ENSURING THE SEISMIC PROTECTION OF THE OVERGROUND OBJECTIVES IN THE NEIGHBORING AREA OF INDUSTRIAL CEMENT PRODUCERS QUARRIES

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Abstract. The paper highlights the research undertaken at three limestone and gypsum quarries belonging to a large cement producer in Romania, in order to evaluate the seismic protection of civil and industrial objectives located near the exploitation perimeters. In this regard, the results obtained from the tests on the determination of seismic parameters are presented, in order to assess the seismic effect generated by the blasting works on civil and industrial objectives located in the vicinity of exploitation areas.

Keywords: seismic protection, constructions, limestone, quarry, blasting

ЗАБЕЗПЕЧЕННЯ СЕЙСМІЧНОГО ЗАХИСТУ НАЗЕМНИХ ОБ'ЄКТІВ НА КАР'ЄРАХ, ЩО ВИДОБУВАЮТЬ ВАПНЯК ТА ГІПС

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Анотація. У статті висвітлено дослідження, проведене на трьох кар'єрах вапняку та гіпсу, що належать великому виробнику цементу в Румунії, з метою оцінки сейсмічного захисту цивільних та промислових об'єктів, розташованих поблизу периметрів експлуатації. У зв'язку з цим представлені результати, отримані в результаті випробувань з визначення сейсмічних параметрів, з метою оцінки сейсмічного ефекту, що виникає підривними роботами на цивільні та промислові об'єкти, розташовані в районі експлуатаційних зон.

Ключові слова: сейсмозахист, споруди, вапняк, кар'єр, вибухові роботи

1. Introduction

Carrying out blasting works in quarries with the help of explosives determines the appearance of a seismic effect that is manifested by the vibration of the ground, with direct implications on the stability and integrity of the objectives in the area (Radoi et al., 2017).

Elements sensitive to ground oscillations can be varied: civil and industrial constructions (residential blocks, administrative buildings, factories, halls, etc.) works of art (on the surface: bridges, towers, retaining walls, etc. or underground: tunnels, tanks, sewers, etc.). In certain situations, natural areas and especially steep slopes of hills and mountains are also affected.

In the first three areas that characterize the explosion phenomenon, the propagation of the waves generated by it led to the crushing, breaking, throwing and cracking of the massif, and in the fourth area, to the appearance of elastic deformations, respectively of the ground oscillations, whose main parameters can be determined by direct measurements or mathematical calculations.

The evaluation of the seismic effect can be done by monitoring some parameters that characterize the seismic waves produced by quarries explosions such as: frequency of oscillations, amplitude of displacement, velocity of soil particles oscillations, oscillations acceleration, duration of their manifestation. Thus, at the level of the Department of Security of Explosives and Pyrotechnic Articles within INCD INSEMEX Petroșani, a seismic wave monitoring procedure was developed which includes the steps to be taken and the requirements for obtaining results with high accuracy, using state-of-the-art equipment.

2. Methodology

2.1. Procedural aspects

The methodology used in order to ensure the seismic protection of the overground objectives against blasting activities in surface mining operations involves the following steps (Gheorghiosu et al., 2015):

Step 1. Determining the measurement locations

- identification of the blasting location (explosion epicenter);
- establishing on the quarry map, the measurement locations - these will be established in the points of maximum interest, at objectives located in the area adjacent to the current mining operation, located near the blasting fronts, on the mediator / direction of the front.

Step 2. Location of measuring equipment

- the placement in the field of the measuring equipment, in the previously established positions and their placement in places that do not produce the amplification or attenuation of the seismic effect. The placement of the equipment in the field, on the measuring position, will be performed in accordance with the manufacturer's recommendations;
- setting the measuring equipment to start the measurement before the explosive charges are triggered, at a predetermined time difference from the measured event;
- detonation of explosive charges according to the firing plan;
- shutting down equipment.

