refrigerate the ventilation air. During the tests, atmospheric temperatures ranged from -14° to 32° F on the surface and from 5° to 23° F in the working area of the tunnel. Figure 3 shows the daily temperature ranges during the test shots.

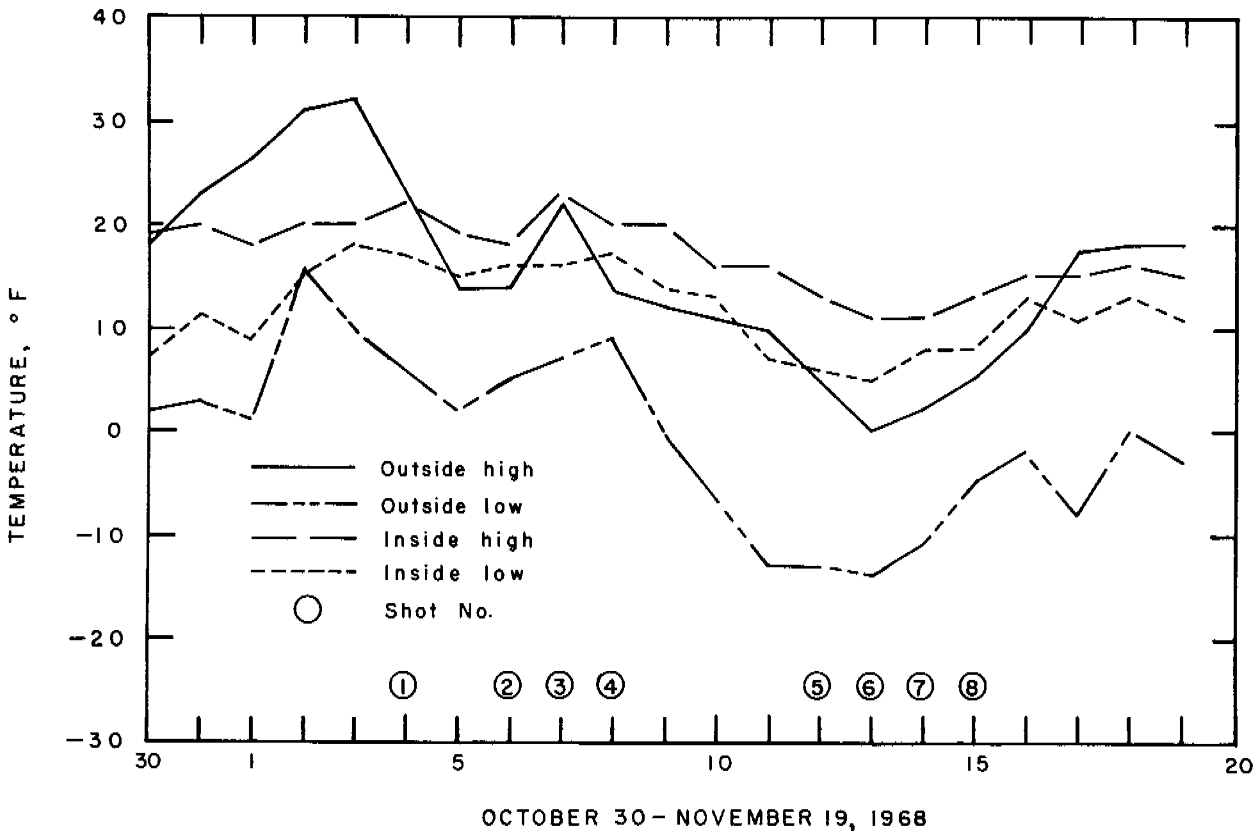


FIGURE 3. - Atmospheric Temperature Range Outside and Inside Tunnel.

DESIGN OF THE EXPERIMENT

Eight shots were fired in a 2 x 2 x 2 factorial design to test each of the three variables at two levels. The amount of drifting below the silt zone was not sufficient to permit replication of the experiment. Table 1 shows the design of the experiment.

TABLE 1. - Combinations of variables tested

Shot No.	Cut	Delay cap	Explosive
1	"V"	Millisecond	40 pct special gelatin.
2	Burn	Half-second	60 pct ammonia dynamite.
3	Burn	Millisecond	60 pct ammonia dynamite.
4	"V"	Half-second	40 pct special gelatin.
5	"V"	Half-second	60 pct ammonia dynamite.
6	Burn	Millisecond	40 pct special gelatin.
7	Burn	Half-second	40 pct special gelatin.
8	"V"	Millisecond	60 pct ammonia dynamite.

