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Case studies of solving blasting problems for control of fragmentation and wall damage

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Abstract

Rock blasting has two sides of technical skill. In terms of rock blasting, the optimum result is one that maximizes production and minimizes the damage to the remaining rock. To control fragmentation the proper amount of energy must be applied at appropriate sites taking into account rock mass characteristics. On the other hand, the remaining rock mass itself is required to remain stable as a part of a structure. A special type of blasting technique must be used which minimizes the damage done in the remaining rock. This paper presents two case studies of solving problems for control of fragmentation and damage to the rock mass.

1. Introduction

Fragmentation has been one of the major concerns in blasting research because the degree of fragmentation has a major effect on the efficiency of the mining operation as well as mining costs. Fragmentation is largely affected by the nature of the rock together with explosive properties, and blast geometry and initiation sequence. One of the most important characteristics of rock is its variability. Understanding of rock mass is the key to the success of rock blasting. To control fragmentation the proper amount of energy must be applied at appropriate sites taking into account rock mass characteristics. On the other hand, the remaining rock mass itself is required to remain stable as a part of a structure. A special type of blasting technique must be used which minimizes the damage done in the remaining rock. This paper presents two case studies of solving problems for control of fragmentation and damage to the rock mass.

The 1st case shows the significance of the structural control in fragmentation. A series of investigations were carried out to figure out the causes of poor degree of fragmentation at a limestone quarry, which is the largest open pit mine in Korea. The problems were identified by means of field investigation and numerical analysis. The 2nd case shows an effort to develop a blasting technique for reducing damage to remaining rock. The techniques most commonly used to control damage in the final walls of excavations are smooth blasting, pre-splitting and air decking. A new method, which is similar in principle to that of air decking, was developed and tested in a granite quarry.

2. Case 1: Improving fragmentation

The limestone mine is one of the largest open pit mines in Korea where over ten working benches run. Although a same blast pattern had been applied to all the working places, the degree of fragmentation appeared to be good at some places but poor at other places. It implies that the parameters related to the rock mass must affect the results of a blast. A series of investigation was carried out to identify the cause of the problem.

2.1 Rock properties and blast pattern

Limestone samples were taken from several working places for laboratory testing. The mechanical properties did not vary significantly from one site of a mine to another. The average values are shown in Table 1.

Table 1 Properties of limestone.

Density	2.72	g/cm^3
P-wave velocity	4,510	m/sec
S-wave velocity	2,440	m/sec
Compressive strength	890	kg/cm^2
Tensile strength	110	kg/cm^2
Young's modulus	2.1 x 10^5	kg/cm^2
Poisson's ratio	0.17	

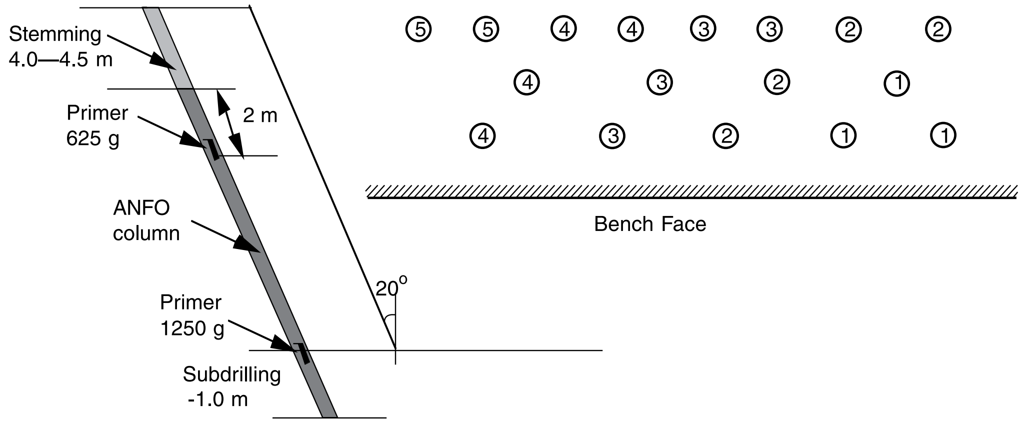

Fig. 1 Typical bench blast pattern.

