https://doi.org/10.33271/nvngu/2024-1/020

F. Bahloul[*1],
orcid.org/0009-0007-0560-6756,
A. Hafsaoui[1],
orcid.org/0000-0002-1720-9527,
A. Idres[2],
orcid.org/0000-0001-8029-0930,
F. Boutarfa[2],
orcid.org/0000-0001-5182-7559,
A. I. Kanli[3],
orcid.org/0000-0001-5642-5866,
A. Benselhoub[4],
orcid.org/0000-0001-5891-2860

1 – Natural Resources and Planning Laboratory, Mining Department, Faculty of Earth Sciences, Badji Mokhtar University, Annaba, Algeria
2 – Laboratory of Mining Resources Valorization and Environment (LAVAMINE), Mining Department, Faculty of Earth Sciences, Badji Mokhtar University, Annaba, Algeria
3 – Istanbul University-Cerrahpasa, Istanbul, Turkey
4 – Environmental Research Center (C.R.E), Annaba, Algeria
[*] Corresponding author e-mail: fabahloul9@gmail.com

INFLUENCE OF THE ROCK MASS STRUCTURE AND THE BLASTING TECHNIQUE ON BLAST RESULTS IN THE HELIOPOLIS QUARRY

Purpose. To find a relative methodology which will help the systematic analysis of the parameters influencing the blasting plan and a better understanding of the mechanisms of fragmentation of rocks with explosives.

Methodology. The approach uses the Kuz-Ram model to predict blast performance. Three models were used to consider the effect of blast plan geometry on the quality of blast rock fragmentation. A new blasting plan is proposed using the Langefors method and the Kuz-Ram empirical model. The results obtained were compared with those of previous blasts.

Findings. The research results show that the optimal fragmentation of 89.2 % with a balance between fine particles of 5.7 % and outsized blocks of 5.1 % of rocks by explosive in the Heliopolis aggregates quarry is highly dependent on the type and quantity of explosive used, the direction of initiation, and the cracks caused by the waves of shock (back effects).

Originality. The present work is concerned with the problem of the quality of rock blasting which will ultimately affect the costs of drilling, blasting and the efficiency of all mining operations. Parameters influencing the processes of rock fragmentation during mining operations are specified.

Practical value. The purpose of blasting is to disaggregate the material in order to facilitate its recovery by the extraction equipment. It is therefore necessary to correctly define the blasting plan by optimizing these geometric parameters, the nature and the quantity of explosive, the initiation sequences aim to have the right particle size distribution.

Keywords: *rock mass, discontinuity, Kuz-Ram, fragmentation, fxplosive, Guelma, Algeria*

Introduction. The blasting operation is thus the first process of particle size reduction, and plays a particularly important role in mining, a well-planned blast makes it possible to limit the work of secondary breakdown of the oversize blocks that can be generated by the blast, and to improve the working conditions of other downstream operations such as loading, transport, crushing and grinding [1]. Improving the fragmentation of blasted rocks requires studying and analyzing the factors influencing the particle size distribution after blasting, which may be classified into three categories: rock mass properties, geometric and explosive parameters [2].

Most of the research is oriented to study the influence of the characteristics of the rock mass on the blasting results. The propagation of seismic waves induced by blasting changes significantly at rock discontinuities and the deep rock masses [3]. Discontinuity persistence and spatial distribution of rock bridges have a significant influence on the evolution of blasting-induced damage [4].The cracking of the mass starts from the discontinuity immediately after the detonation in the case of the inclined discontinuities, However, for the horizontal and vertical discontinuities, the cracks firstly initiate from the borehole [5], and the smaller the angle between the discontinuity and axis of the blast holes, the more stress occurs in the rock [6]. The drill and blast method causes fine cracks in the rock mass, which leads to safety and stability problems [7]. Then the results of the blast are influenced by the presence of discontinuities, by the heterogeneity of the rock mass, and by the presence of the free surface, to ensure good fragmentation, it is important to have the right understanding of the effects of these parameters on the results of blasting.

Several studies have been conducted on the influence of controllable parameters, The improvement in blasting performance depends mainly on the blast hole charge structure [8], the type of explosive and the blast hole diameter [9], the position of the detonator [10], and the initiation time of the blasting [11]. However, blast geometry parameters and explosive properties play an important role in backbreaking [12].

The main objective of this work is to find a methodology for the design of a blasting plan allowing the good fragmentation of hard materials, and to have the correlation between the parameters which affect the results of the blasting operation and the particle size distribution of fragmented rocks using the Langefors method and the empirical Kuz-Ram model to propose another blasting model.

