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Enhancement of blasting techniques for reducing seismic and acoustic nuisances: A case study of El-Hassa Quarry, Algeria

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Summary

The minimal environmental impact, the size of the fragments obtained, and the maximum amount of blasted rock are major concerns for optimizing blasting in mines. The study undertaken in this work allowed us to clarify some points related mainly to blasting. The significance of the latter comes from the fact that it is the main operation in a technology chain, on which the success of extraction technology and exploitation in general depends. Seismic waves, sound waves, and their effects on the environment were always a substantial problem. In this context, significant results were obtained by using the technique of combining electric detonators with micro delays (EDM) and delays (EDD) whose use of a sequential exploder gave a wide interval to decrease the instantaneous load by the possibility of having a blasting with 231 delays. Therefore, the decrease in particulate speeds and vibrations facilitates protection of the environment as well as the elimination of noise.

Keywords

blasting • seismic • electric detonators • sequential exploder • exploitation

1. Introduction

A widespread practice in quarrying activities involves utilizing explosives to break down rock formations [Coltrinari 2016, Pandula et al. 2022], where controlling the blast action is crucial for improving energy efficiency. The process is aimed at producing shattered rock masses with predetermined coarseness criteria.

The vibration characteristics induced in underground structures by nearby surface blasting are notably influenced by factors such as explosive weight per delay, travel distance (depth), and the properties of the transmitting media, including elastic modulus and density [Singh et al. 2015].

On the one hand, the detonation of explosives and explosive mixtures leads to a swift change in state, involving the transformation of the unstable chemical components of explosives into more stable detonation oxides. These oxides are present in all three aggregate states, predominantly as gases and dust [Mikić et al. 2017].

On the other hand, the environmental repercussions of mining blasts can pose risks to both objects within the mining zones, and those in proximity to mining operations [Hidayat 2021].

Historically, rock blasting relied on suboptimal empirical designs, leading to inefficient fracture and fragmentation. Incorrect detonator placement in current practices results in wasted energy and poor stress distribution, yielding inadequate fragmentation. Following stress wave theory, Zhang determined that placing a single detonator in the middle of the explosive column in each blast hole optimizes the results. Implementing this insight in 40 sublevel caving production rings resulted in a remarkable 107% increase in ore extraction compared to conventional methods [Ylitalo 2021].

The ground vibrations generated by a blast carry the potential to inflict substantial harm on neighboring buildings and structures. It is widely recognized that these vibrations are influenced by numerous factors, such as the type and the properties of the rock, geological parameters, the maximum charge per delay, the distance between the structure and the blasting site, blast geometry, and the total charge [Balamadeswaran et al. 2016].

When assessing the performance of blast timing, the current practice indicates that the performance should be evaluated according to the reliability of the individual detonator, for instance, the misfire rate, and detonator life time. However, for a production blast, the analysis should be conducted while taking into account the entirety of the blasting system, meaning that we should examine all of the detonators involved instead of just one as traditionally performed. In other words, it is necessary to include all the interdependent relations in addition to single component reliability [Silva and Gernand 2018].

Given the intricate interplay between detonation waves and shock waves in multipoint detonation, there is limited literature on harnessing in-hole detonation wave interactions with electronic detonators in bench blasting operations. Certain conclusions regarding the dual initiation mechanism remain insufficiently acknowledged, with conflicting perspectives in existence. Hence, there is a need for an in-depth examination of the interactions between detonation waves, shock waves, and the rock mass during dual initiation. Such multifaceted study should aim to derive qualitative principles and quantitative insights, unveiling the transmission of explosive energy and the rock-breaking effects within the context of dual initiation in blast holes [Leng et al. 2021].

Per Anders Persson [Gladious et al. 2016], who designed the non-electric initiating method known as NONEL, put it on the market in 1972. All cast boosters, dynamites, and cap-sensitive explosives are compatible with NONEL products. Nonel is a shock tube detonator used to start explosions. It is typically used to blast rock in mines and quarries as well as to destroy buildings.

In turn, the most recent innovation in electronic detonators has been created in 2022 by Hanwha Company called Hanwha Electronic Impacting Framework 2nd Era (HEBS II) [Hanwha 2022]. This electronic detonator contains a timing precision of 0.02%, delay timing of up to 50,000 ms, and it is backed by electronic gadgets with an Android Framework. This exposition describes how the advancement of electronic detonators within the start framework enhances efficiency and security in impacting compared to Nonel.

The main objective of this work is to present a new blasting technique in quarries to minimize seismic and acoustic vibrations in the conditions found in the El-Hassa-Bouira quarry.