Type of Cut

Two of the cuts more commonly used in drift mining, the "V" and the burn, were chosen for the experiment. Figure 4 shows the blasthole and delay patterns used with each cut. The V-cut round consisted of six vertical rows of four holes each, with the two center rows drilled to meet at the back. Two shorter holes, called "busters," were drilled within the "V" to break up any large chunks which might tend to be formed in this zone. The burn cut was made up of five holes at the center of the face with only the four outer holes being loaded. Four relievers were drilled 2 ft from the center of the burn cut and the rest of the round was similar to that used with the V-cut.

Type of Delay

Two series of delay caps are available commercially, the millisecond delays and half-second, or slow, delays. The delay patterns shown in figure 4 were used with both the millisecond and half-second delays, with one exception. In the V-cut round with half-second delays, the "buster" holes contained delay Nos. 0 and 1, rather than Nos. 1 and 2, to prevent unexploded caps and powder from being thrown down the drift upon detonation of the cut holes. Table 2 shows the delay periods of the two series of caps used in the experiment.

TABLE 2. - Length of delay of millisecond and half-second delay series, seconds

Delay No.	Msec series	1/2-sec series
0..............	0	0.025
1..............	.025	.5
2..............	.050	1.0
3..............	.075	1.6
4..............	.100	2.3
5..............	.125	3.0