Figure 1 shows the typical pattern of bench blasting applied at the mine. Burden is about 3.5 m and spacing ranges from 5 to 10 m. Blasthole diameter is 102 mm. Collar distance ranges from 4 to 4.5 m filled with drill cuttings while explosive column with ANFO. Bench height ranges from 10 to 20 m. Two primers are placed at middle and toe part of the bench.

2.2 Assessment of blasting performance

Blasting performance was assessed by comparing the size distribution of the fragments. Image processing technology was used in the measurement of fragmentation. Muckpile images were recorded with video camera at several working places, and transmitted to a desktop computer. The digital images were analyzed to produce size distribution using the image analysis program, WipFrag, by Wipware.

Figures 2 and 3 show the log histograms and cumulative graphs at different sites. Log histogram gives a non-cumulative distribution of fragment weights in each of ten linearly subdivided size classes. The linear y-axis scale (0 to 50%) gives the weight in each class interval as a percentage of the total sample of measured net elements. The logarithmic x-axis scale gives the fragment size Dn, the nominal diameter of a sphere with the same volume as the frag-

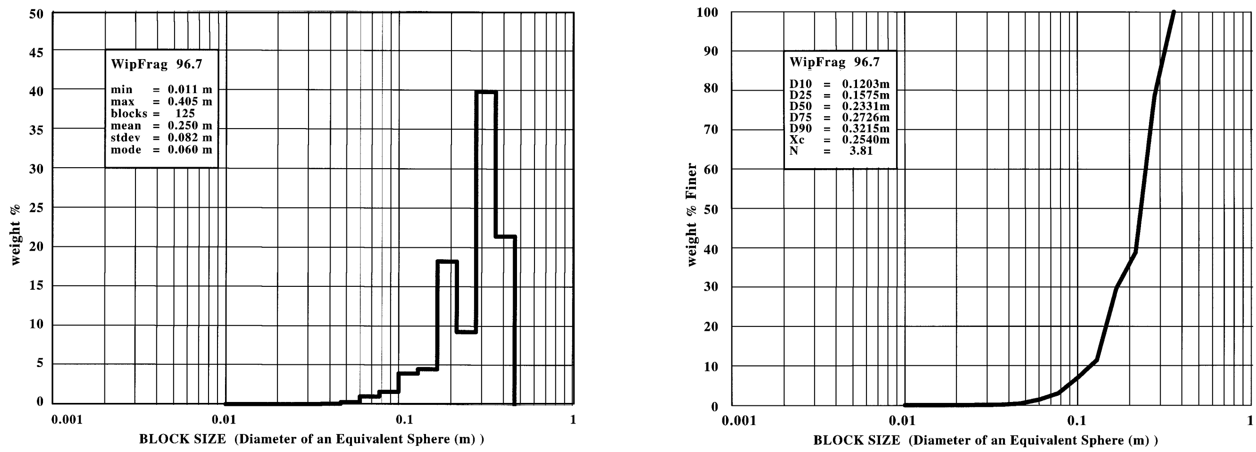

Fig. 2 Log histogram and cumulative graph, site 1.