2. Blasting techniques solutions

A solution must be found to the problems pertaining to the use of explosive substances at mining sites. Generally these problems are related to seismic and acoustic nuisances.

In view of the above, we present a study proposing a new blasting technique, whose reliability will be validated using the law of Chapot.

As a witness of disasters caused by seismic and acoustic nuisances, various cracks in the walls of nearby houses are shown in Figure 1.

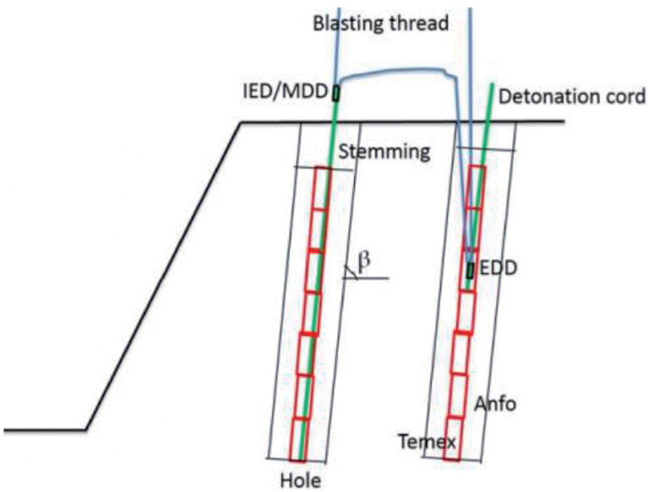
Our main objective is to minimize the problems mentioned above by reducing the instantaneous charge, and by using a sequential exploder with a mixture of detonators: micro delays (EDM) and delays (EDD) in the same blast plan (Fig. 2). Although there exists a 'Surface Miner' which replaces the explosive slaughter close to the inhabitants, this particular machine is doomed to fail in Algeria due to the increase in the cost per one ton of rock extracted compared to the typical extraction chain (drilling, blasting, and crushing).

3. Blasting parameters

The felling of rocks in the El-Hassa quarry is based on drilling and shooting works, the parameters of which are presented in Table 1.

Source: Authors' own study

Fig. 1. Cracks in the walls of nearby houses



Source: Remli et al. [2019]

Fig. 2. EDM and EDD priming scheme in holes

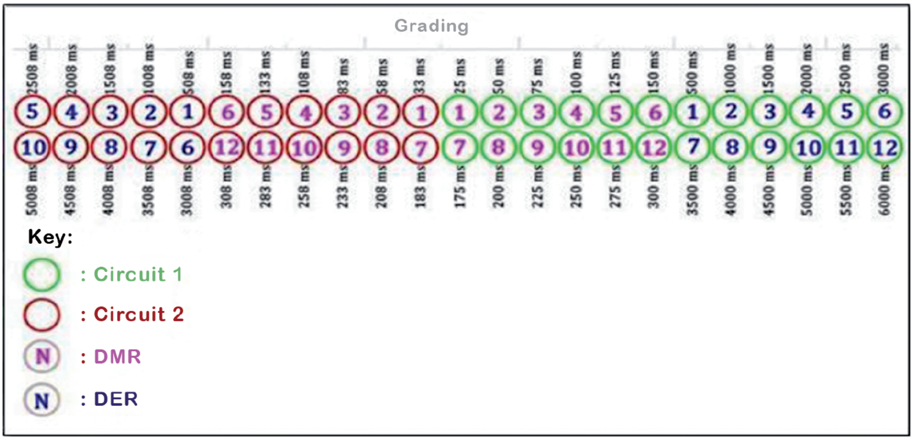
Table 1. The parameters and the distribution of detonators within the blast holes

	EDM												EDD												
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1st Circuit
Number of holes	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	2nd Circuit
Number of holes	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	/	/	
Hole diameter [mm]	102																								
Bench height [m]	15																								
Depth per hole [m]	16																								
Stemming [m]	3.5																								
Explosive quantity per hole [kg]	85.86																								
Total quantity of explosives [kg]	3950																								

4. Performing the technique on site

The blast plan in El-Hassa quarry consists of 46 holes. These holes are distributed in 2 rows (with 23 holes in each row). The priming of explosive charges is conducted by combining the electric micro delay and delay detonators. Linking these with the sequential exploder is performed in two (02) circuits.

The priming of the charges is conducted outside the holes depending on the type of electric detonator. The EDMs are connected with a detonating cord (12g) outside the hole, whereas the priming by the cord is done in the upper cartridge (downward lateral priming) (Fig. 3).



