OPTIMIZATION OF THE IMPACT OF BLASTING ON THE ENVIRONMENT IN THE VICINITY OF THE KUČÍN QUARRY

OPTIMALIZÁCIA DOPADU TRHACÍCH PRÁC NA ENVIRONMENT V OKOLÍ LOMU KUČÍN

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Abstract

Blasting operations are having always had a crucial role in human life. Depending on the conditions and parameters of disintegration may exceed acceptable – secure borders when they become harmful and can cause major damage. With the growing mass of explosive charges and increasing the intensity of wave seismic waves that propagate in the rock environment and gradually vibrates the different parts of the environment. If the intensity of vibration is large enough, there may be a violation of the environment, or even to its destruction. The paper presents the results of the optimization of blasting in the Kučín quarry. The results of seismic effects of blasting in the Kučín quarry verified the methodological basis for evaluating the effects of seismic blasting in all quarries in Slovakia.

Abstrakt

Trhacie práce majú a oddávna mali rozhodujúcu úlohu v živote človeka. V závislosti od podmienok a parametrov rozpojovania, môžu prekročiť únosné – bezpečné hranice kedy sa stávajú škodlivými a môžu zapríčiniť veľké škody. S rastúcou hmotnosťou nálože trhaviny rastie aj intenzita vlnenia seizmických vĺn, ktoré sa šíria v horninovom prostredí a spôsobujú kmitanie jednotlivých časti tohto prostredia. Ak je intenzita kmitania dostatočne veľká, môže spôsobiť porušenie prostredia, či dokonca jeho deštrukciu. Článok prezentuje výsledky optimalizácie trhacích prác v lome Kučín. Výsledky hodnotenia seizmických účinkov trhacích overované v lome Kučín sú metodickým základom pre hodnotenie účinkov seizmického odstrelov vo všetkých lomoch na Slovensku.

Keywords

blasting operations, seismic effect, particle velocity, seismic safety

Kľúčové slová

trhacie práce, seizmické účinky, rýchlosť kmitania, seizmická bezpečnosť

1 Introduction

The rock mass is composed of rock material and natural aggregate blocks of material and debris. Rock mass can be described as a solid part of the earth's crust in the original deposit, formed orogenic activity, including discontinuities and fill incurred by the geological evolution of the Earth's crust. The rock mass discontinuities along with creating an environment in which to propagate seismic waves caused by shocks. Attenuation of seismic waves depends on the degree of desintegration of the ground, which made blasting (Bongiovanni at all., 1991, Don Leet, 1960, Dojčár, et al., 1996, Siskind, 2001). Measuring the impact of seismic waves is performed to knowing which way to dampen their spread. The existing technical possibilities of documenting their spread was limited. Only use the latest generation of sensitive devices allow sufficient accuracy. The use of multiple devices on the same quality allows for a recording and analysis of measurements at the same time all over the analyte line spread of seismic waves. This method eliminates measurement error, which statistically occurs when repeated measurements at different distances because of the uncertainty of the amount of charges, the timing, change of blasting explosives and explosives distribution in space.

The aim of the article is to identify the existence of a critical distance and for confirmation of the determination of the critical distance at which there is maximum impact blasting through the action of seismic waves on the rock mass.

2 Seismic effects of rock blasting

The intensity of seismic effects is directly proportional to the following parameters of the explosive charge:

- weight of explosive charge,
- brisance of explosive charge,
- explosive charge density.

Part of explosive charge energy which is not applied for rock disturb penetrates into the surrounding as a shock impulse generating speading of energy omnidirectionally from the blasting point in the form of different types of elastic shock waves, the most important of them are the Rayleigh and Love surface waves. The velocity of volume waves spreading, longitudinal (pull-stress) and transverse (shearing) ones is conformable to sound speed in this particular environment.

The characteristic physical quantities for individual oscillation (harmonic motion) i.e. also for seismic waves are the followings:

- amplitude,
- oscillation frequency.

