OPTIMIZATION OF BLASTING PARAMETRS IN OPEN CAST QUARRIES OF EL HASSA-BOUIRA (NORTHERN ALGERIA)

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ABSTRACT

In recent years, Algeria has known a rapid growth in the construction projects, such as: buildings, roads, and infrastructure, which increased the demand for aggregates production in quarries. However, vibrations and noises generated by blasting operations have a negative impact on the residents living nearby. For this reason, blast tests were performed in the open cast quarries of the company Sarl El Hassa-Bouira (Northern Algeria) using instantaneous electric detonators (IED), micro delays (MDD) and delays (EDD) to minimize the instantaneous load. We also minimized noise and vibration during the blasting. A seismograph allowed us to take further measurements.

Keywords: Quarry, blasting, seismic and acoustic vibrations, electric detonators, rock fragmentation.

1 INTRODUCTION

Blasting rock is the most important link in the mineral rock extraction technology chain. Fragmentation has an important role in a number of industrial processes in which fragmentation is required in the most efficient and controlled manner. Thus, the development of safe and effective methods for blasting rocks has a considerable interest in the mining industry. Successful felling operations can lead to the most appropriate distribution of rock fragments with minimum production cost. Blasting must achieve the production objectives while ensuring protection of the immediate environment of the quarry. The vibrations as well as the noise generated by the blasting are a particularly sensitive point for the neighbouring populations.

Mining blasts mean a controlled use of explosive charges adhering to a precise timing sequence based on an assigned blasting order. Changing the timing may lead to a changed order in blasting and, thus, a failure of blasting sequence. This may bring about high levels of vibration, poor fragmentation, and/or an undesirable rock mass movement. Although timing is important in determining mine blast results, methodologies or tools to assess the performance of complete blasts based on a delay type and timing sequence are rare [1].

Controlled Rock Fragmentation means suitable size distribution of the fragmented rock after blasting, for higher efficiency and lower costs in loading, transport and crushing of the blasted rock at mines, quarries and construction works. Oversize (boulders) should be minimized, and sometimes undersize (fines) to increase the product value from quarries [2]. Rock fragmentation from blasting is determined by many factors, namely the properties of the rocks in-situ, e.g. jointing and fracturing, properties of the explosives used, blast pattern design and shot timing. As compressive strength, porosity, density, Young's modulus, Poisson's ratio, and rock fracturing and jointing cannot be altered, any fragmentation optimization must fit within the limitations placed by the rock mass. However, fragmentation may be influenced by the properties of explosives, blast design, and timing. Among the properties of explosives that affect fragmentation are Chapman-Jouget (C-J) pressure, density of explosive and the detonation velocity of explosive. As for the blast pattern design elements, there is burden, spacing, powder factor, stemming length and type, hole depth and diameter besides sub-drill length [3].

The examination of how fragmentation occurs around a single blast hole is a starting point to understand the mechanisms of rock fragmentation. The process starts with the detonation of explosives in a hole to transmit a radial shock wave into the rock mass. Via exceeding the uniaxial compressive strength of the rock, the detonation and initial shock wave lead to crushing around the hole. Nearby the hole, the shock wave attenuates to a stress wave [3]. This continues, and breakages occur. As soon as the compressive wave reaches a free face, it shows in tension, thus, causing failure cracks and bench face spalling [4, 5]. After the stress wave, other factors of gas pressure follow. The pressure in the hole due to gas increases the radial fractures, and the material flaws expand. Dominant fractures grow with a rise in the fracture zone [4]. Gas pressure dissipates when it reaches the free face. The gas pressure bows the bench face and pushes it forward [5]. It is important to check the impact of fragmentation caused in single holes, including the stress waves from secondary holes [3]. Subsequent fragmentation occurs due to the collision between blasted rocks and impact of the rocks with the ground [6]. The basic principles of blasting optimization may be used as guidelines to improve fragmentation via modifying the geometry of blast pattern. As a result, smaller particle size fragmentation may occur via decreasing the burden and spacing. However, this

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fragmentation is not necessarily optimized as reducing the pattern geometry may lead to a rise in fines and other side-effects [7].