Source: Authors' own study

Fig. 3. Analysis of the duration of instantaneous charges' detonation

In turn, the EDDs connect directly to the (Temex) explosive cartridge (or Samex/Marmanit…), and the thread of the delayed detonators is 9 m. It is enough to cede 1.5 m of blasting thread outside each hole to be connected and plugged into the sequential blaster for firing.

In practical terms, considering the features of sympathetic detonation, it is feasible for the complete detonation of explosives in blastholes to occur without the need for detonating the cord, provided that the critical distance between two explosives is sufficiently large [Ma et al. 2020]. Removing the detonating cord also minimizes the noise due to its detonation. For this reason, some companies such as El-Hassa, SGMSG, GICA... etc., have signed a request to increase the length of the EDM thread in order to completely eliminate the use of the detonating cord.

Utilizing EDD (Electronic Delay Detonators) beyond the designated blast holes is forbidden, as it poses a risk of a complete blasting failure caused by substantial delays, and that could sever the connection with neighboring primers and the rear hole [Remli et al. 2019].

5. Time-Based Blasting Parameters

The total duration of the rock mass explosion is 6,000 ms (Fig. 4) due to the separation of vibration and acoustic waves generated by the instantaneous charge, which is also an essential factor in reducing blasting damage. These delays also help to maintain the shape of the bleacher as well as minimizing the rear effect caused by the shock wave that will influence the next holes to be drilled.

Source: Authors' own study

Fig. 4. Distance between the blasting site and measurement point (Boudiaf Mohamed MS)

6. Chapot's Law

Pierre Chapot has made a significant contribution to the development of knowledge in the field of geophysics applied to public works with a remarkable participation in his research in the field of the propagation of vibrations in the ground. He formulated an equation linking the vibration velocity measured at a D distance and the energy of an explosive blast [Chapot 1981].

$$V = k\left(\frac{D}{\sqrt{Qu}}\right) - \alpha$$

where:

V – vibration speed in mm/s,

D – the 'blasting–sensor' distance in m,
Qu – the unit load (instantaneous) of explosive in kg,
K – the site coefficient,
α – coefficient characterizing wave mitigation.

$$Qu = \frac{Qtot}{Nd}(\text{kg})$$

where:
Qtot – total amount of explosive per blast,
Nd – number of detonations

for the use of a conventional exploder with instant "IED" detonators.

$$\text{Nd} = 1 \text{ detonation}$$

$$Qu = \frac{3950.02}{1}$$

for the use of a classic exploder with 'IED – EDM'.

The National Office of Explosive Substances (O.N.E.X) manufactures micro delay detonators with a delay of 12 degrees. Therefore:

$$\text{Nd} = (12 + 1) = 13 \text{ detonations}$$

$$Qu = \frac{3950.02}{13} = 303.84 \text{ kg}$$

for the use of a classic exploder with 'IED+EDM+EDD'.

The National Office of Explosive Substances (O.N.E.X) manufactures half-second delay detonators, with a delay of 12 degrees. Therefore:

$$\text{Nd} = (1 + 12 + 12) = 25 \text{ detonations}$$

$$Qu = \frac{3950.02}{25} = 158 \text{ kg}$$

Interpretation:

$$X = \frac{158}{303.84} \cdot 100 = 50\%$$

The addition of 'EDD' to the pyrotechnic chain reduced the instantaneous explosive load to around 50% compared to the previously applicable system (IED+EDM).

For the use of a sequential exploder with 'EDM + EDD':

we can blast every hole (out of the 46 holes) separately, with two (02) circuits of the sequential exploder (24 detonations × 2 circuits = 48 > 46).

$$\mathrm{Nd} = \mathrm{Nh} = 46 \text{ detonations}$$

$$Qu = 85.87 \text{ kg}$$

$$X = \frac{85.87}{303.84} \cdot 100 = 28\%$$

The use of this new technique reduced the instantaneous explosive load to 72% compared to the previously used system (IED+EDD).

Application of the form:

$$V = k\left(\frac{D}{\sqrt{Qu}}\right) - \alpha$$

where:

- *D* – the measurement sensor (geophone) was placed at the level of 'Boudiaf Mohamed middle school' at a distance of 2200 m to the northwest of the blasting site,
- *Qu* – the (instantaneous) unit load of explosive was calculated for each pyrotechnic chain,
- *K* – the site coefficient ranges from 300 to 6000, *k* = (1500 to 2800) for limestone,
- α – coefficient characterizing wave mitigation, usually equal to 1.8.