Methods and materials. The main purpose of blasting is to obtain optimal fragmentation without generating induced nuisances such as cracking of the rock mass, projection, seismic waves, and to facilitate its recovery by the extraction machines, so if the results of the blasting operation represent a very high rate of blocks out of gauge, in this case it is necessary to carry out a secondary debitage which can be done using the use of a quantity of explosive or by mechanical means (rock breaker) which automatically increases the cost of the blasting process and delays the steps of the other processes that follow.

A poorly fragmented material is more difficult to load, which has a negative impact on the performance of loading and transport equipment, this leads, on the one hand, to a reduction in the productivity of the quarry, and on the other hand, to faster wear of these mining machines. It is therefore necessary to correctly define and optimize the following blasting plan parameters:

1. The geometric parameters (depth, inclination, diameter, burden, spacing of holes and rows, number of holes and rows, the shape of the arrangement of the holes).

2. Blasting charges (nature and quantity of explosives).

3. Initiation sequences.

4. The particle size distribution of fragmented rocks after the blasting operation.

A new blasting model has been developed using the Langefors method, which is the most manipulable and these results are satisfactory and effective, because it has the advantage of integrating a maximum of elements without requiring powerful means of calculation which is not the case of certain software using mathematical routines such as calculation by finite elements or by iterations.

The Langefors theory gives us satisfactory results, and it correctly translates the direction of the variations of the key paramètres, but it does not characterize the rock mass by a single parameter which is the pulling resistance, most of the time whose value is unknown a priori. Moreover, it remains incomplete at certain points because it does not predict the quality of the fragmentation of the pile of rock felled.

Generally, blasting takes place in a heterogeneous environment, which complicates the design of a blasting plan. The calculation method based on the Kuznetsov-Rammler model is the theory that allows a quantitative study of the characteristics of the rock mass unlike the Langefors method.

Generally, blasting is done in a heterogeneous environment, which complicates the design of a blasting plan. At this point, the optimization of the proposed blasting plan is completed by the Kuz-Ram method, which is the most usable today.

This research applies the empirical Kuz-Ram model to analyze the particle size distribution of three blast models on a limestone-type rock in the Heliopolis-Guelma quarry.

Site description. About 5 km from this wilaya, to the north, on the national road Annaba Guelma (RN 21) is the Daïra of Heliopolis, which has a number of quarries including the UCPM quarry (Unit for construction and production of materials). From a strategic and geological point of view, this massif is located in Douar BouZitoune with an area of 30 Ha 22 Ares, it is also limited by: Hammam Ouled Ali to the North, city of Guelma to the South, Heliopolis to the East and the municipality of El Fdjouj in the West (Fig. 1) [13].

Geological setting. The neritic formations are 160 km long East-West and 80 km North-South, this area would have emerged at the end of the Cretaceous and would have subsequently undergone a slight displacement towards the South. The most complete series is represented by the eastern end of Djebel Debbagh which passes under the water table to reappear as a window at the Roman pool of Heliopolis and in the southern corner of the Nador station. This series includes: compact limestone with intercalation of 150 m thick marls of Senonian age, massive Albian and lower Cenomanian limestone, compact Aptian limestone and upper Cenomanian reef limestone [14, 15].

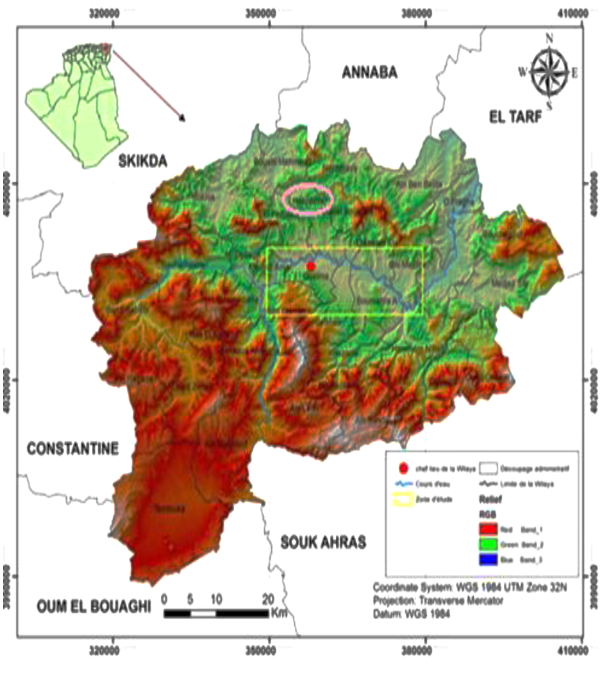

Fig. 1. Geographic location of the study area

The rock mass of the Heliopolis quarry is part of the north-eastern massifs of the Constantine neritic series. This complex is subdivided into two partially overlapping parts, the first neritic sequence comprising a series of condensed formations predominantly carbonated and siliceous from the Jurassic and Triassic, and the second is the allochthonous formations predominantly clayey-marly and quartzic [15].

