Evaluation of the seismic effect due to blasting works in quarries, an important factor in the safe exploitation of mineral resources

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Abstract. Demolition using civilian explosives in open-pit mining operations presents technical and economic advantages. This method also produces effects with direct impact in the zone close to the quarry. If the intensity of vibrations exceeds certain limits, they can cause discomfort to people, affect stability of buildings and integrity of buildings located near the basalt quarry, and even cause morphological changes to the terrain in the area near the quarry. This paper describes ways to design/determine areas in the quarry where a certain quantity of explosives can/cannot be used under maximum security conditions, from the point of view of seismic vibrations, thus protecting people and civil/industrial buildings in the mining area.

1 Introduction

The paper presents a way to reduce the vibrations produced by carrying out demolition works with explosives in a quarry, namely the determination of quantities of explosives that can be used so that the intensity of seismic waves does not affect the buildings in the area close to the quarry.

Much research has been done in the field of seismic protection, considering the vibrations produced by blasting in quarries [1], mathematical relationships have been developed and applied in case studies in which the conditions for carrying out blasting work that present a reduced seismic risk have been established. [2]. Most of the mathematical processing has taken into account the quantities of explosive used in the blasting/delay, distance between the blast location and measuring location, the oscillation speed of the soil particles. [3]

Theoretically presenting the field situation (fig.1) zone A represents a quarry developed on a certain surface, and the randomly figured points A1÷A5, locations where blastingworks take place using civilian explosives.

Zone B is adjacent to the exploitation area A, and contains the points B1÷B8, randomly figured at different distances from the points A1÷A5, which may represent the main objectives of interest, respectively, civil/industrial buildings, roads/highways, etc.

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Activity carried out in zone A (A1÷A5) generates seismic waves (s) which, if they exceed a certain intensity, may affect the integrity and stability of civil/industrial objectives in zone B (B1÷B8).

Zones A and B present specific characteristics given by the physical-mechanical properties of the rocks, the morphology of the terrain, these influencing the propagation mode of seismic waves (amplifies/reduces the propagation speed, intensity, reflection) from the generation points A1÷A5 to the reception points B1÷B7, respectively, from zone A to zone B of interest.

The important factors that can influence the generation of seismic waves (s), their propagation through zones A and B, as well as the value of the parameters characterizing the seismic waves recorded at points of interest B1÷B7 are:

   - the total explosive quantities/delay used at points A1÷A5 (the blasting fronts).

   - the distance from points A1÷A5, the blasting fronts located in area A (quarry) and points B1÷B7 to seismic wave receptors located in area B (objectives to be protected).
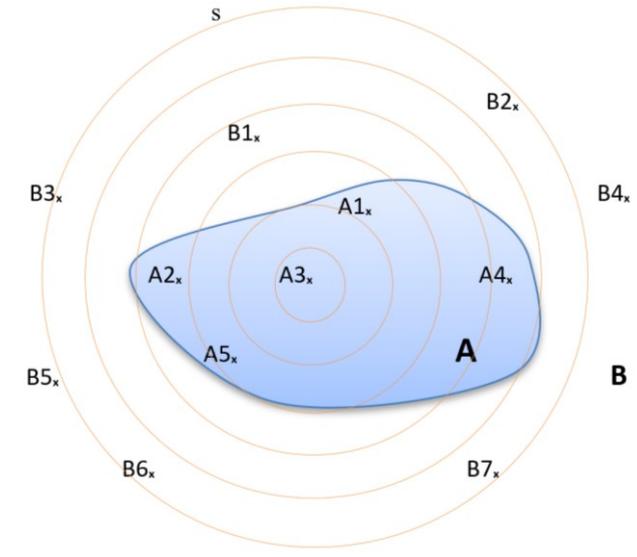

Fig. 1. Theoretical schematic presentation (Zone A - quarry, Zone B – adjacent, s – seismic waves produced by blatingworks at point A3)

The following presents the method of determining the quantities of explosive/delay that can be used in zone A of the quarry (A1÷A5), so that the intensity of the seismic waves (s) is reduced, thus ensuring the integrity and stability of the objectives in zone B (B1÷B7) adjacent to the quarry.