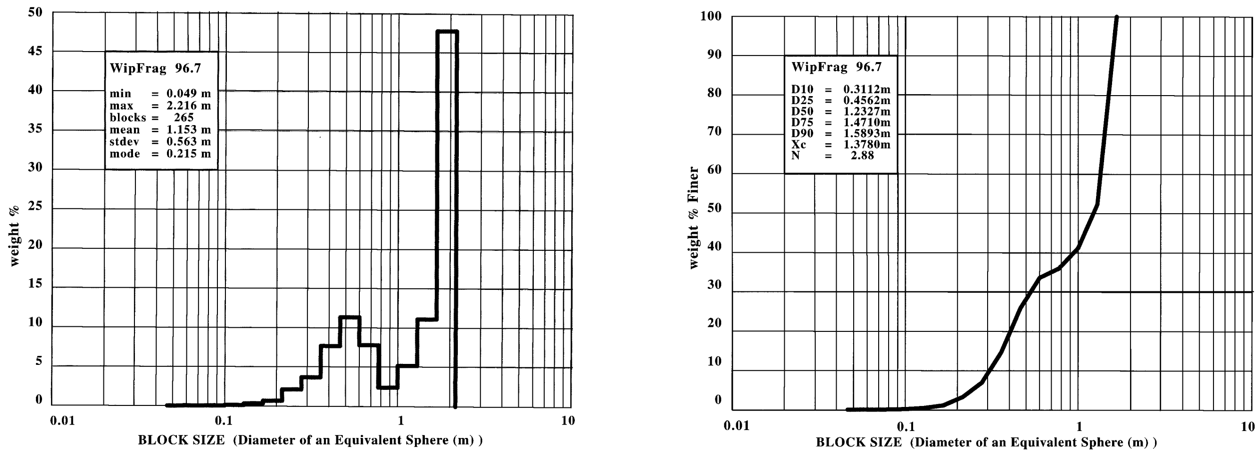

Fig. 3 Log histogram and cumulative graph, site 2.

ment. Cumulative graph gives the cumulative size distribution graph in the form most often used to present the results of sieving. The linear y-axis scale (0 to 100%) gives the percentage of fragments finer than a given size Dn, equivalent to the percent passing a sieve with this mesh opening. The logarithmic x-axis scale gives the fragment size Dn, the diameter of an equivalent sphere. Quite different degree of fragmentation occurs although same blast patterns are applied to rocks of similar mechanical properties.

2.3 Joint structure

The strike and dip of joint planes were investigated on the bench faces and rose diagrams were constructed as shown in Fig. 4. As shown in the figure, major joint sets were developed in similar trend except couple of benches. Figure 5 shows the direction of bench face and joint. The results show that prominent joint sets make various angles with bench face at each working places. It may yield different fragmentation effect at each place.

2.4 Numerical evaluation of the effects of joint structure on rock mass fracturing

The presence and orientation of discontinuities in rock masses are known to have a great influence on blasting efficiency as well as slope stability. Natural discontinuities tend to dominate the nature of the fracture pattern. Blast layouts should, therefore, be designed to take rock structure into account. Proper orientation of the free surface with respect to pronounced joint planes considerably improves the blasting results[1-2].

An orthogonal joint pattern is a prominent structural pattern, often found in the field. Several idealized examples were selected here to investigate the effects of joint struc-

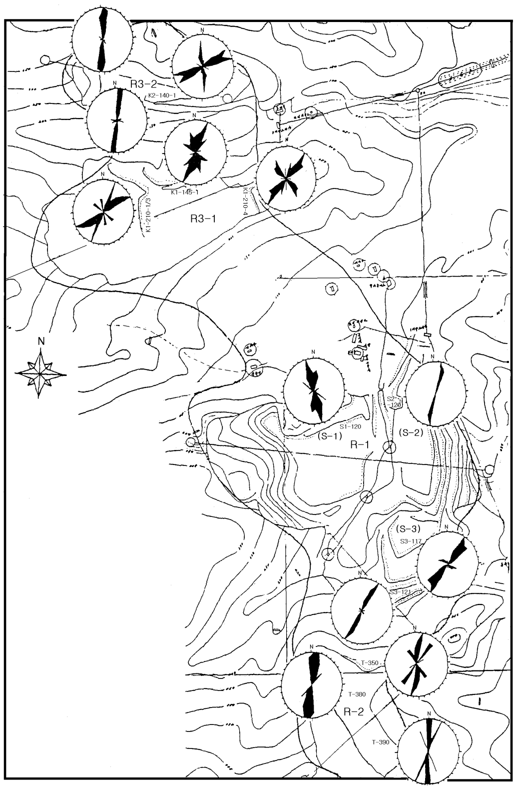

Fig. 4 Joint distribution.