Step 3. Creating the database

- downloading and archiving the measurement results in the computer;
- listing the reports generated by the equipment software;
- centralization of the database in order to carry out the evaluation process;
- the parameters underlying the assessment of the seismic effect are:
- velocity of oscillations of soil particles, V;
- acceleration of oscillations, a;
- frequency of oscillations, f;
- displacement of particles, u.

2.2. Equipment used for measuring and recording seismic wave parameters - Seismograph

At present, the specialized companies have developed the infrastructure for monitoring the seismic effect from the blasting works in the quarries and provide a wide range of equipment (Gheorghiosu et al., 2016).

Such equipment intended for measuring seismic waves is called Seismographs, and has a high-performance measurement accuracy.Well-known manufacturers in the field include NOMIS in the United States and INSTANTEL in Canada.

INCD INSEMEX Petroșani is equipped and uses NOMIS type (figure 1) and INSTANTEL type (figure 2) seismographs for seismic monitoring which are very complex devices and which can measure and record the parameters that characterize seismic waves.

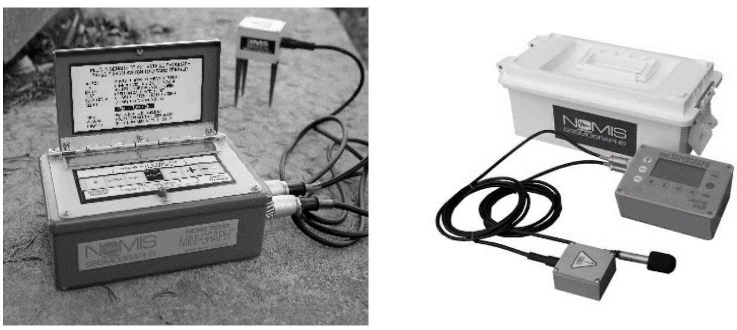

Figure 1. NOMIS seismographs

Figure 2. INSTANTEL seismographs

The measuring assembly consists of the storage and recording data unit to which are coupled the sensors (transducers) that are particularly sensitive to ground vibrations, produced on three components: transverse, vertical and longitudinal.

INSTANTEL type seismograph (MINIMATE PRO 6) has some additional technical facilities. Thus, the software module (Blastware Advanced module Software) provides the logistics component necessary to communicate with the computer, but also has the possibility to calculate specific parameters in assessing the seismic effect, before performing the shooting, as well as after performing it, with reference to measurement values, compared to the requirements of standards (regulations) in different countries, thus making possible a diversified assessment of the seismic effect.

As a result, it is possible to classify the results according to the Australian Standard - 2187.2-1993, British Standard QLD, British Standards - 6472: 1992 Curves 128, 16, 20, 60, 8, 90, Czech Standard, Danish Standard - Harmoniska Svangningar European Standard - DIN4150, French Standard - Ministry of Environment, French Standard - Weighting Function, Indian Standards DGMS [A], DGMS [B], New Zealand Standards - 4403: 1976 and ISO - 2631-2-1989 Combined curves, Slovak standard, Standard Spanish - Criterion Prevención 22.381, Swiss Standards - Mining Standard SN 640 312a, Tightening Standard SN 640 312a, Traffic Standard SN 6 40 312a and Standard USBM - RI8507 and OSMRE.

The report (figure 3) generated by the software that includes the maximum recorded values of the parameters measured on the 3 components (longitudinal, transverse, vertical), respectively velocity (mm / s), acceleration (g), frequency (Hz), displacement (mm) and general information on the blasting work, can be stored and listed after each monitoring action.