The land of Heliopolis is a plateau made up of loose rocks (sands, clays and scree) of the Quaternary age, where the subsoil is made up of recent formations of the Miopliocene age (sandstones, clays). More particularly the zone where the deposit is located given the compactness of the gray to beige limestone rock which does not allow the infiltration of rainwater in depth, hence the non-existence of sources of outlets on the flanks and at the foot of the deposit. The rocky massif of the bouzitoune quarry, is part of the north-eastern massifs of the Constantine neritic series [15, 16].

Tectonic of the study region. The region corresponding to the chain of the Tell Atlas and the Tell, of which the Numidian chain is a part, is extremely twisted and there are examples of tectonic accidents of all kinds represented there. The tectonic effects in the region of Guelma are manifested mainly by phenomena of compression and intense repression of the folds which are generally discharged towards the South and the South-East. These folds, often stacked on top of each other, and overlap like interlocking scales. This phenomenon of scaled structure is frequent in the Atlas chain. In these overturned folds, the reverse flanks are most often removed by compression and/or stretching. The syncline flanks are observed in places, in areas more or less spared by tectonic effects. As for the anticlinal vaults, they are quite rare and when they exist, they are rather in the state of brachy-anticlines or domes, structured in horst and graben.

In the region of Guelma, the folds of East-West orientation are represented at the level of the chain of Taya-Debagh and which extend towards the East by the massif of Bou Zitoun and Djbel Houara [17].

Topographic map of the quarry. The UCPM Quarry (Construction and Materials Production Unit) is located in Mechta, Bouzitoune (altitude 362 m), the Heliopolis quarry deposit is a hillside deposit with a slope varying from 25 to 30°. The opening of this quarry consists in making a half-trench starting from the base of the depression to its top which must be common to all levels of the quarry. Mining works start from the top to the bottom of the anticline with a single edge, the mining is carried out according to seven bleachers, which have heights of 13 to 15 m (Fig. 2).

The rock mass to be broken down is generally massive limestone with intercalation of dolomites where the matrix is composed of more or less continuous blocks. The most obvious character of observation of the rock mass is the presence of the surfaces of the discontinuities of various geometrical aspects. These discontinuities are, from a mechanical point of view, surfaces that do not ensure the continuity of the solid mass [18].

At the level of the limestone quarry Heliopolis (Guelma-Algeria) several types of discontinuities have been identified (Fig. 3).

Optimization of the granulometry of fragmented rocks by the Kuz-Ram model. Drilling represents the fundamental step for mining extraction, in the first blasting plan, which digs 35 holes inclined at 80°; they are drilled in two rows with a spacing of 1.80 m and a burden of 2.5 m. The hole is continuously laoded with a 17.5 kg quantity of Marmanit III as priming

Fig. 2. Topographic map of the limestone quarry – Heliopolis (Google Earth)

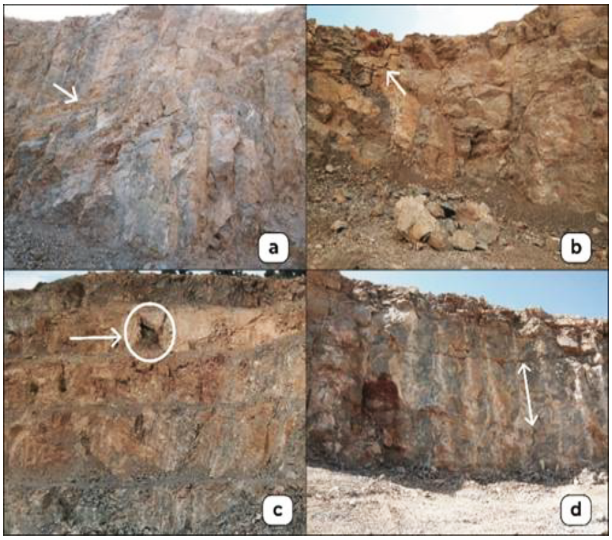

Fig. 3. Different types of discontinuities in the rock mass of the Heliopolis quarry:

a – stratigraphic joints; b – joints; c – karsts; d – faults

laod, a 25 kg quantity of Anfomil and 24 kg of Timex as the main charge.