The previous theoretical description is customized for a case study as follows:

  - Zone A, bazalt quarry - Măgura Sârbi-Brănişca (fig. 2) where basalt is mined by the HeidelbergCement company.
  - A1÷A3, blasting 1(i1), blasting 2(i2), blasting 3(i3)
  - Zone B, the bazalt quarry - Măgura Sârbi-Brănişca is located southwest of Măgura Sârbi, located on the edge of the Bretea Muresană and Sârbi localities, at a 3 km distance from the Bretea Muresană railway station. Approximately 250 m from the nearest quarry crushing facility is the Deva-Arad highway. [4]

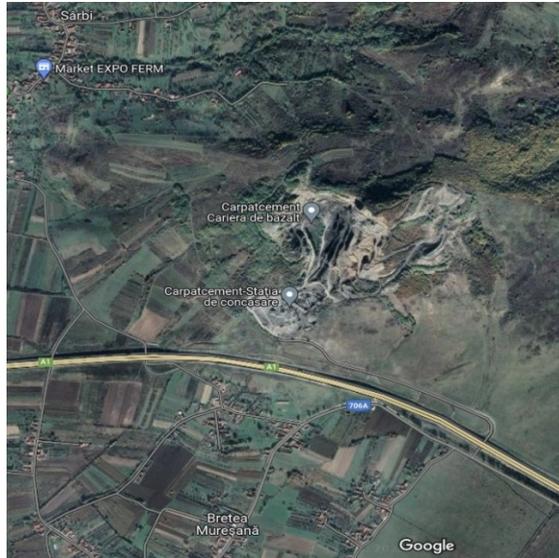- B1÷B10, measuring points for oscillation velocity.

Fig. 2. The Quarry - Măgura Sârbi Brănişca (Google Earth Pro)

Seismic monitoring was carried out by installation of seismic sensors in some locations, close to the quarry, at various known distances from the detonated blasting fronts, as shown as an example in the figure 3 for the first blast, i1. [5]
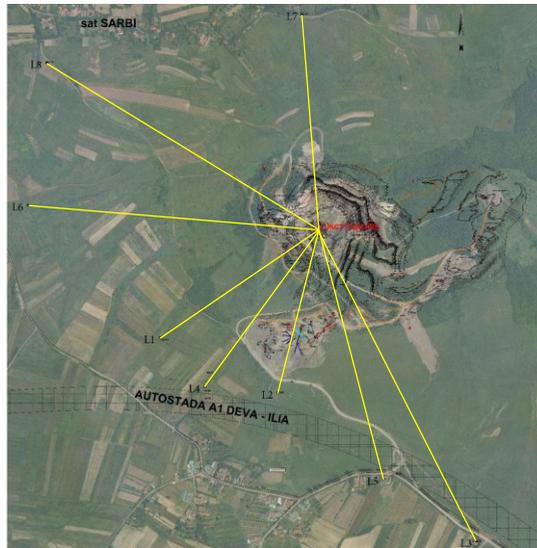

Fig. 3. Blasting 1 (i1) –The locations for measurement (Google Earth Pro)

The monitoring process mainly aimed at recording the parameter "particle oscillation velosity" which is a parameter by which the intensity of seismic vibrations produced by blasting in quarries can be evaluated.

