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ASSESSMENT OF THE GROUND VIBRATION GENERATED BY BLASTING IN QUARRIES

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Abstract

In order to have a proper image of the seismic effect generated by blasting works performed in quarries, the assessment methods applied before starting the blasting activity using explosives for civil use have to take into account as many information as possible with regard to blasting conditions, type of explosive, blasting technique, characteristics of the environment in which the explosive is detonated and in which the seismic waves are generated. Given the complex mode of propagation of seismic waves in the vicinity of quarries, the assessment process may show differences between anticipated values and those measured when performing blasting in quarries. The differences ascertained highlights the importance of seismic measurements in situ, the appropriate way to establish the safety level in carrying blasting in quarries with regard to the seismic effect.
This paper presents the results obtained by applying the empirical formulas for estimating the seismic effect and the evaluation of the seismic effect by applying methods and criteria based on the results recorded to the seismic measurements made in quarries. The results obtained according to the requirements of the general standards or other technical regulations, make possible to observe the level of risk regarding the seismic effect for the purpose of applying technical measures to reduce it if the situation requires.

Key words: blasting, explosives, seismic effect, quarry

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1. Introduction

The article presents a comparison between the results obtained by estimating the seismic wave parameters (particle oscillation velocity, frequency and acceleration) using empirical formulae and the values of these parameters obtained from on-site measurements.

Empirically or measured values will not be compared to some limits of various parameters, which are used to interpret the intensity of the particle vibration caused by the blasting. The seismic effect generated by blasting works in quarry is determined by a series of natural and technological factors that must be considered when studying the influence of environmental oscillations to objectives from the near area perimeters where explosions occur (Vasilescu et al., 2014). The design and managing of the blasting work must aim at:

- massive blasting of the rock volume to a grain corresponding to the technological requirements;
- protecting the civil and industrial objectives of the area to the effects of blasting (shock wave, fly-rock and seismic effect).

Of these, the most outstanding issues is seismic protection.

2. Material and methods

The methods of assessment contain mathematical expressions that have parameters as reference which characterize seismic waves:

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displacement rock particle, *u* (mm); particle velocity, *V* (cm/s); particle acceleration, *a* (m/s^2), frequency, *f* (Hz) (Tat et al., 1985).

To evaluate the seismic effect, different methods can be used, such as:

- ***The relative energy method*** (Enescu and Bujor, 1987; Fodor, 2007), (Eq. 1):

$$ER = a^2 / f^2 \tag{1}$$

where: *a* – maximum particle acceleration and is given by Eq. (2):

$$a = 877.95\, Q^{3/4} / r^2 \qquad \text{g } (m/s^2) \tag{2}$$

where: *r* – distance to the explosion area; *Q* – explosive charge weight (t).

Depending on the acceleration value, the vibration levels expressed in the acceleration values resulting in the deterioration degree are:

- ✓ < 0.002 g - level of construction sensitivity to vibration below which there is no danger to the building;
- ✓ 0.005 g - total safety of the building, vibrations of the windows;
- ✓ 0.01 g - rigidity level below which there are no significant damage to construction;
- ✓ 0.05 g - the breaking limit of individual building elements, a limit above which there is a risk of serious damage;
- ✓ 0.23 g - the stability limit of the buildings over which the buildings are destroyed.

The frequency of vibration is calculated using Eq. (3):

$$f = 1/T \tag{3}$$

where: *f* - frequency of vibration; *T* - the vibration period.

T is calculated with the relationships (Eqs. 4, 5):

- for hard rocks:

$$T = 0.0065\, \sqrt[6]{Q}\ , \quad \text{(s)} \tag{4}$$

where: *Q* - explosive charge weight, in trinitrotoluene equivalent ETNT, kg.

- for soft rocks:

$$T = 0.06 Q^{0.21}, \qquad \text{(s)} \tag{5}$$

Depending on the *ER* value, 3 safety classes are proposed: *ER* < 0.27 total safety; 0.27 < *ER* < 0.54 precaution for badly built buildings; *ER*> 0.54 danger for all buildings.

- ***Zeller criterion*** which is defined by (Eq. 6) (Fodor, 2007):

$$ER = a_z^{\,2} / f \tag{6}$$

where: a_z – maximum acceleration; *f* - the frequency of vibrations associated with maximum acceleration.

