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Materiały Wysokoenergetyczne / High Energy Materials, ***2019****, 11 (2), 48 − 62; DOI: 10.22211/matwys/0178*
ISSN 2083-0165

Research paper / Praca doświadczalna

Some results were presented during the 16th International Conference IPOEX2019, Ustroń Zawodzie, June 17-19, 2019, Poland.

Optimizing the seismic effects of blasting in quarries by timing
Zastosowanie opóźnień strzałowych do optymalizacji efektów sejsmicznych podczas prac strzałowych w kamieniołomach

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Abstract: *Recently, negative effects of the blasting operations and quantification of the seismic safety are regarded as very important technical problem in quarries. The impact of blasting operations is accompanied by both positive and negative seismic effects. For example, vibrations generated by explosion create very positive effect − when help to break the rocks, but, on the other hand, also result in negative effect − when affect constructions and natural environment in the vicinity of a blasting works site. If the vibrations are large enough, then the nearby objects could be damaged or destroyed. This article highlights the results of the blasting operation monitoring in limestone Lopušné Pažite quarry on Slovakia, which based on the rule that the negative effects depend on their range and strength. This method is applied in all quarries in Slovakia, which are close to settlements.*

Streszczenie: *Współcześnie, niepożądane skutki prac strzałowych oraz ilościowa ocena bezpieczeństwa sejsmicznego są szczególnie ważnym tematem badawczym w górnictwie odkrywkowym. Prowadzeniu prac strzałowych towarzyszą zarówno pożądane, jak i niekorzystne efekty sejsmiczne, np. drgania generowane wybuchem powodują z jednej strony efekt pożądany, czyli pozwalają na kruszenie skał, jednak z drugiej strony zagrażają konstrukcjom i środowisku naturalnemu w otoczeniu miejsca prowadzenia prac strzałowych. Jeżeli drgania są wystarczająco silne, wtedy konstrukcja pobliskich obiektów może zostać uszkodzona, lub obiekty te mogą ulec całkowitemu zniszczeniu. W pracy przedstawiono wyniki monitoringu prac strzałowych wykonanych w kopalni odkrywkowej wapienia w Lopušné Pažite (Słowacja), które bazują na zasadzie, że skala oddziaływania efektów niepożądanych zależy od zasięgu ich oddziaływania i siły. Zaprezentowana metoda jest stosowana we wszystkich kamieniołomach na Słowacji, w pobliżu których znajdują się obszary zamieszkane.*

Keywords: *blasting operations, seismic waves, particle velocity, seismic safety, blasting timing*
Słowa kluczowe: *operacje strzałowe, fale sejsmiczne, prędkość cząsteczki, bezpieczeństwo sejsmiczne, opóźnienia strzałowe*

1. Introduction

Blasting operations have and always had an important role in the mining of raw materials in human society. Depending on the conditions and the blasting operations parameters, these operations may exceed the acceptable safe limits for environment and society. Extensive charge used during mining operations can cause great damage. Blasting operations generate seismic waves with different maximum particle velocities and wide spectrum of frequencies. The intensity vibrations of seismic waves is proportional to the weight of the applied explosive. If the vibrations are characterized by sufficient energy, surrounding buildings can be damaged or destroyed. Evaluating the negative effects of the blasting operations and quantification of the seismic safety is nowadays very actual and technically challenging problem.

Many countries at the standardization of the seismic effects of the blasting on the surroundings, in which the blasting is carried out, enter the data either applying a standard or a directive. The assessment criteria of the blasting effects on the building objects are nearly the same all over the world as they are focused on the criterion of the vibration velocity. Despite the fact that there exists a standardized criterion, dominant quantitative differences can be observed at the determination of the boundary value. Countries such as Slovakia, Czech Republic or Germany unlike other countries they assess in praxis mainly lower values (5-10 mm·s^{-1}). Higher permissible values are allowed *e.g.* in Russia 30 mm·s^{-1} and in the USA 50 mm·s^{-1} ([1-3]).

Identifying these harmful effects and determining the seismic safety is nowadays a very current issue ([4, 5]). It is necessary to find a convenient method of assessment, which not only secures the safety of the object integrity, but also determines the most effective blasting operations technology on the other hand [6, 7]). Impact assessment of seismic effects caused by blasting operations depends on the distance and blasting of the objects and the size of the load in the individual timing stages used in blasting ([8, 9]). To determine the size limit load and the minimum distance, it is necessary to establish the attenuation characteristics of seismic waves in the assessed area [10-15]. Technically unjustified – high seismic safety leads to the reduction of charges and blasts, which has an adverse effect on the economy of rock disintegration and mining. On the contrary, the underestimation of seismic effects can cause great material damage [16-19].