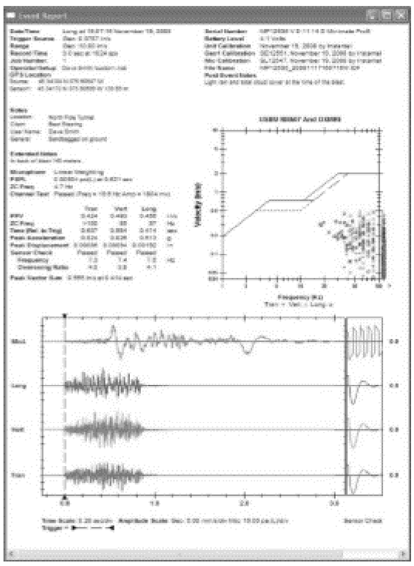

Figure 3 - The report with the values recorded in the measurements

2.3. Technical requirements for performing seismic measurements

Seismic measurements are complex actions that require knowledge of many technical aspects in different fields (Bordos et al., 2017; Vasilescu et al., 2019)

Personnel performing seismic monitoring must be specially trained and know very well the measurement procedure, seismographs and auxiliary components (geophones, software, etc.) but also aspects related to explosives, the parameters of blasting techniques, seismic waves and their parameters.

In order to have high precision results, the specifications of seismograph manufacturers must be observed for seismic measurements. The main factor that can influence the obtaining of the results with a high precision, is the location / fixing of the geophone (seismic sensor).

The sensors (geophones) are provided at the top with an arrow that must be oriented in the direction of the event so that the sensor of the geophone inside the transducer remains positioned in its natural axes.

By orienting and positioning the arrow of the geophone towards the source of production of the event, the best conditions for recording the event on all channels are ensured. Manufacturers also recommend the installation of geophones in a safe condition so that the results obtained are correct.

Improper fixing can allow the transducer to move independently on the measuring surface, often resulting in large distortions of the monitoring results.

The method of fixing depends on the type of surface existing, so there is not one valid in all practice applications.

The user must check the surface and fix the geophone to the studied surface so as to ensure a fixed grip of it.

In the seismic monitoring activities performed, in each measuring location the transducers were installed on the ground, according to those shown in figure 4, using the mandrels delivered especially for this purpose together with the device.

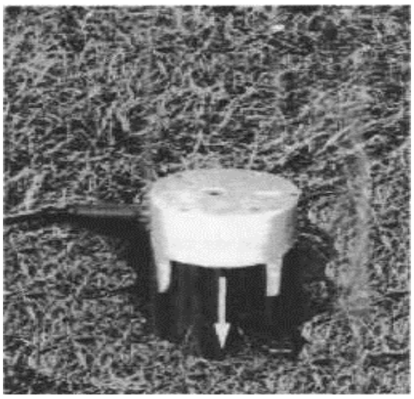

Figure 4 - Fixing the geophone with the help of mandrels

For best results, it is recommended to bury the geophones (figure. 5)

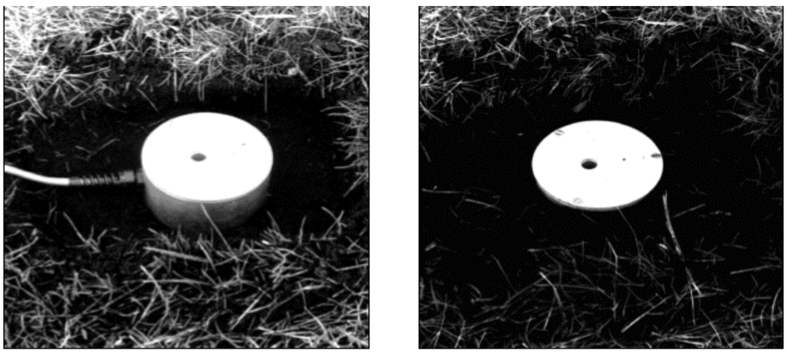

Figure 5 - Burying the geophone

The burial of the geophone is made in a hole from 10 to 15 centimeters deep, pointing the arrow at the top of the geophone in the direction of the event. Press firmly on the top of the geophone to push the tips of the mandrels into the ground and check that the geophone is securely fastened and at the same level.

The soil should be firm and compact, with no loose material between the geophone and the compacted soil material. Then compact the material around the geophone and check the communication between the sensor and the data storage unit.