Based on the *Z* criterion, the Zeller scale is defined, which differentiates 12 classes of influence, so *Z* < 2, with the summary description of the seismic effect as "imperceptible" respectively *Z* =10000000, with the summary description of the seismic effect as "very catastrophic".

- ***Formula for the calculation of the radial component of the velocity*** which is given by Eq. (7):

$$v = 268\left(\sqrt[3]{Q} / r\right)^{3/2} \quad \text{(cm/s)} \tag{7}$$

where: *Q* - explosive charge weight (kg); *r* - distance from the blasting site (m).

- ***Formula for the calculation vector sum of peak particle velocity*** which is given by (Eq. 8):

$$v = 408\left(\sqrt[3]{Q} / r\right)^{3/2} \quad \text{(cm/s)} \tag{8}$$

- ***Formula for the calculation of the maximum vector sum of peak particle velocity*** which is given by Eq. (9):

$$v = K\left(R / W^{1/2}\right)^{-n} \quad \text{(mm/s)} \tag{9}$$

where: *Q* - maximum charge explosive per delay (kg); *R* - distance between the blast and location measurement (m); *K*, *n* – factors determined from a linear least squares regression analysis of log versus log ($R/W^{1/2}$); United States Bureau of Mines (USBM) was estimated that Peak particle velocity (mm/s) = 1140 $(R/W^{1/2})^{-1.6}$.

To perform seismic measurements we used Instantel (Minimate Pro and Minimate Blaster) seismometers. These seismometers can measure parameters that characterize the seismic waves produced by the blasting on the three components (radial, transversal, vertical). General specification of the seismometers are:

- channels 4-6, a second ISEE (or DIN) Triaxial Geophone;
- range: up to 254 mm/s (10 in/s);
- resolution: 0.00788 mm/s (0.00031 in/s);
- frequency range (ISEE / DIN): 2 to 250 Hz, within zero to -3 dB of an ideal flat response / 1 to 315 Hz or 1 to 80 Hz;
- accuracy (ISEE / DIN): +/- 5% or 0.5 mm/s (0.02 in/s), whichever is larger, between 4 and 125 Hz / DIN 45669-1 standard.

2.1. Seismic measurements performed "in situ" in Șicasău quarry, Harghita County

For seismic measurements, the equipment was located in accessible areas located in locations that presented safety and security conditions for the operator (Fig. 1). Blasting parameters which arerelevant to the purpose of the work are specified in Table 1.

2.2. Seismic measurements performed "in situ" in Piatra Roșie Quarry, Constanța County

To perform seismic measurements, the equipment was located in accessible areas located at measuring locations at different distances from the blasting site (Fig. 2). Blasting parameters, relevant to the purpose of the work are specified in Table 2.

2.3. Seismic measurements performed "in situ" in Nicolae Bălcescu Quarry, Constanța County

Two blasting works were monitored, the seismic measurement equipment being located in locations at different distance from the blasting site. (Gheorghiosu et al., 2013) (Fig. 3). Blasting parameters, which are relevant to the purpose of the work are specified in Table 3.

3. Results and discussion

The results obtained at the blasting from Șicasău Quarry are specified in Table 4. The results obtained at the blasting from Piatra Roșie Quarry are specified in Table 5. The results obtained at the blasting I1 and I2 from Nicolae Bălcescu Quarry are specified in Table 6. The estimation of seismic effects is made by the parameters that define the seismic waves developed by the blasting. The applications that are appropriate for the evaluation process are those that refer to known data, extracted from the information provided by the operator blasting.