The drilling work for the second blasting operation consists of digging 19 holes inclined at 80°, with a spacing of 4 m and a burden of 3 m. The holes are charged in a discontinuous manner with a quantity of 15 kg of Marmanit III as priming charge, and a quantity of 37.5 kg of Anfomil as main laod.

In the third blasting plan, the drilling works prepared 16 holes inclined at 80°, with a diameter of 89 mm and a depth of 13.5 m following a spacing of 1.90 m and a variant burden, that is to say a 2 m burden for 8 holes, after and because of the problem of cracking of the rock mass in the unregulated zone of the previous blast which makes drilling very difficult, in this case it is mandatory to increase the burden to 3 m, but only for 6 holes with a spacing of 1.75 mm, and concerning the last two holes having the same characteristics of the first 8 holes (Fig. 4).

To carry out a particle size analysis of the third blast, it is mandatory to divide the latter into two parts:

The first part with a burden $B_1 = 3$ m, and the second part with a burden $B_2 = 2$ m (Fig. 4),the holes are laoded with a quantity of 7.5 kg of Marmanit III as the priming laod, a quantity of 25 kg of Anfomil and 36 kg of Timex as main load. On the other hand, for the second part the holes are loaded with a quantity of 2.5 kg of Marmanit III as priming load, a quantity of 25 kg of Anfomil and 36 kg of Timex as main load.

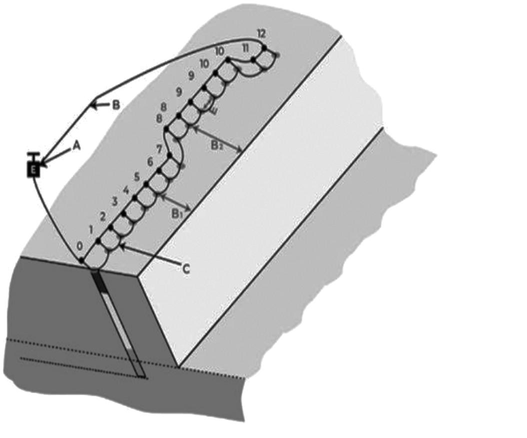

Fig. 4. Schematic of the third blasting operation with explosive:

0 – Instant electric detonator; A – Exploder; B – Electrical wire; C – Detonating cord; E – Spacing; 1–12 – Mecro delayed detonator = 20 ms

The main objective of blasting is to have the right particle size distribution to facilitate its recovery by mining equipment. It is therefore necessary to define the blasting plan by optimizing these geometric parameters, the nature and quantity of explosive, the initiation sequences.

To improve the quality of the fragmentation of the limestone of the aggregate quarry of Heliopolis – Guelma, a new blasting plan (Fig. 5) was developed using the Langefors method, which drills 14 vertical holes, distributed over two rows with spacing of 3.35 m and a burden seat of 2.68 m. The hole is laoded continuously with a 25.89 kg quantity of Marmanit III as priming laod, and a 30.16 kg quantity of Anfomil as a main laod.

The parameters of the blasting plans made by the engineers of the Heliopolis aggregate quarry and the one proposed are recorded in the following Table 1.

The following photos represent the obtained results after each blasting operation with explosive.

The percentages of the particle size distribution and the parameters of the fragmentation of the rocks obtained after each blasting are presented in the following Tables 2, 3.

The following curves show the particle size distribution of the fragmented rocks obtained after the blasting operations studied and the blasting operation proposed.

Results and discussion. All the research has been oriented to study the influence of the natural discontinuities of the rock mass on the fragmentation of rocks with explosives, while the majority of cracks are created by the blasting operation itself (back effect) which minimizes the performance of an explosion by the escape of explosive gases through them, therefore this research is based on improving the work of blasting in the limestone quarry of Heliopolis, on the one hand, to increase production with the minimum of extraction expenses, and on the other hand, to minimize the cracking of the rock mass after the blast by increasing the number of free surfaces for each hole with the correct choice of the initiation sequence (Figs. 4 and 9). When