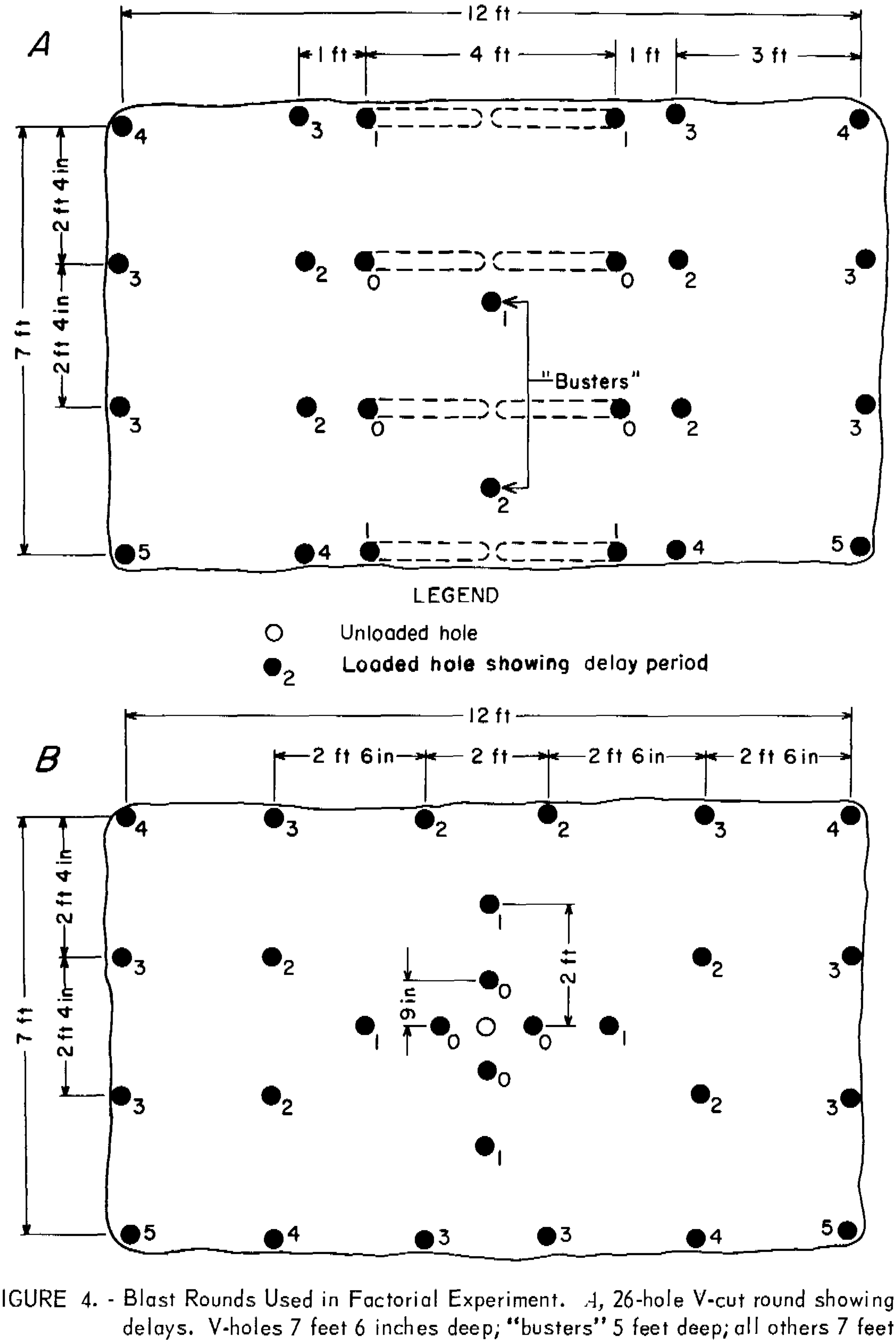


FIGURE 4. - Blast Rounds Used in Factorial Experiment. *A*, 26-hole V-cut round showing delays. V-holes 7 feet 6 inches deep; "busters" 5 feet deep; all others 7 feet deep. All holes 1½ inches in diameter. *B*, 29-hole burn-cut round showing delays. All holes 7 feet deep and 1½ inches in diameter.

Type of Explosive

Detonation pressure, which is a function of detonation velocity and density, is one of the better indicators of an explosive's ability to perform work. Ideally, this experiment would have compared an explosive with a relatively high detonation pressure with one with a relatively low detonation pressure, the ratio being about 4 to 1. However, the only explosives available in the State of Alaska in 1-1/4-in cartridges were 40 percent special (ammonia) gelatin and 60 percent high-density ammonia dynamite. Because explosives are sold by weight, they are compared on a weight basis rather than a stick basis. Table 3 gives the principal properties of these two explosives, and table 4 shows the powder loads used in the experiment.

TABLE 3. - Properties of explosives

Property	40 pct special gelatin	60 pct ammonia dynamite
Cartridge count (1-1/4- by 8-inch cartridges per 50 lb)	92	110
Density...g/cc..	1.53	1.30
Detonation velocity...ft/sec..	16,000	12,000
Calculated detonation pressure...kbar..	75	38
Water resistance	Excellent	Fair to good
Fume class	Very good	Good

TABLE 4. - Powder loads for V-cut and burn-cut rounds

Cut and type of holes	No. of holes	Depth, ft[1]	No. of sticks			
			Per hole		Total[2]	
			Gelatin	Dynamite	Gelatin	Dynamite
V-cut:						
"V"	8	7-1/2	6	7	48	56
"Buster"	2	5	4	5	8	10
Other	16	7	5	6	80	96
Total	26	-	-	-	136	162
Burn cut:						
Burn	4	7	7	8	28	32
Center	1	7	0	0	0	0
Other	24	7	5	6	120	144
Total	29	-	-	-	148	176

[1] 182 ft of drilling in V-cut round; 203 ft in burn-cut round.
[2] 74 lb of explosives in V-cut round; 80 lb in burn-cut round.

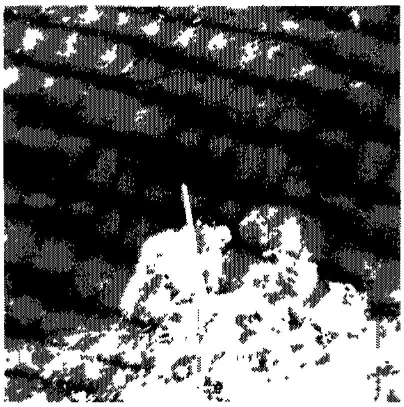
EXPERIMENTAL PROCEDURE

The standard mining cycle of drilling, blasting, ventilating, barring down, and mucking was followed during the experiment. A three-man crew was used. Safety was stressed during all phases of the operation. Figure 5 illustrates the sequence of the experimental work.