Very seldom is a conventional blast set off where all charges are detonated in the same instant. Usually, there is a specific time interval and direction or directions for delaying the charges [20]. For tunnels, drifts and shafts where there is no free face parallel to the axis of the holes, longer delay periods are utilized. These are intended to provide sufficient time delay for the fractured rock from the initial holes to be expelled so that there is room for the rock blasted by the following holes to expand [21]. In construction and in surface mining, millisecond delays are used between charges in a blast. There are several basic reasons for doing so, [22]:

– to assure that one or more free faces progress through the shot, providing a consistent burden,
– to enhance fragmentation between adjacent holes,
– to reduce ground vibration and airblast,
– to provide a means of directing the heave or displacement of the blasted material.

According to arrangement the blastings can contain [3]:

– one explosive charge placed in the blast holes or in explosive chamber,
– more explosive charges placed in the blast holes or explosive chambers,
– supplementary charge or charges.

According to timing the blastings can be divided into:

– instantaneous (simultaneous initiation of all explosive charges),
– timed (the partial blasts explode in different time sequences).

In one time sequence more explosive charges can explode simultaneously which are considered one partial charge. In timed blasting there are two time sequences taken into consideration (Δt):

– $\Delta t \geq 250$ ms (seismic waves attenuation before explosion of the next partial charge),
– $\Delta t < 250$ ms (occurrence of effects interference of partial charge components).

The required length of boundary sequence timing depends on rock environment and it can decrease from value 250 ms up to $\Delta t = 10$ ms. The maximum reduction of vibration velocity can be achieved at initiation sequence of the charge [3, 23]:

$$\boldsymbol{\tau} = \frac{\mathbf{10^5}}{\mathbf{c_p}} \text{ [ms]} \tag{1}$$

where c_p is velocity of longitudinal seismic waves in rock environment between blast and protected object. If it is an instanteneous blasting, the calculation will consider the total weight of explosive. In case of a timed blasting the effect of timing, if shorter than 250 ms, can be only experimentally verified.
In accordance with chosen value τ, the total weight of charge (Q_c), [kg], can be:

$$Q_c = Q_{\check{c}} \cdot N^t, \qquad \text{resp.} \qquad Q_c = Q`_p \cdot N^t \tag{2}$$

where $Q_{\check{c}}$ is the admissible charge of timed blasting (charge per millisecond time stage) [kg], N is the number of charges, resp. group of charges with weight Q_p blasted at time stage τ, t is the exponent dependant on solid mass characteristics (Table 1).

Table 1. Values of exponents dependant on massive characteristics [23]

c_p [m·s^{-1}]	τ [ms]	t
up to 1000	100	0.3
1000-1500	70	0.45
1500-2000	60	0.6
2000-2500	50-40	0.7
2500-3000	40-35	0.8
3000-3500	35	0.9
3500-4000	35	1.0
over 4000	20-10	1.0

If Q_c is given due to Equation 2 than N is calculated. Equation 2 is valid for $N > 6$-12, depending on solid mass characteristics. The stability of blasting concurrence and the entire reduction of seismic effects in solid mass can be achieved only for $N > 6$-8, and in rocks with $c_p = 1000$-2000 m·s^{-1}, for $N > 10$-12 [23].
Blasting works are carried out on the basis of a project that provides for the protection of objects against the seismic effects of blasting. For blasting operations carried out at a small distance from residential buildings, it is likely that the effect of blasting will adversely affect the population. This effect should therefore be optimized so that blasting works can be carried out and residents do not feel the impact of blasting work adversely. Monitoring the rock blasting in quarries in Slovakia was focused on such parameters of rock blasts as size of charge, distance between source and receptor and moreover we dealt with impact of timing on range of seismic effects [2, 22, 23]. The results of seismic effects of blasting in the quarry Lopušné Pažite verified the methodological basis for evaluating the effects of seismic blasting in all quarries in Slovakia.

2. Geology of the area (transmission environment)

Experimental measurements of the optimization of blasting were carried out in the quarry Lopušné Pažite (Fig. 1). The quarry Lopušné Pažite is situated to the west from the village Lopušné Pažite and consists of Jurassic limestones of the Western Carpathians Pieniny Klippen Belt (Figs. 1 and 2). However, several other lithological types except sandy and marlylimestones dominated by biomicritic limestones as marls, siliceous shales and radiolarites can be found within the quarry [24]. The colour of limestones varies from grey, yellow to brown shades and contain calcified fossil remnants. The predominant thin- to medium-bedded limestones are locally intensively folded (Fig. 3). The majority of the discontinuities are represented by bedding planes. The rock mass of the quarry is intensively disrupted by abundance of tectonic structures (joints and faults) of several generations with different strike directions and dips. The rocks are in general weakly weathered, but significantly loosen mainly along the bedding planes.

