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O. Kamli[1],
A. Boutaleb[1], **Dr. Sc. (Tech.), Prof.,**
M. C. Djouama[2], **PhD,**
M. Hacini[1], **Dr. Sc. (Tech.), Prof.**

1 – Kasdi Merbah University, Ouargla, Algeria, email: leadersinovation07@gmail.com
2 – Laboratory of Physical Metallurgy and Materials Properties, Badji Mokhtar University, Annaba, Algeria

EFFECT OF EXPLOSIVE CHARGE-BLAST DISTANCE INTERACTION ON GROUND DAMAGE (BOUKHADRA MINE, ALGERIA)

Purpose. The aim of this research work is to assess the effect of the explosive charge and the blast distance on the stability of the Boukhadra iron mine. The objective is to contribute to the conception of a blasting plan in order to reduce the effect of the vibrations on the slope stability and ground damage.

Methodology. The characterisation of the blasting process was done using geophones to record the particle velocity for sixteen tests, and the DELTA SEIS software to determine the ground displacement influenced by the particle velocity. We also used the PLAXIS 8.2 software to simulate the slope stability under the effect of blasting by calculating the safety factor for the entire mine.

Findings. We concluded that the blasting itself is not the main cause of the slope instability, since the cause of instability is conditioned by structural, blend and phase composition of slope rocks and peculiarities of physicochemical interaction with propagating blast and elastic waves caused by explosive charge blast.

Originality. Numerical simulation of ground displacement under the effect of blasting was performed with the use of two different tools: geophones assisted by the Delta SEIS characterising certain blasting results and the PLAXIS 8.2 software. It was found that “the mass of explosive charge – explosive charge-blast distance” being 130 kg and 177 m respectively leads to a peak particle velocity of 16 mm/s and acoustic overpressure of 147 dB causing a ground displacement of 335 μm.

Practical value. The results are used while preparing technical specifications for conducting drilling-and-blasting operations, which allowed increasing slope stability regarding the effect of blast and elastic waves significantly. In the process of stimulation we found that we found that a safety factor Fs is 0.90 (less than one), which certainly leads to the slope sliding.

Keywords: *blasting procedure, seismic and acoustic vibrations, stability, slope, numerical simulating, iron mine*

Introduction. The Boukhadra (BK) iron mine, where both open pit and underground mining methods are used, is located in the far east of Algeria. The mine is well known for its ore grade which exceeds 58 % on average and its reserves estimated to be more than 50 million tons. However, the BK mine has a big problem of stability mainly due to blasting. Because of its importance in the national economy, this problem must be seriously taken into consideration in order to improve and preserve the slope stability, the surface mining and transportation safety [1].

Certainly, the blasting is the most used operation in both open pit and underground mining, but a bad blast design leads to severely negative impacts because of the propagation of ground vibrations causing the destruction of surrounding structures [2, 3]. For this purpose, the assessment of the blasting execution conditions is essential with the aim of contributing to the development of a controlled blast plan to reduce the amount of the over-break and control the vibrations of the ground. This technique is one of the most common ones used to solve such problem in situ [4].

Thereby, we were inspired by the classic principles of the most used controlled blasting plan, based on the control of blast parameters to reduce its effects, such as the secondary debiting, short and long-holes bench blast, typical bench-blasting [4], as well as by the rock engineering systems RES. This widely used approach is also based on the characterization of the most important parameters influencing blasting and its results on the grounds [5].

In order to visualize our own contribution regarding the most appropriate blast design whose choice concurs with the most influent factors on blasting results and which are: the distribution of the explosive charge in the explosion and the distance of the blast, it is important to emphasize that the value of one parameter of this component should not be taken separately from the others.

On this basis, we launched our investigation in two parts. The first one is a characterization of the results of several blasting tests with well-defined “explosive charge-blasting distance” parameters according to a seismic scale made using three-directional geophones distributed around the exploited zone and assisted by the Delta-Seis treatment program, to detect faults in the field by referring to the regulation. This is based on the assumption that a maximum particle velocity PPV decreases with the distance and the attenuation of the explosive charge at once. This PPV is related to the maximum deformation (to the maximum peak particle displacement PPD) from which there will be damage [6, 7]. We appealed to the principles of formulating Chapot’s law largely trusted in this sense.

The second part of our research work focuses on modeling the stability of the slope of the mine in terms of blasting by determining the safety factors Fs (the slope stability coefficient) [1] with the Plaxis 8.2 calculation code and based on the physical-mechanical characteristics of the Boukhadra mountain rock mass shown in Table 6 – section III. Since the extent of damage on the ground depends largely on its dynamic characteristics [8].

Finally, we can confirm that the optimal blast design, compatible with the conditions of the BK site as well as sites with similar conditions, must adopt values of the parameters of “explosive charge-blast distance” component far from the limit values of damage.

