J. Kor. Inst. Mining Geol.
Vol. 5, No. 4 (1972) p. 187~210

Dynamical Study on the Blasting with One-Free-Face to Utilize AN-FO Explosives

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Contents

Abstract

Drilling position is one of the most important factors affecting on the blasting effects. There has been many reports on several blasting factors of burn-cut by Messrs. Brown[1] and Cook,[2] but in this study the author tried to compare drilling positions of burn-cut to pyramid-cut, and also to correlate burn-cut effects of drilling patterns, not being dealt by Prof. Ito in his theory,[3] which emphasized on dynamical stress analysis between explosion and free face.

According to former theories,[4] there break out additional tensile stress reflected at the free face supplemented to primary compressive stress on the blasting with one-free-face. But with these experimented new drilling patterns of burn-cut, more free faces and nearer distance of each drilling holes make blasting effects greater than any other methods.

To promote the above explosive effect rationary, it has to be considered two important categories under-mentioned.

First, unloaded hole in the key holes should be drilled in wider diameter possibly so that it breaks out greater stress relief.

Second, key holes possibly should have closer distances each other to result clean blasting.

These two important factors derived from experiments with, theories of that the larger the dia. of the unloaded hole, it can be allow ed wider secondary free faces and closes distances of each holes make more developed stress relief, between loaded and unloaded holes.

It was suggested that most ideal distance[5] between holes is about 4 clearance in U. S. A., but the author, according to the experiments, it results that the less distance allow, the more effective blasting with increased broken rock volume and longer drifted length can be accomplished.

Developed large hole burn-cut method aimed to increase drifting length technically under the above considerations, and progressive success resulted to achieve maximum 7 blasting cycles per day with 3. 1m drifting length per cycle. This achievement originated high-speed-drifting works,

and it was also proven that application of Metallic AN-FO on large hole burn-cut method overcomes resistance of one-free-face.

AN-FO which was favored with low price and safety handling is the mixture of the fertilizer or industrial Ammonium-Nitrate and fuel oil, and it is also experienced that it shows insensible property before the initiation, but once it is initiated by the booster, it has equal explosive power of Ammonium Nitrate Explosives (ANE). There was many reports about AN-FO.

On AN-FO mixing ratio, according to these experiments, prowdered AN-FO, 93.5 : 6.5 and prilled AN-FO 94 : 6, are the best ratios. Detonation, shock, and friction sensities are all more insensitive than any other explosives. Residual gas is not toxic, too. On initation and propagation of the detonation test, prilled AN-FO is more effective than powered AN-FO. AN-FO has the best explosion power at 7 days elapsed after it has mixed.

While AN-FO was used at open pit in past years prior to other conditions, the author developed new improved explosives, Metallic AN-FO and Underwater explosive, based on the experiments of these fundmental characteristics by study on its usage utilizing AN-FO. Metallic AN-FO is the mixture of AN-FO and Al, Fe-Si powder, and Underwater explosive is made from usual explosive and AN-FO. The explanations about them are described in the other paper.

In this study, it is confirmed that the blasting effects of utilizing AN-FO explosives are very good.

1. INTRODUCTION

About 20 years elapsed since 1953, when initial studies and experiments on burn cut method are started and ten years AN-FO has been practically utilized in the field of blasting. During the time, burn-cut method has been impoved to large hole burn-cut method to enable high-speed-drifting by shortening the blasting cycles. In another hand, about the compositions of AN-FO, there developed to Al-slurry and Underwater explosive finally. They are now promoted to popularize those explosives expanding from technical studies.

Through the long experiences and researches at Dalsung, Sangdong, Seeheung, Kyungin mine, Jangsung, Hambaik colliery, the Han River sand beach and East Coast Research, it has been estabished unique blasting technology based on theoretical system. On this point, author's opinion is that the explosives must be used on proper objects effectively with best control of energy.

The origin of AN-FO was "Akremite" invented by Lee[(7)] and Akre, 1954, U. S. A. Chemical decomposition of the main component, Amonium Nitrate, is considered as following equations.

$$NH_4NO_3 \rightarrow N_2O + 2H_2O \quad \cdots\cdots (1)$$

This is also decomposed safely under 200—260 °C heating.

$$2NH_4NO_3 \rightarrow 2N_2 + 4H_2O + O_2 \quad \cdots\cdots (2)$$

This decomposition takes place with great rapidity and violence affecting on the influence of extreme heating under confinement, only through initiation by a powerful priming explosive charge. Therefore, Ammonium Nitrate is so insensitive that it cannot be used alone as an explosive. Ammonium Nitrate involves exess oxygen after exploded so that it will be mixed with combustible material as like fuel oil. Next explosion occurs by the initiating impact under the high pressure and temperature.

$$3NH_4NO_3 + CH_2 \rightarrow 3N_2 + 7H_2O + CO_2 + 82kcal/mol \quad \cdots\cdots (3)$$

Like the above equation, AN-FO which theoritically contains 5.51% of fuel oil and it exploded evolves more explosion heat compared with Ammonium Nitrate alone. With addition of fuel oil, gas volume. explosion pressure and sensitivity are greatly improved. Since prilled Ammonium Nitrate gives greater explosion power mixed with fuel oil, it has increased effect on initiated surface and the velocity of detonation which is 15 to 20% higher than any others. It was found that prilled Ammonium Nitrate, although weighing 18% less than to powdered or granulated Ammonium Nitrate, the other types of nitrate, equals blast performance. In fact, blasting effect of Ammonium Nitrate is depended by the particle size, density, confinement degree and charged booster.

And if metallic materials are added to AN-FO, or proper quantity of water is poured into ANFO, gas expansion, detonation velocity and explosion temperature are improved largely.

AN-FO included primer fired within a borehole is capable of doing works as following two ways; ① force of the expanding gase mixture ② the strain wave which is propagated into the rock by the initial pressure pulse. These are related with detonation velocity. If the amplitude of this compressive wave exceeds the compressive strength of the rock, then there will exist a crushed zone around the shot hole. As the wave passes into the elastic solid it will form longitudinal and transverse waves. The longitudinal waves are frequently called push or compression waves because their impact motion to the particles in their path which is in the same direction as the wave propagation. The transverse waves are known as shear waves because their impact motion perpendiular to the path of the waves advance.

Burn-cut method was developed at St. [(8)] Joe, in U. S. A. and was successfully practiced for many years in all parts of the world in tunneling and drifting. For the purpose of furnishing stress relief when the loaded holes are fired, one or more unloaded holes are drilled parallel with loaded holes.

This theory of which more free faces are proved that compressive and shearing action can be done easily, and effectively. In early years designs of burn-cut holes had been presented by Steidle, [(9)] and then about AN-FO explosive there was many reports by Okubo, Yamakuchi, [(10)] M. A. Cook. As shown previous paragraph, the author paid attention to another respects of AN-FO. and did several fundamental tests, experiments, developments of new explosives utilized AN-FO, and compared blasting effect with many other explosives and drillings. At last dynanical analysis of rock breakage between the free face and centre of explosion was dealt.

2. CHARACTERISTIC EXPERIMENT

2-1. Material Samples

(1) Powdered Ammonium Nitrate;

Mitsubishi Chemical Co, Japan, industrial grade, moisture content is 0.24%. Absorbed oil ratio is 9.04g/100g, and color is white.

(2) Granular Type Ammonium Nitrate;

Sumitomo Chemical Co., Japan, industrial grade, contained moisture is 0.15%, and color is white.

Table 1. Particle size distributions of Ammonium Nitrate (AN)

Powdered AN		Granular AN		Prilled AN	
Mesh	Weight %	Mesh	Weight %	Mesh	Weight %
+35	3.19	+6	0	+6	0
−35+42	2.18	−6+7	0.15	−6+7	0.12
		−7+9	8.65	−7+9	12.41
−42+48	12.91	−9+12	30.15	−9+12	25.57
−48+60	11.58	−12+14	55.33	−12+14	42.95
−60+80	58.27	−14+16	3.05	−14+16	3.30
−80+100	5.33	−16+24	1.87	−16+24	3.87
−100	8.76	−24+35	0.73	−24+35	5.45
		−35	0.06	−35	6.09

(3) Prilled Ammonium Nitrate;

Sumitomo Chemical Co., Japan, industrial grade, moisture content is 0.23%, apparent specific gravity is 0.88, color is white, shape is porous. And absorbed oil ratio is 8.87g/100g. Particle size distributions of these Ammonium Nitrate are shown on Table 1.

(4) Fuel Oil;

Domestic Diesel Oil, Korea oil Co. Product. Its specific ations are as follows.

Table 2. Specification of fuel oil Distillation

Article	S.P.G	Cctane Value	Distillate	Distillation End Point	Fluidable Point	Viscosity (Sec.)	Sulfur %
Characteristic Value	0.83/15°C	55	90% at 357°C	385°C	−17°C	43	1.0

Colouring Material; reddish, soluable with oil

(5) Booster; Korea Explosives Co., Gelatine Dynamite with No.8 and No.6 electric detonator.