For the use of a conventional exploder with instant 'IED' detonator:

$$V = 1500\left(\frac{2200}{\sqrt{3950.02}}\right) - 1.8$$

$$V = 4.15 \text{ mm/s}$$

For the use of a classic exploder with 'IED+EDM':

$$V = 2500\left(\frac{2200}{\sqrt{303.84}}\right) - 1.8$$

$$V = 0.41 \text{ mm/s}$$

For the use of a classic exploder with 'IED+EDM+EDD':

$$V = 2500\left(\frac{2200}{\sqrt{158}}\right) - 1.8$$

$$V = 0.22 \text{ mm/s}$$

For the use of a sequential exploder using 'EDM+EDD':

$$V = 2500\left(\frac{2200}{\sqrt{85.87}}\right) - 1.8$$

$$V = 0.13 \text{ mm/s}$$

Table 2. Vibration velocity based on decreasing distance for the use of 'IED and EDM'

Distance [m]	V [mm/s]
2200	0.411981
2000	0.489085
1800	0.591218
1600	0.73084
1400	0.929411
1200	1.226626
1000	1.703093
800	2.544933
600	4.271359
549,75	4.999665
400	8.861972
200	30.85918

Table 3. Vibration velocity based on decreasing distance for the use of 'IED, EDM and EDD'

Distance [m]	V [mm/s]
2200	0.229282
2000	0.272193
1800	0.329034
1600	0.406739
1400	0.517251
1200	0.682661
1000	0.947832
800	1.416346
600	2.377164
400	4.932004
397	4.999292
200	17.17423

Table 4. Vibration speed based on decreasing distance for the use of sequential exploder with 'EDM and EDD'

Distance [m]	V [mm/s]
2200	0.131237
2000	0.155798
1800	0.188333
1600	0.23281
1400	0.296065
1200	0.390743
1000	0.542522
800	0.81069
600	1.360645
400	2.822988
291,19	4.999187
200	9.830216

Table 5. Description and degree of damage corresponding to vibration velocity

Velocity [mm/s]	Frequency [Hz]	Displacement [µm]	Acceleration [m/s²]	Description of damage
0.5	>80	<1	2512.2	No cracking
3	80	6	1507.2	No apparent cracks
5	30	26.5	942	Visible cracks
10	5	320	312.5	Important cracks
>10	1	1560	>62.8	Falling stones in the mine adits

Interpretation:

The interpretation of the values from previous studies was based the data included in Table 6, which illustrates the correlation between vibration speed and damage. Notably, when the particulate speed reaches 5 mm/s, cracks begin to appear.

The seismic nuisance values outlined in the French standard adhere to the vibration thresholds established by international regulations, particularly those delineated in the French circular dated September 22, 1994 concerning quarrying and mining operations (in the absence of national standards). According to these guidelines, the weighted particulate velocity of vibrations resulting from blasting, measured along the three axes of construction, must not exceed 10 millimeters per second in nearby buildings.

Table 6. The peak efficiency of the technique

Detonator circuits		1st circuit	2nd circuit	3rd circuit	4th circuit	5th circuit	6th circuit	7th circuit	8th circuit	9th circuit	10th circuit
Delay/Step		0	8	16	24	32	40	48	56	64	72
EDM	1	25	33	41	49	57	65	73	81	89	97
	2	50	58	66	74	82	90	98	106	114	122
	3	75	83	91	99	107	115	123	131	139	147
	4	100	108	116	124	132	140	148	156	164	172
	5	125	133	141	149	157	165	173	181	189	197
	6	150	158	166	174	182	190	198	206	214	222
	7	175	183	191	199	207	215	223	231	239	247
	8	200	208	216	224	232	240	248	256	264	272
	9	225	233	241	249	257	265	273	281	289	297
	10	250	258	266	274	282	290	298	306	314	322
	11	275	283	291	299	307	315	323	331	339	347
	12	300	308	316	324	332	340	348	356	364	372
EDD	1	500	508	516	524	532	540	548	556	564	572
	2	1000	1008	1016	1024	1032	1040	1048	1056	1064	1072
	3	1500	1508	1516	1524	1532	1540	1548	1556	1564	1572
	4	2000	2008	2016	2024	2032	2040	2048	2056	2064	2072
	5	2500	2508	2516	2524	2532	2540	2548	2556	2564	2572
	6	3000	3008	3016	3024	3032	3040	3048	3056	3064	3072
	7	3500	3508	3516	3524	3532	3540	3548	3556	3564	3572
	8	4000	4008	4016	4024	4032	4040	4048	4056	4064	4072
	9	4500	4508	4516	4524	4532	4540	4548	4556	4564	4572
	10	5000	5008	5016	5024	5032	5040	5048	5056	5064	5072
	11	5500	5508	5516	5524	5532	5540	5548	5556	5564	5572
	12	6000	6008	4016	6024	6032	6040	6048	6056	6064	6072

In our scenario, the majority of buildings fall into categories A or B according to Pierre Chapot's classification. Category A denotes poor quality structures with fragile walls and weak mortar grip, while Category B signifies medium quality constructions. Therefore, we adhere to the specified limit of 5 mm/s for the allowable particulate speed, which should not be exceeded.