Oscillations generated by explosive detonation can be characterized as a non-periodic process with big amplitude and energy. The property of surrounding environment which in many cases cannot be sufficiently characterized has an impact on seismic waves spreading. For example in the rocks the seismic wave transmits through the tectonic failures with dominant attenuation but it spreads quite easily and to big distances along these failures. Oscillation of the surrounding environment of the charge explosion proves similar characteristics as earthquake.

The normal frequencies activated by charge explosion are in the interval between 5-50 Hz. Frequencies *f* <10 Hz conform to charges with equivalent weight m_{ev} > 2000 kg, frequencies *f* > 50 Hz conform to charges with equivalent weight m_{ev}< 5 kg.

According to arrangement the blastings can contain:

- one explosive charge placed in the boreholes or in explosive chamber,
- more explosive charges placed in the boreholes 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 *Dt*:

- *Dt ³ 250 ms* (seismic waves attenuation before explosion of the next partial charge),
- *Dt* < *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 *Dt* = 10 ms.

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. If it is impossible then supposing approximately similar charge components we consider the doubled weight of partial charge component (the weight in one time stage – equivalent weight of charge m_{ev}), or considering charges of different sizes at maximum total weight of two biggest ones. If the weight of a charge is four times bigger than any one of the others then we can consider the weight of this biggest one. The normal gripping and sealing of the charge are required.

The most reliable method of assessment and prediction of vibration intensity is the direct measurement of seismic effects on a particular building by blasting small weight explosive charge. The equipments applied for measuring and recording can be the followings:

- mechanical,
- digital.

The vibration amplitudes and particle velocity are measured and recorded by these equipments and moreover the digital ones evaluate the measured data. The maximum deflection is deducted from the amplitude record and the corresponding vibration frequency and velocity are calculated. Direct measurement of particle velocity is a more efficient method. Three geophones are used as electric seismic detectors and they are placed and fixed to be able to record all three spatial components of vibration (two horizontal and one vertical). The particle velocity is assessed due to the record as the maximum value of one from three components.

For provisional estimation of seismic impact of the blasting on near building the modified Koch relation is applied (STN EN 1998-1/NA/Z1):

$$v = K.\frac{\sqrt{Q_{ev}}}{L}$$

where v = particle velocity of seismic wave [mm.s^{-1}],
Q_{ev} = equivalent weight of explosive charge [kg],
L = the shortest vibration source – receptor distance [m],
K = the coefficient of energy transmission through the geological medium or energy transmission coefficient assessed by seismic measurement dependent on distance between measuring standpoint and blasting site.

Informative values of energy transmission coefficient K are shown in Table 1.

Table 1 Informative values of energy transmission coefficient K due to STN EN 1998-1/NA/Z1

Distance *l* [m]	**Coefficient K [kg $^{-1/2}$. m^{2} . s^{-1}]**	
	Bedrock and semi-bedrock with medium up to very small discontinuity density	**Other rocks except for those in saturated medium**
10	350	250
50	250	150
200	150	120
500 and more	120	100

Values in the above table are valid for particle velocity up to 30 mm.s^{-1}, but they are not valid for saturated medium.

Lower velocity than 10 mm.s^{-1} does not cause any damage, at velocity 20 mm.s^{-1} the first signs of damage can be identified and at higher velocity the receptor could be damaged more seriously leading to total stability failure.

Seismic effects of blasting can be substantially reduced by:

- *distribution of total charge capacity into partial ones.* The final seismic impact can be efficiently reduced by millisecond rock blast timing, as a consequence the delayed timing of particular blasts causes interference of seismic waves and as a result their undesirable effects are mutually elimited. There is an evidence that if the vibration is weaker then the blast easier overcomes the resistance of blasting distance and therefore in some cases it is requirable to to increase the charge weight by 30 – 40%. As a result the amplitude increases but the particle velocity decreases and the gripping of the blasted material will be smaller. We can achieve lower seismic effect considering increase of casting off and smashing of blasted material*;*

- *generation of artificial cut-off (gap)* in the way of seismic wave by the presplit blasting method.

The most efficient seismic effect can be achieved by blasting of sealed explosive charge in geometrically non-limited area i.e. without open space (vibration rock blasts), at shooting and blasting on one open space (cuts) and at bigger gripping of charge (blasting per limited width of open space) . The lowest seismic effect can be identified at secondary shooting and blasting i.e. existence of lot of open space.