3. Results and discussions

Below are the results of the measurements performed at 3 quarries, two of limestone and one of gypsum (Ghicioi et al., 2017; Radoi et al., 2017)

3.1. Măgura Feredeului – Chiscădaga quarry (limestone)

Figure 6 – General view of Măgura Feredeului – Chiscădaga quarry

3.1.1. Parameters resulting from measurements:

No.	Blasting no. Step (Step height)	Measurement locations	Speed of oscillations soil particles V (mm/s)	Measurements uncertainty (±)
0.	**1.**	**2.**	**3.**	**4.**
1.	I 1 Tr. III South (486,69 m)	L1	25,5	0,0072
2.		L2	1,65	0,0176
3.		L3	1,47	0,0308
4.		L4	3,56	0,0533
5.		L5	0,81	0,0214
6.		L6	-	-
7.		L7	14,0	0,0000
8.	I 2 Tr. V (448,28 m)	L1	4,25	0,0126
9.		L2	3,18	0,0392
10.		L3	1,15	0,0075
11.		L4	0,87	0,0135
12.		L5	0,71	0,0093
13.		L6	-	-
14.		L7	69,6	0,0000
15.	I 3 Tr. V-a A (447,83 m)	L1	5,92	0,0044
16.		L2	1,65	0,0099
17.		L3	0,41	0,0031
18.		L4	0,67	0,0229
19.		L5	0,30	0,0038
20.		L6	-	-
21.		L7	35,0	0,0000
22.	I 4 Tr. III South (486,38 m)	L1	1,0	0,0182
23.		L2	1,27	0,0070
24.		L3	7,24	0,0051
25.		L4	7,19	0,0228
26.		L5	0,98	0,0130
27.		L6	3,17	0,0034
28.		L7	2,1	0,0000

Figure 7 – Results of speed parameter measurements at the locations considered relevant at different distances from the front of the blast