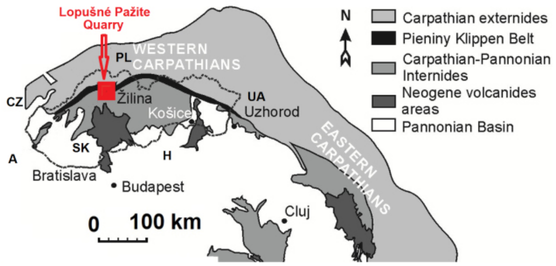

Figure 1. Lopušné Pažite quarry localization and its surrounding

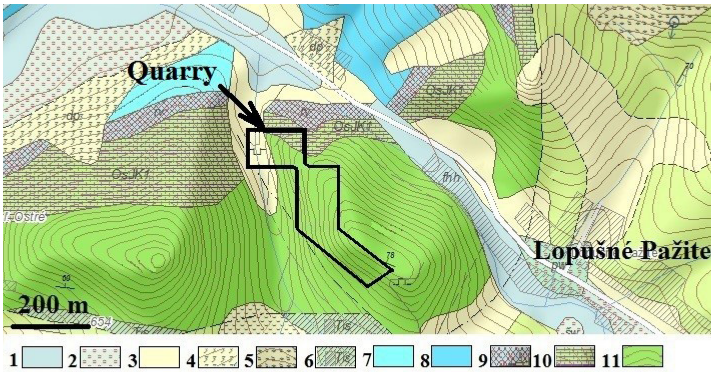

Figure 2. Geology of the Lopušné Pažite quarry and its surrounding:
Quaternary:
1 – fluvial sediments: nondivided overbank loams, or sandy to gravelly loams of valley overbank and overbanks of mountain creeks (Holocene),
2 – fluvial sediments: gravels, sandy gravels and sands of bottom acummulation within low terraces (Pleistocene),
3 – deluvial sediments: nondivided deluvium,
4 – deluvial - proluvial sediments: loamy to rocky dejection cone, locally with gravels and sands,
5 – deluvial sediments: sandy to rocky and rocky (talus fans, flows, rock falls, block fields, screes);
Mesozoic: Pieniny Klippen Belt:
6 – Tisal beds: grey and green spotted marls and limestones, sandy limestones and darkgrey siliceous shales,
7 – Nadposidonion beds: spotted siliceous limestones and dark grey siliceous shales, marls, rarely sandstones,
8 – spotted siliceous limestones and shales, darkgrey sandy shales, sandstones,
9 – red and green radiolarites, radiolarian or opalized limestones, rarely also nodular limestones,
10 – Osnic Formation: Calpionella limestones – light grey, pinky marly limestones (sometimes with hornstones) and grey marly shales,
11 – Koňhor beds: black shaly marls and spotty marly limestones.

Figure 3. Thin-bedded limestone in Lopušné Pažite quarry

3. Experimental

3.1. Test area

General overview of the test area is shown in Figure 4 and the seismic profile at standpoint S4 is shown in Figure 5. Distributions of blastholes and the timing diagrams of the blast I. and of the blast II. are shown in Figures 6 and 7, respectively.

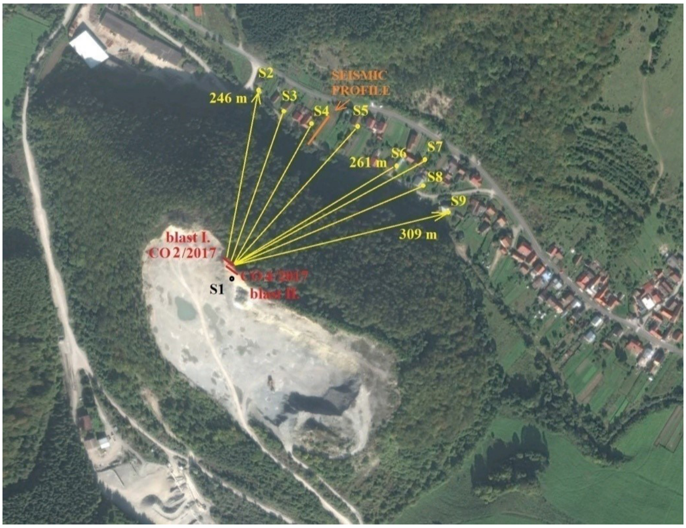

Figure 4. Position and distance blast I. and blast II. in the quarry Lopušné Pažite in relation to the standpoints in the village Lopušné Pažite and in the quarry Lopušné Pažite