I. Geological and geomorphological setting. The Djebel Boukhadra is located in eastern Algeria, 45 km north of Tebessa city, 13 km from the Algerian-Tunisian border. The ferruginous deposit of Boukhadra, belonging to the Atlas Saharan domain, is located in the mountainous Jebel Boukhadra, characterized by a simple anticline structure of NE-SW direction with a periclinal termination NE. Jebel Boukhadra extends over a length of 7 to 8 km and a width varying from 3 to 5 km along a NE-SW (Fig. 1). The iron mine is located between 8°01′ and 8°04′ east and between 35°40′ and 35°50′ north. Djebel Boukhadra is an anticline structure composed mainly by Mesozoic and Tertiary sediments with a Quaternary thin cover. The Triassic deposits encountered in Boukhadra region are represented by marls, gypsum, dolomite, limestone and sandstone. They are found in the West as well as in the South and South East parts of the anticline. The Triassic formation is unconformably in contact with the Cretaceous limestones. The lower part of the Aptian is mainly constituted by marl and reef limestone (rudist); the latter is the main ore bearing formation, while the upper part of the Aptian which is mainly sandstone and limestone are unproductive. Tertiary formations (Miocene) are observed only in the western part of the study area and are represented by polygenic conglomerates, cemented by a matrix of carbonate and interbedded sandstone rocks. The recent Quaternary deposits are formed by a stony material, blocks of limestone, sandstone, debris and conglomerates. Usually, they are encountered as a cover on the mountain sides and all along its foot [9].

The mineralogical analysis has shown that the nature of the substance being exploited is a heterogeneous mineral of chemical formula Fe_2O_3, of density ($d = 2.7$ T/m^3) and of an iron content which varies from 51 to 58 % and even more.

The hydrogeological studies carried out by the ANRH (National Agency of Hydraulic Resources) show that there is no aquifer in the level of the mining area of Boukhadra. The only aquifer in the area is located at a level well below the mine. The level of the mine is at 1463 m while the aquifer is at 818 m [9].

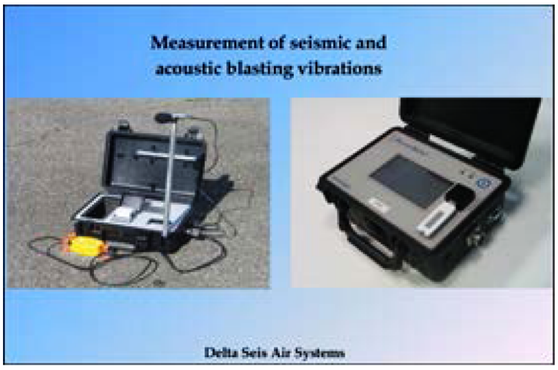


Fig. 1. DELTA SEIS 1 Measuring device

II. Blasts Recording. The analysis of the behavior of rock during blasting requires the recording of the blast information. In fact, the movement of the rock matrix is only a resultant of the vibrations induced by the explosion.

II.1. Regulations concerning seismic and acoustic vibrations. For values of seismic nuisance, we retained the vibration values given by the international regulations, particularly the French law on quarry and mining operations which are the most severe ones (See Annex II) where the limit is 10 mm/s.

For the overpressure thresholds, these values are recalled in the July 1996 law of 125 dB for structures and 145 dB for persons [10].

II.2. Measuring equipment. The measurements were carried out with a DELTA SEIS 1 recorder (serial number 112), equipped with a seismic vibration sensor, three directional geophone and an overpressure sensor, with a homologous NE calibration in less than 12 months, (Fig. 1) [11].

II.2.1. Parameters retained for these blasts. The parameters retained for our case are:

1. Acquisition time: 6 s.
2. Seismic triggering threshold: 0.5 mm/s.
3. Acoustic trigger threshold: 115 dB.

II.2.2. Positioning of sensors. As the theory recommends; the sensors placed on the structures to be studied are three directional geophones (2 horizontal and 1 vertical) with sensitivities of several tens of meters.

For our case, the sensors are placed at the compressed air station, the water station and the underground adits at level 1105 and higher levels.

II.3. Actual blast parameters at surface and underground mining. Tables 1 and 2 show respectively the blasting parameters applied in the BK mine for open pit and for underground mining. Sixteen tests were carried out to assess the effect of blasting on the ground. The parameters we changed during our tests are the explosive charge and the distance between the blast point and the sensors.

II.4. Chapot Law. Pierre Chapot has greatly contributed to the development of knowledge in the field of geophysics applied to public works with a remarkable contribution of his research work in the field of wave propagation in the soil, by writing an equation setting, relating the measured vibration velocity to a distance D and the energy of an explosive charge. It remains the tool for prediction and management of reference vibrations for mine blats. Chapot’s law is written as follows

$$V = K\left[\left(\frac{D}{Q}\right)\right]^{-8}, \qquad (1)$$

with V is vibration speed, mm/s; D is the blast-sensor distance, m; Q is the instantaneous charge of explosive, kg; K is the site coefficient, ranging from 300 to 6000 with an average value of 2500.