Given the high number of recurrent vibration nuisance complaints from inhabitants living in the proximity of mining sites due to the use of explosives, which is the consequence of the increase in production that must meet the demand, we consider that it is imperative to present today the subjects related to the use of explosives. We dare to hope that our modest contribution will make it possible to recall the main measures to be taken during the development of blast plans and use of explosives. This work aims to minimize the problems mentioned above by a mixture of use of instantaneous detonators (IED), micro-delays (MDD) and delays (EDD) in the same blast plan, despite the presence of surface miner that replaces the felling by explosive close to the inhabitants but this machine is doomed to failure in Algeria because of the elevation of cost price of one ton of extracted rock in comparison with the normal chain (drilling, blasting, crushing). The objectives of the present paper are to reduce the negative impacts generated by blasting operations on the safety of residents living nearby the quarries and to optimize the fragmented rock quality.

2 BLASTING DAMAGE

Several studies have been published on blast damage criteria for buildings and other surface structures [8, 9], where many criteria relate blast damage to peak particle velocity as a result of the dynamic stress connected to explosion. Although gas pressure plays a role in the process of rock fragmentation, this damage is understudied. The strength of jointed rock masses seem to be affected by the level of interlocking between the discrete rock blocks separated by discontinuities. The tensile strength of the discontinuities is taken as zero and a small amount of opening or shear displacement will embody a dramatic drop in interlocking of the blocks. The high-pressure gas that expands from the explosion enters the discontinuities, thus causing a breakdown of block interlocking. The distance from the explosive charge and the in-situ stresses will influence the size of damage or strength reduction. The extent of damage caused by gas pressure may fall with the depth below the surface and surface structures. For example, slopes are usually susceptible to gas pressure related to blast damage.

Fracturing related to release of load is another cause of blast damage [10]. This is often explained using the analogy of dropping a heavy steel plate onto a pile of rubber mats. The rubber mats are compressed until the momentum of the falling steel plate has been exhausted. The highly compressed rubber mats accelerate the plate in the opposite direction and in ejecting it vertically upwards, separate from one another. Similar separation between layers is responsible for the ‘tension fractures’ often seen in open pit and strip mines, in which poor blasting practices contribute to wall instability [11], and vertical cracks of up to 55 m. Hoek in [12] argues that blasting is not to induce deep-seated instability in extensive opencast slopes. This is explained by the size of the failure surface of several hundred meters below the surface in a very large slope. In addition, the failure surface is not generally aligned with the blast-induced fractures [12].

3 NOISE AND VIBRATION FROM BLASTING

Base on the Guideline ABN 46 640 294 485 - Noise and vibration from blasting [13], if not conducted properly, blasting is connected with excessive noise and vibrations, also leading to damage on engineering structures. Moreover, people are sensitive to very low vibrations [13].

Outdoor measurement of airblast overpressure

Airblast overpressure is measured at a site:

a) exposed to the direction of blasting;
b) in the distance of minimum 4m from any noise-affected building or structure, or within the boundary of a noise sensitive place;
c) 1.2m and 1.5m from the ground [13].

Outdoor measurement of ground vibration

In the measurements, a ground-borne vibration transducer is to be attached to a mass of at least 30kg to ensure good coupling with the ground where the blast site and the measurement site cannot be shown to be on the same underlying strata. The mass must be buried so that its uppermost surface is levelled with the ground surface. The ground-borne vibration transducer is placed at a distance of not less than longest dimension of foundations of a noise-affected building or structure, away from such a building or structure and be positioned between that building and the blasting site. Airblast overpressure and ground vibration requirements must be complied with in monitoring and recording assessment.

When observing the compliance with airblast overpressure and ground vibration requirements (including when investigating community complaints about noise or vibration impacts), the following information must be collected and recorded:

1) Maximum instantaneous charge (MIC) in kilograms (kg)
2) Location of the blast within the quarry (including which bench level)
3) Airblast overpressure level, dB (linear) peak
4) Peak particle velocity (mms^{-1})
5) Location, date and time of recording the MIC
6) Meteorological conditions (including temperature, relative humidity, temperature gradient, cloud cover, wind speed and direction)
7) Distance from the blast location to any noise-affected buildings or structures, or the boundary of any noise sensitive place [13].