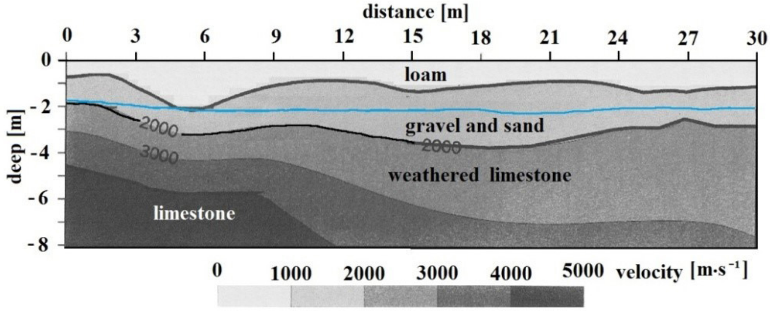

Figure 5. Seismic profile at standpoint S4: the position seismic profile is shoving in Figure 4 (in orange), blue line shows the level of ground water

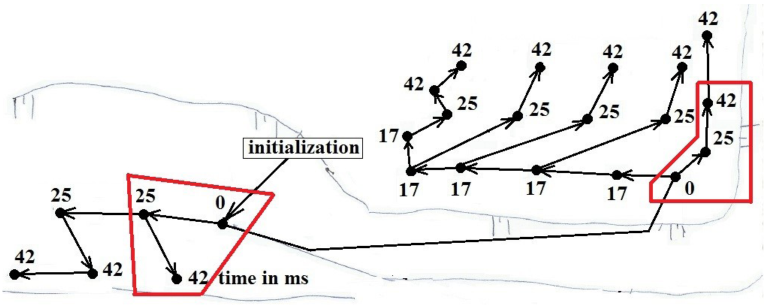

Figure 6. Distribution of blastholes and the scheme of timing blast I.: in the red field there are blastholes that have been fired simultaneously at one time stage

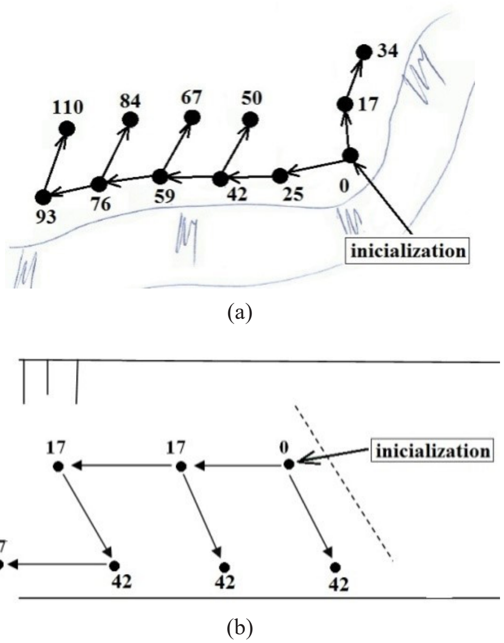

Figure 7. Distribution of blastholes and the scheme of timing blast II.

3.2. Testing devices

The following digital seismic devises were used for measuring and graphic records of the seismic effects:
- digital seismograph VMS 2000 MP by Thomas Instruments and seismic receivers by Geospace (Fig. 8),
- digital seismograph ABEM Vibraloc and seismic receivers by ABEM (Fig. 9),
- digital seismograph UVS 1504 and seismic receivers by Nitro Consult,
- digital seismograph Svantek, and seismic receivers by Svantek (Fig. 10)
- digital seismograph BRS 32, and seismic receivers by Brož.

Figure 8. Standpoint – S1 and localisation of digital seismograph VMS 2000 MP and seismic receivers by Geospace located 18.6 m away from the first initiated borehole of the blast I. in the quarry Lopušné Pažite

Figure 9. Standpoint – S2 with seismographs ABEM Vibraloc and seismic receivers ABEM installed in the distance of 241 m from the first blast I. and in the distance 246 m from the second blast II. in the village Lopušné Pažite

Figure 10. Standpoint – S9 with seismographs Svantek and seismic receivers Svantek installed in the distance of 311 m from the first blast I. and in the distance of 309 m from the second blast II. in the village Lopušné Pažite

Seismographs provide a digital and graphical record of all tree components of a velocity of particle oscillation of a medium: horizontal radial (v_x), horizontal transverse (v_y) and vertical (v_z). Seismographs VMS 2000 MP, UVS 1504, Svantek, BRS 32 and ABEMVibraloc work autonomously and automatically perform testing of individual channels without influence of an operator into the measured and registered characteristics of oscillation. These seismographs have their own converter with automatic 14 bits dynamic range what respond to 0.05-250 mm·s^{-1}.
There were used the following geophones:

– electrodynamics geophones Nitro Consult with frequency range 1-1000 Hz and sensitivity 20 mV·(mm·s)$^{-1}$,
– tree-components geophones Geospace, Svantek, Brož and ABEM with frequency range 2-1000 Hz and sensitivity 10 mV·(mm·s)$^{-1}$.