The conditions for carrying out seismic monitoring in terms of the parameters of the blasting technique (geometric and quantitative) applied in the quarry:
- stepped height: 10m for blasting i1 and i2; 13m for blasting i3;
- explosives for civil use, used:
  - ANFODET used as the basic explosive;
  - RIOGEL XE with diameter 65mm and RIOGEL HE with diameter 60mm, used as initiation explosive charge;
- characteristics for shot blasting holes: diameter 89mm and inclination 85°;
- number of holes loaded with explosive: 58 for blasting i1, 61 for blasting i2, 74 for blasting i3;
- number of rows of blasting holes: 4 rows used at all blasting (i1),(i2) and (i3);
- burden: 4 m for blasting i1, and 3m for blasting i2 and i3;
- distance between holes from the same row: 3,5m used at all blasting (i1),(i2) and (i3);
- distance between rows: 3,5 m used at all blasting (i1),(i2) and (i3);
- the length of holes: 10m at blasting i1 and i2; 13m at blasting i3;
- the length of stemming: 2,5m blasting i1 and I3; 2m at blasting i2;
- the length of column explosives: 7,5m at blasting i1, 8m at blasting i2, 10,5m at blasting i3;
- initiation: nonelectric detonators;
- the quantity of explosive / hole: blasting i1- 31,78 kg, consisting of explosive ANFODET initiated with RIOGEL XE with diameter 65 mm și RIOGEL HE with diameter 60 mm, blasting i2- 35,14 kg, consisting of explosive ANFODET initiated with RIOGEL XE with diameter 65 mm și RIOGEL HE with diameter 60 mm and blasting i3- 42,04 kg, consisting of explosive ANFODET initiated with RIOGEL XE with diameter 65 mm și RIOGEL HE with diameter 60 mm;
- the quantity of explosive / delay: blasting i1- 63,56 kg (2 hole / delay), blasting i2- 70,28 kg (2 hole / delay), blasting i3- 84,08 kg (2 hole / delay).

All quantities of explosives are expressed in kg ETNT (TNT equivalent).

The non-electric initiation system network was used for a sequential rock removal from the massif, consisting of surface connectors that provided the delay and shock tube detonators to initiate the explosives in the shot holes.

2 Methods of determination

Methods for appreciation the seismic effect include mathematical formulas that take into account the parameters of seismic waves, for example, particle oscillation velocity, V (mm/s), frecvency (Hz), particle motion, particle displacement, u (mm), particle acceleration, a (m/s^2).

The amount of explosives that can be used in a quarry instantaneous / delay can be determined from the dependence of the oscillation velocity - the distance between the point of the explosion and point the measurement is made - the amount of explosive blasting expressed by the relation [6]:

$$V = K \cdot R_r^m \quad \text{(cm/s)} \tag{1}$$

where:

R_r - reduced distanc

$$R_r = R/\sqrt{Q} \quad \text{(m.kg}^{-1/2}\text{)} \tag{2}$$

where:

K and m - constant for a particular quarry blasting process;

R - the distance between the place of the explosion and the measurement point (m);

Q - quantity of explosive (kg ETNT – equivalent in trinitrotoluene).

Sizes constants K and m are determined by the method of least squares statistical processing the minimum 25 pairs of values of distance and velocity particles, measured in at least two blasting using various amounts of explosives.

Velocity must be measured at the point of maximum interest are located on the frontal direction and in the blasting under which the amount of the low speed oscillations of soil particles.

Knowing the amount of allowable soil particle velocity oscillations can be set reduced distance value, the amount of which is proper that quarry blasting technology used geological environment which seismic waves propagate.

The amount of explosive that can be blasting instantaneous calculate allowable speed according to fluctuations determined by construction type that should be protected and/or degree of injury accepted by the relation:

$$Q_{inst} = (R/R_r)^2 \cdot K_1 \quad \text{(kgETNT)} \tag{3}$$

where:

K_1 - coefficient depending on the number of blasting made during the year;

- ♦ up 10 $K_1 = 0.98$
- ♦ 11 ÷ 50 $K_1 = 0.90$
- ♦ 51 ÷ 100 $K_1 = 0.72$
- ♦ 101 ÷ 250 $K_1 = 0.64$
- ♦ over 250 $K_1 = 0.56$

The blasting millisecond, the amount of explosive that blasting delay is calculated by the formula [7]:

$$Q_{max/delay} = 2/3 Q_{inst.} \quad \text{(kg ETNT)} \tag{4}$$

The permissible oscillation velocity is that velocity can be considered that the before accepted effects on the types of constructions to be protected are not exceeded.