(6) Explosives for comparing

New Ammonium Nitrate Explosive, No.2 (Asai Chemical Co. Product, Japan)

a) Ingredient

Amonium Nitrate	77.5%
Dinitro Naphthalene	7.0%
Strach Powder	2.0%
Wood Powder	1.5%
Salt	12.0%
Moisture	0.63%

b) Characteristic Value

Trauzle lead block test	290–310cc
Ballistic Pendulem test	68–73mm
Detonation velocity	4500–5500m/s
Explosion temperature	2230°C
Sympathic Detonation	3–4
Specific gravity	1.0
Limiting point of Explosion	40–50cm/10kg
Degree of Safety (Oxygen Balance)	400g/100g
Heat of Explosion	790kcal/kg

2-2. Material Mixing Ratio of AN-FO

Mixing ratios of Ammonium Nitrate and oil are 94.5 : 5.5, 94 : 6 and 93.5 : 6.5. Ammonium Nitrate is dyed by colouring agent and mixed with oil by Ball Mill. Mixing time is about 30 minutes. The best mixing ratios were compared by its detonation velocity. Dautriche Chronograph is used for measurement of detonation velocity. The experiment results are as follow.

Table 3. Detonation velocity v.s mixing ratio

Article		Mixing ratio	Charged Density	Amount of Explosive (g)		Detonation Velocity (m/sec)
				ANFO	Booster	
Powdered AN		94.5 : 5.5 94 : 6 93.5 : 6.5	1.03	218	30	3340 3190 3430
Granular AN		94 : 6	0.98	205 145	145 90	Unexplosion 1570
Pcwdered and Granular mixture AN (1 : 1)		94 : 6		260 230 200	30 60 90	Unexplosion 〃 〃
Prilled	Mixed by Wagmer type	94.5 : 5.5 94 : 6 93.5 : 6.5	0.99	208	30	2870 3040 2910

AN	Mixed by the Ball Mill without balls	94.5 : 5.5 94 : 6 93.5 : 6.5	0.92	190	30	2420 2410 2460

The detonaton velocity of poweered AN is quicker than that of prilled AN from the result. The detonation velocity of powdered AN becomes quicker in order of 94 : 6, 94.5 : 5.5, 93.5 : 6.5. Prilled AN is the best result at 94 : 6. The report by Prof. Yamaguchi and Sidamura also insist that 94 : 6 prilled AN-FO has the quickest detonation velocity. Fuel oil added to Ammonium Nitrate increases gas volume and explosion pressure increases when AN-FO is exploded. Ammonium Nitrate alone makes 350cal/g heat. But 6% oil contained AN-FO makes 900cal/g heat. Prilled Ammonium Nitrate has a large surface compare any others to be initated and its property has a force of oil absorption. Prilled Ammonium Nitrate absorbes only adequate amount of oil fortunately, and coating on the prill surface is the important thing. When Ammonium Nitrate contained oil, its explosion sensitivity increases and its blasting energy also increases.

2-3. Shock Sensitivity Test

Drop Hammer Sensitivity Tester was used and of which hammer weight is 10kg. Steel column is ϕ12.7×12.5mm. Shock hardness is 65°. Samples were mixed before 3–4 hours by Wagmer and put into the decicater. Next, Samples are packed with aluminum paper (ϕ12.7mm), each weight is 0.1g. The characteristic eyperimental results of their samples were as follow.

Table4. Shock Sensitivity(exploded/numbers of test)

Fall height (cm)	Powdered AN-FO	Granular AN-FO	Prilled AN-FO	Ammonium Nitrate Explosive (ANE)
15				0/10
20				1/10
30				8/10
45	0/10			
50	0.3/10 (1/30)	0/10		
55	0.8/10 (2/26)	0/20		
60	1.5/10 (5/34)	1/10	1/10	
75	3/10	1/10	1/10	
70	3/10		1/10	

As shown table 4, we can see that powdered AN-FO is more sensitive than Prill, and AN-FO is more insensitive than ANE. This discrepancy, derived from its initiation mechanisms, which are different feom each other. In the other hand, prilled AN-FO is also sensitive by heat. Ignition point of Prilled AN-FO is 385°C, and that of powdered AN-FO is 410°C.

2-4. Friction Sensitivity Test

Bam Standard Friction Sensitivity Tester was used. Sample (0.05g) is put on the friction plate and added load of pendulum and operated by electric power. Table 5 is the result. The room temperature is 19°C. And maximum load is 36kg.

Table5. Friction Sensitivity Test

	Friction Load (kg)	Reaction of Smoke		reaction
		Immediately after friction	At 8–10 sec. after friction	
Powdered ANFO	36	6	—	—
	10.8	—	4	2
	9.6	—	—	6
Drilled ANFO	36	6	—	—
	11.2	—	2	4
	9.6	—	—	6
ANE	36	6	—	—
	12.8	—	4	2
	11.2	—	—	6

The figures on the table indicate nutmbers of test. Both of the two agents are very insensitive.

2-5. Detonation Velocity Changes along the Time Elapse

This test is done to seek the relation between the detonation velocity along the elapse time. Dautriche Chrongraph is used for the measurement. Sample is mixed with 94 : 6, and packed in vinylon case to protect moisture. The measurements are taken at 3-4 hours, 4, 7, 9, 11, 16, 23 and 20 days after manufactured. The charged densities are constant and prill is 0.915, powder is 1.0. The averages of the three times test results are shown as follows.

Table 6. Detonation Velocity and Time Elapse

Sample \ Elapse time	Detonation Velocity (m/sec)								
	3-hr	2days	4	7	9	11	16	23	30days
Prilled AN-FO	2360	2590	2630	2420	2540	2640	2410	2380	2440
Powdered AN-FO	3240	3230	3390	3550	3490	3280	3250	3140	3170

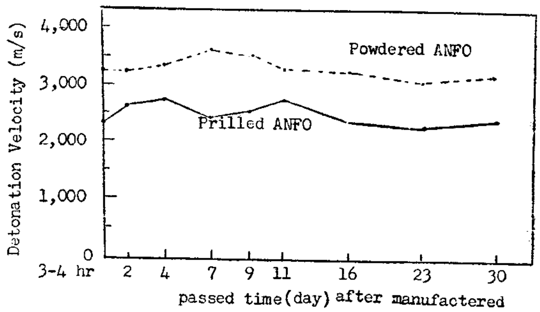


Fig. 1. Detonation Velocity and Time Elapse

As shown in Fig. 1. both of powdered and prilled AN-FO are not almost changed its detonation velocity. But after 7 days powdered AN-FO has the quickest detonation velocity and prilled AN-FO has it after 4 days and 11 days. As the time goes by, it is considered that fuel oil is stabilize to Ammonium Nitrate. This experiment was done during the dry season from Oct. 25 to Nov. 24. Report of Profs.[11] Ito and Wakazono also shows similar effect after 7 days.

2-6. Charged Density

This test is the measurement of influence of the detonation velocity by charged density. Sample is mixed with 94 : 6 and charged in the steel pipe. The measurement instrument is Dautriche Chrongraph. Prilled AN-FO was charged by the loader or hand. Domestic gelatine dynamite 30g was used for booster. The averages of three times measurements are as follows.

When powdered AN-FO is charged 0.95 density, its detonation velocity is higher than

Table 7. Charged density Test

Samples	Charged Density	Detonation Velocity (m/sec)	Loading Method
Powdered AN-FO	0.95 1.03	3260 3180	hands 〃
Prilled AN-FO (mixed by Ball Mill)	0.8 0.92 0.95	2340 2670 2630	loader hands 〃

that when it is 1.03. Prilled AN-FO of 0.9 is higher than that of 0.95. It is thought that prilled AN-FO due to the porosity is more resistable against detonation velocity.

By Dr. Ito Koichi,[12] since AN-FO has dead pressure phenomenon easily compared with formal powdered explosives, it had maximum velocity at ρ (1.0～1.11g/cm^3) and was undetonated at ρ (1.2～1.3g/cm^3) in the steel pipe. It is called channel effect that there is a phenomenon of dead pressure that AN-FO would be sometimes undetonated when AN-FO has been compressed by the shock wave through the clearance in the bore hole.

2-7. Initiation and Progration of the Detonation Test.

Initiation and propagation of the detonation was meassured using below materials. In the two steel gas pipe with same inner and outer diameter 27mm and 34mm respectively but with the different length 15cm and 50cm each other, detonaor and explosives were charged. Used kind of boosters were gelatine dynamite, composition B (TNT 40%, RDX 60%), Hexogen

(RDX), Pentrite with No. 6 electric detonator. As shown in Fig2. Fig3, after one edgeof steel pipe was put with rubber-plug, samples of explosive charged. Next, booster and cork-plug were settled at another edge. The degrees of complete explosion were examined with the fractured pieces of steel. As the prilled AN-FO was exploded completely by a No. 6 detonator, it was excluded from table. The experimented results

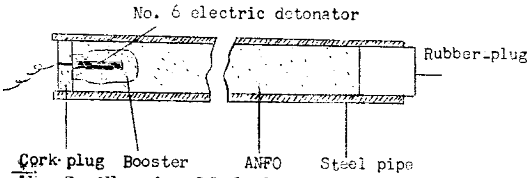


Fig. 2. Charging Method (Experimental No. 1-18)

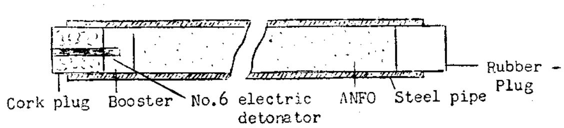


Fig. 3 Charging Method (Experimental No. 19, 20)

are as table8.