This law, which is the foundation for the knowledge of the propagation of vibrations in the soil, is transmitted to buildings or structures such as historical monuments,

II.5. Recording and analysis of seismic and acoustic vibrations. The results of the seismic and acoustic vibrations obtained by our recordings, using Delta Seis 4.4, are shown on a data sheet (Fig. 2).

Table 1

Blasting parameters in open pit used in the mine

Designation	Quantity	Unit
Bench height	7.5	m
Hole length	8.5	m
Bench inclination	80 to 85	Degree
Blast hole inclination	90	Degree
Hole diameter	165	mm
Stemming length	3	m
Number of holes	40	Unit
Load per hole	125	kg
Total amount of explosive	5000	kg

Table 2

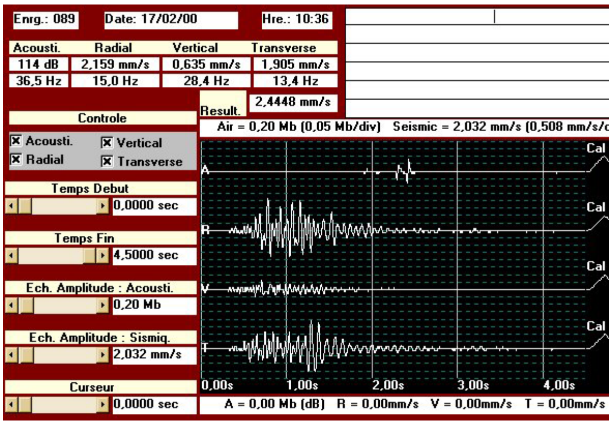
Blasting parameters in underground mining used by the mine

Designation	Quantity	Unit
Number of holes	20	Holes
Hole diameter	64	mm
Hole length	1.6 to 3	m
Stemming length	0.5 to 1	m
Load of a hole	70 to 100	kg
Total amount of explosive	1400	kg
Anfomil	1200	kg
Marmanite	200	kg

II.5.1 Blasting results and interpretation. The results of the seismic vibrations measured near to the nearest inhabited house (more than 700 m) from the blasting or earth-moving locations, were all less than 10 mm/s, defined limit value by the judgment of 22/09/1994 for the mines blasting carried out in quarries and massive rock mines for a frequency band of 5 to 30 Hz. The Acoustic overpressure is generally less than 125 dB, i. e. below the allowed limit for mining in quarries and massive rock mines (125 dB).

Because measuring points at recording distances of less than 300 m are used a lot in field, they were selected during blasting (blasts 63, 64 and 65).

Only the 3rd blast with a unit charge of 130 kg, at a distance of 177 m, has reached the maximum limit for the risks of damage to buildings-record 112 65 (Table 3, Fig. 3).



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Acousti.	Radial	Vertical	Transverse
114 dB	2,159 mm/s	0,635 mm/s	1,905 mm/s
36,5 Hz	15,0 Hz	28,4 Hz	13,4 Hz

Result. 2,4448 mm/s

Air = 0,20 Mb (0,05 Mb/div) Seismic = 2,032 mm/s (0,508 mm/s/

Controle
☒ Acousti. ☒ Vertical
☒ Radial ☒ Transverse

Temps Debut 0,0000 sec
Temps Fin 4,5000 sec
Ech. Amplitude : Acousti. 0,20 Mb
Ech. Amplitude : Sismiq. 2,032 mm/s
Curseur 0,0000 sec

