DESIGN OPTIMIZATION OF DRILLING AND BLASTING OPERATIONS: A CASE STUDY ON COPPER ORE MINING IN ASAREL

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ABSTRACT. Drilling and blasting are significant technological operations in open-pit mines. They directly affect the cost of extraction and processing of the rock mass and indirectly through the impact of the fragments' size of the blast material on the efficiency of the subsequent processes of loading, hauling and crushing. The purpose of this paper is to explore a methodological approach for optimization of blasting parameters based on the reduction of the specific consumption of explosives. This is achieved by examining the influence of a geometric parameter - the burden between the drill rows on the explosive effect. In addition, the correlation between the relative consumption of explosives for extraction and fragmentation per ton of mine mass and geometric parameters of blasting. Data from in-situ experiments is used for assessment according to criteria for stability of the rock massif and seismic actions caused by blasting operations.

Keywords: optimization; drilling and blasting operations; open-pit mines

ОПТИМИЗАЦИЯ НА ПРОБИВНО – ВЗРИВНИТЕ РАБОТИ ПРИ ДОБИВА НА МЕДНА РУДА В РУДНИК АСАРЕЛ

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РЕЗЮМЕ. Пробивно – взривните работи са ключов технологичен процес в добива на руда. Те повлияват директно върху себестойността на добитата и преработена скална маса и косвено - чрез въздействието на зърнометричния състав на раздробения материал върху ефективността на последващите процеси - товарене, транспорт и трошене. Авторите са насочили изследването си към методологичен подход за оптимизиране параметрите на взривяване, който се основава на намаляване на специфичния разход на взривно вещество посредством изследване влиянието на геометричен параметър – разстоянието между сондажните редове, върху взривния ефект и изследване на относителния разход на взривно вещество за добив и раздробяване на тон минна маса в зависимост от геометричните параметри на взривяване. Използвани са данни от полеви опити, които са проведени за оценка по критерии за устойчивост на скалния масив и взривно – сеизмичното въздействие.

Ключови думи: оптимизация; пробивно-взривни работи; добив по открит способ

Introduction

Drilling and blasting operations have a significant role in mining since the rock mass contains useful minerals that must be first broken, then crushed, and finally ground in mills. Drilling and blasting operations influence directly the cost of extraction and processing of the rock mass and have an indirect influence on the following technological processes.

This determines the core objectives of technological blasting, namely:

- complete removal of the rock mass within the design contour of the blasting field with a desired grain size distribution of the blasted material;
- to preserve the environment from the harmful effects that arise from the explosion to a level, considered practically safe.

The relation "mining conditions - primary explosive effect – side effects of the explosion" are complex, and some of the factors remain unknown or uncertain with a sufficient degree of reliability. This predetermines the need for constant monitoring and research in order to ensure safety, easy implementation and economic profitability of the processes.

This research is aimed at improving the parameters of technological explosions to:

- optimize the parameters of the blasting works to achieve maximum fragmentation effect, compliant to state-of-the-art mining practices worldwide.
- achieve the desired granulometric composition (particle size distribution) of the blast-cause fragmented mining mass.
- define the relationship between blast parameters and the level of seismic action of the blast.

According to the established state-of-the-art blasting practice, detailed research is carried out to determine the prime factor influencing the explosive effects - the structure of the rock mass.

The blastability zones are clearly drawn by both research and the investigated experimental blasting. For each blast field, the design of the drilling and blasting parameters is performed on the basis of:

- an expert assessment of the location of the field and
- an assessment of the structure of the exposed surface of the working field. That is the distance between the visible damages in the vertical and horizontal directions.

For each blastability zone, the integral indicator characterizing the blasting effect is determined, represented by the "optimal relative consumption of explosive (sc. specific charge)" for blasting per unit volume of rock mass and fragmentation of the rock mass with the desired grain size distribution (granulometry).