4 MAIN ASPECTS OF BLASTING IN STONE

Quarries Bench Excavation

For sequential excavation of benches (or steps) of the rock, quarries or open-pit mines use the drill and blast technique. Among the geometric features there is a grid of drill holes with spacing (S) along the free face (the wall of the bench) and spacing (B) across the wall, height (H) of the bench and corresponding length (L) of the drill hole, and diameter (D) of the drill hole. Every hole is regarded as having to break its own area (AR). In the blast design, we take into account the rock type, the ratio of B to D, the type of explosive, the delay interval between explosions in the same blast and the explosive charge weight per delay [14].

Ground Vibrations Generated by Blasting

The resulting seismic waves generate ground vibrations from blasting. The primary or compression waves have the highest velocity and first arrive at a point or particle. The secondary or shear waves follow. The compression and shear waves are referred to as the body waves. The slowest and last to arrive is the rayleigh wave, being the major component of the surface waves [15, 16]

According to [17], the velocities of compression and shear waves, VC and VS respectively, are:

$$(VC)^2 = \frac{2G(1+\upsilon)}{p(1-2\upsilon)} \quad (1)$$

$$(VC)^2 = \frac{G}{p} \quad (2)$$

where $G = \frac{E}{2(1+\upsilon)}$, E= Young's Modulus, υ = Poisson's Ratio and p = density of the medium [17].

5 EXPERIMENTATION

Geographical situation and nature of the geological structure of the quarry Sarl El Hassa

The aggregate quarry operated by Sarl El Hassa, which is a limited liability company, is located approximately 8km northwest of town of Ahl El Kser in Bouira city (Algeria). Its geological structure is mainly composed of marl schist and pelites, and the whole is capped with crystalline limestone.

Blasting parameter test:

Fragmentation of rocks in the Sarl El Hassa quarry is based on the availability of explosive products and accessories in Algeria (absence of Nonel product), so it is usual to use the EDD just in underground mines to minimize the vibrations and risks of collapse of the galleries generated by the blasting. On the other hand, professionals in Algeria use just IED (number 0) and MDD (number 1 to 12) and thus cause problems among residents mentioned above. Therefore, this test combines between the IED, MDD and EDD, then, the drill plan for this test modified a little compared to the planes pregnancies, so the calculation parameters results are shown in Table 1.

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Table 1. Blasting parameters

Parameters	**Using EDD**	**Using IED et MDD**
Holes number	83	83
Holes length	10 m	10 m
Bench Height	9 m	9 m
Burden	3.8 m	3.5 m
Spacing	4 m	4 m
Holes diameter	102 mm	102 mm
Holes Inclination (β)	85°	85°
Number of rows	03	03
Sub-drill	1 m	1 m
Charge of explosive in a hole	54 kg	49 kg
Total amount of explosives (Temex + Anfo)	4 067 kg	4 067 kg
Specific Consumption	390 g/m^3	390 g/m^3

Use of delays and instantaneous charge

In this experiment, we used the instantaneous detonators (IED), a micro delay (MDD) of 25 ms and a delay (EDD) of 500 ms, they are of low intensity and their distribution is illustrated in Table 2:

Table 2. Holes number blasted in the same time

	IED	MDD												EDD											
	0	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Holes number	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

The maximum instantaneous charge = the number of holes exploded at the same time * the amount of the explosive charge in one hole, then;

Instantaneous charge of IED and MDD is, 4 * 49 kg = 196 kg.

Instantaneous charge of EDD is, 3 * 54 kg = 162 kg.

The holes are primed according to the type of electric detonator. The IED and MDD are connected out of hole with the detonating cord 12 g (Fig.1), which in its turn causes the explosive charge to knock down a quantity of rocks. On the other hand, the EDD connects directly into the explosive cartridge Temex and the cord connected in it inside the hole (in the middle or at the bottom depending to the detonator thread length). The cord supports the weight of the cartridge and prevents for cut of thread during the priming operation; on the other hand, it has been used for safety by the possibility of exploding the explosive charge in case of failed holes. It is enough to cede 0.5 m of detonating cord and 2 m of the blasting thread outside each hole, so the connection of the electric blasting thread of the volley is made in parallel and plugged in the normal exploder for blast.