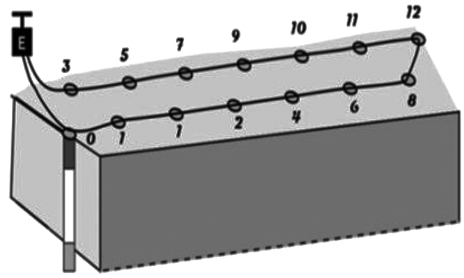

Fig. 5. Schematic of the proposed blasting plan

Table 1

Summary table of parameters of existing and proposed blasting plans

Blasting parameters	Blast-1	Blast-2	Blast-3a	Blast-3b	Blast-4 proposed
Burden, m	2.5	3	3	2	2.68
Spacing, m	1.80	4	1.75	1.90	3.35
Hole diameter, m	0.89	0.89	0.89	0.89	0.89
Number of rows	2	1	1	1	2
Distance between rows, m	1.80	–	–	–	2.68
Intermediate stemming length, m	–	0.80	–	–	–
Hole inclination, °	80	80	80	80	90
Number of holes	35	19	6	10	14
Explosive quantity per hole, kg	66.5	52.5	68.5	63.5	56
Anfomil, kg	25	37.5	25	25	30.16
Timex 50, kg	24	–	36	36	–
MarmanitIII, kg	17.5	15	7.5	2.5	25.89
Volume blasted per hole, m^3	58.5	180	72.24	52.28	125.7
Specific charge, kg/m^3	1.13	0.29	0.94	1.21	0.44

Table 2

Target and predicted values of rock fragmentation obtained after the studied blasting operations and the blasting operation proposed (B-4)

Fragmentation	Targeted fragmentation (m)	Predicted fragmentation (%)				
		B-1	B-2	B-3a	B-3b	B-4
Oversize (undesirable)	0.8	1.5	24.3	2.8	0.0	5.1
Optimum (targeted)	0.4	85	71.8	84.4	85.5	89.2
Undersize	0.05	13.5	3.8	12.8	14.5	5.7

Table 3

Rock fragmentation parameters obtained after the blasting operations studied and the blasting operation proposed (B-4)

Parameters	B-1	B-2	B-3a	B-3b	B-4
Tirability Index	7.9502	7.9502	7.9502	7.9502	7.9502
Average fragment size, cm	18	46	20	14	29
Uniformity coefficient	1.21	1.29	1.18	1.40	1.42
Characteristic size (D60), m	0.24	0.61	0.27	0.19	0.37

an explosive detonates a shock wave is produced which moves from the center of the blast hole to the periphery causing radial and tangential tensions in the rock, once the shock wave reaches the free surface it is reflected in this case the solid mass around the hole will be well cracked. So these free surfaces play the role of a barrier stopping the propagation of the shock wave in the rock mass of the blasting that comes afterwards.

In practice, to cause the detonation of an explosive, it is necessary to create an explosive wave on contact with it, which is obtained using an electric detonator or detonating cord. In elongated loads, it is very important to emphasize the priming

Fig. 6. Fragmented rocks after each blasting operation:

a – first operation; b – second operation; c – third operation; d – proposed blasting plan

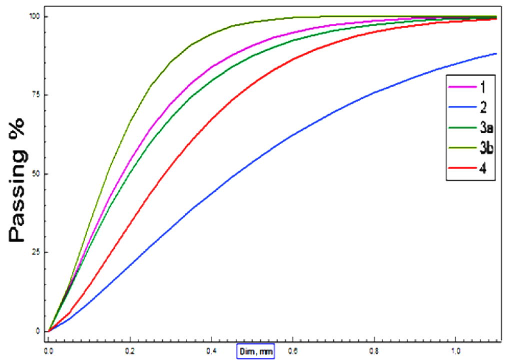

Fig. 7. Obtained curves of particle size distribution after the blasting operations:

1 – first blast; 2 – second blast; 3a and 3b – third blast; 4 – proposed blast

mode. Indeed, if the electric detonator makes it possible to initiate the explosion of an elongated charge from its base or its top, it is not the same for the detonating cord. In other words, if the charge is initiated by the detonating cord, the impulse is always perceived at the top of the charge; thus the explosive wave goes from the top to the bottom of the bleacher, where as in most cases we try to obtain the opposite which allows the shock wave to be completely reflected.

In the case of the Heliopolis quarry, the initiating charge (Marmanit) connected to the detonating cord would give the necessary impetus to the main charge (anfomil). In this case the detonating cord transmits the explosive wave almost at the same time to the two explosives used. Thus the hope of seeing the Marmanit initiate anfomil is in vain.

The best result would be obtained if the main charge is primed by the primer charge; a solution is possible if the detonating cord were to be introduced inside an insulating tube, in this case, the anfomil being not in direct contact with the cord will be initiated by the marmanit, and this makes it possible to obtain a frank detonation with the very desired effects for a good fragmentation.

According to the results recorded in Table 2 indicates a variation of percentages of undesirable and fine fragments, which depends on the type and quantity of explosive used, the shape and the distance between the holes, the type of initiation used and the degree of cracking of the mass to be pulled.