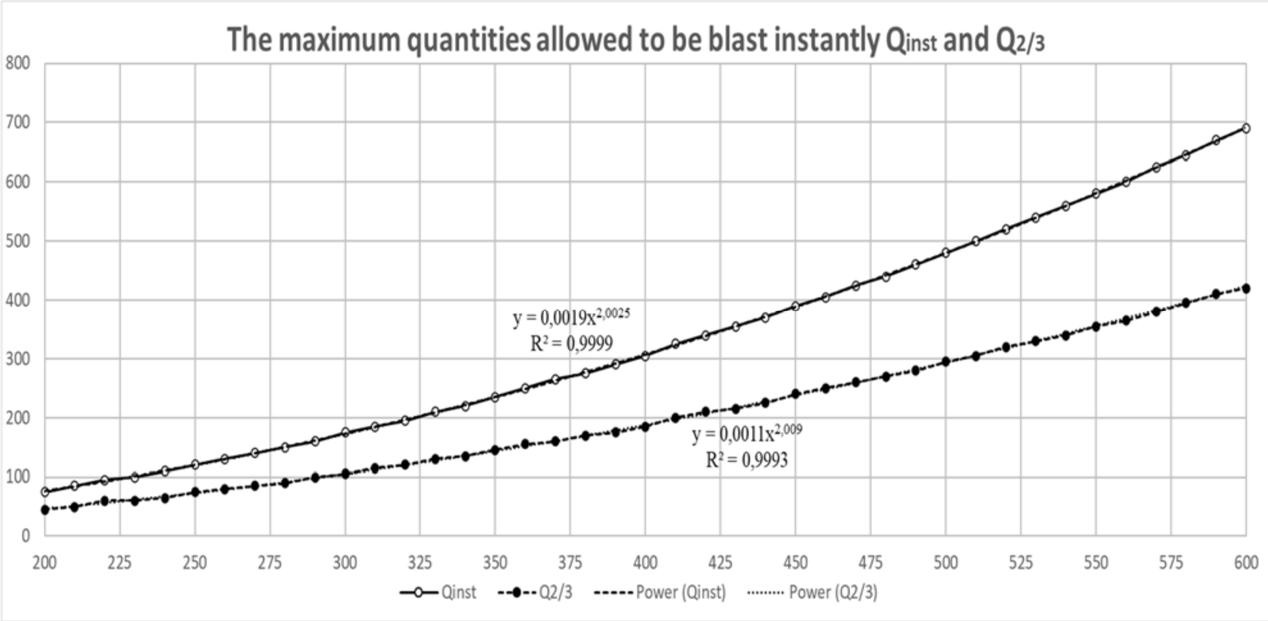

Figure 8 – Graphical variation of the values corresponding to the maximum amount of explosive required to be fired instantly (Q_{inst}) and the maximum amount of explosive determined according to the nearest seismic protected objective ($Q_{2/3}$), in relation to the real distance (R_r)

3.1.2. Blasting parameters:

- diameter of boreholes: 115 mm;
- the bottom burden of vertical/inclined holes: 3.5 m;
- the distance between the holes in row: 3.5 m;
- the length of holes - vertical/inclined: 24 m;
- the stemming length - in vertical/inclined holes: 8.0 m
- the length of the explosive column - in vertical/inclined holes: 16.0 m;
- ambient temperature: 18 degC – 20 degC

3.1.3. Explosives used:

- base charge: Anfodet, granular explosive type ANFO (explosive with TNT equivalent = 0.7) – 123 kg/hole;
- priming charge at the bottom of the hole: Riogel Troner XE, gelatinous explosive type (explosive with TNT equivalent = 1) – 2.3 kg/hole and Riogel Troner HE (TNT equivalent explosive gel = 1) – 8.4 kg/hole;
- means of initiation used: DETINEL type non-electric initiation systems;

3.1.4. Seismic characteristics specific to the Măgura Feredeului quarry:

- the oscillation velocity of the soil particles, maximum allowed: 0.5 cm/s;
- scaled distance: 21.65;
- seismic constants, specific to the quarry conditions and the blasting technique:
  - m = - 0.857
  - K = 6.969
- the maximum number of annual primary blasts: 115.

3.2. Călanul Mic – Sâncrai quarry (gypsum)

Figure 9 – general view of Călanul Mic – Sâncrai quarry

3.2.1. Parameters resulting from measurements:

No.	Blasting no. Step (Step height)	Measurement locations	Speed of oscillations soil particles V (mm/s)	Measurements uncertainty (±)
0.	**1.**	**2.**	**3.**	**4.**
1.	I 1 Tr. III (253,55 m)	L1	131,1	0,0020
2.		L2	0,3	0,0087
3.		L3	190,06	0,0031
4.		L4	5,1	0,0063
5.		L5	122,6	0,0032
6.		L6	-	-
7.		L7	2,2	0,0023
8.	I 2 Tr. I. (270,78 m)	L1	1,9	0,0057
9.		L2	1,7	0,0135
10.		L3	12,7	0,0016
11.		L4	2,0	0,0087
12.		L5	170,3	0,0098
13.		L6	-	-
14.		L7	5,1	0,0086
15.	I 3 Tr. I (269,44 m)	L1	1,4	0,0065
16.		L2	1,0	0,0092
17.		L3	12,8	0,0006
18.		L4	15,0	0,0087
19.		L5	46,7	0,0084
20.		L6	7,5	0,0010
21.		L7	77,7	0,0007
22.	I 4 Tr. I (270,98 m)	L1	3,5	0,0031
23.		L2	2,5	0,0108
24.		L3	12,4	0,0032
25.		L4	1,4	0,0006
26.		L5	0,9	0,0087
27.		L6	5,1	0,0086
28.		L7	29,5	0,0086

Figure 10 – Results of speed parameter measurements at the locations considered relevant at different distances from the front of the blast