This geophones were installed on a special board with sharp steel bits that ensured continual contact with the base. Distances between the standpoints (measure positions) and the blasting site are shown in Table 2.

Table 2. Distances between the standpoints and the blasting site

Standpoints	Bench blasting	Distances from blast to standpoints	
		slanting [m]	horizontal [m]
Quarry S1	blast I.	29.2	18.6
Village S2		–	241
Village S3		–	220.5
Village S5		–	246
Village S6		–	258
Village S9		–	311
Quarry S1	blast II.	30.2	19
Village S2		–	246
Village S3		–	223
Village S4		–	247
Village S5		–	254.5
Village S6		–	261
Village S7		–	299.7
Village S8		–	284
Village S9		–	309

Measurements of the velocity of seismic waves propagation were performed at the measuring point S3 using the Terraloc MK 8 seismograph. The purpose of the measurement was to determine the depth of groundwater and the velocity of seismic waves propagation in subsurface structures in the vicinity of the receptors. From the seismic measurements, the groundwater level was determined at a depth of 2 m and the velocity of the seismic waves propagated from 2000 $m \cdot s^{-1}$ at a depth of 2.5 m to 4000 $m \cdot s^{-1}$ at a depth of 5 m or more.

3.3. Source of vibrations

The source of seismic effects was created by operational bench blast I. and research bench blast II. at the limestone deposit situated approximately 0.25 km in the east from the Lopušné Pažite village. The bench blasts were carried out in the western part of the first etage of the quarry Lopušné Pažite (Fig. 4).

Table 3. Parameters of operational and research bench blasting (applied explosives: Emulex and Austinit)

Test*	Number of blasthole	Diameter blasthole [mm]	Lenght blasthole [m]	Slope blasthole [°]	Total charge [kg]	Total charge at one time stage [kg]
blast I.	18	90	22.5	75	2175	110
grd	4	102	10	2	126	31.5
blast II.	12	75	23.5	75	1500	106.25
grd	7	102	10	2	220.5	31.5

* grd – ground drilling

Non-electric initiation system used in the tests were:
− Blast I.: – 25 pieces Indetshock MS 20/50.
− Blast II.:– 36 pieces I Shockstar and 20 pieces Surface connector.
In both Blast I. and Blast II. there were used timing stages 17, 25 and 42 ms (Fig. 7).

4. Analysis of the seismic effects of bench blasting

The equipments placed at the particular measuring standpoints were gauged before the measurements and their responsiveness was assessed. At the measuring standpoints the graphical responses of individual parts of the seismic vibration were recorded at bench blast I. and bench blast II. The individual graphical records were 1-4 s. The seismic measuring equipments were set at the measuring standpoints in order to evaluate the impact of the generated technical seismicity. The measured values particle velocity and their frequencies of the seismic effects generated by the bench blastings in the quarry Lopušné Pažite are depicted in Table 3.
Our investigation was focused on the detailed analysis of the seismic waves generated by the first operational blast I. and they were recorded at the measuring standpoints S1 until S9. These measuring standpoints were in different distances from the source and it enabled us, according to various arrival times of the seismic waves, to assess the particle velocity in the Lopušné Pažite quarry as well as to the residential objects in the village Lopušné Pažite.
On a detailed analysis of the blast I. timing scheme, we found that at the time of the 25 and 42 ms timings, the charge was triggered at three boreholes at the same time. Instead of 110 kg, 141.25 kg was fired in one timer (Fig. 6). In the timing scheme blast II., between the firing of the individual boreholes, time interval of 8 to 9 ms was chosen, because it corresponds to the propagation velocities of the seismic waves measured in the underlying rocks (Table 1). This is how we achieved the greatest possible attenuation of the seismic effects of the aperture (Fig. 11). The ground drilling blast was performed separately, about 2 min before the bench blast II.