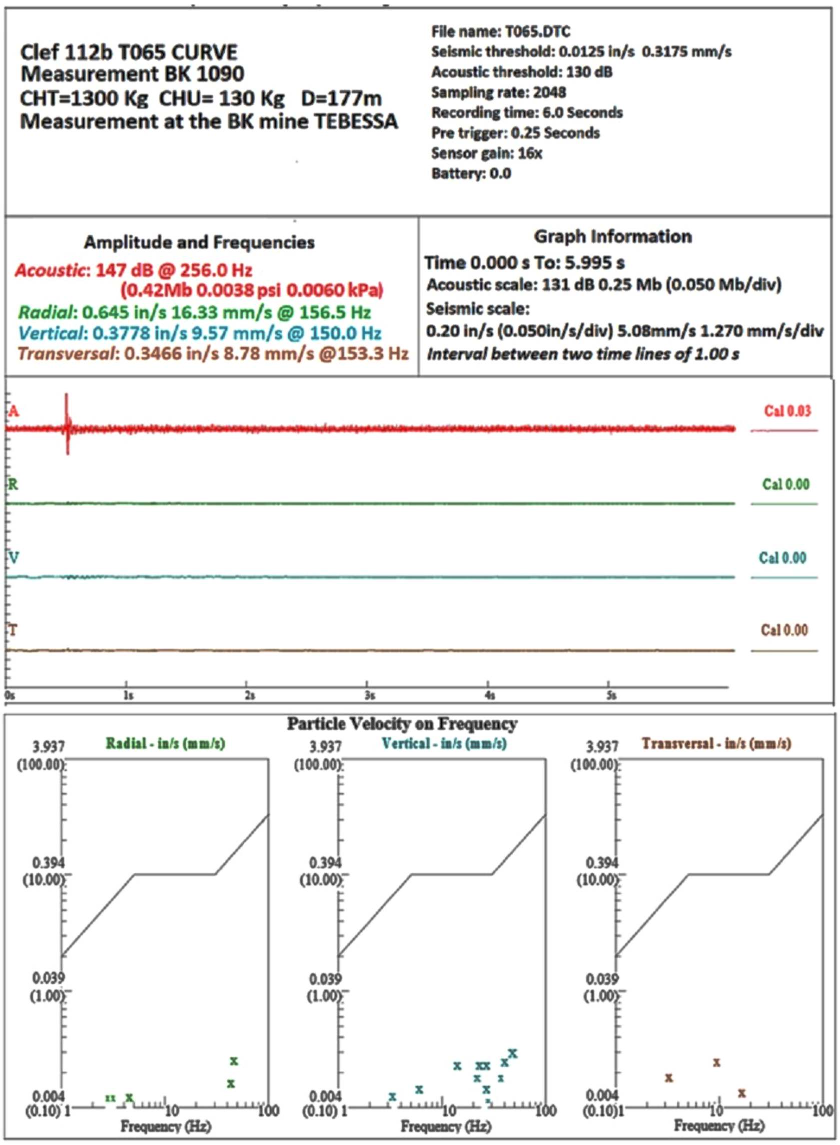
A = 0,00 Mb (dB) R = 0,00mm/s V = 0,00mm/s T = 0,00mm/s

Fig. 2. Technical sheet of blasting results

Table 3

Results of seismic and acoustic vibrations

Test	Reference device	Measurement location	Instantaneous charge (Kg)	Distance (m)	*Vr* (mm/s)	*Vv* (mm/s)	*Vt* (mm/s)	Acoustic (dB)
1	112b T063	BK 1090	77.5	281	3.35	1.94	2.90	144
2	112b T064	BK 1120	82.5	125	2.03	1.56	2.38	115
3	112bT065	BK 1090	130	177	16.33	9.57	8.78	147
4	112b T066	Transfo (1090)	120	690	1.06	1.17	1.11	136
5	112b T067	Transfo (1105)	120	690	1.08	1.19	1.11	136
6	112b T068	Water Tower (1105)	82.5	710	0.24	0.22	0.22	122
7	112b T069	Water Tower (1090)	82.5	730	1.03	0.54	0.79	108
8	112b T070	Water Tower (1120)	77.5	678	1.48	0.92	0.67	131
9	112b T071	S.A.C (1105)	93.75	708	1.43	0.97	1.22	127
10	112b T072	S.A.C (1090)	77.5	695	0.38	0.78	0.27	108
11	112b T073	S.A.C (1120)	120	700	0.29	0.49	0.25	127
12	112b T074	S.A.C (1095)	156.25	700	1.08	1.05	2.54	106
13	112b T075	S.A.C (1135)	77.5	700	1.14	0.37	0.70	106
14	112b T076	S.A.C (1075)	152.5	700	0.21	0.51	0.14	106
15	112b T077	S.A.C (1120)	152.5	700	0.84	0.54	1.60	116
16	112b T078	S.A.C (1135)	77.5	700	0.33	0.83	0.44	108



Clef 112b T065 CURVE
Measurement BK 1090
CHT=1300 Kg CHU= 130 Kg D=177m
Measurement at the BK mine TEBESSA

File name: T065.DTC
Seismic threshold: 0.0125 in/s 0.3175 mm/s
Acoustic threshold: 130 dB
Sampling rate: 2048
Recording time: 6.0 Seconds
Pre trigger: 0.25 Seconds
Sensor gain: 16x
Battery: 0.0

Amplitude and Frequencies
Acoustic: 147 dB @ 256.0 Hz (0.42Mb 0.0038 psi 0.0060 kPa)
Radial: 0.645 in/s 16.33 mm/s @ 156.5 Hz
Vertical: 0.3778 in/s 9.57 mm/s @ 150.0 Hz
Transversal: 0.3466 in/s 8.78 mm/s @153.3 Hz

Graph Information
Time 0.000 s To: 5.995 s
Acoustic scale: 131 dB 0.25 Mb (0.050 Mb/div)
Seismic scale:
0.20 in/s (0.050in/s/div) 5.08mm/s 1.270 mm/s/div
Interval between two time lines of 1.00 s

Fig. 3. Particle velocity curve on frequency, blasting 65

Because it satisfies the intersection of the use of a high unit load for a small distance having as a rule that, the relation between the values of the explosive load and the blast distance is reversible. Such test recording was intended as an illustration, since the recording distance is below the allowed conditions (less than 300 m) associated to a relatively high explosive charge; we have noticed that such blasting parameters are used in the site.