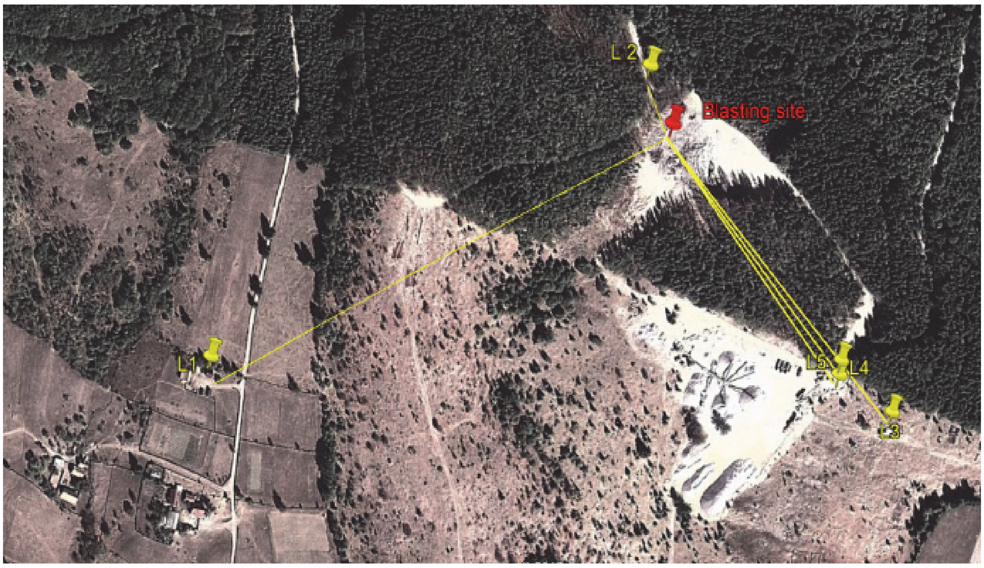

Fig. 1. Location of seismometers in Șicasău Quarry

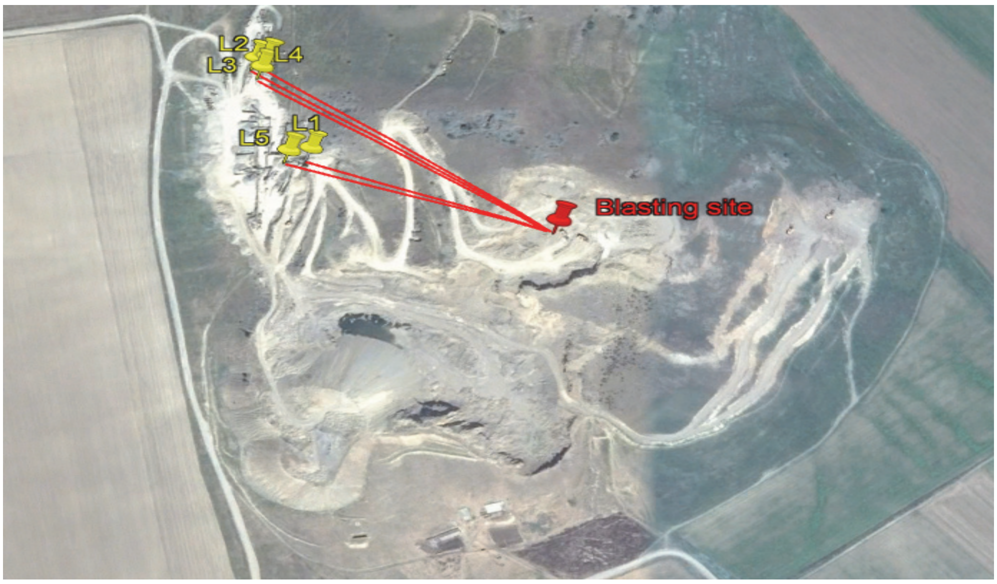

Fig. 2. Location of seismometers in Piatra Roșie Quarry

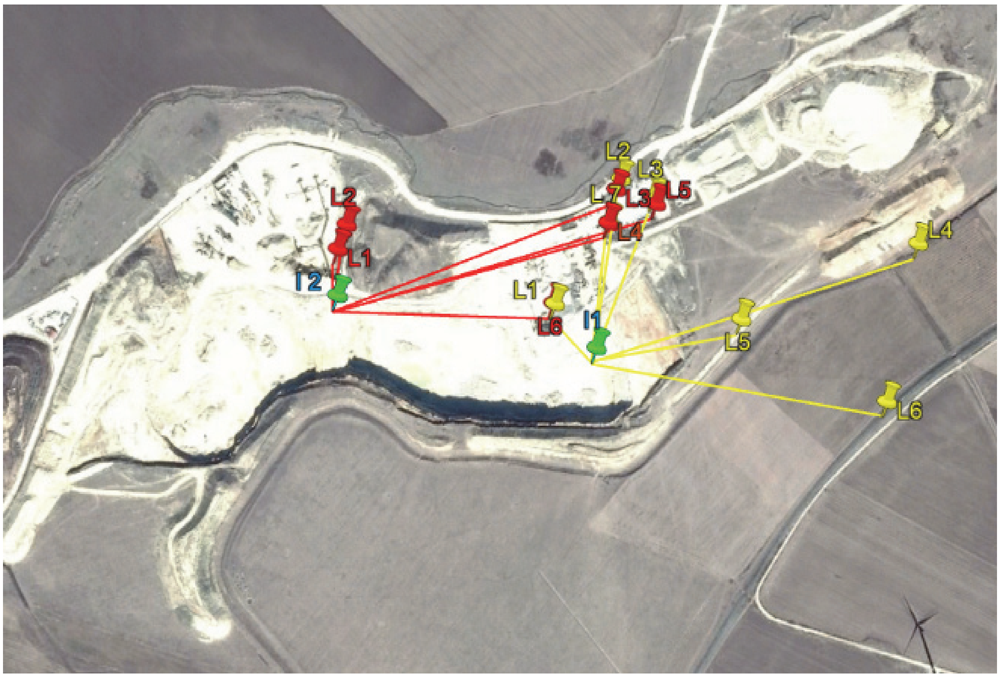

Fig. 3. Location of seismometers in Nicolae Bălcescu Quarry

Table 1. The blasting parameters

No. crt.	*Type of explosive*	*Explosive charge weight / hole (kg ETNT)*	*Maximum explosive charge weight / delay (kg ETNT)*	*Number of holes*	*Type of rock*
1.	ABS ANFO (explosives of base), EM – EX (emulsion explosives, initiation charge)	12.0÷35.8	35.8	99	andesite

Table 2. The blasting parameters

No. crt.	*Type of explosive*	*Explosive charge weight / hole (kg ETNT)*	*Maximum explosive charge weight / delay (kg ETNT)*	*Number of holes*	*Type of rock*
1.	ABS ANFO (explosives of base), Hydromite (emulsion explosive), Austrogel (explosive gelatinous)	56.5	56.5	25	andesite

Table 3. The blasting parameters

No. crt.	*Blast*	*Type of explosive*	*Explosive charge weight / hole (kg ETNT)*	*Maximum explosive charge weight / delay (kg ETNT)*	*Number of holes*	*Type of rock*