Most blastings are performed between these two extremes. Increasing the number of open space and decreasing the charge gripping by applying appropriate bore schemes and blast planning (geometry and timing) it is already possible in the preparatory process to minimize the probable seismic effects of the planned blasting.

Identification of these adverse effects and determine seismic safety is currently very topical issue. It is necessary to find a suitable path evaluation method, which on the one hand, ensured security property of non-infringement and, on the other hand, would determine the most effective technology blasting (Kalab, Knejzlík, 2004). Impact assessment of seismic effects caused by blasting works depends on the distance and blasting the objects and the size of the booster in individual timing stages used in blasting. To determine the size limit charges and minimum distance is needed to determine attenuation characteristics of seismic waves in the monitored area. (Dojčár et al., 1996, Kalab at all., 2011).

Examination of these adverse effects and determines seismic safety is currently a very active and inevitable problem. It is necessary to find an economical way which on the one hand, ensured security property of non-infringement and, on the other hand, would determine the most effective technology blasting. Technical unfounded - high seismic safety leads to narrowing and blasting bombs, thus reducing the efficiency of disintegration and conquest. Conversely, underestimation of seismic effects can cause substantial damage to property.

Koch relationship, called the law attenuation of seismic waves can be very well defined, the complex geological conditions, however, may have a very low correlation (Holub, 2006, Dojčár et al., 1996, , Pandula and Kondela, 2010). To construct the law attenuation of seismic waves be used not only to record the vibration of expression as a whole, but also the parts of the record corresponding to each time step.

These standards define the informative value of the constant transmission of seismic waves to the subsoil of rock and of semi rocks and other rocks off rocks in the aquifer environment depending on the distance from the blast point. Table 1 was used to estimate the maximum amplitude of vibration velocity with respect Koch, unless more precise information about the rock environment.

3 The shorter geological structure Kučín quarry (transmission medium)

From geological point of view it constitutes the bearing zone between the zeolite tuff Kučín and Pusté Čemerne a whole. The influence of surface erosion and segmentation modeling but its continuous progress is interrupted either sediments quaternary cover (in the valley Hrabovecký stream), or cross-disruptive disorders and thus divided into individual parts.