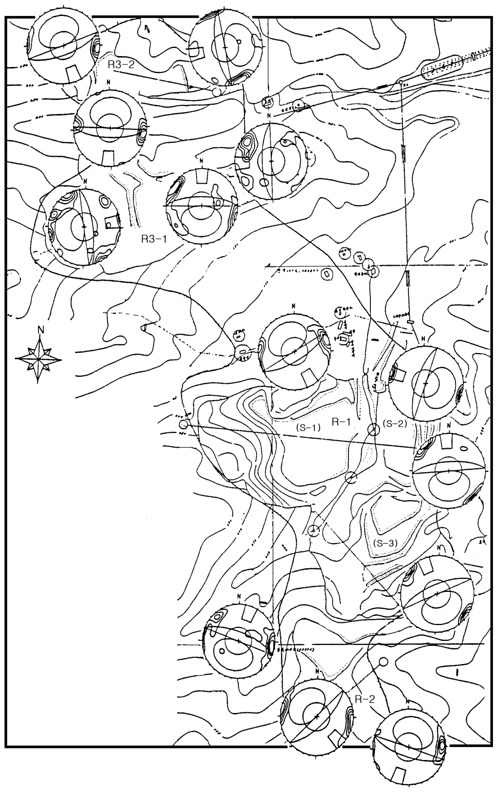

Fig. 5 Direction of bench face and joint.

Table 2 Input parameters for examples 1 to 4.

Joint properties:	
Normal stiffness (K_n)	100 MPa/cm
Shear stiffness (K_s)	100 MPa/cm
Friction coefficient (μ)	0.5
Friction angle	26.6^o
Tensile strength of intact rock	5 MPa
Other parameters:	
Rock density	1.8 g/cm^3
Borehole pressure	
$P = Po\ e^{-at}$ Po = 2.8 Gpa;	a = 0.4 /ms
No mass or stiffness proportional damping	

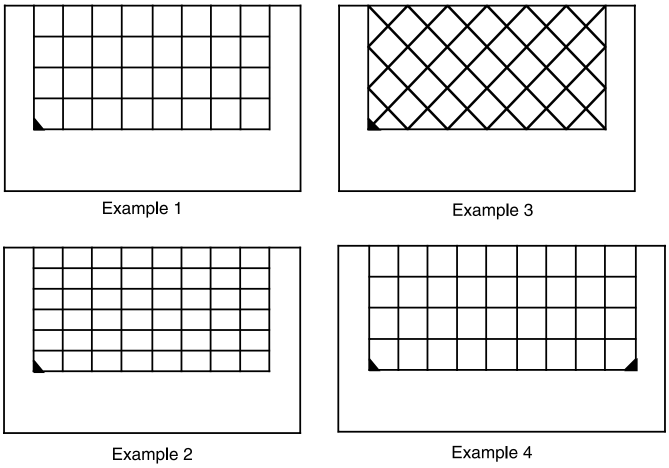

Fig. 6 Modeling of jointed rock mass.

tures on blasting efficiency. Figure 6 shows the joint configuration of each example. Example 1 was chosen as a standard joint pattern having four-crossed joint sets with 50 cm of spacing. The direction of each joint set is parallel and normal to the free surface, respectively. In example 2 the spacing of joint set 1 is reduced to 33 cm. In example 3, the joints are arranged to make an angle of 45^o with the free surface. Example 4 is for modeling two-hole simultaneous blasting. Input parameters used in the examples are given in Table 2.

The pressurization of a borehole due to blasting is simulated by forces applied to the block edges forming a borehole. As a practical convenience, the borehole is assumed to be square and only the quarter part facing the free surface is considered. The borehole is represented by the solid mark in the figures. The borehole wall pressure is assumed to be[3]:

$$P(t) = P_o e^{-at}$$

where P_o = peak wall pressure
a = decay constant

The units of P and P_o are GPa, t is in ms, and a is in 1/ms. The pressure is assumed to be turned off after 10 ms.

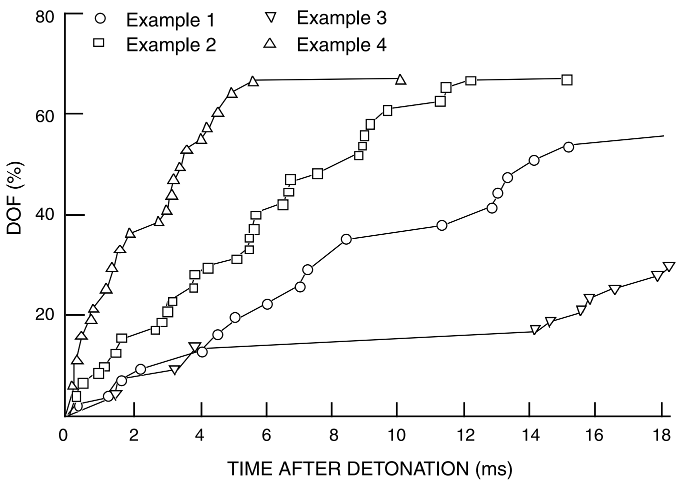

Fig. 7 Degree of fracturing (DOF-%) with time.