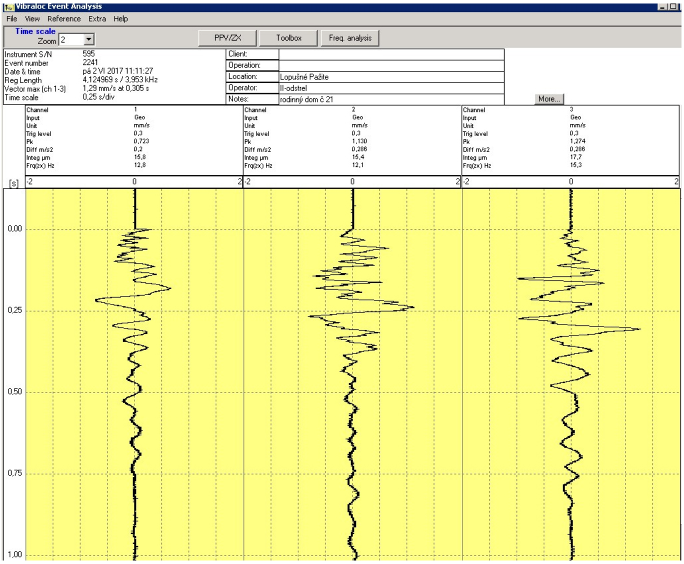

Figure 11. Graph of individual components of seismic waves during blasting recorded in standpoint S2 in village Lopušné Pažite – ***seismograph*** Vibraloc at bench blast II.

The particle velocity values measured on a residential object S3 at a distance of 221 m from the blast were smaller (Fig. 12) than the particle velocity values measured on the residential object S9, which was 309 m away from the blast. Residential building S9 was in the direction of deposition of layers of rock environment and the residential object S3 was in across to the storage of layers of rock environment.

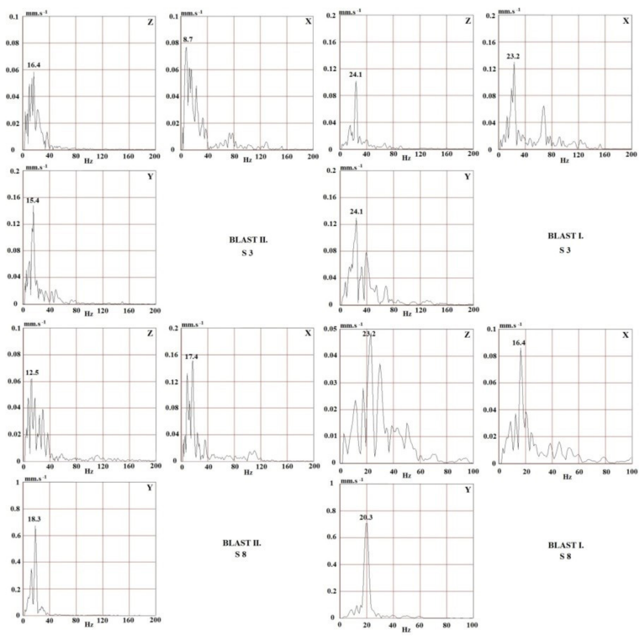

Figure 12. Graphs of frequency characteristics of individual components of seismic waves during blasting recorded in standpoint S3 and S8 in the village Lopušné Pažite at bench blast I. and bench blast II.

Frequency analysis of each component of particle velocity indicated that at the blast II. the frequency band was narrowed and the maximum frequencies reached lower than at the blast I. Energy blast II. the standpoint S3 offset had a frequency of less than 10 Hz on the *x* component. This was the reason for reducing the permissible particle velocity below the border 3 mm·s^{-1} (Fig. 13). Similarly, the frequency analysis showed the reduction of the maximum frequencies and the narrowing of the frequency band also on other measuring positions, S8 (Fig. 12). The measured maximum values of the seismic effects generated by blast I. and blast II. in the quarry Lopušné Pažite are shown in Tables 4 and 5. These values served us as a basis for the determination of the law of the seismic waves at Lopušné Pažite quarry (Table 5, [3]).

Table 4. Measured values of the frequency and particle velocity at blast I. and blast II.