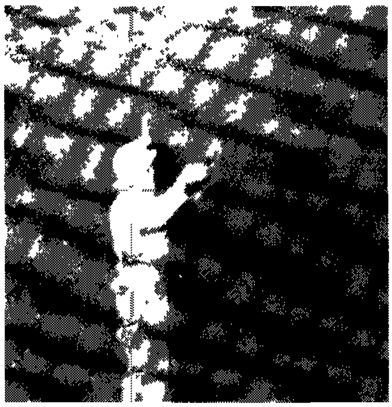
Drilling

Loading powder

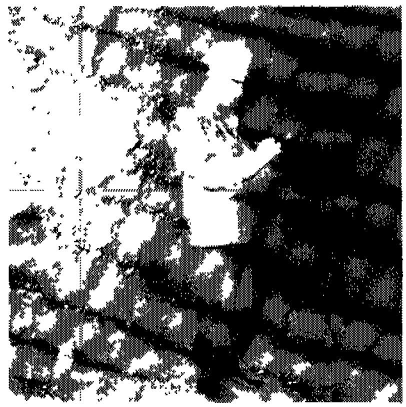
Firing



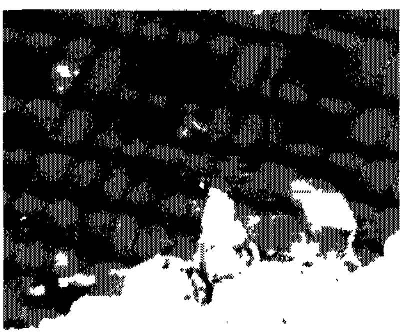
Muck pile



Barring down

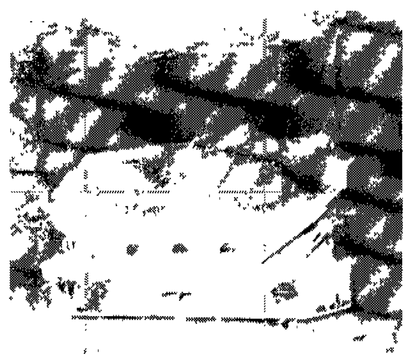


Recording results



Loading gravel

Clearing loader



Hauling

FIGURE 5. - Sequence of Experimental Work.

The blast rounds were drilled with an air-leg-mounted percussive drill using a 1-1/2-in-diam tungsten carbide bit. Although penetration rates ranged from 3 to 5 ft/min, the tendency of the drill cuttings to refreeze in the borehole behind the drill bit created difficulties in extracting the steel and slowed the drilling cycle markedly. To alleviate this problem, the drilling was done dry, and the drills were modified to supply a greater amount of air for cuttings removal. While drilling was in progress, all personnel in the tunnel were equipped with respirators for protection against dust. Further experiments were planned to test the feasibility of wet drilling with antifreeze.

The time required to drill out a round ranged from 1 hr 40 min to 4 hr 45 min with the average being slightly more than 3 hr. The drilling time per round was primarily a function of the degree of difficulty in steel extraction rather than of penetration rate. The softer upper gravels, with their higher water content, required a longer drilling time than the lower gravels, where penetration was slower but plug-ups were fewer. Because of wide variations in the hardness of the various components of the gravel, the blastholes meandered considerably and were quite ragged. Upon completion of the drilling, all the holes were cleaned pneumatically and checked for proper depth.

The equipment was then removed from the face and the proper amount of powder and caps was brought in. First a buffer cartridge of explosive was tamped in the bottom of each hole. Next a cartridge primed with the proper delay cap was loaded, but not tamped. Another buffer cartridge was then placed in the hole, and the rest of the cartridges were loaded and firmly tamped. No stemming was used. Utmost care was required in loading the 1-1/4-in cartridges into the ragged 1-1/2-in holes. Although 1-1/8-in cartridges would have been preferable, they were not available.

Before the shunts from the caps were removed, all electricity to the drift was disconnected to minimize the hazard of stray currents. The blaster tested each cap, connected the caps in a series circuit, tested the circuit, and connected the circuit to a leadline shunted at the surface. All personnel were removed from both the experimental drift and the CRREL silt tunnel, and all personnel on the surface were warned of the shot. The single entrance to the tunnel minimized the need for guards. The blaster removed the shunt from the leadline, tested the complete circuit, and after giving a loud vocal signal, fired the shot with a "push down" generator blasting machine. The ventilation system was turned on immediately after firing.