The results obtained by the first blasting show that the percentage of oversized blocks is low (1.5 %); on the other hand, a significant percentage of fine particles (13.5 %), the hole is loaded with a quantity of 67.33 kg of explosive with a mixture of Anfomil, Timex and Marmanit to blast a volume of 58.5 m^3 per hole. To solve this problem it is necessary to increase the distance between the holes, the rows and to minimize the quantity of charged explosive in a hole, by neglecting the explosive Timex.

Concerning the second blasting, it is the opposite, the particle size obtained represents a large percentage of undesirable fragments (24.3 %), but a small percentage of fine particles (3.8 %), in this case to blast a volume of 180 m^3 per hole, the latter is laoded with two types of explosives (Anfomil and Marmanit) of a quantity of 63.67 kg, thus to reduce the percentage of oversized blocks, the spacing and the bench must be reduced.

In the third blasting, a major problem was created during the drilling work due to the significant cracking of the solid mass in place, to have the essential parameter which influences the results obtained, the blasting plan is divided into two parts, the first with a bench of 3 m and the second with a bench of 2 m. In this case a mixture of three types of explosive with a quantity of 70.96 and 77.55 kg/hole was used to successively fragment a volume of 72.24 and 52.28 m^3 of limestone. The results obtained show that the percentage of undesirable blocks of the first part (2.8 %), on the other hand, are nil for the second part; the percentage of fines successively of the first and the second are (12.8, 14.5 %). So this blasting operation gave mediocre results, essentially bad fragmentation with a very high rate of fine particles, and it created cracks (back effects) in the rock mass of hole 10 (Fig. 4), since it is loaded by a large amount of explosive (Marmanit III, Timex and Anfomil), and because of the incorrect choice of the blasting sequence.

The appropriate solution to this problem requires:

1. To create a free surface by changing the blasting sequence (Fig. 9).

2. To neglect the explosive (Timex) so the holes are loaded only with two types of explosive (Anfomil, Marmanit III).

3. To increase the distance between the holes (Spacing).

To minimize these rear effects caused by excessive blasting as much as possible, a blasting method is used which consists of creating a crack in the rock mass of the following plane, before any blasting action. It is recommended to carry out the holes for preliminary adjustment of the profile which will be drawn before the actual blasting holes, and have the effect of cutting the rock according to the plane of the holes, without back effect, nor significant displacement of the land: in this case the holes are close together and contain only a small quantity of explosive.

Conclusion. Satisfactory fragmentation represents the main objective of any mining company; for this it is necessary to study the parameters that influence quantitatively and qualitatively the results of a blast, such as the characteristics of the rock mass and the parameters of a blasting plan

Improving the mining works of the Heliopolis aggregate quarry requires the use of new optimization and analysis techniques to design blasting plans that ensure good fragmentation with appropriate dimensions.

Fig. 8. Cracks created after blasting (Back effects)

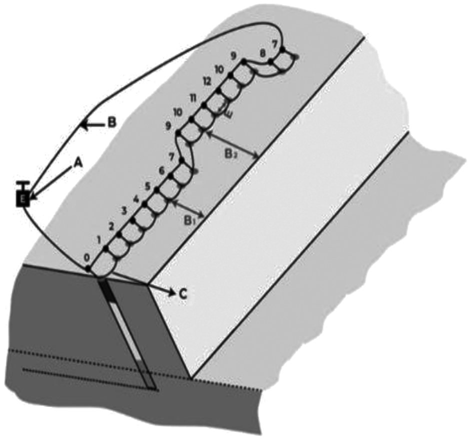

Fig. 9. Proposed initiation sequence for the third blasting operation:

0 – Instant electric detonator; A – Exploder; B – Electrical wire; C – Detonating cord; E – Spacing; 1–12 – Mecro delayed detonator = 20 ms

The analysis results obtained by the Kuz-Ram empirical model of limestone fragmentation in the Heliopolis construction materials quarry show an optimal grain size of 89.2 % with a dimension of 400 mm, undesirable fragments of 5.1 % with a size of 800 mm, and fine particles of 5.7 % with a size of 50 mm. To ensure these results, we must rely on the following points:

1. Blasting must be carried out by the type of punctual initiation instead of the type of lateral initiation.

2. The holes must be loaded with two types of explosives (Marmanit III as the initiation charge and Anfomil as the principal charge).

3. Holes should be drilled vertically instead of inclined holes, with a staggered (triangular) mesh.

4. Choose the preferred initiation sequence to increase the number of free surfaces of each hole.

The effectiveness of blasting in this quarry depends essentially on the type and quantity of explosive used, the type of initiation, and the free surface, which reduces cracking of the rock mass after the completion of the blasting operation, which makes the next blast more profitable.