Except the blast 65, we noticed that the results related to the blasts 63 and 64 are the highest. However, they still remain below the regulatory limits. Although, the values of the distances of blasts are outside the statutory conditions, the choice of the values of explosive charges relatively associated with the latter was rational.

II.5.2. Estimation of charges – Calculation of the site coefficient K. The practical study of the vibrations in the case of mine blasting is carried out by measuring the particle velocity at a given distance, three orthogonal geophones, one longitudinal, one transversal and one vertical are available for measuring the three components of the particle velocity. This latter is then calculated according to the formula (mm/s)

$$V_{\downarrow}(p=)N(V_{\downarrow}l^{\uparrow}2+V_{\downarrow}t^{\uparrow}2+V_{\downarrow}v^{\uparrow}2). \qquad (2)$$

The method which consists of using for the resultant the square root of the sum of the maximum velocities measured on the three components is erroneous because these speeds are not maximal at the same instant. Therefore, it is necessary to use the maximum value of the component defined at the instant T by the formula. The particle velocity is calculated according to the Chapot formula, previously mentioned $(mm\overline{s})$

$$V = K\left[\left(\frac{D}{\sqrt{Q}}\right)\right]^{-1.8}; \qquad (3)$$

$$K = V\left[\left(\frac{D}{\sqrt{Q}}\right)\right]^{-1.8}, \qquad (4)$$

where V is the vibration speed, mm/s; D is the sensor-blasting distance, m; Q is instantaneous charge of explosive, K.

For blasts (112b T063, 112b T070, 112b T072, 112b T075, 112b T078), the instantaneous charge of explosive was fixed with the variation of the blasting-sensor distances; the general observation is that increasing the distance automatically leads to an increase in the site coefficient K (Table 4).

For the blasts (112b T074, 112b T075, 112b T076, 112b T077, 112b T078), the blasting-sensor distance was fixed with the variation of the instantaneous loads; the general observation is that the increase in the charge generates a decrease in the site coefficient K.

So, the relationship between the values is as follows: charge of the explosive and the distance of the blast-sensor are reversible, which means that when the charge of explosive increases, the site coefficient decreases. On the other hand, when the distance is increased, site coefficient increases.

II.5.3. Simulation of blasts and values interpretation. The simulation of the blasts allows presenting the danger zones, and having a visualization of the movemement of the rock matrix following the explosion.

II.5.3.1. Simulation results. The results of the displacement and the acceleration of the seismic waves obtained by the seismic analysis using software Delta Seis 4.4 are presented in Table 5. They are far from the regulation thresholds (320 μm) because the accelerations are higher, except for blast 65 where the value of the displacement exceeds the limits of the regulations (limits of damage) (Table 5). It should be noticed that the test blasts having low frequencies (112b T069, 112b T071, 112b T074, 112b T077) have high displacement limits with low accelerations. For the tests with high frequencies, they have generally low displacement limits with higher accelerations.

Table 4

Calculation of the site coefficient K

Measures	Distance (m)	Instant Charges (kg)	Particle Velocity (mm/s)	*K*
112b T063	281	77.5	3.35	1709.18
112b T064	125	82.5	2.38	266.82
112b T065	177	130	16.33	2274.37
112b T066	690	120	1.17	2027.73
112b T067	690	120	1.19	2062.39
112b T068	710	82.5	0.24	613.81
112b T069	730	82.5	1.03	2768.82
112b T070	678	77.5	1.48	3681.59
112b T071	708	93.75	1.43	3242.6
112b T072	695	77.5	0.78	2029.14
112b T073	690	120	0.49	849.22
112b T074	700	156.25	2.54	3562.41
112b T075	700	77.5	1.14	3007.92
112b T076	700	152.5	0.51	730.65
112b T077	700	152.5	1.60	2292.26
112b T078	700	77.5	0.83	2189.97

III. Simulation by Plaxis. To perform an analysis of the stability of the entire mine, by calculating the safety coefficient for blasting due to underground exploitation at 1105 level, a two-dimensional modeling of the studied area was established using FEM under a Plaxis calculation code version 8.2.

III.1. Calculation of the safety factor Fs by FEM. The estimation of slopes stability is generally established using a coefficient called safety coefficient Fs. This coefficient is defined as the relationship between the moment of results of the strengths resistant in the sliding and the moment of the strengths provoking the sliding with regard to a fix point.

Theoretically: $Fs > 1$ indicates that the slope is stable; $Fs = 1$, the slope is in state of equilibrium limit and when $Fs < 1$, the slope can only slide.