Prilld AN-FO is always detonated perfectly with only a No. 6 electric detonator. The initiation and propagation sensitivity of prilled AN-FO is better than powdered AN-FO. That sensitivity is very important role on blasting. Therefore, prilled AN-FO has an advantage of saving the amount of booster. In fact, AN-FO is influenced much by the amount and kinds of

Table 8. Initiation and Propagation of The Detonation Test

○: complete blast
△: incompletete blast

No.	Gelatine Dynamite			Composition B			RDX			PENT		type of AN	length of pipe	Remarks
	5g	7g	10g	3g	7g	10g	3g	10g	40g	3g	10g			
1					○									very large broken pieces
2					○							granular	15cm	〃
3					○									〃
4				○										small broken piece
5				○										〃
6	△											powder	〃	〃
7		△												〃
8	○													very large broken pieces
9				○										〃
10		○										granular	〃	〃
11	○													〃
12	△													38cm pipe remained
13			○											long and large broken pieces
14				△								〃	50cm	14cm pipe remained
15					○									large broken pieces.
16						△								10cm pipe remained
17							○							very large broken pieces
18										○		〃	15cm	〃
19								△				〃	〃	30cm pipe remained
20									△					27 〃 〃

booster. And generally if diameter of cartridge is increased, the detonation velocity is also increased, when AN-FO is used. About this relation, Otsuka[13] Otsuka and Miyakosi explained in their report.

2-8. Experiment of Critical Cartridge Diameter

In this experiment the four kinds of steel gas pipes of which inner diameters are 36.4mm, 28mm, 22mm and 17mm respectively and the sample of which mixing ratio of AN-FO is 94 : 6 were used. Charging method is the same with the previous paragraph, and its results are shown table 9.

Table 9. Critical Diameter Test

○: complete blast
△: incomplete blast

No.	Diameter (mm)	Thickness of the pipe(mm)	Gel. dy. booster(g)								No.6 electric cap	Amount of AN-FO charged(g)
			1	2	3	5	10	13	15	18		
1~4	36.4	2.8									○	454
5~8	28	2.8									○	265
9~12	22	2.4									○	166
13	17	2.1									○	99
14											△	
15											△	
16											△	
17	17	2.1	△									98
18				○								97
19												96
20				○								
21	36.4	2.8							△			465
22									△			463
23									△			
24									○			
25									○			
26										○		460
27	28	2.8			△							475
28						△						473
29						○						
30						○						
31	22	2.4			△							170
32						○						
33						○						
34						○						
35	17	2.1						△				102
36									○			101
37									△			
38										○		99

From the above tests we can see that critical diameter is 17mm. Practically minimum diameter of AN-FO cartridge is 25mm, but with 17 mm, small diameter, it can be exploded as a result of the test. With Prof. Sidamura's report, [14] the detonation velocity of AN-FO over 50mm of diameter is more than 4500/sec, and 21.6mm of diameter is 2800/sec, and 16mm of diameter does not exploded clearly.

2-9. Residual Gases After Blasting

The densities of gases were measured in tunnel after blasting with AN-FO. The measurements are done after both 5 minutes and 15 minutes without ventiliation. Used tester is Kitakawa Type Tester. The results are shown in table 10.

Table 10. Residual gases

kinds of gas	pre-blast	Post blast	
		5 minutes	15 minutes
CO_2	0.05%	0.4%	0.3%
CO	—	trace	0.005%
NO_2	—	—	0.0007%
NO	—	—	—

As shown in Table 10 the amount of produced harmful gases are less than those of Ammonium Nitrate Explosive. According to Prof. Danaka, (15) the amount of produced gases per ton of the usua explosives are CO: 2.6—75.0 ppm/kg, NO_2:0.8 6.6ppm/kg and CO_2:164–810 ppm/kg and CO_2:164–810 ppm/kg·While those of AN-FO are CO:1.1–5.45 ppm/kg, $NO_2$0–7.2ppm/kg and CO_2:22–614 ppm/kg.

2-10. Rock Blasting Experiment

This experiment was done at the open pit of Ssangyong Cement Co. purposing to compare blasting effect of powdered AN-FO and Ammonium Nitrate Explosive in limestone quarry. The mixing ratio of Ammonium Nitrate to fuel oil is 94 : 6, and they were charged in wooden box. The holes were drilled with diameters of 80mm and 40mm. Priming boosters were settled in the middle of the holes. In the 80mm hole, 5 catridges of gelatine dynamite were charged. AN-FO showed same results as Ammonium Nitrate explosive under table.

(See next page.)

3. BLASTING EXPERIMENTS AND D-RILLING PATTERNS

3—1. Burn-Cut Method

The general properties of AN-FO has become clear as a results of basic efficiency study. In advance of this, the practical blasting experiments were carried out for the purpose of improving blasting method end consideration on the dynamic breakage mechanism.

3–1–a) Experimented place and rock type

Sangdong Tungsten Mine, Kangwon-Do, Rock type is degenerated clay-slate stone.

3–1–b) Drilling machines

For the purpose of drilling rationalization on the burn-cut, new drills, made in U.S.A., such as R-48I, Ⅱ #R-38I, Ⅱ, #L M-47, JR-38 and 658-4W was used instead of S-49, made in Japan.

3–1–c) Determination of least resistance line

According to the equation of Daw's(16) shearing breakage theory,

$$Ca=\frac{nd}{2W(n+1)}$$

where, Ca; rock coefficient

d; diameter of hole

W; least resistance line

nd; the length of charged chamber

and explosive Shinkiri (112.5g), dia 32mm, was used and diameter of hole was 35mm.

Therefore, the relation between the least resistance line and the numbers of explosive cartridges become

$$W=\frac{nd^2}{2Ca\,(nd+d)}=\frac{nd}{2Ca\,(n+1)}$$

new next table will be obtained get by the above equation.

With the experiments which were carried out under those conditions, the least resistance line. W does not increase much in propotion to the numbers of explosive within the same hole. Burn-cut will be favorable not only in the rock whose coefficient is 0.02239 before, but also in the rocks which have various hardness and strengths.

3–1–d) Charging and ignition method.

The order of ignition is indicated with number in Fig. 8. The ignition, of course, is effective by using the electric detonator. The amount of charging is determined with the least resistance line indicated in figures. And determination of charging stages are shown by patterns in Fig. 5.6.7. The use of excessive explosives different from any other blasting may compact the open

Table 11. Results of Rock Blasting Experiment

Division / hole	Kind of explosives	Numbers of hole	Hole diameter (mm)	Length of hole (mm)	Priming booster	Least resistance line (m)	Clearance of holes (m)	Amount of explosive (g)	Amount of explosive per ton (g)
Large hole	AN-FO	3	80	830	Gel.dy. 1 ea	3	4	26,000	84.1
Small hole	ANE	23	40	480	–	1.5	1.5	1,800	76.3
	AN-FO	10	40	480	Gel. dy. 1 ea	1.5	1.5	1,900	76.3

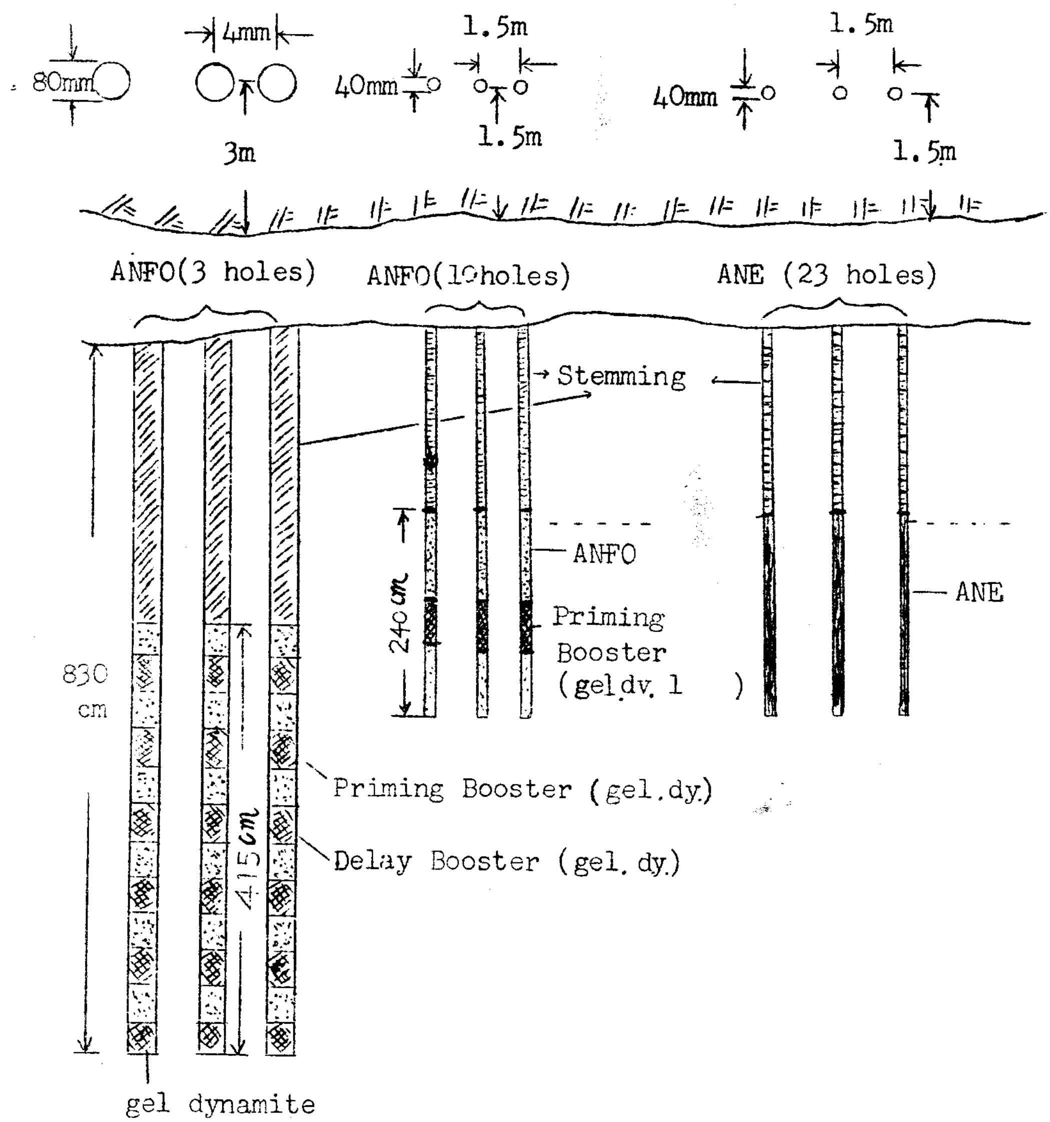


Fig. 4. Blasting experiment at open pit.