After a 30-min waiting period, the engineer in charge entered the drift to check for fumes and bad roof. The carbon monoxide and methane contents of the air at the face were measured. Upon authorization of the engineer in charge, the crew entered the drift, inspected the roof, and barred down all loose slabs. Although the roof of the tunnel was reasonably competent, slabs did occur all along the gravel portion as well as in the immediate area of the blast. This widespread slabbing was probably caused by sublimation of the ice in the gravel as a result of exposure to air and may have been enhanced by exposure to the hot gases produced by the shots. The roof had a tendency to form slabs at the silt-gravel contact.

Each shot was loaded with a Joy[3] model 8 BU gathering-arm loader, designed for use in coal, into an electrically powered, self-dumping, 9-yd shuttle car. Considerable difficulty was experienced when small quartz pebbles lodged between moving parts of the loader and stopped the machine. Time studies were taken of the loading cycle for each shot. Because of the relatively low moisture content in the gravel, muck piles left overnight before loading showed little tendency to refreeze. Refreezing had been a problem in the silt strata, where the moisture content was much higher.

RESULTS OF TEST SHOTS

After each shot the following five parameters were measured to describe the shot:

1. Length of advance.
2. Length of muck pile.
3. Number of large blocks.
4. Loading time.
5. Cleanup time spent while shuttle car waited for loading.

In addition, the degree of fragmentation of each muck pile was qualitatively described as fine, medium fine, medium, medium blocky, or blocky. Table 5 describes the eight test shots in detail.

The location of the face was measured before and after each shot to determine the length of advance. The length of the muck pile was determined after the shot by measuring the distance from the face to the point at which the floor was no longer completely covered by broken material.

Any piece of material which required secondary breakage before it could be handled by the loader was considered to be a large block. Except in shot 8, where secondary blasting was used on five particularly difficult blocks, secondary breakage was effected by pick or sledge hammer.

[3] Reference to specific trade names is made for identification only and does not imply endorsement by the Bureau of Mines.

TABLE 5. - Results of test shots

Type of cut, delay, and explosive	Advance, ft	Yards broken	Powder factor[1]	Swell factor[2]	Fragmentation	No. of large blocks	Length of muck pile, time	Loading time		Cleanup time with car waiting[3]	
								Min	Min/yd	Min	Min/yd
Burn cut:											
1/2-sec, dynamite	6.5	25.0	3.20	1.64	Medium fine..	2	45	55.75	2.23	0.58	0.023
1/2-sec, gelatin.	7.0	24.5	3.27	1.63	Fine.........	2	48	53.48	2.18	.62	.025
Msec, dynamite...	6.0	20.8	3.85	1.73	Medium fine..	1	55	42.40	2.04	6.20	.298
Msec, gelatin....	6.5	21.9	3.65	1.83	Medium blocky	5	77	50.93	2.33	7.45	.340
V-cut:											
1/2-sec, gelatin.	6.0	20.2	3.66	1.78	Medium blocky	7	51	57.42	2.84	8.08	.400
1/2-sec, dynamite	6.5	21.9	3.38	1.87	Medium.......	6	68	58.97	2.69	9.48	.433
Msec, gelatin....	6.0	23.5	3.15	1.87	Medium blocky	7	61	61.00	2.60	7.42	.316
Msec, dynamite...	6.5	24.4	3.03	1.84	Blocky.......	6	60	60.07	2.46	13.47	.552

[1] Pounds of explosive per cubic yard of rock in place. Average = 3.38.
[2] Yards of broken material hauled per yard of in-place material excavated. Average = 1.77.
[3] Time shuttle car spent waiting to be loaded while cleanup was taking place.

A time study was taken during the mucking of each shot. The time required to perform the various functions in the loading cycle is affected by the operator's ability and efficiency, the condition of the equipment, maneuvering room at the face, the moisture content of the broken gravel, and other factors. However, the efficiency of the loading and cleanup portions of the mucking cycle depend primarily on the quality of the muck pile. Loading time can be defined as the amount of time spent loading each yard of gravel. This time is primarily dependent on the degree of fragmentation, but it is also affected by the amount of scatter and the shape of the muck pile, as well as by the factors previously mentioned. Cleanup time is the time required by the loader operator to clean up and face up the muck pile for efficient loading. The hauling was done with one shuttle car. With a favorable muck pile, the loader operator could do most of the required cleaning up and facing up while the shuttle car was hauling and dumping its load and returning to the face, and he sometimes had time between loads for extra work such as breaking oversized pieces or trimming the roof. With an excessively scattered muck pile, however, the time required for cleanup exceeded the shuttle car's travel time. The time the shuttle car spent at the face waiting to be loaded while the loader was still cleaning up was recorded as "cleanup time with car waiting." This time can be affected by all the factors mentioned above, but it is primarily a function of the scatter of the muck pile.