The reduction of the mechanical characteristics (phi-c reduction) is an option available in PLAXIS 8.2 [12], which makes it possible to calculate safety coefficients, the characteristics tg φ and C are gradually reduced until the rupture is obtained

$$\sum Msf = \frac{\tan\varphi input}{\tan\varphi reduced} = \frac{Cinput}{Creduced} = \frac{resistance\ available}{rupture\ strength}. \quad (5)$$

III.2. Numerical model of the study area. The numerical model corresponds to the cross section of the proj-

Table 5

Delta Seis 4.4 displacement and acceleration results

Test	Device reference	Particle Velocity (mm/s)	The maximum acceleration (mm/s^2)	Displacement max (microns)
1	112b T063	3.35	371	29
2	112b T064	2.38	291.60	20
3	112b T065	16.33	442.10	335
4	112b T066	1.18	438.10	18
5	112b T067	1.19	477.60	17
6	112b T068	0.24	45.45	5
7	112b T069	1.03	31.48	20
8	112b T070	1.48	185.80	10
9	112b T071	1.43	72.18	40
10	112b T072	0.78	295.40	4
11	112b T073	0.49	67.79	6
12	112b T074	2.54	74.76	91
13	112b T075	1.14	127.50	2
14	112b T076	0.51	65.10	32
15	112b T077	1.60	53.90	66
16	112b T078	0.83	143.80	2

ect. The study area is located between levels 865 and 1135 (N120 °E) where level 1105 is the underground part (Fig. 4). It is a succession of quarry tiers, alternating iron ores and bands of limestone and marl; with a height of 440 m, a width of 780 m and an edge angle equal to 70°. The physical-mechanical properties of the Boukhadra rock mass are given in Table 6 [9].

III.3. Calculation of safety coefficient before blasting. The safety coefficient is about 1.16, indicating that the edge of the quarry is stable with small displacements at the top (Fig. 5).

The quarry is affected by plastic points of cut-off tension type, which is explained by the appearance of cracks in the massive rock. Thus, the appearance of the

Table 6

Physical-mechanical properties of the Boukhadra mountain rocks

Model	Limestone	Iron-ore	Marl
Mohr –coulomb	Drained	Drained	Drained
γ_{unsat} [KN/m^3]	26	27	22
γ_{sat} [KN/m^3]	26.5	29	26
G_{ref} [KN/m^2]	$8.131 \cdot 10^5$	$8.400 \cdot 10^5$	$1.680 \cdot 10^5$
E_{ref} [KN/m^2]	$1.984 \cdot 10^6$	$2.100 \cdot 10^6$	$4.470 \cdot 10^5$
C_{ref} [KN/m^2]	350.000	320.000	33.000
φ [°]	50.000	45.000	23.000
ψ [°]	25.000	22.000	11.000