Table 12. Number of explosive cartridge and least resistance line (17)

at Ca=0.02239

division \ numbers	1	2	3	4	5	6	7	8
m (m/m)	75.2	150.49	225.69	300.93	376.16	451.39	526.62	601.86
nd	2.1d	4.3d	6.4d	8.6d	10.7d	12.8d	15.0d	17.1d
$\frac{n}{n+1}$	0.6824	0.8113	0.8648	0.8958	0.9145	0.9275	0.9375	0.9447
W (cm)	53.32	63.40	67.58	70.00	71.46	72.48	73.26	73.83

hole by the broken rocks. And safety fuse may be cut by the initial explosion. The use of safety fuse must be forbidden. Thus, M.S. delay electric detonator should be used for its safety and many initiating stages delayed.

3-1-e) Experimental Drilling Patterns

The distributions of drilling holes, which is deviced by the author, are drawn compared with old type, pyramid-cut. These drilling positions must be situated exactly because they affect precisely to the efficiency of the blasting. Various patterns of burn-cut have im portant roles on the amount of secondary reflected tensile stress by the unloaded holes. Reflected stress, in other word, stress relief is the ease with which the rock between the unloaded holes and the loaded. holes fails and expands freely into the unloaded holes. The following burn cut diagrams (Fig. 8, 9) are thought to be designed by the author at first in our country.

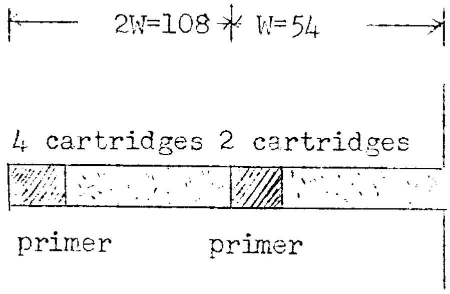


Fig. 5. Charging method of two stages in the key hole

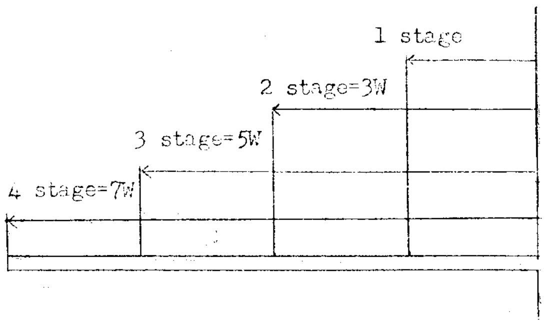


Fig. 6. Charging method of multiple stages in the key hole.

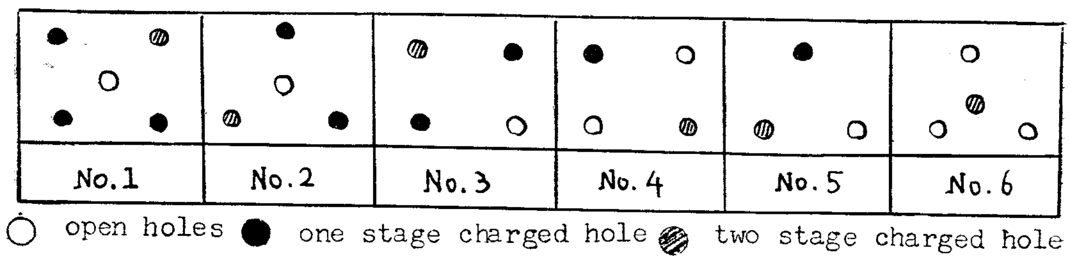


Fig. 7. Types of key holes

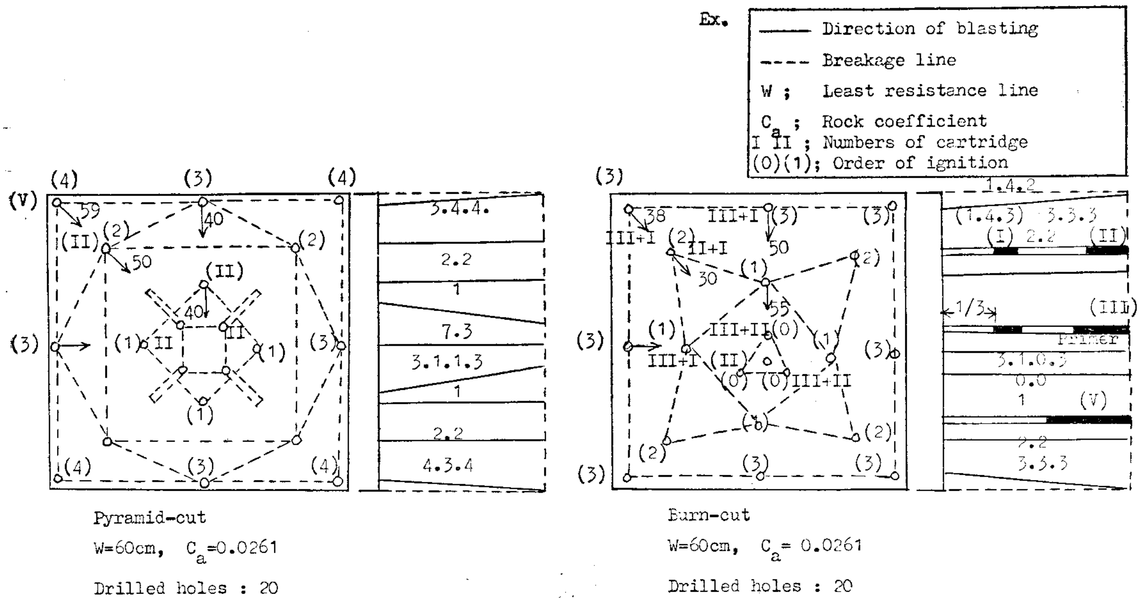


Fig. 8. Drilling Patterns of Improved Burn-Cut and Pyramid-Cut.

3-1-f) Results of experiment and studies

Two methods on the above experiments are compared to their operational efficiency as follow. (Table13)

Table. 13. Burn-cut and Pyramid-cut

Article / experiment No.	1		2		3		4	
condition	W=60cm Ca=0.02610		W=70cm Ca=0.02239		W=80cm Ca=0.01959		W=50cm Ca=0.01741	
blasting methed	Pyra-mid cut	burn-cut	Pyra-mid cut	burn-cut	Pyra-mid cut	burn-cut	Pyra-mid cut	burn-cut
Round per shift	2	4	2	3	1	2	1	1
Total working time (min)	780	1560	780	1170	370	780	390	390
The time of the standing machines (min)	30	30	30	30	30	30	30	30
The time of the retreating 〃 (min)	15	15	15	15	15	15	15	15
The time of odd jobs (min)	12	24	12	18	6	12	6	6
The other time consumed (min)	120	240	120	180	60	120	60	60
The time of movement drills (min)	92	92	64	69	55	60	50	50
Number of bore holes	20	20	14	16	12	13	11	11
The time of change the bits (min)	180	410	168	268	62	151	58	58
Number of bit	75	171	70	112	26	63	24	24
Bit numbers/m	6	6	4.2	4.2	3.1	3.1	2.1	2.1
Exact drilling time (min)	331	749	371	590	162	392	171	171
Drilling ratio (cm/min)	3.8	3.8	4.5	4.5	5.2	5.2	6.8	6.8
The total drilling length (m)	12.59	28.46	16.7	26.55	8.42	20.38	11.62	11.62
Drilling length/one bore hole (m)	0.63	1.42	1.19	1.66	0.70	1.57	1.06	1.06
Advanced length of drifting (m)	0.50	1.28	0.05	1.50	0.58	1.41	0.92	0.95
Advanced length drifting/shift (m)	0.25	0.320	0.525	0.5	0.58	0.705	0.580	0.95
Amount of mined ore (ton)	5.8	14.848	12.18	17.4	6.728	16.365	10.672	11.02
Amount of mined ore/shift (ton)	2.9	3.712	6.09	5.8	6,728	8.1825	10,672	11.02
Amount of mined ore man (ton)	1.45	1.856	3.045	2.9	3,364	4.089	5.336	5.51

Amount of used explosive (kg)	52	74	44	66	46	58	41	48
Amcunt of used explosive/ton (kg)	9	5	3. 61	3. 8	6. 8	3. 5	3. 8	4. 3
Amount of used water/shift (G/A)	15	17	20	21	20	24	28	28
Amount of used oil/shift (G/A)	0. 41	0. 4	0. 4	0. 4	0. 4	0. 4	0. 4	0. 4
Man/advanced length of drifting	8. 00	6. 25	3. 81	4	3. 45	2. 84	2. 17	2. 11
(man/ton)	0. 689	0. 539	0. 328	0. 345	0. 297	0. 245	0. 187	0. 181

Note; (1) excavated area: 2×2m (2) drilling machine: S–49
(3) working man: driller 1. assistant 1 (4) air pressure: 60 lbs/in²
(5) W is least resistance line when loaded Shinkiri Dy. 4 cartridges

According to the table 13, the advantages of new drilling patterns can be summarized as below;

(1) There is no necessity to drill with angle as like pyramid-cut.