Research methodology

Rock fragmentation resulting from blasting operations has an influence on secondary fragmentation, loading, hauling, and crushing. The concept on optimum fragmentation is an interesting topic in mining engineering. There is no proper definition on optimum fragmentation, but it is considered such if it fulfils all of the following conditions:

- Minimum cost from drilling to grinding in the fragmentation chain: drilling-blasting-crushing-grinding.
- Maximum ore recovery.
- High productivity.
- Minimum impact on safety and environment.

The chosen methodology for optimization is "reduction of the specific consumption (sc. charge concentration) of explosive per linear meter of blasted mine mass" through examination of the influence of a geometric parameter, the burden between the drill rows, on the blasting effect. In addition, the correlation between the relative consumption (sc. specific charge) of explosive for extraction and fragmentation per ton of mine mass (q, kg/t) and geometric parameters of detonation – average (burden) for 1st row boreholes, spacing between boreholes in the row, burden between drill rows, is considered to evaluate the different optimization results.

This was achieved by designing and performing a test blasting in a predefined zone, in accordance to the following parameters:

- acreage of the blasting field in accordance to the development of the mining works on the defined section.

- diameter of the boreholes.

- energetic parameters of the explosive charge in the drill hole - number of the charges, length of the main and upper charge; length of the intermediate stemming; length of the upper stemming; schedule of commutation of the charges in time and space.

The drilling and blasting processes on the test field are in accordance to the established practice of the copper mine. The actual parameters of the blasting are determined when loading the boreholes.

Expert assessment is executed after test blasting by visual examination of the blasted pile. The grain size distribution of the fragmented rock mass (percentage of oversized rock fragments and average piece size) is investigated.

The excavation of the material is monitored closely. After the loading, the ejection distribution of the rock mass is documented at the level of the floor and inside the borders of the blasting field.

The quantitative indicators of the test blasting - extraction of mining mass per linear meter of drilling and relative consumption of explosive are determined.

In-situ test

Copper ore mine Asarel-Medet is a world leader in the open-pit development of copper deposits with a content of less than 0.5%.

Asarel copper porphyry deposit is located in the Razslatitsa area, Sredna Gora, 8 km northwest of the town of Panagyurishte, Pazardzhik region.

The geological structure of the Asarel deposit consists of Proterozoic metamorphites, Paleozoic granites, Turonian sediments, upper cretaceous andesites, tuffs, tuff breccias, diorite, quartz-diorite, granodiorite porphyrites and monzodiorite porphyrites.

The local tectono-structural position of the Asarel deposit is quite complex. The Asarel graben - syncline, locked between the Mial and Petrich faults and the area of the deposit are strongly torn by three systems of faults with different age relationships - northwestern, northeastern and meridional. The mutual intersection of the disturbances from these systems has formed a block-fault character of the deposit.

The blasting works in the Assarel mine are performed in complex geological conditions. The combination of multiple fault zones, inhomogeneous rocks, rock massifs with varying degrees of cracking and alternation of dry with waterlogged boreholes (even within a single blast field), springing and flowing water through boreholes complicate daily blasting and require an unique approach for almost every blast.

Mining and technical conditions:

- semi-trench excavation in the presence of a free surface parallel to the length of the borehole.

- bench height from H = 11 m to H = 15 m.

- angle of inclination of the bench $\alpha = 75\ 0^{o}$.

- design diameter of the blasting boreholes - d = 251 mm.

- design relative consumption of explosive - q = 0.190 kg / t (determined for difficult for blasting zone).

The relationship “relative explosive consumption - explosive effect” is explored by adjusting the distance between boreholes in accordance to the adopted approach.

The test is limited in the area of the blast field with a bench height $H \geq 11.5$ m to take into account the requirements for normal operation of the drilling charges (ratio between geometrical parameters and diameter of the drilling).

Expert analysis found that the rock mass in the slope of the bench is intensely cracked to a large block structure.