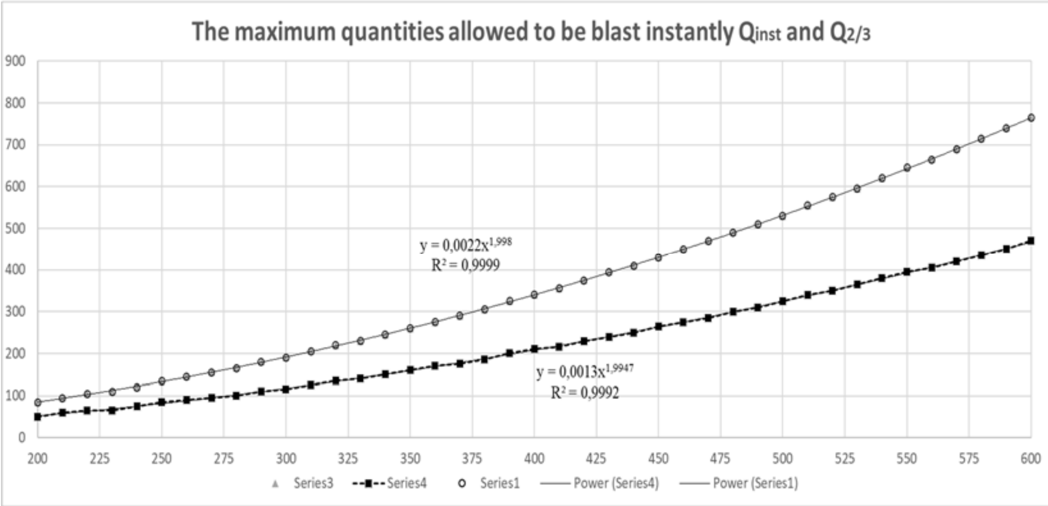

Figure 11 – Graphical variation of the values corresponding to the maximum amount of explosive required to be fired instantly (Q_{inst}) and the maximum amount of explosive determined according to the nearest seismic protected objective ($Q_{2/3}$), in relation to the real distance (R_r)

3.2.2. Blasting parameters:

- diameter of boreholes: 110 mm;
- the bottom burden of vertical/inclined holes: 3.0 m;
- the distance between the holes in the row: 3.0 m;
- the length of holes - vertical/inclined: 8 m;
- the stemming length - in vertical/inclined holes: 3.0 m
- the length of the explosive column - in vertical/inclined holes: 5.0 m;

3.2.3. Explosives used:

- base charge: Anfodet, granular explosive ANFO type (explosive with TNT equivalent = 0,7) – 35 kg/hole;
- priming charge at the base of the hole: Riogel Troner XE gelatinous explosive type (explosive with TNT equivalent = 1) – 2.3 kg/hole and Riogel Troner HE gelatinous explosive type (explosive with TNT equivalent = 1) – 2.08 kg/hole;
- means of initiation used: DETINEL type non-electric initiation systems;

3.2.4. Seismic characteristics specific to the Călanul Mic-Sâncrai quarry microperimetry:

- the oscillation velocity of the soil particles, maximum allowed: 0.5 cm/s;
- scaled distance: 20.58;
- seismic constants specific to the quarry conditions and the blasting technique:
  - m = - 0.539
  - K = 2.551
- the maximum number of annual primary blasts: 40.