(2) The speed of excavation is higher than the other. While the length of excavation is 0. 5m–0. 5mby the pyramid-cut, that of obtained by new blasting is 1. 0m–1. 5m (now 1. 5m–2. 3m). Therefore, the amount of mined ore by new blasting increases quitely.

(3) The expenses for the amount of explosive per ton and for the initiating materials are lower than those of pyramid-cut.

(4) The length of drilling in pyramid-cut has a close relationship with length of resistance line, but burn-cut hasn't.

(5) The damages of blast rocks are few because the scattering of blast rock pieces are few owing to the presence of keyhole.

(6) Pyramid-cut needs massive and more explosives to be charged at the bottom of the bore hole, but it has known in this experiment that charging should be uniformed all through the hole. The concentrated charging might make a partial preakage but it remains the other part.

3-2. **Large Hole Burn-Cut**

The burn-cut method was succeeded in increasing the excavation length per round from average 1. 5–2. 1m to 2. 3m. And improving the burn-cut, the author took the experiment of large hole burn-cut using the Taper Bit $2\frac{1}{4}$ ″. This is the basis of high speed excavation by both the rationalization of the working cycle and effective use of the machine.

3–2–1) Drilling method

With the new drilling method, large hole burn-cut has a small cut holes which are closed around the pilot hole. The diameter of the pilot hole is very large $2\frac{1}{4}$ ″. The drilling machines such as RH656–4W, BBD–50 and BBC–22 was used with the rod such as Seco or Capco Bit $7\frac{1}{8}$ ″ ×$3\frac{1}{4}$ ″, No. 1, No. 2, No. 3, No. 5 and extention rod. For the pilot hole, Capco or Seco $2\frac{1}{4}$ ″ Detachable Tapered Cross Bit was used here. For the remove of the rock powder, the pilot hole was drilled upward with the angle of 5 degrees at least. Next, the hole was drilled parallelly to the first hole after wood stock was put into the first hole. The cut holes around the pilot hole were designed under the condition that they were neighboring not being penetrated each other at the bottom of the holes.

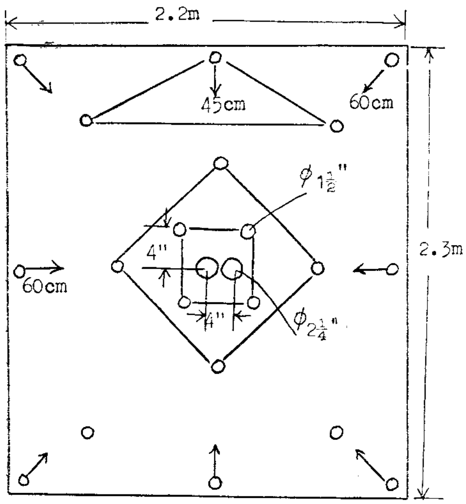
B–2. Charging explosives

The amount of charging explosives are generally same as burn-cut, but all the holes except the key holes are inserted pieces of wood in order to prolong the length of charging. As same with burn-cut priming booster is placed at the bottom of the hole. Among the key holes, cut (loaded) hole is charged with long Ammonium Nitrate Explosive cartridges or Metallic AN-FO with the aim to prolong the length of charged. The sintering phenonemenon, even though in the case of over charging, does not happen because distances between the cut holes are approached to a certain degree of not being penetrated.

3-2-c) Experimental drilling paterrns

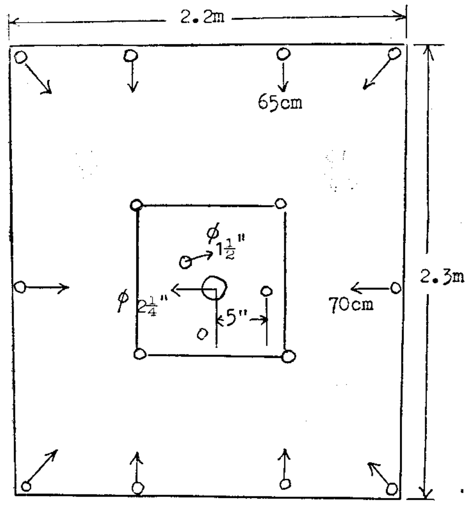
Execept the large pilot hole, all the other conditions are same with that of burn-cut.

The drilling patterns are as follow, Fig. 9.



Numbers of hole: 22

Least resistance line: 60cm



Numbers of hole: 18

Least resistance line: 70cm

Fig. 9. Drilling Patterns of Large Hole burn-Cut

3-2-d) Experimental results and studies

Their experimental results are Table 14.

Discussion of the above table,

1) Light heavy weight drilling machine is demanded, because it takes about 55 minutes to drill the pilot hole with the light weight drilling machines such as RH-656-4W.
2) After the pilot hole has been drilled, a little movement of cut-hole positions do not care. But this is the very different point from the Coromant-cut.
3) It is effective that the distance between pilot-hole and out-hole and out-hole are so close as to be penetrated.
4) Primary booster should be charged next to kicker. The kicker-overcharge is desirable for the complete blasting in the case of the long distances between the bottoms of the holes.
5) In the large hole burn cut, Metallic AN-FO explosives more effective than any other.
6) Simultaneous blasting of the laoded hole decrease the quantity of explossives and increase the blasting effect.

4. DYNAMICAL STUDY ON ROCK BREAKAGE MECHANISM

4-1. Theory of Rock Blast

The phenomenon of rock breakage with rock blasting was considered simply by the static stress of gas expansion, but recently, in addition to that, (18) the theory(19) of the dynamic stress which affects the breakage is risen.

4-1-a) Breakage in the neighbourhood of the centre of explosion

The pressure of explosion is suggested about tens of thousands of atmospheric pressure. The rock, which suffer from impulsive load of this extra-high pressures, becomes to have the property of fluid in the neighbourhood of the centre of explosion. As a result of an explosion,

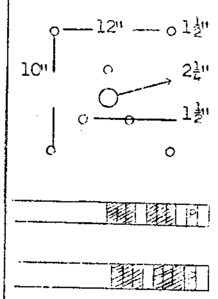
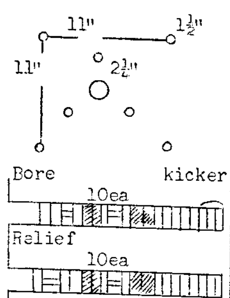
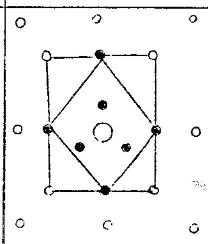
Date		July, 29, 1971	July, 30, 1971	July, 31, 1971
Place		lower 1 level 4 cross	lower 1 level 3 cross	lower 1 level 3 cross
Rock type		Clay-slate stone Ca=0.01741, R=80cm	Clay-slate Stone Ca=0.02239, R-70cm	Clay-slate Stone Ca=0.02239 R=70cm
Level size		Excavation 2.3 x 2.2m	Excavation 2.3 x 2.2m	Excavation 2.3 x 2.2m
Bore hole	Numbers of hole	18	22	20
	hole diameter (inch)	Pilot $2\frac{1}{4}$" Round $1\frac{1}{2}$"	Pilot $2\frac{1}{4}$", Round $1\frac{1}{2}$"	Pilot $2\frac{1}{4}$", Round $1\frac{1}{2}$"
	average depth of hole (m)	2.25	3.10	3.10
	distance of holes (cm)	10	10	10
	Charging density	0.85	0.8	0.8
Explo-sives	Amount of Charged explosive		Gel. Dy (12 / Metallic AN-FO 4) x 3 Gel. Dy (10 / Metallic AN-FO 4) x 4 17.1kg	Gel. Dy. (12 / Metallic AN-FO 4) x 3 Gel. Dy. (10 / Metallic AN-FO 4) x 4 Gel. Dy. (8 / Metallic AN-FO 4) x 13 Total · 29.25 kg
	numbers of priming booster	112.5 x 3 x 1	112.5 x 8 x 6	
	Length of cartridge		Gel. Dy: 12cm Metallic AN-FO : 18cm	Gel Dy: 12cm Metallic AN-FO : 18cm
	detonator	Domestic No.6	Domestic No.6	Domestic No.6
	Safety fuse	No.2 type	No.2 type	No.2 type
drills and bits		RH 656-4W No.3 Rod	RH 656-4W Capco No.4	RH 656-4W Tapered Bit $2\frac{1}{4}$"
result	drifting length	2.25	3.10	3.10
	results	good	good	good
The sketch of drilling * Rod diameter No.1 Rod : (40mm) No.2 Rod : (39mm) No.3 Rod : (38mm) No.4 Rod : (37mm)		 D : Priming Booster □ : Gel. Dy ▨ : ANFO	 No foot leg lumpore : 5' ⊟ Wooden spacer	 expension of explosives : 643g/t

Table 14. Experimental results of the large hole burn-cut at Sandong Mine

high degree of plastic fluid wave is produced and the temperature of exploded gases rises many thousands degrees Centigrades, so that rocks in the portion of blasting center are fused ranging a few mm's to tens of mm's radius. Thus, the produced dynamic stress is released accordingly and that temperature is decreased that rock masses are brocken to several particles.