An established practice when performing blasting operations in the Asarel open-pit mine is to make control measurements of the charge length in case of doubt for leakage or washout of explosives through cracks in the massif. In case of a detected problem, the borehole is recharged with additional explosives. In this way, the blasting squad secures achievement of the planned results in terms of ejection and comminution of the rock mass. This practice increases the relative cost of blasting and the risk of harmful effects. In this regard, it is recommended, that when performing blasting works in the fault zones of the Asarel open-pit mine (in the presence of running water) explosive loading should be applied in the boreholes through a strong polymer liner. The liner will protect the explosive from leaching and will prevent it from being displaced into the borehole by the sand carried by the running water. This will contribute to the improvement of the economic indicators of the blasting technological process, due to the elimination of the need for recharging.

Blast effect

The evaluation of the explosive effect is made by the following steps:

1. overview of the blasting pile – visual assessment: normal compared to previous blasting works in this area; oversized rock pieces and average grain size.
2. operation of the excavator - assessment of granulometry and level of the floor when the field is completely excavated.
3. quantitative indicators - design volume - 90624 t; total amount of explosives - 15950 kg (mass of charge explosive); relative consumption of explosive - 0.176 kg/t; mining yield per linear meter of drilling - 183.08 t/m.

Comparison and evaluation of results

The test blasting is performed according to a new blasting pattern with a change of the following parameters:

- Spacing between boreholes in the row.
- Burden between drill rows. In a rectangular grid 9,50 x 9,00 m (relative distance = 1.055) and boreholes with lengths from 5 m to 10 m (Figure 1).

The newly designed blasting field is with an area equal to the regular but it reaches design savings as follows:

- Field drilling: 34 m.
- Quantity of explosives per field: 834.5 kg.
- Relative consumption difference: - 0.006 kg/t.

Analysis and conclusions

The results of the test blasting pattern prove the suitability of the methodology. The same granulometry of the fragmented rock mass was achieved with the reduced relative consumption of explosives. This new approach can lower the cost of blasting operations, reduce the side effects on the environment due to the lower quantity of explosives used and increase the productivity by reducing the boreholes. Therefore, the used methodology, based on "reduction of the specific consumption of explosive per linear meter of blasted mine mass" fulfils the criteria for optimization.

Table 1. *Comparison between the results of regular blasting and test blasting*

	Number of boreholes	Σ length of boreholes	Σ length of the explosive charge	Quantity of explosives for the blast field	Relative consumption of explosives
	-	[m]	[m]	[kg]	[kg/t]
[1]	[2]	[3]	[4]	[5]	[6]
Regular grid (9mx9m)	43	400.0	163.6	9818.2	0.121
Test grid (9.5mx9m)	41	366.0	149.7	8983.6	0.115
Difference	-2	-34.0	-13.9	-834.5	-0.006