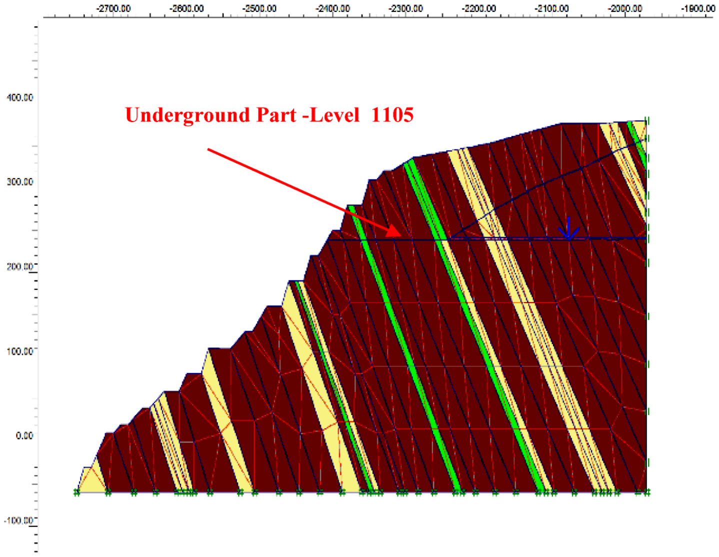


Fig. 4. Digital Model

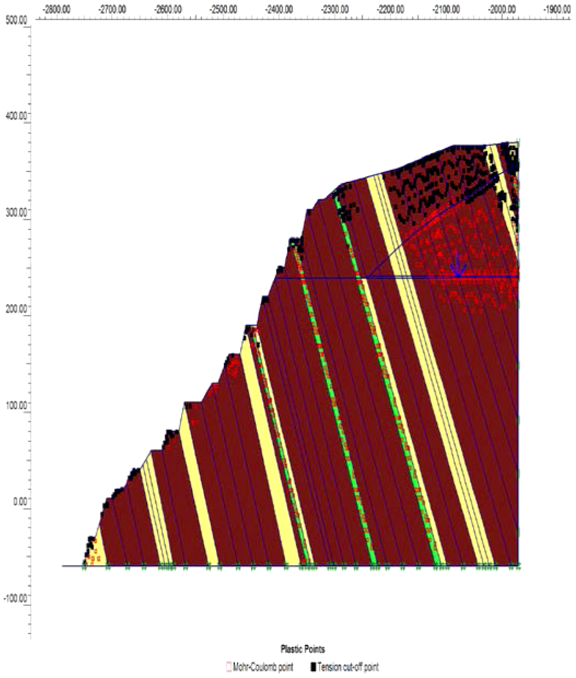


Fig. 5. Total Displacements

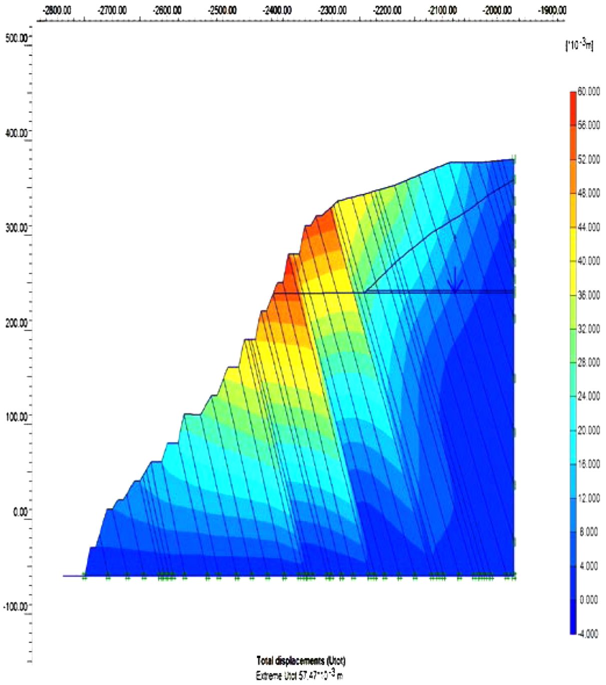


Fig. 6. Plastic points

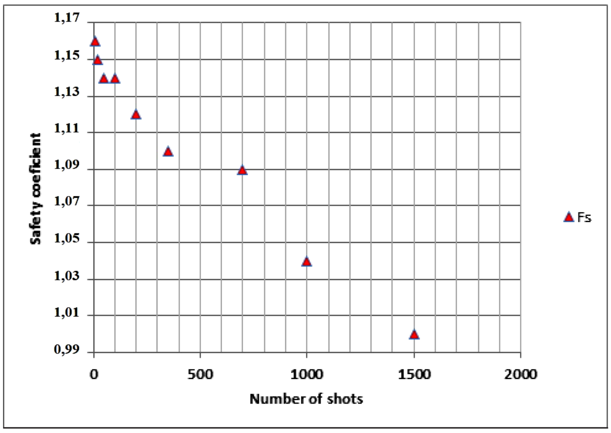


Fig. 7. *Values of Fs as a function of blasting*

Mohr-Coulomb points indicates that these zones are in the limiting state of rupture (Fig. 6).

III.4. Calculation of the safety coefficient after blasting. The modeling by the Plaxis software v 8.2, after several blasts, shows a small decrease in Fs values from about 1.16 before blasting to more than 1 after blasting (at around 1.08 for most values), which indicates that the slope of the BK mine remains stable for these blasts (Fig. 7). It has also been found that other values of Fs have decreased to less than 1 (the characteristic value of the ultimate state of rupture) after blasting indicating that, for these values the slope of the BK mine is no longer stable and it can only slip. Indeed, the instability encountered at the BK mine is due to blasting process, specifically (as proved on the first part of our work) to blasts where the values of the influential parameters were taken without correlation and outside the regulatory conditions (case of the blast limit 65).

General conclusion. Our work is done in two parts, on a characterization of the blasting and a simulation of the blasting phenomenon with respect to the stability of the BK iron mine.

We have found that the two parts complement each other and confirm the same results, on the one hand, and, on the other hand, there is lack of correlation between the main parameters, some of which are taken outside the regulatory conditions which are at the origin of the instability.

This is exactly what we have demonstrated with the reference blast 65, whose values of the parameters of the “explosive charge-blast distance” component lead to exceeding the current regulatory limits for seismic and acoustic vibrations, these values being for our case study “the limit values of damage”.

In conclusion, we can say that our case study can provide a working platform in blasting design that is technically, safely and economically successful for mines and quarries with conditions similar to the Boukhadra mine conditions.