In this portion of blasting center, the acted main stress is tensile stress to form radius directional fractures as temperature decrease gradually.

4-1-b) The breakage near the free face.

If we take polar-coordinates (r, θ, ϕ) which original points are coincided with the explosion centre and the main stress of ϕ direction is σ_3. Stresses acted on the γ_θ plane are σ_1 and σ_2, σ_1 acts as compressed stress and σ_2 or σ^3 acts as a tensile stress. On the least resistance line, σ_2 max equals to σ_3 max. Generally, on the free face and its neighbour, it shows σ_3 max$\geqq\sigma_2$ max, which means to occur radiative fractures by the infuence of σ_2.

4-1-c) Tensile breakage by the reflected shock wave

If the stress wave of explosion propagates through rock mass and reaches to free face with right angle, the stress wave form doesn't change only allow to become the direction of propagation reverse. While it reached with inclination a longitudinal and a transverse waves are formed, the wave propagates as a compressed wave first, and in case of reflection, it acts as a tensile wave. Therefore, if the acted stresses are greater than the compressed or tensile stress of rock mass, breakage will be occured. This phenomenon is illustrated as follow.

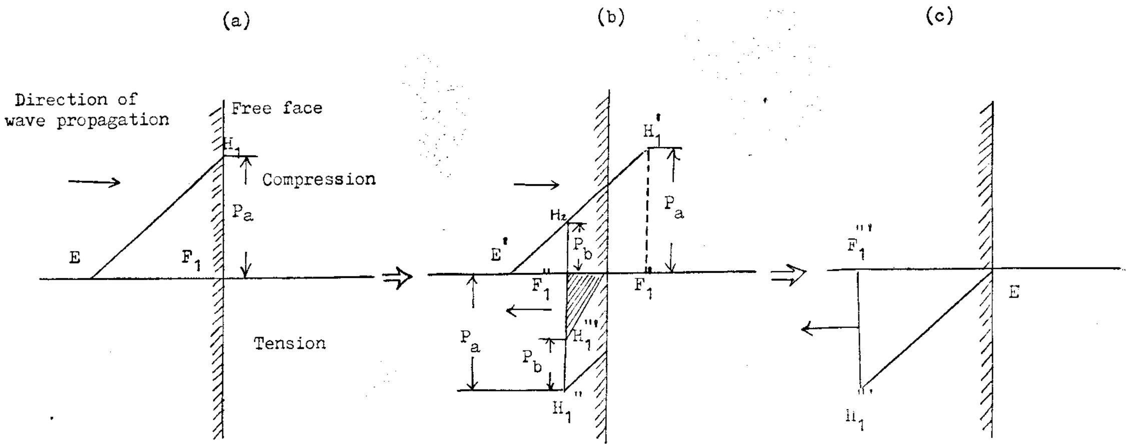


Fig. 10. Dynamics of spalling near the free face

Supposing that the wave has triangular form, the compressed wave reaches to free face with an amplitude of Pa like (a), then like (b), the head of shock wave will come to H_1' F_1', but by reflection of wave it come to $H_1''F_1''$. In this case, the compressed wave $F_1''H_2$ acts with the tensile wave $H_1''F_1''$ that the resultant shock wave becomes a tensile wave with an amplitude of $H_1'''F_1''$ (P_a-P_b). After this, the shock wave changes to tensile wave completely. The tensile stress which is produced by the above progress makes a flat breakage in the rock mass.

4-1-d) The breakage by the pressure of gas

According to Dr. Murata, [20] when the explosives burst in the spherical charged hole, the rock around the hole crushed to fine particles by the effect of shock, so that the area of hole is expanded. Within the hole, the gas which is produced by the explosion is sealed up that constant gas pressure which has no relation with time makes the rock broken.

The pattern of fractures near the explosion centre is radial direction and near the free face, the cracks band parallel with the face. This crater form of fracture patterns may be thought due to tensile main steess.

4-2. The Formulae of Stress in cases of One-Free-Face.

The dynamic and the static stresses of any points in the rock mass from the explosion origin are written as follow.

4-2-a) Dynamic stress

(I) If the rock is a perfect elastic body with density ρ, the strain and the stress of any point is formulized by the polar-coordinates as follow.

$$\left.\begin{aligned}
e_{\gamma\gamma} &= \frac{\partial U_r}{\partial r} \\
e_{\theta\theta} &= \frac{1}{r}\cdot\frac{\partial U_\theta}{\partial\theta}+\frac{U_\gamma}{\gamma} \\
e_{\phi\phi} &= \frac{1}{\gamma\sin\theta}\quad\frac{\partial U_\phi}{\partial\phi}+\frac{U_\theta}{\gamma}\quad\cot\theta+\frac{U_\gamma}{\gamma} \\
e_{\phi\theta} &= \frac{1}{\gamma}\left(\frac{\partial U\phi}{\partial\theta}-U\phi\cot\theta\right)+\frac{1}{\gamma\sin\theta}\cdot\frac{\partial U\theta}{\partial\phi} \\
e_{\phi\theta} &= \frac{1}{\gamma\sin\theta}\cdot\frac{\partial U_\gamma}{\partial\gamma}+\frac{\partial U_\gamma}{\partial\gamma}-\frac{U\phi}{\gamma} \\
e_{\gamma\theta} &= \frac{\partial U_\theta}{\partial\gamma}-\frac{U_\theta}{\gamma}+\frac{1}{\gamma}\cdot\frac{\partial U_r}{\partial\theta} \\
\widehat{\gamma\gamma} &= (\lambda+2\mu)\,e_{\gamma\gamma}+\lambda\,(e_{\theta\theta}+e_{\phi\phi}) \\
\widehat{\theta\theta} &= (\lambda+2\mu)\,e_{\theta\theta}+\lambda\,(e_{\phi\phi}+e_{\gamma\gamma}) \\
\widehat{\phi\phi} &= (\lambda+2\mu)\,e_{\phi\phi}+\lambda\,(e_{\gamma\gamma}+e_{\theta\theta}) \\
\widehat{\theta\phi} &= \mu e_{\phi\phi},\ \widehat{\phi\gamma}=\phi e_{\phi\gamma},\ \widehat{\gamma\theta}=\mu e_{\gamma\theta}
\end{aligned}\right\}\quad(1)$$

where U : displacement

$\widehat{\gamma\gamma}$, $\widehat{\theta\theta}$, etc : stress

$e_{\gamma\gamma}$, $e_{\theta\theta}$, etc : strain

γ : distance from the centre

λ, μ : Lame's constant

$$\mu=\frac{E}{2(1+\nu)}$$

$$\lambda=\frac{E}{2(1+\nu)(1-2\nu)}=\frac{\mu}{1-2\nu}$$

E : Young's modulus

ν : Poisson's ratio

(II) In case of one free face

In this case, the ways which shock shock waves reach to the arbitrary point A are summarized in the following three categories.

i) The longitudinal wave which progagates to A directly (I_p)

ii) The reflected longitudinal wave which reflected at the face (Rp)

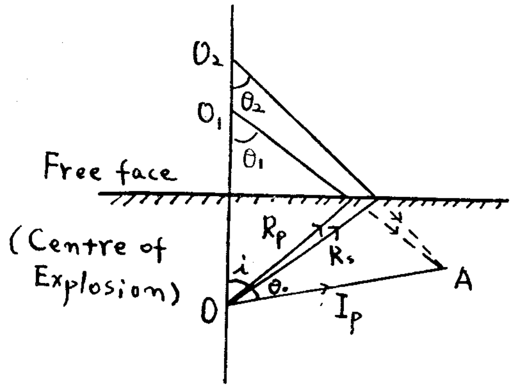


Fig. 11. Paths of waves impinged on a point A in rock mass

iii) The reflected transverse wave which is made from the reflected longitudinal wave (Rs)

The waves made from the explosion are a longitudinal and a transverse waves, but the velocity of longitudinal wave is speedier than that of transverse wave that rock is influenced first by the longitidinal wave.