3.3. Lespezi – Fieni quarry (limestone)

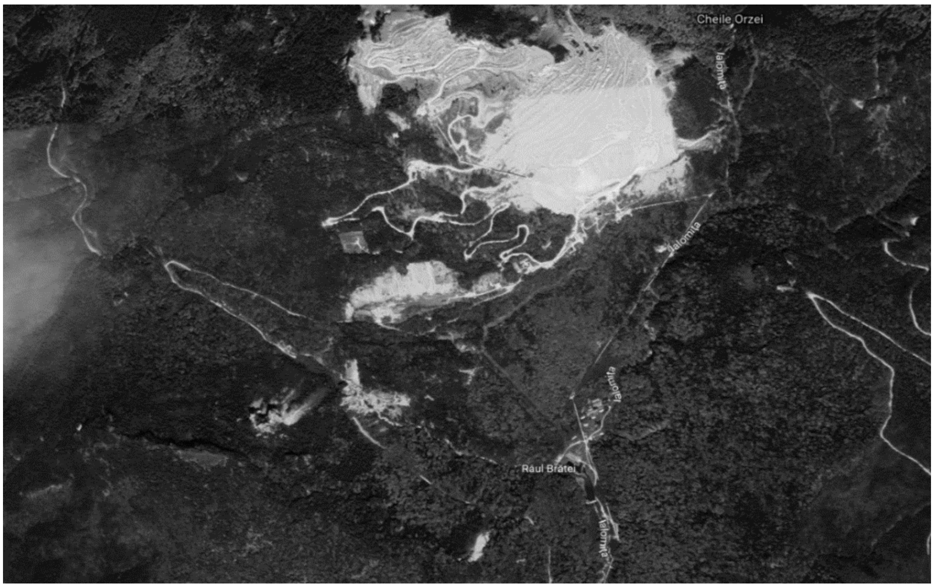

Figure 12 – general view of Lespezi – Fieni quarry

3.3.1. Parameters resulting from measurements:

No.	Blasting no. Step height	Measurement locations	Speed of oscillations soil particles V (mm/s)	Measurements uncertainty (±)
0.	**1.**	**2.**	**3.**	**4.**
1.	I 1 Tr.1310m	L1	577	57,47
2.		L2	284	28,29
3.		L3	196	19,52
4.		L4	391	38,94
5.		L5	706	70,32
6.		L6	638	63,55
7.		L7	995	99,10
8.	I 2 Tr.1290m	L1	983	111,19
9.		L2	625	70,70
10.		L3	550	62,22
11.		L4	784	88,69
12.		L5	1032	116,74
13.		L6	884	100,00
14.		L7	1362	154,07
15.	I 3 Tr.1310m	L1	713	73,05
16.		L2	420	43,03
17.		L3	226	23,16
18.		L4	539	55,23
19.		L5	764	78,28
20.		L6	650	66,60
21.		L7	1084	111,07
22.	I 4 Tr.1620m	L1	864	76,39
23.		L2	950	84,00
24.		L3	883	78,07
25.		L4	890	78,69
26.		L5	387	34,22
27.		L6	181	16,00
28.		L7	691	61,10

Figure 13 – Results of speed parameter measurements at the locations considered relevant at different distances from the front of the blast