Acknowledgement. *The authors of the present work thank those in charge of the Heliopolis mine for their support and considerable help. The authors also wish to thank the Directors of the Natural Resources and Planning Laboratory, and the Laboratory of Mining ResourcesValorization and Environment (LAVAMINE) for their accompaniment in the realization of this research work.*

References.

1. Alipour, A., & Asadizadeh, M. (2023). Rock fragment size prediction using RSM in bench blasting: a focus on the influencing factors and their interactions. *Arabian Journal of Geosciences, 16*(1), 61. https://doi.org/10.1007/s12517-022-11072-8.

2. Adesida, P.A. (2022). Powder factor prediction in blasting operation using rock geo-mechanical properties and geometric parameters. International. *Journal of Mining and Geo-Engineering, 56*(1), 25-32. https://doi.org/10.22059/ijmge.2021.310930.594870.

3. Jiang, X., Xue, Y., Kong, F., Gong, H., Fu, Y., & Zhang, W. (2023). Dynamic responses and damage mechanism of rock with discontinuity subjected to confining stresses and blasting loads. *International Journal of Impact Engineering, 172,* 104404. https://doi.org/10.1016/j.ijimpeng.2022.104404.

4. Jayasinghe, L. B., Shang, J., Zhao, Z., & Goh, A. T. C. (2019). Numerical investigation into the blasting-induced damage characteristics of rocks considering the role of in-situ stresses and discontinuity persistence. *Computers and Geotechnics, 116,* 103207. https://doi.org/10.1016/j.compgeo.2019.103207.

5. Xue, Y., Jiang, X., Kong, F., Li, Z., Gong, H., Yang, F., & Chen, H. (2022). Rupture of rock with discontinuities under blasting distur-

bance: Insights from discrete element method modeling. *Simulation Modelling Practice and Theory, 116,* 102486. https://doi.org/10.1016/j.simpat.2022.102486.
6. Yari, M., Ghadyani, D., & Jamali, S. (2022). Development of a 3D numerical model for simulating a blast wave propagation system considering the position of the blasting hole and in-situ discontinuities. *Rudarsko-geološko-naftnizbornik, 38*(2), 68-78. https://doi.org/10.17794/rgn.2022.2.6.
7. Verma, H.K., Samadhiya, N.K., Singh, M., Goel, R.K., & Singh, P.K. (2018). Blast induced rock mass damage around tunnels. *Tunnelling and Underground Space Technology, 71,* 149-158. https://doi.org/10.1016/j.tust.2017.08.019.
8. Gao, F., Tang, L., Yang, C., Yang, P., Xiong, X., & Wang, W. (2023). Blasting-induced rock damage control in a soft broken roadway excavation using an air deck at the blasthole bottom. *Bulletin of Engineering Geology and the Environment, 82*(3), 97. https://doi.org/10.1007/s10064-023-03087-6.
9. Dhekne, P. Y., Balakrishnan, V., & Jade, R. K. (2020). Effect of type of explosive and blast hole diameter on boulder count in limestone quarry blasting. *Geotechnical and Geological Engineering, 38,* 4091-4097. https://doi.org/10.1007/s10706-020-01280-y.
10. Ylitalo, R. M., Zhang, Z. X., & Bergström, P. (2021). Effect of detonator position on rock fragmentation: Full-scale field tests at Kevitsa open pit mine. *International Journal of Rock Mechanics and Mining Sciences, 147,* 104918. https://doi.org/10.1016/j.ijrmms.2021.104918.
11. Saadatmand Hashemi, A., & Katsabanis, P. (2020).The effect of stress wave interaction and delay timing on blast-induced rock damage and fragmentation. *Rock mechanics and rock engineering, 53,* 2327-2346. https://doi.org/10.1007/s00603-019-02043-9.
12. Hosseini, M., Khandelwal, M., Lotfi, R., & Eslahi, M. (2023). Sensitivity analysis on blast design parameters to improve bench blasting outcomes using the Taguchi method. *Geomechanics and Geophysics for Geo-Energy and Geo-Resources, 9*(1), 9. https://doi.org/10.1007/s40948-023-00540-4.
13. Khadri, R., Khedidja, A., Nafaa, B., & Maha, K. (2023). Geophysical and geological contribution to determining the neritic limestone aquifer structure of Hammam Bradaa–El Fedjoudj (Seybouse medium), Northeastern Algeria. *Mining of Mineral Deposits, 17*(1). https://doi.org/10.33271/mining17.01.067.
14. Baazi, H. (2023). Aquifer Vulnerability Assessment by DRASTIC and SI methods: The case study of Guelma Plain, Northeast Algeria. *Engineering, Technology & Applied Science Research, 13*(1), 10045-10050. https://doi.org/10.48084/etasr.5520.
15. Bouaicha, F., Dib, H., Bouteraa, O., Manchar, N., Boufaa, K., Chabour, N., & Demdoum, A. (2019). Geochemical assessment, mixing behavior and environmental impact of thermal waters in the Guelma geothermal system, Algeria. *Acta Geochimica, 38,* 683-702. https://doi.org/10.1007/s11631-019-00324-2.
16. Aissaoui, M., Maizi, D., Benhamza, M., Azzouz, K., Belaroui, A., & Bengusmia, D. (2023). Identification and mapping of potential recharge in the Middle Seybouse sub-catchment of the Guelma region (North East of Algeria): contribution of remote sensing, multi-criteria analysis, ROC-Curve and GIS. *Acque Sotterranee-Italian Journal of Groundwater, 12*(1), 25-37. https://doi.org/10.7343/as-2023-628.
17. Benmarce, K., Hadji, R., Hamed, Y., Zahri, F., Zighmi, K., Hamad, A., ..., & Besser, H. (2023). Hydrogeological and water quality analysis of thermal springs in the Guelma region of North-Eastern Algeria: A study using hydrochemical, statistical, and isotopic approaches. *Journal of African Earth Sciences,* 105011. https://doi.org/10.1016/j.jafrearsci.2023.105011.
18. Rahma, K., Abdelhamid, K., Djamel, B., & Nafaa, B. (2023). Integrated gravity and resistivity investigationsof the deep Hammam Bradaa aquifer, Northeast Algeria: Implications for groundwater exploration. *Journal of African Earth Sciences,* 105013. https://doi.org/10.1016/j.jafrearsci.2023.105013.