The value of 0.5 cm/s can be considered an accepted value, vibrations induced on the building structures can be possible damages for village type buildings, gas and petrol wells, under pressure pipes, mine shaft, and very fragile structures. [8]"

3 Results

Seismic characteristics specific for this quarry resulting from statistical processing:
- Reduced distance: 35,16;
- Specific seismic constant for perimeter and blasting technique:
    - o m = - 2,944;
    - o K = 17811,4;

Knowing Rr (reduced distance), of Măgura Sârbi-Brănişca quarry, was established dependence of the quantity of TNT equivalent explosive, the actual distance between the front that shoot - seismic protected objectives and permissible velocity oscillations particles.

The results of the seimic measurements performed are in table 1. [9]

Table 1. Masurements results

No crt.	Blasting	The maximum quantity of explosive / delay $Q_{max.delay.}$ [Kg ETNT]	Locations measurement	Velocity particles W [mm/s]	Distance between the blast location and measuring location R [m]
0.	1.	2.	3.	4.	5.
1	i 1 Tr. VIII	≈64 kg ETNT	L1	0,72	581
2			L2	0,72	506
3			L3	0,38	1052
4			L4	1,28	771
5			L5	0,58	616
6			L6	0,36	983
7			L7	0,87	953
8			L8	0,39	970
9.	i 2 Tr. VIII	≈71kg ETNT	L1	1,43	573
10.			L2	0,99	484
11.			L3	0,48	1092
12.			L4	1,17	599
13.			L5	0,70	989
14.			L6	1,30	678
15.			L7	0,54	984
16.	i 3 Tr. VIII	≈85 kg ETNT	L1	1,11	573
17.			L2	0,72	484
18.			L3	0,43	1092
19.			L4	1,572	599
20.			L5	0,41	989
21.			L6	0,33	984
22.			L7	0,46	678
23.			L8	0,38	748
24.			L9	0,889	533
25.			L10	2,157	580

As an additional safety measure, it was considered appropriate that the quantities of explosive/delay stage to be used in the quarry be reduced by approximately 33% of the instantaneous quantity determined, applying formula (4). (Table no. 2). [10] [11]

Table 2. The maximum quantities of explosives allowed to blasting instantly and $Q_{max/delay}$

No crt	Distance [m]	$Q_{inst.}$ [kg E TNT]	$Q_{max/delay}$ [kg E TNT]
0.	1.	2.	3.
1	300	75	50
2	350	102	68
3	400	133	89
4	450	169	112
5	500	208	139
6	550	252	168
7	600	300	200
8	650	352	234
9	700	408	272
10	750	468	312
11	800	533	355

Explaining the results in the table, respectively, if there is a distance of 450m between the blasting location and the nearest bilding to be protected, a quantity of 112 kg of explosive per delay can be used.

4 Conclusions

The input/processing data taken into account were the distances from the blasting to the measurement locations, the quantities of explosive/delay used in the blasting, the particle velocity values, respectively the vector sum of the velocities measured on three components, transverse, radial, longitudinal). Also, in the subsequent calculation stage, the coefficient corresponding to the number of blasting in the quarry was introduced.

The quantities of explosive/delay statistically determined to be used in the quarry, at different distances from the objectives that must be protected from the effect of seismic waves, are greater than those frequently used in the blasting, so it is not necessary to modify the parameters of the currently applied blasting technique, if it is found that the seismic waves is maintained within safe limits.

The evaluation of the values from the measurements does not present a risk situation that presents a possible danger to the integrity/stability of the buildings located in the zone bordering the basalt quarry - Măgura Sârbi Brănișca.

Even if, in the basalt quarry - Măgura Sârbi Brănișca, the number of blasting works is relative small (maximum 15 every year), factors such as physical-mechanical characteristics of the rocks, terrain morphology, may change the current conditions at the date of measurements and interpretations regarding seismic protection.

In this regard and considering the buildings in the zone adjacent to the quarry, special attention will be paid to the permanent control and monitoring of the blasting works in order to verify cooformity with seismic requirements.

In the event that the particle velocity value measured during subsequent blasting works exceeds the safety threshold adopted as a reference (0.5 cm/s) for seismic level protection,

must be applied the technical solutions that will reduction of the vibrations, until the blastink works are carried out without major impact on the surrounding area.

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