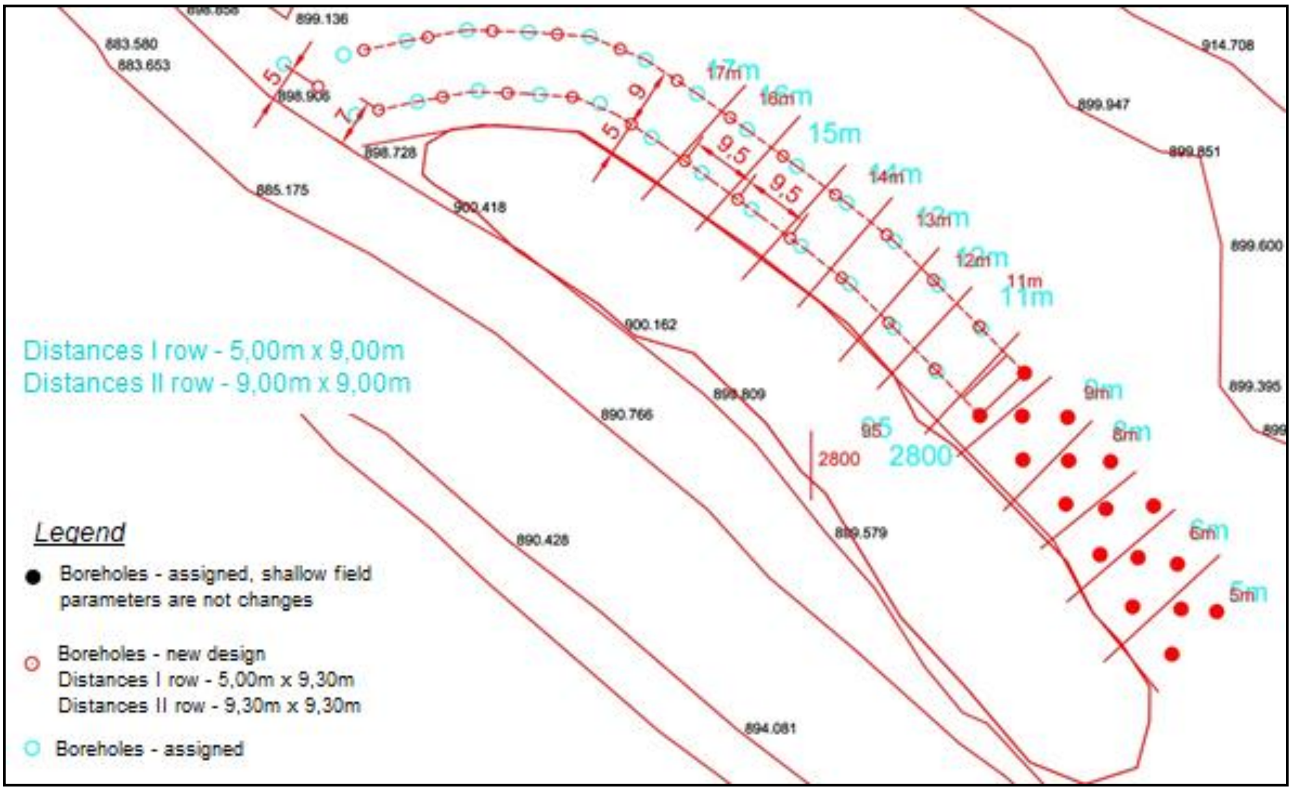

Fig. 1. Plan of the blasting field for the in-situ test – Asarel mine

Design recommendations

Contour blasting by the method of pre-splitting of the rock massif is recommended in order to preserve the integrity of the massif. Blasting technology includes blasting the pre-split row and blasting the production rows to eject the rock mass in front of the pre-split crack (Figure 2)

The boreholes for the pre-split row are drilled with a diameter $d_c \leq 110$ mm above the design angle of the slope of the non-working bench.

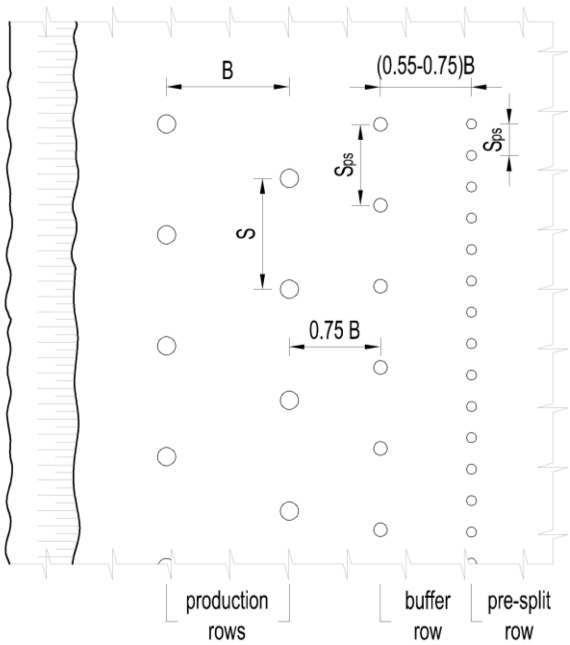

Fig.2. Recommended drilling pattern (pre-shielding of the rock massif)

The recommended diameter of the boreholes from so-called buffer row is d_c = 165 mm. The blasting parameters: B and S of buffer row of boreholes are with values of 75% of the determined for the given diameter of the production boreholes. The amount of charge is 55-75% of the defined boreholes for the production. The blasting parameters of the pre-split row are presented in Table 2.