Вплив структури гірської маси й техніки підривних робіт на результати вибуху в кар'єрі Геліополіс

Ф. Балул[*1], *А. Хафсауї*[1], *А. Ідрес*[2], *Ф. Бутарфа*[2], *А. І. Канлі*[3], *А. Бенселгуб*[4]

1 – Лабораторія природничих ресурсів і планування, департамент гірничої справи, факультет наук про Землю, Університет Баджі Мохтар, м. Аннаба, Алжир
2 – Лабораторія валоризації гірських ресурсів і навколишнього середовища, департамент гірничої справи, факультет наук про Землю, Університет Баджі Мохтар, м. Аннаба, Алжир
3 – Стамбульський університет Джеррахпаша, м. Стамбул, Туреччина
4 – Науково-дослідний центр з охорони довкілля, м. Аннаба, Алжир
[*] Автор-кореспондент e-mail: fabahloul9@gmail.com

Мета. Знайти відповідну методику, яка допоможе систематично аналізувати параметри, що впливають на план вибухових робіт, і краще розуміти механізми руйнації гірських порід під час використання вибухових речовин.

Методика. У цьому підході використовується модель Куз-Рама прогнозування ефективності підривання. Були використані три моделі з метою оцінки впливу геометрії плану вибухових робіт на якість дроблення гірської породи. Запропоновано новий план підривних робіт з використанням методу Лангефорса та емпіричної моделі Куз-Раму. Отримані результати були порівняні з результатами попередніх вибухових робіт.

Результати. Результати дослідження показують, що оптимальне дроблення на рівні 89,2 % з балансом між дрібними частинками 5,7 % і великими блоками 5,1 % гірських порід з використанням вибухових речовин у кар'єрі Геліополіс значно залежить від типу й кількості вибухової речовини, що використовується, спрямованості вибуху та тріщин, спричинених ударними хвилями (зворотні ефекти).

Наукова новизна. Дана робота розглядає проблему якості підривання гірської породи, що зрештою вплине на витрати на буріння, вибухові роботи та ефективність усіх гірничодобувних операцій. Встановлені параметри, що впливають на процеси дроблення гірських порід при видобутку корисних копалин.

Практична значимість. Мета підривних робіт – дроблення матеріалу для полегшення його вилучення за допомогою гірничо-шахтного обладнання. Таким чином, необхідно правильно визначити план вибухових робіт, оптимізувавши геометричні параметри, характер і кількість вибухової речовини, послідовність здійснення вибуху з метою отримання оптимального розподілу частинок.

Ключові слова: *гірський масив, розлом, Куз-Рам, дроблення, вибухова речовина, Гельма, Алжир*

The manuscript was submitted 12.07.23.