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Blasting practices in a quarry with karstic cavities

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Abstract: The blasting practices in a limestone quarry with karstic cavities have been presented. The existence of karstic cavities in the quarry has reduced blasting efficiency significantly. In order to improve blasting efficiency different blasting strategies (loading holes with ANFO in plastic bag, recording cavity location along the holes and charging the holes according to this information, and modifying blasting pattern according to karstic cavities) had been implemented and the results were evaluated on per ton cost basis. It was concluded that efficient blasting in such aquarries requires determining the size and shape of karstic cavities and based on this information, to modify the blast pattern and charge the holes. The suggested method is to record the cavity along the drill hole and to generate 3D model of cavities. By doing this, the production cost in the limestone quarry has decreased from 0.407 $/t to 0.354 $/t.

Key words: blasting; fragmentation; karstic cavities; limestone quarry

1 Introduction

Drilling and blasting is the most important front-line process in the mining cycle. Any improvements in efficiency in this process are quickly realized by all of the downstream processes that are loading, hauling and crushing. The efficiency of drilling and blasting is characterized by the required fragmentation. The optimization of fragmentation from blasting can significantly affect the overall profitability of the operation [1-3].

The main parameters affecting fragmentation can be grouped as controllable (blast geometry, explosive properties and initially system) and uncontrollable (rock mass condition) parameters. The controllable parameters are chosen using empirical rules of thumb and site investigation on the basis of determined rock mass condition. The variability in the rock mass condition will change the size of fragmentation. In order to control the size of fragmentation in a variable rock mass environment, the controllable parameters, especially blast geometry and charging should be modified according to variability.

It is not always easy to identify variability in the rock mass condition, *e.g.* intact rock properties, joint characteristics, presence of faults, dikes and karstic cavities. Among these characteristics, karstic cavities occur very randomly relative to other characteristics. Karstic cavities are a complex geological feature and the result of rock solubility and various geological processes. Karstic cavities are mainly formed in soluble rocks such as gypsum, dolomites and limestones [4-5]. Limestones are the main input for cement factories and they are mined by means of drilling and blasting. The existence of karstic cavities in limestone quarries significantly affects the efficiency of drilling and blasting. Therefore, the efficiency of drilling and blasting is very related to the determination of these cavities before blasting.

In this study, the drilling and blasting practices in a limestone quarry with karstic cavities have been investigated. This quarry provides 6×10^5 ton/year limestone to the cement factory in Sivas, Turkey. The limestone production is made by means of open pit mining with a bench height of 8 m and bench width of 20 m. The ore is broken by drilling and blasting. The required fragmentation size is −50 mm for crushing plant. Therefore the oversize blocks have been resized by a hydraulic hammer in the quarry. However the existence of karstic cavities causes several problems and as a result decreases the efficiency of drilling and blasting. These problems are (a) Drill rod and bit stucking during drilling; (b) Removal of cuttings due to pressure lost in cavities; (c) Charging problems; (d) Existence of unexploded ANFO after blasting and (e) Oversize fragmentation.

All of these problems have caused significant increase in overall production cost. Except first two

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problems, the other problems have been thought to be overcomeable. In order to reduce the effect of karstic cavities in blasting, a number of blasting strategies have been investigated. These are (a) Strategy I: Loading the holes with ANFO (Amonioun Nitrat and Fuel oil) in plastic bags; (b) Strategy II: Loading the holes according to the location of karstic cavities and (c) Strategy III: Changing the holes geometry on the basis of karstic cavities.

The results of each strategy were evaluated on a cost per ton basis and visually in site investigation. The results have shown that changing the hole geometry during the drilling process increases the efficiency in fragmentation, and results in cost reduction.

2 Drilling and blasting practices

At the limestone quarry, the blast holes were drilled by Tamrock Ranger 600. The standardized blast design established for the best practice strategy was a 2.5 m × 2.2 m rectangular pattern with vertical 76-89 mm diameter blast holes. The bench heights were 8 m and blast holes are drilled to a depth of 9 m. The explosive length was 7.5 m and drill hole cuttings were utilized as stemming material. Each hole was loaded with 28-32 kg of ANFO and about 1 kg of dynamite was used as primer. The primer is initiated with MS delay fuse.