1.	I1	ABS ANFO (explosives of base), Austrogel (explosive gelatinous)	56.5	56.5	109	limestone
2.	I2	ABS ANFO (explosives of base), Hydromite (emulsion explosive), Austrogel (explosive gelatinous)	138	138	88	limestone

Table 4. The values of velocity

No. crt.	*Measurement locations*	*Distance from the blasting site (m)*	*Peak particle velocity measured on three components: V_R -Radial, V_T -transversal, V_V-vertical (mm/s)*
1.	L1	420	$V_R = 0.21$; $V_T = 0.28$; $V_V = 0.165$
2.	L2	50	$V_R = 47.1$; $V_T = 31.8$; $V_V = 36.2$
3.	L3	300	$V_R = 4.06$; $V_T = 0.145$; $V_V = 0.7$.
4.	L4	230	$V_R = 6.858$; $V_T = 4.445$; $V_V = 6.858$
5.	L5	230	$V_R = 5.59$; $V_T = 6.73$; $V_V = 5.59$

Table 5. The **v**alues of velocity

No. crt.	*Measurement locations*	*Distance from the blasting site (m)*	*Peak particle velocity measured on three components: V_R -radial, V_T -transversal, V_V-vertical (mm/s)*
1.	L1	320	$V_R = 0.310$; $V_T = 0.190$; $V_V = 0.065$
2.	L2	450	$V_R = 0.300$; $V_T = 0.430$; $V_V = 1.220$
3.	L3	460	$V_R = 0.510$; $V_T = 0.250$; $V_V = 0.130$
4.	L4	450	$V_R = 4.060$; $V_T = 2.720$; $V_V = 5.750$
5.	L5	350	$V_R = 0.290$; $V_T = 0.455$; $V_V = 0.340$