If the longitudinal wave propagates to the rock mass with the velocity of C_L,

the radius directional displacement Ur is expressed as

$$U_\gamma=U(\gamma,\tau)=Up(\gamma)\cdot U\omega(\tau)$$

Also $\tau=t-\gamma/C_L$

$$\text{then}\quad \frac{\partial U(\gamma\tau)}{\partial\gamma}=\frac{dUp(\gamma)}{d\gamma}\cdot U\omega(\tau)+\frac{dU\omega(\tau)}{d\tau}\cdot\frac{\partial\tau}{\partial\gamma}\cdot Up(\gamma)\quad\cdots\cdots(2)$$

Let us consider the displacement velocity

$$v(\gamma,\ \tau)=\frac{\partial U(\gamma,z)}{\partial t}=\frac{dU\omega(\tau)}{d\tau}\cdot\frac{\partial\gamma}{\partial t}\cdot Up(\gamma)$$

and $\partial\tau/\partial\gamma=-1/C_L$, $\partial\tau/\partial t=1$

equation (2) becomes

$$\frac{\partial U(\gamma,\tau)}{\partial \gamma}=\frac{dUp(\gamma)}{d\gamma}\cdot U_{\omega}(\tau)-\frac{v(\gamma,\tau)}{C_L}$$

So this term is put into (1), any states of stress are obtained.

i) Direct longitudinal wave

If we take polar-coordinates (r_0, θ_0, ϕ_0) whole origin is coincided with explosion centre,

$$\widehat{\gamma\gamma}_{ip}=(\lambda+2\mu)\left\{\frac{dU_{p0}(\gamma_0)}{d\gamma_0}\cdot U\omega_0(\tau_{ip})-\frac{v_0(\gamma_0,\tau_{ip})}{C_L}\right\}+2\lambda\frac{U_0(\gamma_0,\tau_{ip})}{\gamma_0}$$

$$\widehat{\theta\theta}_{ip}=\widehat{\phi\phi}_{ip}=\lambda\left\{\frac{dU_{p0}(\gamma_0)}{d\gamma_0}\cdot U\omega_0(\tau_{ip})-\frac{v_0((\gamma_0,\tau_{ip})}{C_L}\right\}+2(\lambda+\mu)\frac{U_0(\gamma_0,\tau_{ip})}{\gamma_0}$$

$$\widehat{\phi\theta}_{ip}=\widehat{\phi\theta}_{ip}=\widehat{\gamma\theta}_{ip}=0$$

ii) Reflected longitudinal wave

As the angle of incidence from the origin to free face is same with the angle of reflection, if we take another polar-coordinates (r_1, θ_1, ϕ_1) whose origin is 0_1 which is the symmetrical point of 0.

$$\widehat{\gamma\gamma}_{rp}=(\lambda+2\mu)\left\{\frac{\partial U_{p1}(\gamma_1,\theta_1)}{\partial\gamma_1}\cdot U\omega_1(\tau_{rp})-\frac{v_1(\gamma_1\theta_1,\tau_{rp})}{C_L}\right\}+2\lambda\frac{U_1(\gamma_1\theta_1,\tau_{rp})}{\gamma_1}$$

$$\widehat{\theta\theta}_{rp}=\widehat{\phi\phi}_{rp}=\lambda\left\{\frac{\partial Up_1(\gamma_1,\theta_1)}{\partial\gamma_1}U\omega_1(\tau_{rp})-\frac{v_1(\gamma_1\theta_1,\tau_{rp})}{C_L}\right\}+2(\lambda+\mu)\frac{U_1(\gamma_1\theta_1,\tau_{rp})}{\gamma_1}$$

$$\widehat{\gamma\theta}_{rp}=\mu\frac{1}{\gamma}\cdot\frac{\partial Up_1(\gamma_1,\theta_1)}{\partial\theta_1}\cdot U\omega_1(\tau_{rp})$$

$$\widehat{\gamma\phi}_{rp}=\widehat{\theta\phi}_{rp}=0$$

iii) Reflected transverse wave

Like the previous article, we can take new polar coordinates (r_2, θ_2, ϕ_2) whose origin is O_2

$$\widehat{\gamma\gamma}_{rs}=\lambda\left\{\frac{1}{\lambda_2}\cdot\frac{\partial U_{\theta p}(\gamma_2,\theta_2)}{\partial\theta_2}\cdot U_{\theta\omega}(\tau_{\gamma s})+\frac{U_{\theta p}(\gamma_2,\theta_2)}{\gamma_2}\cdot U_{\theta\omega}(\tau_{\gamma s})\cdot\cot\theta_2\right\}$$

$$\widehat{\theta\theta}_{rs}=(\lambda+2\mu)\left\{\frac{1}{\gamma_2}\cdot\frac{\partial U_{\theta p}(\gamma_2,\theta_2)}{\partial\theta_2}\cdot U_{\theta\omega}(\tau_{\gamma s})+\lambda\frac{U_{\theta p}(\gamma_2,\theta_2)}{\gamma^2}\cdot U_{\theta\omega}(\tau_{rs})\cot\theta_2\right\}$$

$$\widehat{\phi\phi}_{rs}=(\lambda+2\mu)\frac{U_{\theta p}(\gamma_2,\theta_2)}{\gamma_2}U_{\theta\omega}(\tau_{\gamma s})\cdot\cot\theta_2+\lambda\frac{1}{\gamma_2}\frac{\partial U_{\theta p}(\gamma_2,\theta_2)}{\partial\theta_2}\cdot U_{\theta\omega}(\tau_{\gamma s})$$

$$\widehat{\gamma\theta}_{rs}=\mu\left\{\frac{\partial U_{\theta p}(\gamma_2,A_2)}{\partial\gamma_2}\cdot U_{\theta\omega}(\tau_{\phi s})-\frac{v_{\theta p}(\gamma_2,\theta_2)}{C_T}\cdot v_{\theta\omega}(\tau_{rs})-\frac{U_{\theta p}(\gamma_2,A_2)}{\gamma_2}\cdot U_{\theta\omega}(\tau_{rs})\right\}$$

$$\widehat{\phi\theta}_{rs}=\widehat{\phi\gamma}_{rs}=0$$

where propagation velocity of transverse

$$C_T=\sqrt{U/\rho}$$

Thus, in case of one-free-face, the stress of any arbitrary point can be determined by the measurements of diplacement $U(\gamma,\tau)$ displacement velocity $v(\gamma,\tau)$, the differential coefficient $dU_p(r)/dr$ and the propagation velocity of elastic wave.

While in case of two free faces, the dynamic stresses of any point are composed of the stresses of one-free-face plus the stresses of a reflected longitidinal and a reflected transverse wave which are made from using another free face. These stresses can be expressed as the same form of one free face.

4-2-b. Static Stress.

Where the explosives exploded within the hole, the influence of static stress, owing to the gases, can be expressed as below.

In order to analyze stress easily, take bipolar coordinates instead of perpendicular coordinate.

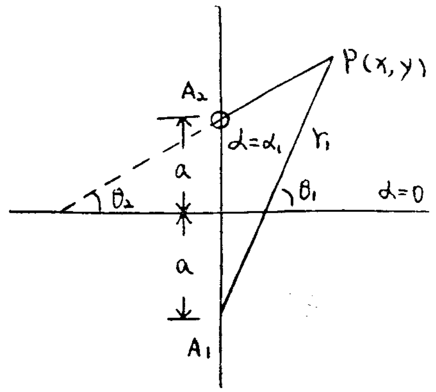


Fig. 12. Bi-polar coordinate

Then, x and y in perpondicular coordinate is expressed as

$$x=a\ \sin\beta/(\cosh\alpha-\cos\beta)$$

$y = a \sinh\alpha / (\cosh\alpha - \cos\beta)$

where, a: distance between the origin of perpenicular coordinate and two poles of bi-polar coordinate.

$$\alpha = \log\frac{\gamma_1}{\gamma_2},\quad \beta = \theta_1 - \theta_2$$

r_1, r_2: distance between pole and an aribitrary point P. Now, let us match the charged hole to the circle of and the free face to the circle which has an infinite radius,

$$\alpha_1 = \log\frac{W+\gamma+a}{W+\gamma-a},\quad a = \sqrt{W^2-\gamma^2}$$

where W: least resistance line

r: radius of charged hole

Stress on an arbitrary point P (x, y) is.

$$\sigma_\alpha = \frac{1}{a}\left\{(\cosh\alpha - \cos\beta)\frac{\partial^2}{\partial\beta^2} - \sinh\alpha\frac{\partial}{\partial\alpha} - \sin\beta\frac{\partial}{\partial\beta} + \cosh\alpha\right\}F$$

$$\sigma_\beta = \frac{1}{a}\left\{(\cosh\alpha - \cos\beta)\frac{\partial^2}{\partial\alpha^2} - \sin\alpha\frac{\partial}{\partial\alpha} - \sin\beta\frac{\partial}{\partial\beta} + \cos\beta\right\}F$$

$$\tau_{\alpha\beta} = -\frac{1}{a}(\cosh\alpha - \cos\beta)\frac{\partial^2 F}{\partial\alpha\cdot\partial\beta}$$

Also, the Airy s stress coefficient of two dimensional elastic body, F, is satisfied with next equation.

$$\left(\frac{\partial^4}{\partial\alpha^4} + 2\frac{\partial^4}{\partial\alpha^2\partial\beta^2} + \frac{\partial^4}{\partial\beta^4} - 2\frac{\partial^2}{\partial\alpha^2} + 2\frac{\partial^2}{\partial\beta^2} + 1\right)\cdot F = 0$$

The Jeffery's[21] general solutions to this is,

$$F = E_0\alpha(\cosh\alpha - \cos\beta) + (A_1\cosh 2\alpha + B_1 + C_1\sinh 2\alpha)\,.\,\cos\beta$$

where, $B_0 = 2M\cosh\alpha_1$

$A_1 = -M\sinh\alpha_1$

$B_1 = M\sinh\alpha_1$

$C_1 = M\cosh\alpha_1$

$M = ap/2\sinh^3\alpha$

P : pressure within the explosion-hole

Thus, we can analyze any states of stress by measuring P.

4-3. Theory of Burn-Cut

It has been considered that the static stresses owing to the gas pressure had an important role to the rock breakage, but now, in addition to that, the influences of shock waves make same effect to it. In other words, the shock waves propagate to the rock as compressed wave first, but after reflected at the free face, they are changed to tensile waves. Thus, in case of having free face, rock is affected by these two kinds of wave, if not, affected compressed wave only.