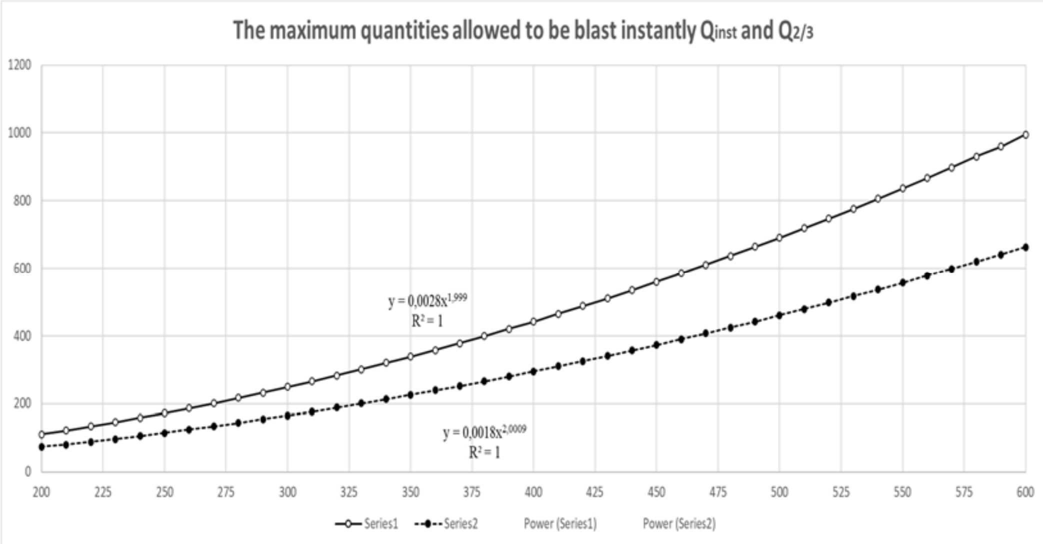

Figure 14 – Graphical variation of the values corresponding to the maximum amount of explosive required to be fired instantly (Q_{inst}) and the maximum amount of explosive determined according to the nearest seismic protected objective ($Q_{2/3}$), in relation to the real distance (R_r)

3.3.2. Blasting parameters:

- diameter of boreholes: 115 mm;
- the bottom burden of vertical/inclined holes: 3.0 m;
- the distance between the holes placed on the same row: 3.2 m;
- the length of holes - vertical/inclined: 22 m;
- the depth of the deep sink / inclined holes: 1.5 m;
- the stemming length - in vertical/inclined holes: 3.0 m;
- the length of the explosive column - in vertical/inclined holes: 19.0 m;

3.3.3. Explosives used:

- base charge: Austinite, granular explosive ANFO type (explosive with TNT equivalent = 0,7) – 85 kg/hole;
- priming load:
  - at the base of the hole: EMULEX 2 + (explosive emulsion type with TNT equivalence = 1) – 3.125 kg/hole and EMULEX 1 (explosive emulsion type with TNT equivalence = 1) – 3.125 kg/hole;
  - at the middle of the base charge: EMULEX 2 + (explosive emulsion type with TNT equivalence = 1) – 3.125 kg/hole;
- means of initiation used: DETINEL type non-electric initiation systems;

3.3.4 Seismic characteristics specific to the Lespezi quarry:

- the oscillation velocity of the soil particles, maximum allowed: 0.5 cm/s;
- scaled distance: 16.14;
- seismic constants specific to the quarry conditions and the blasting technique:
  - m = - 1.460
  - K = 14.053
- the maximum number of annual primary blasts: 70.

3.4. Safe operating conditions in the three monitored quarries:

- The direction of the detonation transmission in each borehole: from the base of the hole to its mouth;
- Blasting activities should be avoided during periods of high rainfall;
- Priming at several points is recommended if the length of the explosive columns in the boreholes is greater than 10 meters. The distance between the priming charges shall be a maximum of 10 meters;
- The delay between two decking points in the same hole will be max. 25 milliseconds.

4. Conclusions

To determine the parameters - constants K, m and scaled distance Rr, which are the basis of the methodology for assessing the safe amount of explosive from a seismic point of view, the oscillation velocity of soil particles were monitored at several blasts and specific to the quarry conditions presented in the paper.

The measurement locations were located in the points of maximum interest, at objectives located in the neighboring area to the quarries - shown on the maps provided by the mining company, and located at the closest distances from the blasting bench.

Knowing the scaled distance, it was established the dependence between the amount of explosive in TNT equivalent, the real distance between the blasting place, the seismic protected objectives and the permitted velocity of the oscillations of the soil particles.

In order to ensure the integrity of civil and industrial construction located in the immediate vicinity of quarries, their proper management and operation must be carried out in compliance with the recommended safe conditions of use, as well as the quantities of explosives, maximum permitted to be blast instantaneously or per delay according with the actual distance between the nearest construction and the epicenter of the explosion (according to the values presented in the table).

Given the year-by-year increase in blasted volumes, the development and expansion of quarry benches, the need to use larger quantities of explosives and the dynamics in changing of types of explosive materials and initiation, it is necessary to re-evaluate the seismic effect in quarries at intervals of up to three years.

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