Table 6. The **v**alues of velocity

No crt.	*Blast*	*Measurement locations*	*Distance from the blasting site (m)*	*Peak particle velocity measured on three components: V_R -radial, V_T -transversal, V_V-vertical (mm/s)*
1.	I1	L1	70	$V_R = 3.470$; $V_T = 2.030$; $V_V = 4.220$
2.		L2	300	$V_R = 0.940$; $V_T = 0.930$; $V_V = 0.945$
3.		L3	306	$V_R = 1.015$; $V_T = 3.920$; $V_V = 2.475$
4.		L4	530	$V_R = 0.920$; $V_T = 0.920$; $V_V = 0.620$
5.		L5	230	$V_R = 0.510$; $V_T = 1.020$; $V_V = 0.630$
6.		L6	470	$V_R = 1.385$; $V_T = 1.3050$; $V_V =1.100$
7.		L7	144	$V_R = 0.425$; $V_T = 0.085$; $V_V = 0.185$
8.	I2	L1	60	$V_R = 0.520$; $V_T = 0.445$; $V_V = 0.485$
9.		L2	104	$V_R = 0.750$; $V_T = 0.750$; $V_V = 0.350$
10.		L3	478	$V_R = 5.740$; $V_T = 3.070$; $V_V = 4.000$
11.		L4	460	$V_R = 0.495$; $V_T = 0.500$; $V_V = 0.500$
12.		L5	546	$V_R = 0.350$; $V_T = 0.130$; $V_V = 0.590$
13.		L6	336	$V_R = 0.760$; $V_T = 0.830$; $V_V = 0.380$

Table 7. Quantitative parameters used in quarries

Quarry	*Explosive charge weight (kg ETNT)*	*Maximum explosive charge weight / delay (kg ETNT)*	*Distance from the blasting site (m)*
Șicasău	2410	35.8	50
Piatra Roșie-Cerna	1412	56.5	450
Nicolae Bălcescu I1	6158.5	56.5	70
Nicolae Bălcescu I2	12144	138	478

Thus, the values determined for use in 4 quarries were considered the quantitative blasting parameters (NUCLEU Project, 2017) (Table 7). In order to assess the seismic effect from the "particle's acceleration" point of view Eq. (2) was applied, which uses known terms, the total quantity of explosives designed to be used for a blasting and the distance between the blasting place and the location of measurement.

The estimated values are presented in Table 8. All the measured values are well above the particle acceleration value of 0.005 g, in some specialized literature presented as a "total building safety" level, with only possible window vibrations. Also, there were differences between the predicted values and the measured values, with an exception, the acceleration measured from 478 m on the transverse component, was identical to that designed at the blasting 12.144 tons of explosive.

For the analytical determination of the vibration period and frequency Eqs. (3) and (4) were used. Values are shown in the Table 9. Most values of the predicted frequency differ from the values of the prevailing measured frequencies. The ratios between accelerations and frequencies predicted results in values much lower than the 0.27 level considered "total safety range" by applying the "relative energy method" calculated with Eq. (1). Also, the intensity factor *Z*, calculated by applying the Eq. (6) shows a value much less than 2, which include the summary description of the seismic effect in the "imperceptible" class of influence.

The parameter through which it can be determined the degree of influence of the blasting on the nearby objectives, is the "particle velocity". (Gheorghiosu et al., 2015). The parameter can also be determined analytically, a priori, by the different empirical formulas, in this case applying the Eq. (7) with the results mentioned in Table 10 and the Eq. (8) with results listed in Table 11. The data in Table 10 shows the approximation of the values between the calculation and the measurement on the vertical component, as regards the blasting in Șicasău Quarry. The other values are totally different.

Using Eq. (8), the data from Table 11 was obtained, where it can be seen that most of the calculated and measured values are different, closer being the ones from the blasting I2 in Nicolae Bălcescu Quarry. Using Eq. (9), the data from Table 12 was obtained where it can be seen that most of the calculated and measured values are different. In Figs. 4 and 5, the graphs resulting from the processing represent the measured values, respectively the peak particle velocity and scaled distance for determining the coefficients *K* and *n*, specific to each blast condition from Nicolae Bălcescu Quarry. Fig. 4 sets the specific coefficients (K=17.45 and n=-0.307) when using 56.6 kg explosives. Fig. 5 sets the specific coefficients (K=1.608 and n=0.333) when using 138 kg explosives. The analysis of the data, shows that the particle velocity values are depend on the amount of explosives used per delay (Gheorghiosu et al., 2017). The peak particle velocity value increases with the amount of explosive per delay.

4. Conclusions

The assessment methods applied before starting the blasting activity using explosives for civil purpose have to take into account as many information as possible with regard to blasting conditions, type of explosive, blasting technique, characteristics of the environment in which the explosive is detonated and in which the seismic waves are generated etc.