Stand points	v_x **[mm·s^{-1}]**	v_y **[mm·s^{-1}]**	v_z **[mm·s^{-1}]**	f_x **[Hz]**	f_y **[Hz]**	f_z **[Hz]**	Test*
S1	59.3	66.1	62.4	2.8	1.1	0.8	blast I.
S2	2.6	1.6	1.7	9.2	0.8	170.8	blast I.
S3	3.7	1.4	1.3	8.5	11	11	blast I.
S5	3.5	2.4	1.2	8.7	24.1	23.4	blast I.
S6	2.1	4.6	3.90	–	–	–	blast I.
S9	2.6	3.0	4.4	10.2	11.7	24.1	blast I.
S1	133.1	117.7	178.3	18.3	36.6	30.1	blast II.
S1	22.4	16.3	9.0	24.4	18.3	28.4	grd
S2	1.1	1.5	0.9	25.8	29.1	21.7	grd
S2	1.1	1.2	0.7	12.1	15.3	12.8	blast II.
S4	0.6	0.7	0.5	6.7	6.9	0.3	grd
S4	2.0	1.8	0.7	10.0	6.8	10.0	blast II.
S5	1.2	1.0	1.2	23.4	14.6	23.4	grd
S5	1.8	1.8	1.9	29.2	17,5	26.3	blast II.
S7	1.2	0.8	0.7	10.5	11.2	12.8	grd
S7	1.7	1.8	2.2	18.6	8.9	19.0	blast II.
S8	0.6	1.8	1.1	17.5	19.2	26.7	grd
S8	1.7	3.5	1.5	13.9	15.5	28.9	blast II.
S9	1.1	1.0	0.8	20.5	20.5	20.5	grd
S9	1.8	1.0	1.0	17.6	20.5	5.8	blast II.

* grd – ground drilling

Table 5. Measured peak values of components of distance, charge, reduced distance and particle velocities at bench blast I. and bench blast II.

L **[m]**	Q **[kg]**	$L_R = L\cdot Q^{-0.5}$ **[m·kg$^{-0.5}$]**	v_x **[mm·s^{-1}]**	v_y **[mm·s^{-1}]**	v_z **[mm·s^{-1}]**
29.2	141.2	2.4	59.3	66.1	62.4
241	141.2	20.3	2.6	1.6	1.7
220.5	141.2	18.6	3.7	1.4	1.3
246	141.2	20.7	3.6	2.5	1.3
258	141.2	1.7	2.2	4.7	3.9
311	141.2	26.2	2.6	3.1	4.4
30.2	106.25	2.9	133.2	117.7	178.3
19	31.2	3.4	22.4	16.3	9.1
246	31.2	44.0	1.1	1.5	0.9
246	106.2	23.9	1.1	1.3	0.7
247	31.2	44.2	0.6	0.7	0.5
247	106.2	24.0	2.0	1.8	0.7

Table 5. continuation

L [m]	Q [kg]	$L_R = L \cdot Q^{-0.5}$ [m·kg$^{-0.5}$]	v_x [mm·s^{-1}]	v_y [mm·s^{-1}]	v_z [mm·s^{-1}]
254.5	31.2	45.5	1.3	1.1	1.3
254.5	106.2	24.7	1.9	1.9	1.9
299.7	31.2	53.6	1.2	0.9	0.7
299.7	106.2	29.8	1.7	1.9	2.2
284	31.2	50.8	0.7	1.9	1.2
284	106.2	27.5	1.8	3.6	1.6
309	31.2	55.3	1.1	1.1	0.9
309	106.2	30.0	1.9	1.1	1.1

In the overall assessment,we also used the measured value from blasting operations in the past. Based on data from Tables 4 and 5 the graphical dependence of maximal component of the particle velocity for reduced distance during a blasting. Figure 13 shows a graph of so called the law attenuation of seismic waves (see [3, 17]) for Lopušné Pažite quarry where the value of Q was used in the following expression:

$$v = (\frac{L}{Q^{0.5}}) = K\left[\frac{L}{Q^{0.5}}\right]^n \tag{3}$$

where „v“ is a measured maximal particle velocity (peak particle velocity components) generated by blasting, [mm·s^{-1}], L is the shortest distance of source of vibrations from their receptors, [m], $L/Q^{0.5}$ is reduced distance, [m·kg$^{-0.5}$], Q is a weight of the charge for one time step, [kg], K is a coefficient depending on the conditions of a blasting, characteristics of transfer environment, kind of used explosive *etc*., n is the indicator of attenuation of seismic waves.