For a distance of 2200 m from the blasting site, where the nearest construction is situated, the vibration speed resulting from the combination of EDM and EDD in two circuits is measured at 0.13 mm/s. This indicates that there would be minimal sensation or impact felt from the vibrations.

For Qu = 3950.02 kg, the radius of the secure area where V = 5 mm/s is **1850.00 m**

For Qu = 3950.02 kg, the radius of the secure area where V = 5 mm/s is **549.75 m**

For Qu = 3950.02 kg, the radius of the secure area where V = 5 mm/s is **397.00 m**

For Qu = 3950.02 kg, the radius of the secure area where V = 5 mm/s is **291.19 m**

7. The maximum efficiency of the discussed technique

With the discussed technique, we were able to have the instant (unitary) charge equal to the explosive charge of a single hole, which means that each hole is detonated seperately.

The following table shows the maximum number of charges/holes that can be executed in the same blast plan. The time of (t = +8 ms) is the adjustable step between the circuits.

With ten (10) circuits and twenty-four (24) detonators in each of them, we would expect a delay of 240. However, by eliminating any detonator that explodes before (t = 72 ms), we are left with 231 detonations, that is 231 holes exploding in sequence one after the other. These are the DMR numbers (1) of the circuits: C1, C2, C3, C4, C5 and C6, also the number (2) of the DMR numbers (2): C1 and C2 (crossed out in Table 7).

Table 7. Acoustic vibration measurement result

Blasting charge [kg]	Unit load [kg]	Distance [m]	Acoustic wave [dB]	Point of measurement	Description of noise intensity
3950.02	85.87	2200	Less than 100	Mohamed Boudiaf School	Acceptable

The total duration of the explosion of these 231 holes charge per charge is 6072 ms. Such large number of delays separates the waves from the seismic and acoustic vibrations, and that is the demonstrable advantage of this particular technique.

$$231 \text{ hole} \times 85.87 \text{ kg/hole} = 19835.97 \text{ kg}$$

At the explosive quantity of 19,835.97 kg, the results of Table 4 will remain the same, because it is the same unit load i.e. $V = 0.13$ mm/s. Therefore, no impact is felt at a distance of 2200 m.

Results of vibration measurements in-situ:

On March 5, 2020, the Minerals-Services design office conducted a measurement of the vibrations generated by the seismic and acoustic waves inherent in the blasting work, using a MINISEIS II seismograph. The sensor of the latter was placed at the level of the 'Boudiaf Mohamed' middle school, at a distance of 2200 m from the blasting site.

The results of the measurements are presented in tables.

Interpretation:

The vibrations emitted by the explosions are below the recorder's release threshold of 0.3 mm/s.

The sound levels caused by blasting are below the admissible norms (<100 dB, whereas the tolerated limit is 130 dB).

8. Conclusions

In this work, we address the particular blasting technique that provides a solution to the problem of seismic and acoustic nuisance.

The explosive substance is the first source of these nuisances that affect the residents – either by causing cracks in the walls of their houses, or by producing loud sound of explosion. Thus, the unit load is the most important parameter that influences the vibration level (both seismic and acoustic), that is, the greater amount of explosive detonating at a given moment, the greater the vibration peak. Controlling this parameter is sufficient to control the speed of propagation of the waves, and therefore also to control the damage caused.

In the light of the experiments studied, it is clear that the rigorous procedure that comes with a explosion carried out by the new technique has many advantages over that of a standard blast, as it delivers high efficiency in a single detonation, and produces less nuisance thanks to the distribution of the load.

Finally, the technique of combining electric detonators with micro delays and delays to the use of a sequential exploder gave a wide interval to decrease the instantaneous load by the possibility of having a detonation with 231 delays. By this token, the decrease in particulate speeds and vibrations facilitates better protection of the environment and leads to the elimination of nuisances. It is expected that the application of this technique will create an attention in mining and environmental studies given its effectiveness and its reduced cost.

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