Table 8. The values of predicted and measured acceleration

Explosive charge weight (tons)	*Distance from the blasting site (m)*	*Predicted acceleration*	*Particle acceleration measured on three components: a_R -radial, a_T -transversal, a_V-vertical*
2.41	50	0.67927g	a_T=1.705g; a_V=1.045g; a_R=0.980g
1.412	450	0.00562g	a_T =0.159g; a_V=0.422g; a_R=0.239g
6.158	70	0.70041g	a_T =0.279g; a_V=0.373g; a_R=0.437g
12.144	478	0.025g	a_T =0.025g; a_V=0.069g; a_R=0.062g

Table 9. Period and frequency of oscillation

Explosive charge weight (kg)	*The vibration period T (s)*	*Predicted Frequency (n^{-1})*	*Frequency measured on three components : f_T -transversal, f_V-vertical, f_R -radial (Hz)*
2.41	0.0238	42.01	f_T =30.5; f_V=49; f_R=43
1.412	0.0218	45.92	f_T=84; f_V=134.8; f_R=86.5
6.158	0.0278	35.92	f_T=27.75; f_V=35.5; f_R=27.75
12.144	0.0312	32.08	f_T=6.5; f_V=9.0; f_R=7.5

Table 10. Particle velocity predicted with formula 7

Quarry	*Distance from the blasting site (m)*	*Explosive charge weight (kg ETNT)*	*Peak particle velocity (mm/s)*	
			Predicted	*Measured*
Șicasău	50	2410	37.08	V_R = 47.1; V_T = 31.8; V_V = 36.2
Piatra Roșie - Cerna	450	1412	1.05	V_R = 4.060; V_T = 2.720; V_V = 5.750
Nicolae Bălcescu I1	70	6158	35.75	V_R = 3.470; V_T = 2.030; V_V = 4.220
Nicolae Bălcescu I2	478	12144	2.81	V_R = 5.740; V_T = 3.070; V_V = 4.000

Table 11. Particle velocity predicted with formula 8

Quarry	*Distance from the blasting site (m)*	*Explosive charge weight (kg ETNT)*	*Peak particle velocity (mm/s)*	
			Predicted	*Measured*
Șicasău	50	2410	42.39	V_R = 47.1; V_T = 31.8; V_V = 36.2
Piatra Roșie-Cerna	450	1412	14.99	V_R = 4.060; V_T = 2.720; V_V = 5.750
Nicolae Bălcescu I1	70	6158	8.16	V_R = 3.470; V_T = 2.030; V_V = 4.220
Nicolae Bălcescu I2	478	12144	5.30	V_R = 5.740; V_T = 3.070; V_V = 4.000