Having open holes, which are utilized as free faces at initial time, in the central parts of excavating face, burn-cut has an better blasting efficiency.

4-3-a) Effect of free face

In an arbitrary point within rock mass, stress produced by an explosion is expressed as a function of power of explosion, distance from the explosion origin and lapse time. Comparing the case which has free face with the case which hasn't under the same blasting conditions, that is affected the tensile stress more than this. Generally, the number of free face are increased, the reflected tensile waves by the free face are also increased that the blasting effect is better.

Generally the displacement (U_0) according to these stresses can be expressed as below.

$$U_0(\gamma_1, \tau_L) = A_0\gamma^{-n}U_\omega(\tau_L)$$

where $\tau_L = t - \gamma/C_L$

A_0 : constant

r : distance between explosion origin and an arbitrary point

C_L : Velocity of longitudinal wave

t : time

n : decreasing exponent (const.)

As shown above equation, the value of displacement, which is a function of distance and time, is decreased because it is inverse proportion to r and U_w, the displacement of least resistance line, is also decreased as the time passes. Therefore, on the relation of explosion origin and free face, the shorter the distance is and the more the numbers and the wider the areas of free faces are, the greater the displace ments by the stresses. Namely, the blasting effect is greater. Thus, if these theories are applicated to burn-cut, the shorter distance between charged hole and open hole is, the greater the blasting effect is, and this is proved true by expriments.

4-3-b) Distance between charged hole and open hole in the central part of excavating face.

The explosive energy (E_1) can be expressed as a sum of energy used for shearing rocks (E_1) energy used for crushing the rock to fine particles (E_2) and energy used for blowing out them (E_3). If full volume of hole is charged, the explosive energy E is

$$E=E_1+E_2+E_3+2(x+2r)\,l.\,e.\,n+k_2F+k_3\cdot\frac{\delta\sqrt{f}\,\pi\gamma^2 f}{1-8\alpha}$$

Also $E=f\pi R^2 l\delta$

$$\therefore\ x=\frac{\pi\gamma^2 f\delta}{2ne}\left\{1-k_2-\frac{k_3\sqrt{f}}{(1-\delta\cdot\alpha)\,l}-2\gamma\right\}$$

If the distance between charge hole and open hole is set to X,

$$X=x+2\gamma=\frac{\pi\gamma^2 f\delta}{2ne}\left\{1-\mathrm{k2}-\frac{k_3\sqrt{f}}{(1-\delta\alpha)\,l}\right\}$$

where E : total explosive energy

E_1 : rock shearing energy

E_2 : energy which is used for the crushing the rock to fine partricles

d : Energy for the moving act the dust.

x : distance between holes

r : radius of hole

f : power of explosives per unit volume

R : radius of explosives

δ : specific gravity of explosives

e : energy used to the breakage of unit cm^2 rock.

l : length of hole

n : number of hole

K_2, K_3 : Constant

Thus, the distance X increases first in proportion to the power and the specific gravity of explosives, but it decreases later. So X must be determined by the standard values of $f\times\delta$.

4-3-c) Relation between the explosion pressure and distance.

If we put the radius of explosive is r_c and the pressure of explosion is P_a, the pressure$P$, which is the pressure of an arbitrary point departed from the charge center, is expressed as,

$$P=P_a(r/r_c)^{-3\gamma}$$

Where γ : the ratio of specific heat at the constant pressure to specific heat at the constant volume of explosion gas.

With the above equation, if the value of γ is increased, value of P is decreased. Thus, in case of large hole burn-cut, if the same explosives used in another methods are not suitable. Because due to the increased distance, the value of P, acting the distance r, is decreased that crushed rocks can not be blown out completely. As a result of this, the new crushed area does not act to the best of its ability as a free face. Thus, in case of large hole burn-cut, Metallic AN-FO which is more powerful than others, must be used.

5. CONCLUSION

From the above experiments and studies, concluded results are summarized as follow.

(1) Most effective mxing ratio of AN and fuel oil are 93.5 to 6.5 for powdered AN-FO and 94:6 for prilled/AN-FO.

(2) Detonation, impact and friction sensitivity of AN-FO are more insensitive than others, and residual gas is little toxic, it was proven.

(3) Initiation and propagation of detonation of prilled AN-FO are superior to that of powdered AN-FO, and AN-FO has the best explosive effect about 7 days after manufactured.

(4) Because AN-FO has equal explosive power of Ammonium Nitrate Explosive, improved

AN-FO (Metallic AN-FO, Underwater explosive) can be developed based on the characteristics of AN-FO.

(5) According to the author's design of new drilling patterns, burn-cut method drifts the tunnel faster than former pyramid-cut method, and consumes less explosives per ton of mined ore.

(6) There break out additional tensile stress reflected at the free face supplemented to primary compressive stress on the blasting with one-free-face. But with these experiments, new drilling patterns of burn-cut, more free-faces and nearer distance of each drilling holes make blasting effects greater than any other methods.

(7) Pyramid-cut has close correlation between charged length and least resistance line, but burn-cut doesn't.

(8) AN-FO which is low density, proper power and has adequate sympathic explosion is fitted in burn-cut blasting.

(9) Former equation, $L=CW^3$ can't be applicated in burn-cut blasting, and there is not over-breakage phenomenon and flying rocks as pyramid-cut has compact charging on the bottom of the holes.

(10) These experiments result that the less clearance between the pilot hele (unloaded) and cut hole (loaded) in the key holes, the more effective blasting can be done.

(11) In case of applying large hole burn-cut method, it brings more improved effect to explosion power by using Metallic AN-FO explosive because least resistance line is longer than the other.

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硝油爆藥類를 活用한 單一自由面發破의 力學的 硏究

許 塡

發破에 있어서 穿孔配置는 發破効果에 影響을 미치는 가장 重要한 要素中의 하나다. Burn-cut 의 爆發의 여러 要素에 關한 硏究는 Brown, Cook에 依해 發表된 바 있으나 本硏究에 있어서는 Burn-cut 와 Pyramid-cut 의 穿孔配置의 對比와 爆源과 自由面사이의 力學的 應力解析에 重點을 두어 伊藤敎授가 展開한 理論에서 다루지 않은 適正穿孔配置에 依한 Burn-cut 의 効果를 連結시켰다.

從來의 理論에 依하면 單一 自由面發破에 있어서는 壓縮應力外에 自由面에서 反射되는 引張應力의 影響을 追加로 받는다. 本 新穿孔 配置에 依한 Burn-cut 는 自由面數의 增加와 距離의 縮少를 꾀하므로서 이効果는 더욱 增大된다.

이와 같은 効果를 爲해서는 다음 두가지 點을 고려해야 한다.

첫째 心拔孔의 無裝藥孔은 補助應力을 크게 하기爲해 可能한 大口徑으로 깊게 穿孔해야 한다.

둘째 각 心拔孔間의 距離를 接近시켜 完全 發破를 期해야 한다. 그 까닭은 口徑이 增加됨에 따라 2次 自由面은 넓어지고 거리가 가까울수록 裝藥孔과 無裝藥孔 사이의 引張應力은 더욱 發達되기 때문이다. 先進國에서는 心拔孔사이의 距離를 4″로 함이 理想的이라고 알려지고 있으나 本實驗에 依하면 더욱 近接될수록 破壞岩石이 增加되고 掘進長도 깊어짐이 밝혀졌다. 나아가서는 掘進長을 더욱 增大시키기 爲해 Burn-cut 로 부터 Large hole Burn-cut 를 開發하여 發破回數 max 7回/日로서 1發破當 3.1m 까지 試圖함으로서 高速度掘進의 起源을 마련했다. 또한 大口徑 Burn-cut 에서는 큰 抵抗을 극복하기 위해 金屬硝油爆藥을 使用함이 더욱 効果的임이 立證됐다. 最近에와서 低廉한 價格과 取扱安全으로 각광을 받고있는 AN-FO 는 비료용 또는 工業用 硝安에 燃料油를 混合한 것으로서 雷管만으로는 鈍感하여 爆發하지 않으나 Gelatin Dynamite 等의 爆發性 銳感劑에 依해 發破孔內에서 일단 起爆되면 從來의 硝安爆藥에 相當한 威力을 發揮케 한다. AN-FO 爆劑의 性能에 關해서는 많은 報告가 있었으나 本 實驗에 依하면 硝油混合比는 粉狀은 93.5:6.5, prill 狀은 94:6 이 最適이며 粉狀 AN-FO 는 prill 狀 AN-FO 보다 恒常 爆速이 높다.

또한 起爆感度, 衝擊感度, 摩擦感度 等 諸感度는 他火藥에 比해 몹시 鈍感하며 傳爆性은 prill 狀이 粉狀보다 優秀함을 얻었다. 發破後 Gas 도 良好하며 AN-FO 는 製造後 7日 前後가 最大効果를 갖는다.

從來 AN-FO 는 지난 여러해 동안 露天掘에만 使用하여 왔으나 筆者는 AN-FO의 基礎性能試驗을 土臺로 이를 利用한 新種爆劑로서 金屬硝油爆藥과 水中爆藥을 發展시켰다.

金屬硝油의 爆藥은 AN-FO와 Al 金屬粉秣의 混合物이며 水中爆藥은 從來爆藥과 AN-FO로 製造한 바 이에 關해서는 다른 論文에 記述했다.

本 硏究에 있어서는 單一自由面 發破에 있어서 硝油爆藥類를 使用한바 그 効果가 매우 良好하였음을 確認하였다.