Using of EDD out of holes is forbidden because the total failure of blasting due to big delay of which will cut the primer of neighbour and back hole.

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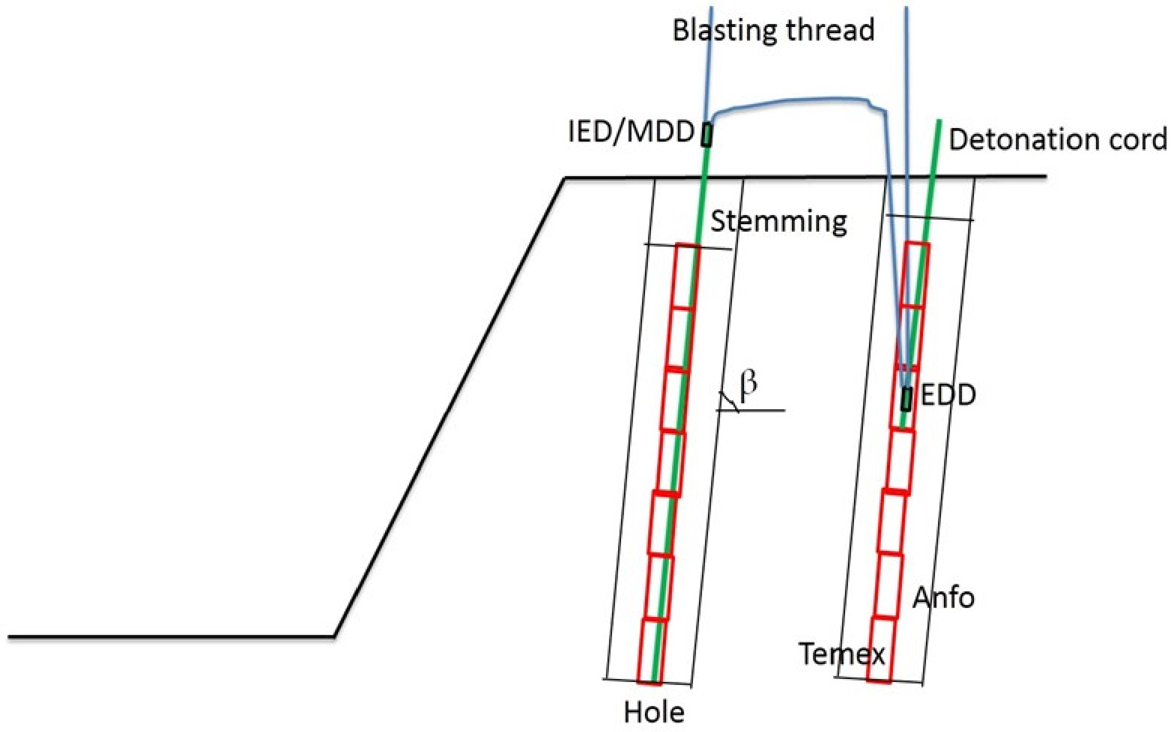

Figure 1. Priming schema of IED, MDD and EDD in holes

In the absence of national norms for speed of vibration, reference was made to the limits set by the French norm, which are the law of Chapot who classifies infrastructures and constructions in three categories:

A: poor grade, deformed walls, mortar without adhesion.
B: construction of average quality.
C: construction of good quality mechanical (solid of walls and foundations)

The environment quarry of Sarl El Hassa is continuous in view of the infrastructures to be protected. They are located on the continuity of limestone formations, which are the object of blasting. Moreover, we take into account:

1- Speed of seismic wave propagation.
2- Quality of construction.

Considering the fact that all constructions and other structures close to the blasting zone are of bad quality (category A), it can be deduced that the vibration velocity of the seismic wave caused by the blasting can reach 5mm/s without any risk.

The measurement point (geophone) attached to the concrete base of the school located 2000m from the blasting point (Fig. 2).