2.1. Loading the holes with ANFO in plastic bag

At the early stages of mining, the existence of karstic cavities was not known and they were realized during loading the holes. At this stage it was realized that most of the holes were loaded with ANFO much more than required amount. It was thought that there were cracks in holes and loaded ANFO lost in these cracks. Therefore, the plastic bags were used to load explosives. This was accomplished as follows.

(a) After completing the drilling of holes, a plastic bag was put into each hole. The length of plastic bag was about 10 m and its diameter was little bigger than that of holes (**figure 1**).

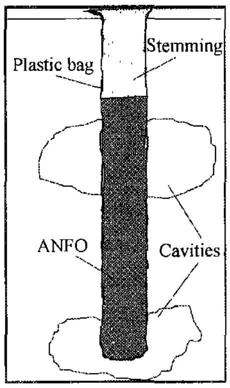

Figure 1 Charging the hole with the help of plastic bag.

(b) Explosive was loaded into these bags and blasted.

Seven sets of blasting were accomplished in this way. The holes geometry, loading and explosive information are given in **table 1**. As can be seen in table 1 that except the fifth blasting, which consisted of only 44 holes, about 90 holes were drilled and loaded with explosive for each set of blasting.

Table 1 Blasting pattern and explosive consumptions for Strategy I

Blast No.	N	D / mm	l_B / m	L_S / m	L / m	l_{St} / m	Explosives		
							m_{ANFO} / kg	$m_{Dyna.}$ / kg	Fuse / number
1	80	76	2.0	2.7	9.0	1.5	2598	48	80
2	87	76	2.0	2.7	9.0	1.5	2900	50	87
3	90	76	2.3	2.3	9.0	1.5	2900	45	99
4	92	76	2.0	2.3	7.5	1.5	2550	92	95
5	44	76	2.0	2.1	9.0	1.5	1100	37	44
6	89	76	2.1	2.0	9.0	1.5	2650	84	89
7	100	76	2.2	2.0	9.0	1.7	2850	95	100

Note: N—number of holes; l_B—burden; l_S—spacing; L—length of hole; l_{St}—stemming, D—diameter of hole.

Significant amount of unexploded ANFO and oversize blocks have been seen during the site investigation following each blasting. The site investigation showed that the usage of plastic bags did not improve the efficiency of blasting, it only reduced ANFO consumption. Thereupon, it was decided to determine the exact location of cavities along the holes and to charge the holes according to the location of cavities.

2.2. Loading the holes according to karstic cavities

Loading holes with ANFO in plastic bags have not solved the problem. Site investigation after blasting showed that considerable amount of ANFO had not been exploded. This situation brought up the idea of recording locations of karstic cavities in holes during drilling, then charging the holes according to this information.

Therefore, during the drilling, the location of karstic cavities along the holes has been recorded. Based on this information, the shape and location of karstic cavities in each hole has been estimated and the holes were charged according to this estimation. Based on the location of karstic cavities along the hole, different charging scheme has been utilized. Some of these schemes are given in **figure 2**.

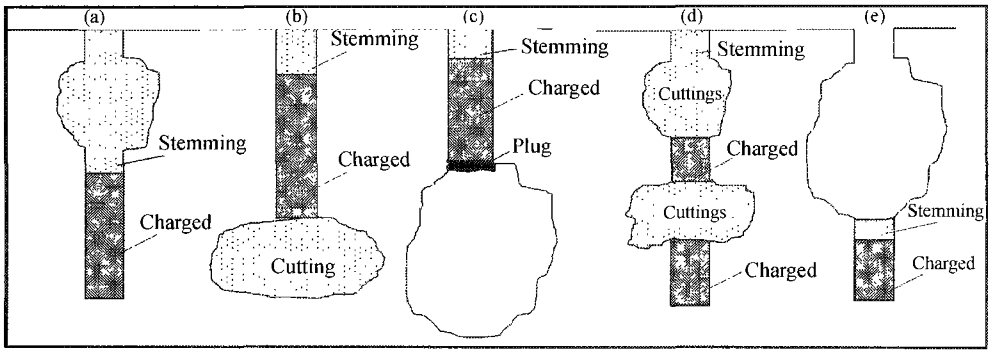

Figure 2 Charging schemes of blast holes.