After the shot was loaded out, the advance, width, and height of the excavation were measured, and the powder factor for the shot was calculated in terms of pounds of explosive per cubic yard of rock in place. Imprecise hole alinement, which was to be expected using an air-leg drill in such an inhomogeneous material, caused variations in the cross section of the drift. This variation in cross section, along with occasional overbreak at the roof and different depths of advance per round, explains the wide range of powder factors seen in table 5. No analysis of powder factor was attempted.

A rough estimate of the amount of material hauled was made by using a factor of 9 yd for a well-loaded shuttle car. A 5-1/2-ft drift height in parts of the silt zone prevented heaping of the shuttle car. The average swell factor of 1.77 yd of broken material hauled per yard of in-place material excavated agrees well with the 1.8 swell factor obtained by Swinzow (7) at Tuto, Greenland. Because the calculated swell factors were rough approximations, no analysis was attempted.

It was noted during the tests that the half-second delays produced much less air blast than the millisecond delays, although this difference was not measured. Shots 6 and 8 were particularly violent. The burn-cut pattern was much easier to drill than the V-cut, an advantage particularly important with inexperienced drillers.

DATA ANALYSIS

A nonreplicated 2 x 2 x 2 factorial experiment permits an analysis of variance of the main effects but does not give sufficient degrees of freedom for checking interactions among them. It is common practice in nonreplicated experiments such as this to use the interaction mean squares to give an estimate of the error variance (2). An analysis of variance was made, using the data in table 5, to determine the effects of type of cut, type of delay, and type of explosive on the number of large blocks, loading time, cleanup time, feet of advance, and length of muck pile. The results are shown in table 6. The mean squares of the individual interactions are included so that they can be compared in magnitude with the mean squares of the main effects, although in the analysis the interaction mean squares are combined to give an estimate of the error variance.

TABLE 6. - Analysis of variance of main effects

	Average	Sum of squares	Degree of freedom	Mean square	F ratio	Significant difference?
NUMBER OF LARGE BLOCKS						
Cut:						
"V"	6.5	32.00	1	32.00	25.6	Yes (99 pct)
Burn	2.5	-	-	-	-	-
Delay:						
Msec	4.75	.50	1	.50	.40	No
1/2-sec	4.25	-	-	-	-	-
Explosive:						
Dynamite	3.75	4.50	1	4.50	3.60	Yes (75 pct)
Gelatin	5.25	-	-	-	-	-
Cut-delay interaction	-	.50	1	.50	-	-
Cut-explosive interaction	-	.50	1	.50	-	-
Delay-explosive interaction	-	2.00	1	2.00	-	-
Cut-delay-explosive interaction	-	2.00	1	2.00	-	-
Total error	-	5.00	4	1.25	-	-
LOADING TIME, MIN/YD						
Cut:						
"V"	2.65	0.409	1	0.409	30.9	Yes (99 pct)
Burn	2.20	-	-	-	-	-
Delay:						
Msec	2.36	.032	1	.032	2.42	Yes (75 pct)
1/2-sec	2.49	-	-	-	-	-
Explosive:						
Dynamite	2.36	.035	1	.035	2.64	Yes (75 pct)
Gelatin	2.49	-	-	-	-	-
Cut-delay interaction	-	.024	1	.024	-	-
Cut-explosive interaction	-	.001	1	.001	-	-
Delay-explosive interaction	-	.014	1	.014	-	-
Cut-delay-explosive interaction	-	.014	1	.014	-	-
Total error	-	.053	4	.01325	-	-
CLEANUP TIME WITH CAR WAITING, MIN/YD						
Cut:						
"V"	0.425	0.1288	1	0.1288	8.39	Yes (95 pct)
Burn	.172	-	-	-	-	-
Delay:						
Msec	.377	.0488	1	.0488	3.18	Yes (75 pct)
1/2-sec	.220	-	-	-	-	-
Explosive:						
Dynamite	.327	.0063	1	.0063	.41	No
Gelatin	.270	-	-	-	-	-
Cut-delay interaction	-	.0385	1	.0385	-	-
Cut-explosive interaction	-	.0122	1	.0122	-	-
Delay-explosive interaction	-	.0033	1	.0033	-	-
Cut-delay-explosive interaction	-	.0074	1	.0074	-	-
Total error	-	.0614	4	.01535	-	-