Borehole wall pressure was approximately calculated using the empirical equation, $P = 2.5\ \rho\ VOD^2 \times 10^{-6}$ where P is detonation pressure in Kbar, r is density in gm/cc, and VOD is velocity of detonation in m/sec[4].

The CBLOCK computer code based on the distinct element algorithm was used for the analysis[5-6].Two kinds of failure modes were considered, joint failure and intact block failure due to tensile stresses developed by concentrated compressional loading. Fracture modes due to wave effects were not considered. When a well-developed joint set makes up of a system of blocks, wave-induced fracture would be localized because the transmission of strain energy carried by wave from one block to the next would be inefficient because of impedance mismatch.

2.5 Results and discussion

To compare the example results, an index representing the degree of fracturing (DOF) was introduced. The degree of fracturing is defined as $N_f/N_t \times 100$, where N_f is the number of fractured blocks, and N_t is the number of total blocks in the structure. Figure 7 shows that the degree of fracturing in example 2 is better than that in example 1 while the degree of fracturing in example 3 is much less than that in example 1 because of the effect of joint orientation relative to the free surface. Fracturing with two simultaneous holes takes place very fast. The DOF has reached about 67% at 7 ms after detonation. The CBLOCK calculations suggest that blasting at 90^o to the major joint set results in better fragmentation efficiency while blasting oblique to the joint planes leads to poor rock fracturing. A blast pattern like Fig. 8 is suggested for better fragmentation. Instead of changing the direction of bench face, the ignition sequence is controlled by considering the direction of the prominent joint at each bench.

3. Case 2: Reducing damage to remaining rock

Air decking is a charging method that has generally been used for the purposes of reducing the detonation pressures in the fields of presplitting and controlled blasting[7]. A new air decking blasting combines the known technique of air decking with the existing two-face simultaneous blasting method to improve both the efficiencies and conveniences of the blasting. In the new method, two cartridges of explosives are generally used for charging a blast hole such that one is placed in the bottom and the other is put in some appropriate location of the upper part of the hole.

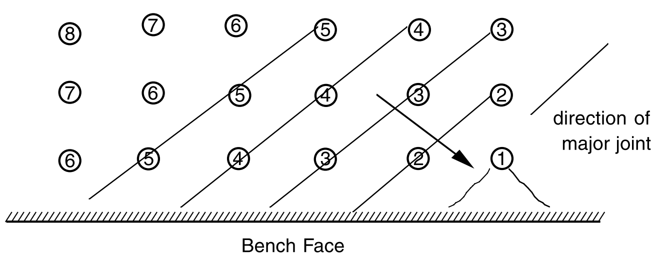

Fig. 8 Initiation system (Corner cut, Echelon plan).

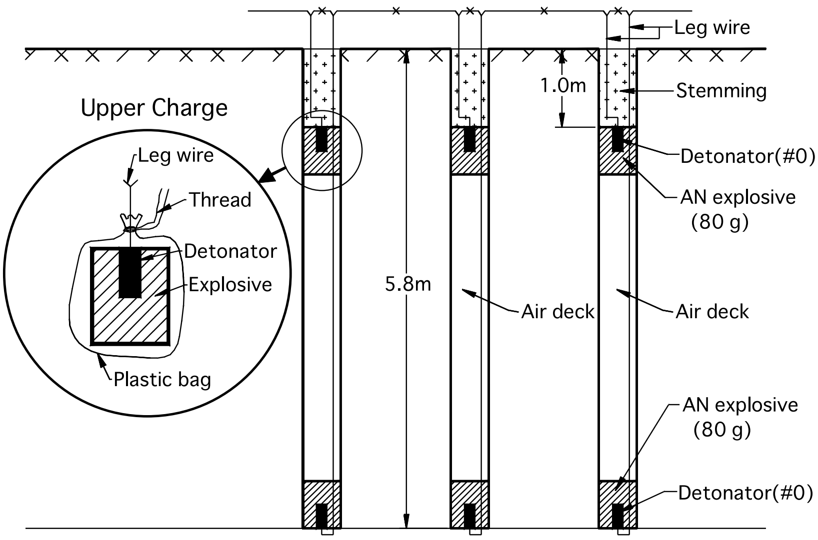

Fig. 9 Charging pattern.