As can be seen in figure 2 that the following loading schemes have been utilized for loading the holes.

(a) If the cavity is similar to the condition given in figure 2(a), then only the bottom of hole is charged. In order to prevent ANFO lost during the loading, a pipe is used in the cavity part of hole and the pipe was taken out after charging.

(b) If the cavity is at the bottom of hole and small (figure 2(b)), then the cavity is filled with drill hole cuttings, and the rest of the hole is charged in a regular way.

(c) If the cavity is at the bottom of hole and big, then the top of cavity is plugged with a cloth or bag, and then the rest of the hole is charged in a regular way (figure 2(c)).

(d) If the number of cavities is more than one, then cavities are filled with drill cuttings, and other parts were charged with a help of pipe if it has enough length (figure 2(d)).

(e) If the cavity is at the middle of the hole, then the bottom portion of hole is charged (figure 2(e)).

Eight sets of blasting had been completed in this way. The blast geometry and charge information of each blasting are given in **table 2**.

Table 2 Blasting pattern and explosive consumptions for Strategy II

Blast No.	N	D / mm)	l_B / m	l_S / m	L / m	l_{St} / m	Explosives		
							m_{ANFO} / kg	$m_{Dyna.}$ / kg	Fuse / number
1	87	89	2.2	2.5	11.0	2.0	3700	87	87
2	70	89	2.2	2.5	8.5	2.0	2400	72	76
3	120	89	2.0	2.5	7.5	1.5	3300	130	153
4	143	76	2.2	2.3	4.0	1.0	1800	43	143
5	80	76	2.2	2.3	9.5	2.0	2600	95	128
6	37	76	2.2	2.3	10.0	2.0	700	38	50
7	60	76	2.0	2.2	5.5	1.0	1036	35	69
8	109	76	2.0	2.2	5.5	1.0	2100	55	109

Note: N—number of holes; l_B—burden; l_S—spacing; L—length of hole; l_{St}—stemming, D—diameter of hole.

As can be seen in table 2 that, the dynamite and fuse consumption has increased due to the double or more charging of holes. Especially the higher cavity rates the higher dynamite and fuse consumption were (table 2).

This strategy seemed to cut down some problems, but its requirement for experienced labor force had created some application problems. So it has been found difficult to apply. Therefore another approach has been investigated.

2.3 Modifying the blast geometry according to cavity

Since the previous methods have not completely solved the problem of oversize fragmentation and existence of unexploded ANFO, a new approach has been developed and evaluated. This new approach requires 3D modeling of karstic cavities on the basis of information obtained during drilling. Plan and vertical sections were used to generate 3D model of karstic cavities. Then these models have been used to revise the blast pattern for charging and blasting. The main assumption of this method was that the karstic cavity is a natural free-face for blasting, therefore the blast pattern was modified according to these free-faces (**figures 3** and **4**). As a result of this model, the holes within the karstic cavities were not charged, instead new holes have been drilled and charged.

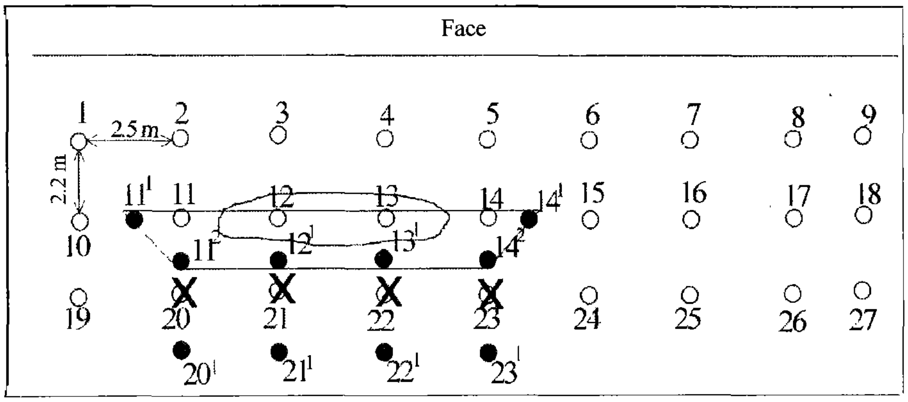

Figure 3 Plan view of blasting pattern.