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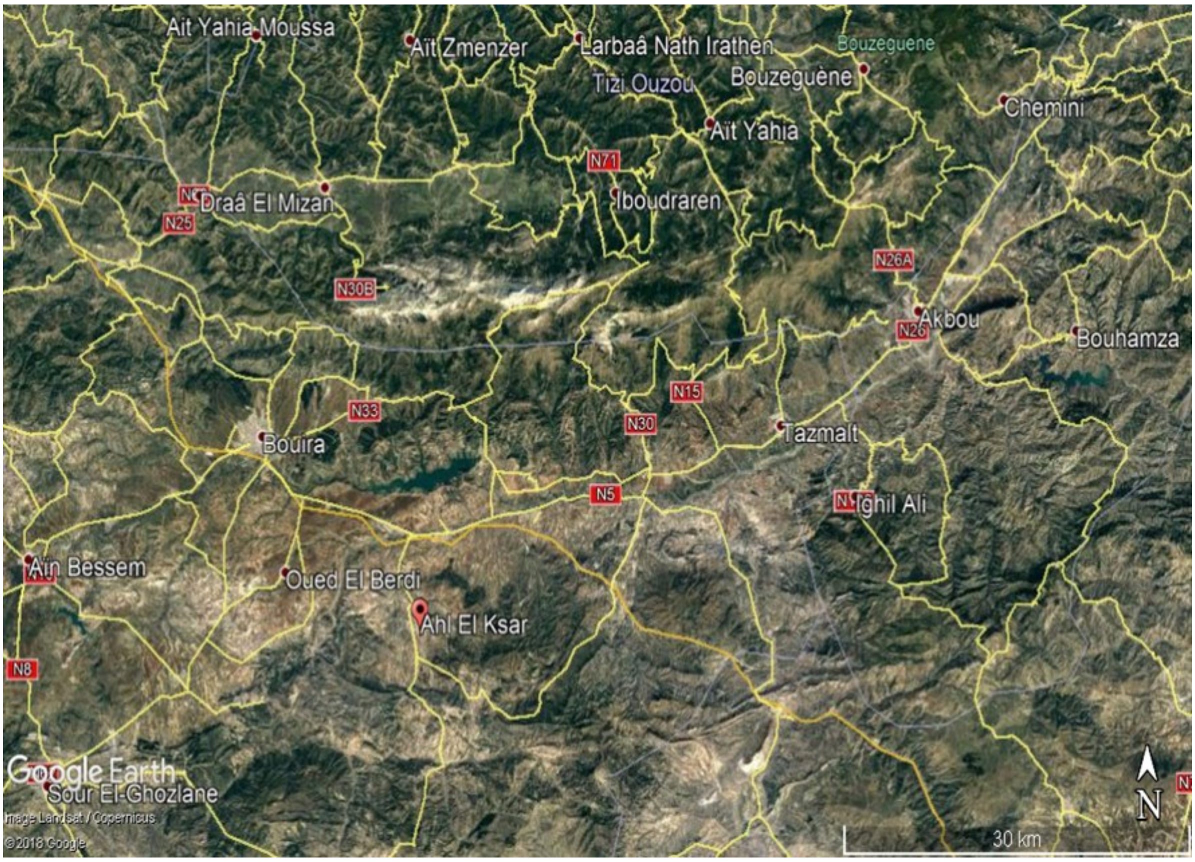

Figure 2. Situation of the quarry compared to residents

6 MEASURING INSTRUMENT

We used a measuring instrument DELTA SIS 113 three-dimensional geophone of second generation, the characteristics of which are in Table 3.

Table 3. Characteristics of three-dimensional geophone

Denomination	**Delta Seins**
Maker	Air system and SIMI
Norm and conformity	ANFOR NF E90 20
Seismic measurement range	0.1-32 mm/s in standard
Tripping threshold	1 mm / s adjustable in steps of 0.1 mm/s from 0.5 mm/s
Acoustic measurement range	0.06 to 5 mbar 110 to 147 dB gross
Acoustic tripping threshold	Adjustable in steps of 1 dB from 115 dB (10 Pascal)
Exploitation software	Whrite 2003

7 RESULTS AND DISCUSSION

Vibration wave

The vibrations are the part of energy transmitted by the ground. The seismograph captures the first wave generated by the blasting of the first explosive charges (number 0) which has an instantaneous charge of 196kg and then the seismograph will pick up the vibration wave twice after 4 seconds, which is generated by explosion of explosive charges of EDD holes number 4, which has a quantity of 162kg.