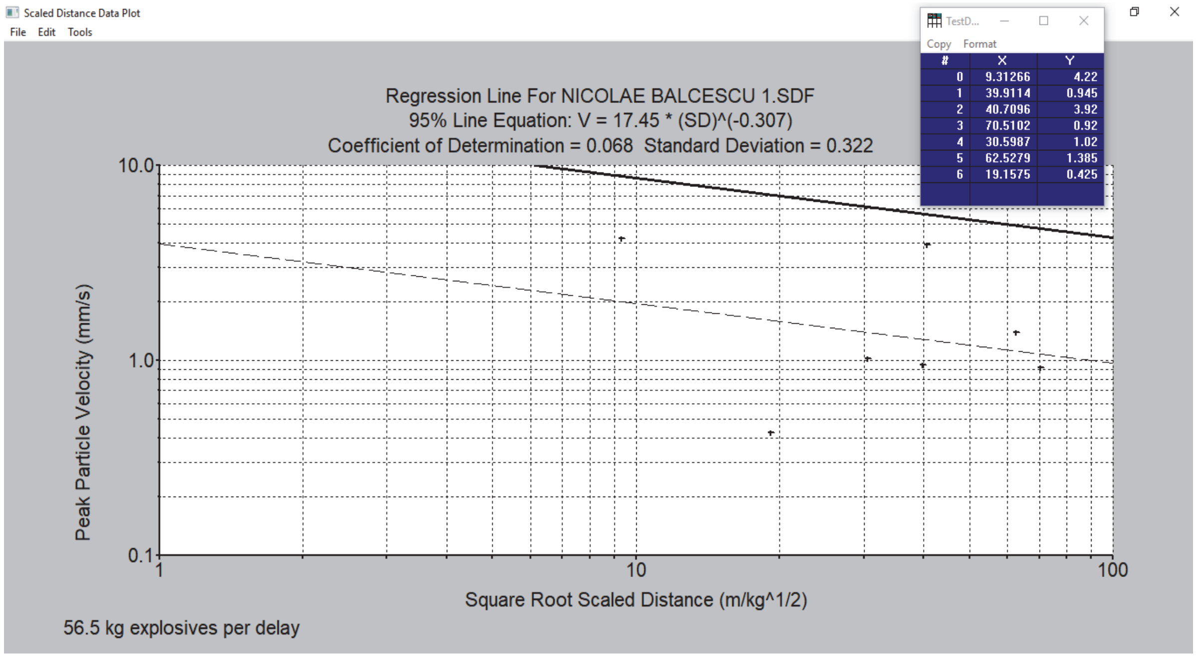

Fig. 4. Regression line for using 56.6 kg explosives

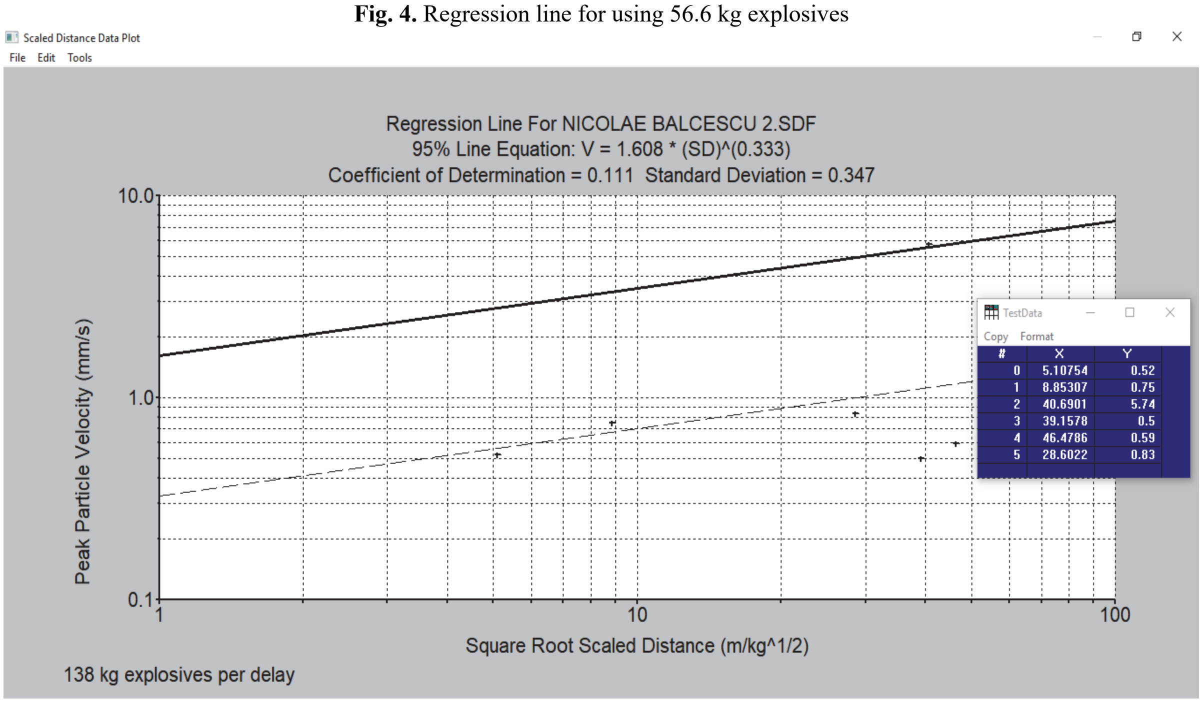

Fig. 5. Regression line for using 138 kg explosives

The differences between predicted and measured values highlighted the importance of making seismic measurements in situ, which is the best way to determine the safety level in carrying out blasting work in quarries regarding to the seismic effect. Using the equations with (*K*, *n*) factors determined for certain sites, even if the rocks may have similar characteristics, prediction may be far from reality.

The particle velocity, the amount of explosive used and the distance between the blast and the measurement location are data that are measured in the field, the factors *K* and *n*, must be determined by statistical methods, which are specific for each site.

Their value is mainly influenced by controllable variables (charge weight / delay, length of delay, direction of initiation) and non-controllable variables (rock type, including water saturation and the degree of cracking).

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