Thus, a void, namely, an air deck comes in between these two upper and lower cartridges. Since there are no restrictions on the number of cartridges, the number of air decks can appropriately be determined according to the size and shape of the rock block to be extracted. An ammonium nitrate explosive is generally preferred in this blasting scheme because it has relatively low detonation velocity and high gas volume. All the charges in a round should be initiated simultaneously by using instantaneous detonators or delay detonators with the same delay number. No plugs are needed.

3.1 Drilling and charging

The diameter of blast hole is 38 mm and the spacing between two adjacent blast holes in a row is approximately 30 cm, except that it is about 20 cm at both ends of the row. Two explosive cartridges, each of which weighs about 80 g, are used to charge a hole. One is located at the bottom of the hole and the other at some location above it. Figure 9 shows the example of charging pattern. The procedures are as follows:

Step 1: Insert a detonator into each explosive cartridge, which is to be used as upper charges of vertical holes in a round.

Step 2: Wrap each cartridge with a plastic bag.

Step 3: Connect two cartridge bags together using a thread of appropriate length such that one of the pair could be inserted into one hole and the other an adjacent hole. The two cartridges are then suspended by a thread connecting them. The length of the string should be determined by the stemming length and the spacing.

Step 4: Stem the charged pair of holes by using sands or rock debris.

Step 5: Repeat the steps 3 and 4.

3.2 Test blasts

Test blasts have been conducted in order to compare the efficiencies of the new air decking blasting method (Test blasts II and III) and the two-face blasting using detonating cord (Test blast I). The two side faces of the rock blocks were cut by diamond wire saw.

3.3 Results and discussion

Table 3 shows the results of test blasts. The displacements of the blocks in Test blasts I, II, and III were found to be 23, 52, and 60 cm, respectively. The results showed that the rear cutting faces of all the blocks appeared to be

Table 3 Test results.

Parameters		Test blast Ⅰ	Test blast Ⅱ		Test blast Ⅲ
Rock block	length(m)	11.65	0.75	5.75	31.0
	width(m)	7.0	7.0	7.0	7.1
	height(m)	8.0	6.0	4.0	5.8
	cutting area(m^2)	174.75	333.0		399.9
	volume(m^3)	652.4	1033.0		1276.6
	displacement(m)	0.23	0.52		0.60
Drilling	vertical holes	38	64		72
	horizontal holes	38	68		75
Powder factor	charge weight g)	10,840	25,781		31,875
	empirical(g/m^3)	24.1	34.0		36.1
	actual(g/m^3)	17.0	25.0		25.5

relatively smooth, and blast induced cracks into rock were rarely found. But relatively small sizes of rock fragments were found in the upper corner parts of blocks. These phenomena may be resulted from the tension failure in the vicinities of the upper free surfaces of the blocks or the development of the potential cracks created from the previous blasts. Such problems may be controlled by changing the powder factor or the length of stemming in a given round.

The powder factor in Test blast III was 25.5 g/m^3. It means that the blasting technique using air decking may be very effective method for dimensional stone quarrying. A similar result was also observed in Test blast II.

4. Conclusions

A series of investigations were carried out to identify the cause of poor degree of fragmentation at a limestone quarry, which is the largest open pit mine in Korea. It was found that most problems were due to the structural characteristics of the rock. A better fragmentation was obtained by controlling the ignition sequence instead of changing the direction of bench face. In order to control the damage to the rock mass, a new method, which is similar in principle to that of air decking, was developed and tested in a granite quarry. The method was shown to be very effective in reduction of noise, working time and labor. The two-face simultaneous blasting using a new air decking technique was especially found to be promising method.

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