However, no seismic vibration value was recorded at the target point, which was 2000m from the blasting points (school and village habitations). The maximum unit load of this test is increased to 196kg, for a total blasting load of 4067kg.

Acoustic wave

This wave corresponds to the part of energy transmitted in the air by the blasting. For that reason, the tolerated limit is 130dB. While in our case, the device has not recorded any value because the acoustic wave is getting weaker before the village is reached.

The total duration of rock mass explosion is 6300ms (Fig. 3) due to the separation of vibration and acoustic waves generated by the instantaneous charge, which is also an essential factor for the reduction of damage related to blasting. These delays contribute furthermore to keeping the shape of bench and minimizing back-blast effect caused by the shock wave that will influence the next holes drilling.

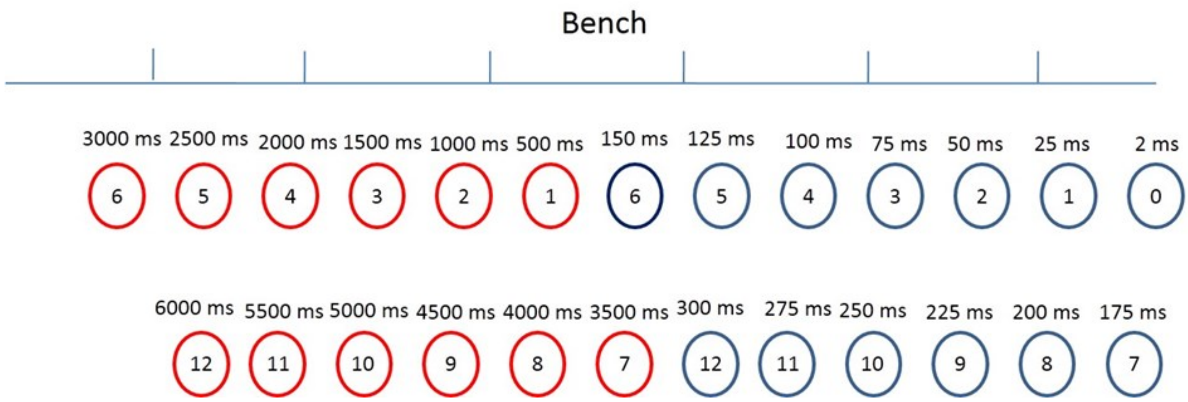

Figure 3. Time of detonation of instantaneous charges

We observe that the slope angle of bench during the use of IED and MDD (Fig. 4) is higher (with a little foot exit) than when blast by the EDD (absence of feet), despite that the holes are drilled with the same inclination (85°), so we can explain this deference by the high rate of energy loss when we use IED and MDD, conversely there is a good performance of it when we use EDD. On the other hand, there is a weak result of fragmented rocks dispersion when using this latest in comparison with other detonators.

In order to achieve a good blasted fragment result, the length of stemming must be minimized when priming by the EDD because the explosive charge is working inside and does not yield a large amount of energy to break up the stemming area. In addition, the quality of blast result (Fig. 5) which does not contain out jigs, also an easy loading of blasted fragments by hydraulic excavators for its transportation to the crushing station.

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Figure 4. Time of detonation of instantaneous charges

Figure 5. Blasting results

8 CONCLUSION

Thanks to the combination of the detonators IED, MDD and EDD in the blast plan, the waves of seismic vibrations and acoustic are minimized with regards to the nearby houses and local residents. On the other hand, the result of blasted fragments is good where the primary crusher made no stop at feeding; also, there is no exit of feet and a good shape of the bench.

In this test, 43% of the EDD were used in relation to the total number of detonators, so the results of the seismic and acoustic vibration waves are based on the percentage used and to do this, studies will be carried out later in order to know the optimal rate to get a discrete blasting.

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