TABLE 6. - Analysis of variance of main effects--Continued

	Average	Sum of squares	Degree of freedom	Mean square	F ratio	Significant difference?
LENGTH OF ADVANCE, FT						
Cut:						
"V"	6.25	0.125	1	0.125	0.80	No
Burn	6.50	-	-	-	-	-
Delay:						
Msec	6.25	.125	1	.125	.80	No
1/2-sec	6.50	-	-	-	-	-
Explosive:						
Dynamite	6.375	0	1	0	0	No
Gelatin	6.375	-	-	-	-	-
Cut-delay interaction	-	.125	1	.125	-	-
Cut-explosive interaction	-	.500	1	.500	-	-
Delay-explosive interaction	-	0	1	0	-	-
Cut-delay-explosive interaction	-	0	1	0	-	-
Total error	-	.625	4	.15625	-	-
LENGTH OF MUCK PILE, FT						
Cut:						
"V"	60.00	28.125	1	28.125	0.20	No
Burn	56.25	-	-	-	-	-
Delay:						
Msec	63.25	210.125	1	210.125	1.52	No
1/2-sec	53.00	-	-	-	-	-
Explosive:						
Dynamite	57.00	10.125	1	10.125	.07	No
Gelatin	59.25	-	-	-	-	-
Cut-delay interaction	-	171.125	1	171.125	-	-
Cut-explosive interaction	-	210.125	1	210.125	-	-
Delay-explosive interaction	-	171.125	1	171.125	-	-
Cut-delay-explosive interaction	-	.125	1	.125	-	-
Total error	-	552.500	4	138.125	-	-

Instead of testing the main effects for significance at a single level, they were tested at three levels: 99, 95, and 75 percent. Significance at the 99-percent level may be regarded as very strong evidence that one parameter produces better results than another, while a significance at 95 percent is fairly strong evidence. Although a 75-percent significance is not a highly conclusive result, it suggests a trend and may be helpful in making decisions in the absence of further information. Values of $F(1,4)$ which indicate significance at the 99-, 95-, and 75-percent levels are 21.2, 7.71, and 1.81, respectively.

Number of Large Blocks

The number of large blocks requiring secondary breakage before they could be handled by the loader varied from one to seven per round. Table 6 shows the burn cut to be superior to the V-cut in producing fewer large blocks. Apparently the "busters" drilled within the V-cuts did not efficiently break up the large blocks formed in that zone. The extra dynamite produced somewhat fewer large blocks than the gelatin, probably because a greater number of sticks of dynamite were used per hole, but this difference was not highly significant. The type of delay had little effect on the number of blocks formed. The mean squares of the interactions appear to be insignificant.

Loading Time

Loading time is the best measure of the effectiveness of a blast because, more than any other single factor, it determines the rate of production in a mine and, in turn, the cost per unit mined. Table 5 shows that the burn cut consistently outperformed the V-cut on the basis of loading time, and this superiority is borne out by the significance at the 99-percent level shown in table 6. Although the millisecond delays and the extra dynamite performed somewhat better than the half-second delays and special gelatin based on loading time, the differences were significant only at the 75-percent level. Of the interaction mean squares, only the cut-delay combination shows any indication of significance, and this would be at a very low level.

Cleanup Time With Car Waiting

The importance of the amount of cleanup time required in the mucking cycle depends on the availability of auxiliary cleanup equipment. At the experimental site it was very important because all cleanup work was done with the loading machine. On the basis of cleanup the burn cut was again superior to the V-cut. As might be expected, shots fired with half-second delays required less cleanup time than those using millisecond delays, with the significance at the 75-percent level. The type of explosive had little effect on cleanup time. The cut-delay interaction mean square indicates possible significance. Table 5 shows that the combination of a burn cut and half-second delays gives the lowest cleanup times.

Length of Advance

The advance per round, which is extremely important in drift mining, was measured to the nearest half foot. Although none of the main effects significantly affected the amount of advance, the cut-explosive mean square indicates a possible interaction between these factors. The longest drill steel available during the experiment was 7-1/2 ft. If deeper holes could have been drilled, more significant differences in length of advance might have been obtained.