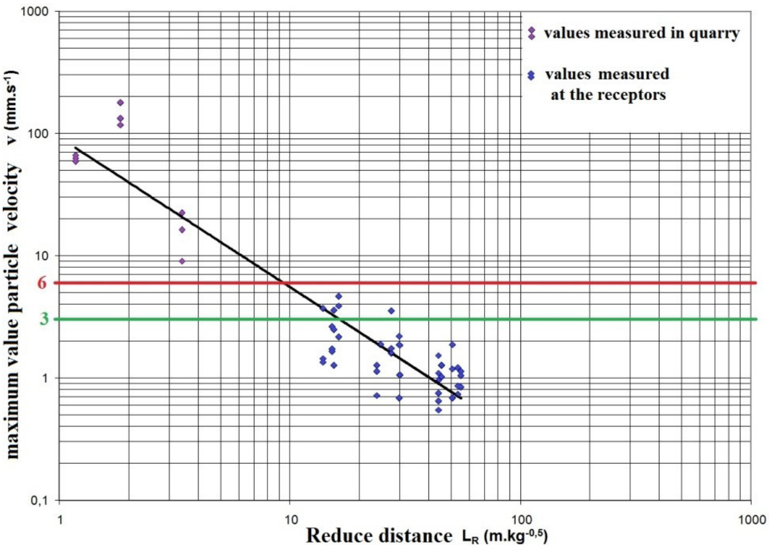

Figure 13. Graphical dependency of maximum vibration velocity components on the reduced distance at bench blasting in the quarry Lopušné Pažite – law of ***seismic waves attenuation:*** *t*he red line marks the maximum secure permissible particle velocity for the building objects (green recommended); the points demonstrate the measured values of the vibration velocity at the individual measuring standpoints of bench blast I. and bench blast II. in the quarry Lopušné Pažite

The seismic waves attenuation law in Figure 13 has the form of a straight line characterized by maximum boundary values of the particle velocity. This solution enables to assess in a very quick and precise way the permissible charge at one time stage Q for each source – receptor distance [17]. The processing of measured results was carried out by the program LeSeiz, composed at the Institute of Geosciences F BERG. The program automatically calculates the regress model of the seismic waves attenuation law. The measured values and the particular regress model are presented simultaneously in both logarithmic and longitudinal coordinates [25]. According to the seismic waves attenuation law it is possible to determine for a particular receptor the charge capacity at a given distance, so the maximum values of the particle velocity components will not exceed the defined maximum particle velocity. In Figure 13 there are marked by blue points the measured values of the vibration velocity at the surveyed objects in the village Lopušné Pažite at bench blast I. and bench blast II. in the quarry Lopušné Pažite (Table 4). The points on the left side of the figure mark the measured values of vibration velocity at the vibration source, *i.e.* near to the blasting in the quarry Lopušné Pažite. The redline stands for the boundary of maximum permissible vibration velocity for this particular soil type „a“ (the level of groundwater is less than 3 m below the surface level).

Quarrying in the area Lopušné Pažite is provided by bench blastings. According to the measured and evaluated values at the operating blastings in the quarry Lopušné Pažite there was appointed the seismic waves attenuation law, on the basis of which it is possible to apply at repeated bench blastings in the quarry Lopušné Pažite the maximum permissible charge at one time stage depending on the following distances (Table 6). The following seismic monitoring confirmed the correctness of the standardized measures for ensuring the seismic security of the surveyed housing object.

Table 6. Maximum permissible charge at one time stage depending on the following distances from blast to receptor in Lopušné Pažite quarry

Distance from blast to receptor L [m]	**Reduce distance L_R [m·kg$^{-0.5}$] for v_d = 6 mm·s^{-1}**	**Maximal charge one time stage Q_{vmax} [kg]**
100	30	25
200	30	100
300	30	156
400	30	400
500	30	625
Distance from blast to receptor L [m]	**Reduce distance L_R [m·kg$^{-0.5}$] for v_d = 3 mm·s^{-1}**	**Maximal charge one time stage Q_{vmax} [kg]**
100	20	11
200	20	44.5
300	20	100
400	20	177.5
500	20	278

5. Conclusions

Presented evaluation method of seismic effects proves again the fact that the issue of provision safety of blasting has not been solved yet. The analysis of vibrograms of particular blastings showed that it is requirable to carry out blastings in accordance with the principle of millisecond blast timing. These timed blastings proved the lowest values of vibration velocity in the vibrograms.

To achieve maximum reduction of the seismic effects in millisecond timing it is necessary to deal with the following issues:

– Distribute the total charge of blasting into maximum number of time stages, the bigger the number of them the lower the seismic effect of the blasting.

– Distribute the total charge capacity equally into time stages (boreholes, groups) as the differences in charge weight falling on a time stage would not exceed 10-15%.
– The diraction of the ignition has to lead beyond protected objects.
– Orientate the blasted rock massive against the protected object by its narrower side.
– Pay attention to the selection of ignition scheme.

To decrease the impact of the technical seismicity is important for the environment and infrastructure in the surroundings of the quarries. The presented methodology is applicable for every operating open pit, especially where the blastings are located in the residential zone vicinity.

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– Received: October 1, 2019
– Revised: December 10, 2019
– Published first time online: December 30, 2019