• the initiation of the charges is carried out by means of detonating cord - /two parallel pieces/.

• Intermediate stemming - air.

The decoupled chained multi-deck blasting charge is constructed of water resistant explosive cartages /pack/ „Elatzit 710“ with diameter Ø 5 0mm and length 400 mm.

The charge should be centered along the axis of the borehole. The configuration of the explosive charge inside the blast-hole is given on figure 3.

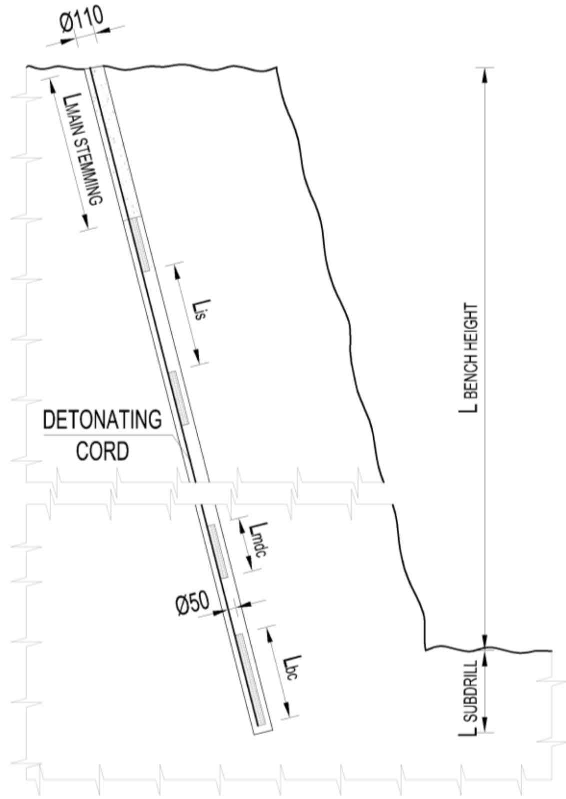

Fig.3. Configuration of the decoupled chained multi-deck blasting charges for pre-splitting

Table 2. *Comparison between the results of regular blasting and test blasting*

Diameter of Drilling	Diameter of Charge (cartridge)	Spacing	Parameters of the blasting contour						
			Bottom charge		Multi-deck chained charge			Stemming	
			weight	length	weight	length	quantity	main	intermediate
[mm]	[mm]	[m]	[kg]	[m]	[kg]	[m]	pcs	[m]	[m]
≤110	$\leq 0.5d_c$	1.00	2.50	0.50	0.50	0.30	14.00	1.50	0.70

According to the established blasting practice, the parameters are determined as follows:

• the charges from the pre-splitting row are detonated first, following the production boreholes of no less than 100ms.

• the boreholes for pre-splitting row are drilled with the same angle and plane of the non-working bench.

• blasting sequence – instantaneous.

Recommendations

Based on the study, the following recommendations are proposed:

4. In a blasting field the distance between a drilled borehole and the next (i.e. geometrical parameters) shall be adjusted depending on the established properties of the rock massif obtained from the previous borehole.

5. Special attention must be given to boreholes in severely cracked structures and/or in the presence of water. Such cases would require an individual approach with appropriate technology and measures, e.g. applying a polyethylene liner.

6. In some cases, accommodating an alternative approach, such as the "Hydrox" system can be beneficial. Applying this methodology can assist to:

- reduce the impact of plastic deformations in the rock massif and thus,
- improve the overall and local stability of individual steps and benches.
- reduce the harmful impact on the environment.
- decrease explosive consumption and so the total cost of the process.

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