Length of Muck Pile

The length of muck pile was used as a measure of throw, although in retrospect, a profile of the muck pile would have been a better tool in predicting the efficiency of the loading operation. Although there was little difference in the total muck pile lengths produced by the burn cut and the V-cut, the V-cut threw more rock large distances from the face, which is borne out by the "cleanup time with car waiting" figures. The millisecond delays gave longer muck piles than the half-second delays, but because of the large amount of the scatter in these data, the difference was not significant. Type of explosive had no effect on muck pile length. The experimental error was distributed fairly uniformly among the interactions.

Degree of Fragmentation

To obtain a good estimate of the degree of fragmentation in a muck pile, a screen analysis should be run on a sizable portion of the material. Because of the time and cost involved, this procedure is impractical except for very small shots. The fragmentation in each shot in the test series was therefore estimated qualitatively. Table 5 shows that the burn cuts and slow delays produced somewhat finer fragmentation than the V-cuts and the millisecond delays. The type of explosive had no apparent effect on fragmentation.

CONCLUSIONS

The burn cut produced better overall fragmentation and fewer blocks requiring secondary breakage than the V-cut. The burn cut also performed better from the standpoint of loading time and cleanup time. The type of cut did not affect the length of advance or length of muck pile.

The shots using half-second delays required less cleanup time than those using millisecond delays, but the millisecond-delayed shots required less loading time. Both differences were at a low (75-percent) level of significance. Based on combined loading and cleanup time there is practically no difference between delays. The half-second delays produced somewhat finer overall fragmentation than millisecond delays, but there was no significant difference in the number of blocks requiring secondary breakage. The half-second delays tended to give a shorter muck pile, but this difference was not quite significant. Type of delay had no effect on the length of advance.

The dynamite produced fewer blocks requiring secondary breakage than the special gelatin, but the overall fragmentation was about the same. The dynamite shots required somewhat less loading time, but when loading time and cleanup time are combined, there is very little difference between explosives. The type of explosive had no effect on the length of advance or length of muck pile.

The blasting program for the remainder of the excavation at Fox was based on these experimental results. The burn cut was used with half-second delays, although further testing would have been required to definitely establish the superiority of half-second delays. Both of the explosives tested proved satisfactory.

Much of the scatter in the results of the experiment can be attributed to the inhomogeneous nature of the frozen gravel and the difficulty in drilling a precise blast round with an air-leg drill. Any inhomogeneous, conglomeritic rock would probably yield similar results. Shots fired in a more competent, homogeneous rock might give different and more consistent results.

The tests demonstrated the feasibility of using a factorial experiment in a production setting as an aid in designing underground blasts. Properly designed tests will not seriously affect the rate of production in a drift. Other parameters which could be evaluated in a test of this type are hole diameter, hole spacing and burden, stemming, powder distribution (use of spacers), primer location, number of primers, and delay pattern, to name a few.

REFERENCES

1. Abel, John F. Permafrost Tunnel, Camp Tuto, Greenland. U.S. Army Corps of Engineers Snow, Ice, and Permafrost Res. Establishment Tech. Rept. 73, 1969, 19 pp.

2. Davies, Owen L. Design and Analysis of Industrial Experiments. Hafner Publishing Co., New York, 2d ed., 1967, p. 265.

3. McCoy, John E. Use of Mechanical System To Tunnel in Permafrost. U.S. Army Cold Regions Res. and Eng. Lab. Tech. Note, 1964, 53 pp.

4. Rausch, Donald O. Ice Tunnel, Tuto Area, Greenland. U.S. Army Cold Regions Res. and Eng. Lab. Tech. Rept. 44, 1958, 36 pp.

5. Sellman, Paul. Geology of the USA CRREL Permafrost Tunnel, Fairbanks, Alaska. U.S. Army Cold Regions Res. and Eng. Lab. Tech. Rept. 199, 1967, 26 pp.

6. Swinzow, George K. The Alaska Permafrost Tunnel. U.S. Army Cold Regions Res. and Eng. Lab. Tech. Note, 1967, 70 pp.

7. _____. Tunneling and Subsurface Installations in Permafrost. Paper in Proceedings, Internat. Conf. Permafrost, November 11-15, 1963, Nat. Acad. Sci. Nat. Res. Council Pub. 1287, 1966, pp. 519-526.

8. _____. Tunneling in Permafrost II. U.S. Army Cold Regions Res. and Eng. Lab. Tech. Rept. 91, 1964, 18 pp.

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