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Оцінка впливу характеристик вибухової речовини й радіусу дії вибуху на стійкість укосів (рудник Бухадра, Алжир)

О. Камлі[1], *А. Буталеб*[1], *М. С. Джуама*[2], *М. Хасіні*[1]

1 – Університет Касді Мербах, м. Уаргла, Алжир, email: leadersinovation07@gmail.com

2 – Лабораторія фізичної металургії та матеріалів, Університет Баджи Мохтар, м. Аннаба, Алжир

Мета. Оцінити вплив заряду вибухової речовини та відстані поширення ударної хвилі на стійкість укосів рудника Бухадра. Ставиться завдання внести вклад у концепцію планування вибухових робіт, щоб зменшити вплив вібрацій на зсувну стійкість схилів, а також пошкодження підстави пласта.

Методика. Опис характеристик вибухового процесу було виконано з використанням сейсмографа для запису даних щодо швидкості частинок у 16 тестах, а також програмного забезпечення DELTA SEIS для визначення величини зміщення ґрунту під впливом швидкості частинок. Використане програмне забезпечення PLAXIS 8.2 для моделювання зсувної стійкості схилів під впливом буропідривних робіт, з урахуванням коефіцієнта міцності для всієї шахти.

Результати. Ми надійшли до висновку, що самі по собі безпосередньо вибухові роботи не є головною причиною нестійкості схилів, оскільки причина нестійкості обумовлена структурним, компонентним і фазовим складом порід схилів і особливостями фізико-хімічних взаємодій із поширюваними ударними та пружними хвилями, викликаними вибухом зарядів вибухових речовин.

Наукова новизна. Проведено чисельне моделювання зміщення ґрунту під впливом вибухових робіт з використанням двох різних інструментів: записи сейсмограм із застосуванням програми Delta SEIS, що характеризують результати впливу вибухових робіт, і програмного забезпечення PLAXIS 8.2. Встановлено, що „маса заряду вибухової речовини – відстань, на яку поширюється ударна хвиля“ при показниках 133 кг і 177 м відповідно, веде до максимальної коливальної швидкості 16 мм/с і акустичному перенапруженню у 47 дБ, викликаючи зсув ґрунту у 335 µm.

Практична значимість. Результати використані при підготовці технічної документації на проведення буропідривних робіт, що дозволило істотно підвищити стійкість схилів до дії ударних і пружних хвиль. У процесі моделювання ми виявили, що коефіцієнт міцності становить 0.90 (менше одиниці), що, природно, веде до зсуву схилу.

Ключові слова: *вибухові роботи, сейсмічні та акустичні коливання вібрації, стійкість, схил, чисельне моделювання, рудник*

Оценка влияния характеристик взрывчатого вещества и радиуса действия взрыва на устойчивость откосов (рудник Бухадра, Алжир)

О. Камли[1], *А. Буталеб*[1], *М. С. Джуама*[2], *М. Хасини*[1]

1 – Университет Касди Мербах, г. Уаргла, Алжир, email: leadersinovation07@gmail.com

2 – Лаборатория физической металлургии и материалов, Университет Баджи Мохтар, г. Аннаба, Алжир

Цель. Оценить влияние заряда взрывчатого вещества и расстояния распространения ударной волны на устойчивость откосов рудника Бухадра. Ставится задача внести вклад в концепцию планирования взрывных работ, чтобы уменьшить влияние вибраций на оползневую устойчивость склонов, а также повреждения основания пласта.

Методика. Описание характеристик взрывного процесса было выполнено с использованием сейсмографа для записи данных о скорости частиц в 16 тестах, а также программного обеспечения DELTA SEIS для определения величины смещения грунта под воздействием скорости частиц. Использовано программное обеспечение PLAXIS 8.2 для моделирования оползневой устойчивости склонов под воздействием буровзрывных работ, с учетом коэффициента прочности для всей шахты.

Результаты. Мы пришли к выводу, что сами по себе непосредственно взрывные работы не являются главной причиной неустойчивости склонов, поскольку причина неустойчивости обусловлена структурным, компонентным и фазовым составом пород склонов и особенностями физико-химических взаимодействий с распространяющимися ударными и упругими волнами, вызванными взрывом зарядов взрывчатых веществ.

Научная новизна. Проведено численное моделирование смещения грунта под влиянием взрывных работ с использованием двух разных инструментов: записи сейсмограмм с применением программы Delta SEIS, характеризующих результаты воздействия взрывных работ, и программного обеспечения PLAXIS 8.2. Установлено, что „масса заряда взрывчатого вещества – расстояние, на которое распространяется ударная волна“ при показателях 133 кг и 177 м соответственно, ведет к максимальной колебательной скорости 16 мм/с и аккустическому перенапряжению в 47 дБ, вызывая смещение грунта в 335 µm.

Практическая значимость. Результаты использованы при подготовке технической документации на проведение буровзрывных работ, что позволило существенно повысить устойчивость склонов к действию ударных и упругих волн. В процессе моделирования мы обнаружили, что коэффициент прочности составляет 0.90 (менее единицы), что, естественно, ведет к смещению склона.

Ключевые слова: *взрывные работы, сейсмические и акустические колебания вибрации, устойчивость, склон, численное моделирование, рудник*

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