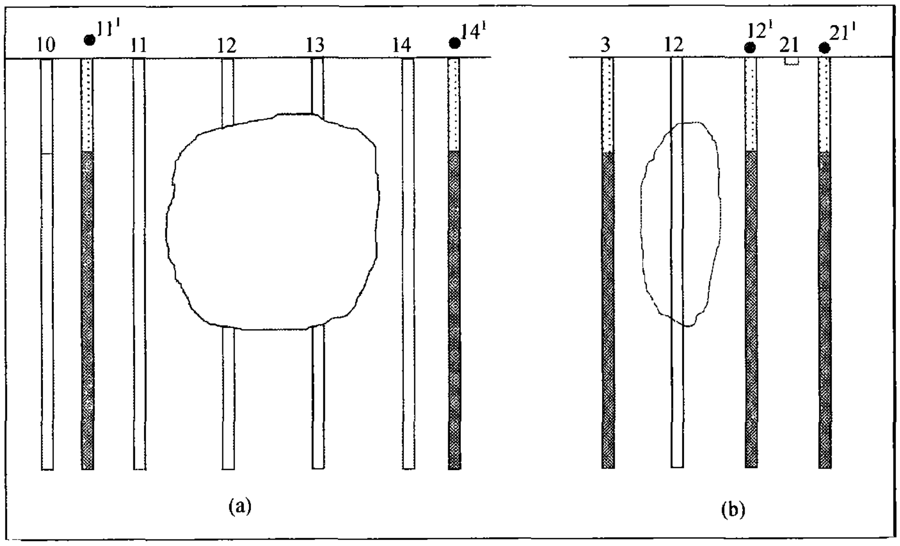

Figure 4 (a) cross and (b) longitudinal section of blast pattern.

As can be seen in figures 3 and 4 that, the 12th and 13th holes intercept a big cavity. This cavity was assumed to create a free-face then the new holes (11^1, 11^2, 12^1, 13^1, 14^1 and 14^2) were drilled and charged. In addition to that the planned holes (20, 21, 22 and 23) had not been drilled instead of the holes 20^1, 21^1, 22^1 and 23^1 had been drilled and charged.

The eight sets of blasting have been performed in this way. The blast geometry and blasting information are given in **table 3**. The results of this approach have shown that the blasting efficiency has increased. The better fragmentation was obtained, overall production cost decreased.

Table 3 Blasting Pattern and Explosive Consumptions for Strategy III

Blast No.	N	D / mm	l_B / m	l_S / m	L / m	l_{St} / m	Explosives		
							m_{ANFO} / kg	$m_{Dyna.}$ / kg	Fuse / number
1	120	89	2.2	2.5	8.0	2	3700	80	136
2	146	89	2.2	2.5	8.0	2	4150	110	173
3	163	89	2.2	2.5	9.0	2	4150	80	189
4	174	89	2.2	2.5	9.0	2	5200	105	200
5	121	89	2.2	2.5	9.0	2	4450	80	150
6	65	89	2.2	2.5	8.5	2	1500	41	91
7	77	89	2.2	2.5	8.5	2	2200	50	97

Note: N—number of holes; l_B—burden; l_S—spacing; L—length of hole; l_{St}—stemming, D—diameter of hole.

3 Results and discussion

Different drilling and blasting strategies to improve blasting efficiency have been evaluated. The results of each strategy were compared by means of visual site investigation after blasting and calculating the total cost per ton of the broken rock.

Site investigation had shown that the third strategy had overcome the problem of unexploded ANFO. Unexploded ANFO was not seen after the blasting, and also visual inspection showed significant decrease in the number of oversize boulders.

Another proper approach to evaluate different strategies is a comparison of unit production costs. Since the objective is to minimize the production cost of per ton rock, then the resulting cost of each strategy should be calculated. For that reason, the comparable costs were estimated. These are drilling cost, blasting cost and secondary breaking (hydraulic hammer) cost. In this quarry, the required size of broken rock should be provided before loading for hauling. Therefore a hydraulic hammer is used to break oversize boulders.

In order to estimate the drilling and secondary breaking cost of per ton limestone, the unit cost of driller and hydraulic hammer has been estimated as $/h that includes ownership and operating costs. The results were 54.11 $/h for driller and 44.46 $/h for hydraulic hammer. Then the total working time of driller and hammer had been recorded for each blasting. Since the production of each blasting had been found by weighting, the unit production cost was calculated by multiplying the total working time with the unit cost of equipment and dividing the result by total production. The blasting cost consisted of the cost of ANFO, dynamite and fuse. The summary of the results is given in **table 4**.

Table 4 The unit cost of each blasting strategy

Strategy	Blast No.	L_t/m	L_c/m	R_c/%	Q/t	V_n/(m·s^{-1})	t_h/s	Dc/($·t^{-1})	Hc/($·t^{-1})	Ec/($·t^{-1})	Tc/($·t^{-1})
Strategy I	1	760.0	—	—	7548.0	38.0	29.80	0.143	0.176	0.182	0.501
	2	903.5	—	—	8925.9	37.6	13.08	0.146	0.065	0.172	0.383
	3	853.0	—	—	10444.5	37.4	25.70	0.118	0.109	0.147	0.374
	4	748.7	—	—	5597.8	37.4	4.90	0.194	0.039	0.255	0.488
	5	328.0	—	—	2750.0	36.4	0.50	0.177	0.008	0.225	0.410
	6	757.5	—	—	7168.1	37.8	3.83	0.151	0.024	0.203	0.378
	7	817.0	—	—	9101.6	37.3	1.55	0.130	0.008	0.173	0.311
	Avg.	—	—	—	—	—	—	0.151	0.061	0.194	0.407
Strategy II	1	664.5	60.0	9.03	11000	20.45	2.5	0.160	0.010	0.175	0.345
	2	581.5	59.0	10.15	7000	21.73	2.0	0.207	0.013	0.186	0.406
	3	594.5	27.5	4.63	9500	17.39	3.0	0.195	0.014	0.202	0.410
	4	601.5	9.5	1.58	6200	27.14	3.5	0.193	0.025	0.180	0.399
	5	804.0	92.0	11.44	8500	22.30	2.0	0.230	0.010	0.178	0.418
	6	333.5	59.0	17.69	3500	23.05	1.5	0.224	0.019	0.129	0.371
	7	216.5	3.5	1.62	3500	30.86	5.5	0.108	0.070	0.181	0.359
	8	600.5	28.5	4.75	6000	32.03	5.0	0.169	0.037	0.201	0.407
	Avg.	—	—	—	—	—	—	0.186	0.025	0.179	0.390
Strategy III	1	972.0	3.0	0.003	10164.0	32.90	3.00	0.157	0.013	0.197	0.368
	2	1121.5	57.5	5.130	12366.2	27.40	4.50	0.179	0.016	0.187	0.382
	3	865.5	19.0	2.200	15778.4	25.20	6.75	0.118	0.019	0.146	0.283
	4	1536.5	36.5	2.380	16843.2	31.40	5.25	0.157	0.014	0.168	0.339
	5	1142.0	39.5	3.460	11712.8	27.51	2.50	0.192	0.009	0.202	0.403
	6	492.0	67.5	13.720	5898.2	28.90	2.75	0.156	0.021	0.151	0.327
	7	616.0	73.0	11.850	6987.2	24.60	1.50	0.194	0.010	0.175	0.379
	Avg.	—	—	—	—	—	—	0.165	0.015	0.175	0.354

Note: L_t—total hole length; L_c—total cavity length; R_c—cavity rate; Q—total production; V_n—penetration rate; t_h—hydraulic hammer working time; Dc—driller cost; Hc—hydraulic hammer cost; Ec—explosive cost; Tc—total cost.

As can be seen in table 4 that the cavity length is not known for strategy I because it was not recorded. The cavity length of each hole had been recorded for strategies I and II. The lowest total cost is obtained by applying Strategy III. The obtained hydraulic hammer cost for Strategy III was about one forth of Strategy I.

However, the increase of the drilling cost is about 6%, the decrease of the explosive cost is about 11% relative to Strategy I. In general, the total average cost decreased about 15%, from 0.407 $/t to 0.354 $/t.

The relation between the cavity rate and the unit cost for Strategy II is given in **figure 5**. As can be seen in figure 5 that the drilling cost increases with the cavity rate. The main reason for that is the total drilling time is longer for holes having cavities because of cavity measurements and drill rod stockings. On the contrary explosive and hydraulic hammer cost decreases when the cavity rate increases. The reason for explosive cost is the decrease of the total explosive charge due to cavities.

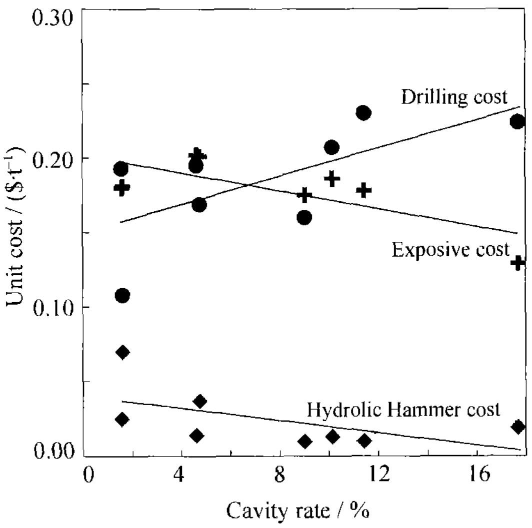

Figure 5 The results of Strategy II.

The relation between cavity rate and unit cost for Strategy III is given in **figure 6**. The conclusion drawn from figure 6 is also very similar to the conclusion drawn from figure 5. The only difference is the slope of each cost. Figure 6 provides smaller slopes than figure 5.

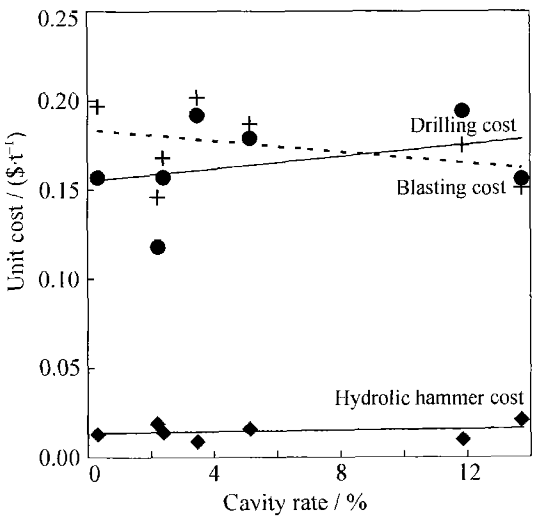

Figure 6 The results of Strategy III.

Figure 7 represents the average cost of each strategy. It is clear that the total cost was decreased. However the drilling cost is high for Strategies II and III. The reason for that is time lost for recording of cavity information.

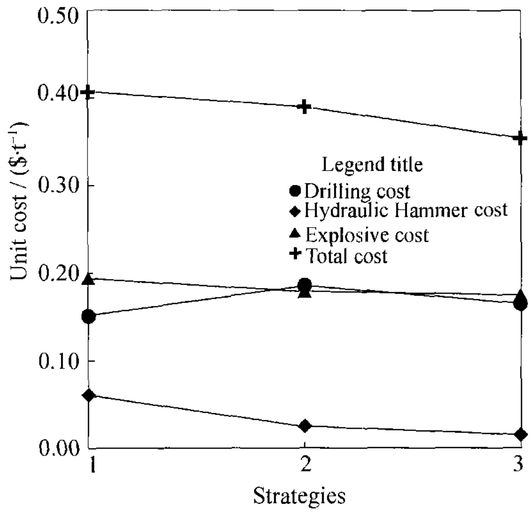

Figure 7 Comparison of strategies.

4 Conclusions

Three different drilling and blasting strategies in a quarry with karctic cavities were evaluated. It has been found that in order to increase blasting efficiency and to reduce the production cost, the shape and size of karstic cavities should be determined on the basis of information gathered during blast hole drilling. This approach has resulted 15% (0.05 $/t) decrease in total production cost. In addition to that, the need for hydraulic hammer has decreased significantly. The total drilling, blasting and secondary breaking cost has found to be 0.354 $/t, which was reduced from 0.407 $/t.

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