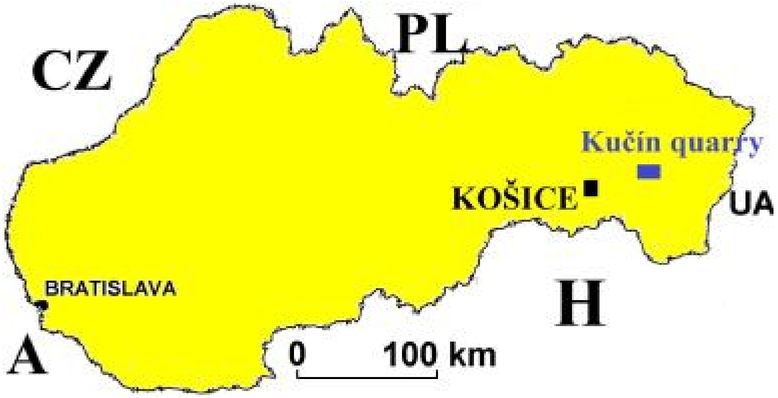

Fig. 1a Kučín quarry lokalization and its surrounding

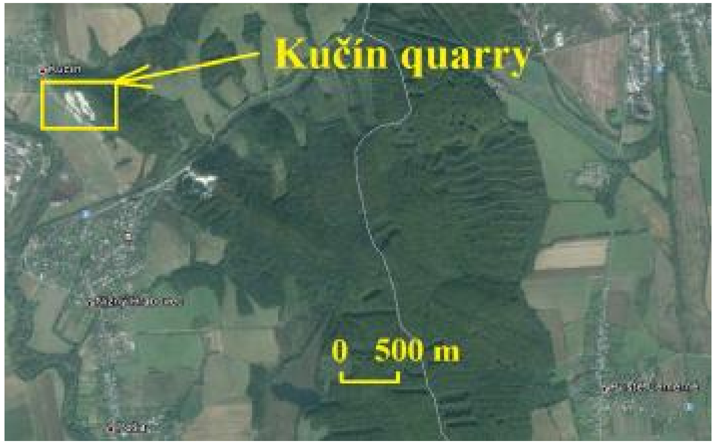

Fig. 1b Kučín quarry lokalization and its surrounding

Part Kučín – below this is described in the bearing zone between Kučín and Pusté Čemerné (Fig. 1a, Fig. 1b), which builds morphologically protruding mound Červený kameň (232.0 m s. l.). The length of this part of the surface is 1250 m, width 150 - 200 m (175 m diameter). Average power of the body, there is 106.93 meters (of 3 exploratory drilling line) and bow is approximately 56° to the southwest (Pandula and Kondela, 2014).

Fig. 3a Measuring opinion 1- residential house no. 44 in the Kučín village

Fig. 3b Three-component seismometers American company GEOSPACE position located at the entrance of a residential building

Fig. 2 Measuring opinion Kučín quarry – a position located, three-component seismometers GEOSPACE were placed 10.2 meters from the blast

4 Using the apparatus and measurement methodology

The following digital seismic devises were used for measuring and graphic records of the seismic effects (Pandula and Kondela, 2014). See also Fig. 2, Fig. 3a, Fig. 4a and Fig. 5a:

- digital seismograph VMS 2000 MP by Thomas Instruments and seismic receivers by Geospace (Fig. 2 and Fig. 3b);
- digital seismograph ABEM Vibraloc and seismic receivers by ABEM (Fig. 4b);
- digital seismograph UVS 1504 and seismic receivers by Nitro Consult (Fig. 5b).

Distance positions and by blasting operation in a Kučín quarry are in Table 2.

Fig. 4a Measuring position 2 – prior to entry into a house in the Kučín village Kučín

Fig. 4b Seismometer was placed on a foundation wall in front of the house

Table 2 Distance positions and by blasting operation in a Kučín quarry

Number - blast	Position	Coordinates - blast			Distance from blast (m)		Note
		x	y	z	leaning	horizontal	
1	Kučín quarry q	-	-	-	-	-	
	1	-	-	-	-	62.11	
	2	-	-	-	-	150.25	
2	Kučín quarry q	-	-	-	-	-	
	1	-	-	-	-	70.05	
	2	-	-	-	-	147.43	
3	Kučín quarry q	-	-	-	-	13.2	
	1	-	-	-	-	50.7	
	2	-	-	-	-	71.6	
	3	-	-	-	-	125.8	
4	Kučín quarry q	-	-	-	-	10.1	
	1	-	-	-	-	68.8	
	2	-	-	-	-	77.5	
	3	-	-	-	-	105.4	

Fig. 5a Measuring position 3 – prior to entry into a house in the Kučín village

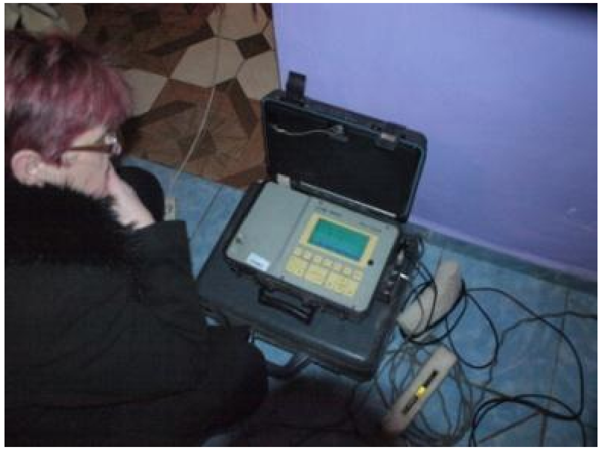

Fig. 5b Seismometer was placed at the ntrance of a residential building

Fig. 6 Position and distance fourth blast in the Kučín quarry in relation to the measuring standpoints in the Kučín village

5 Source of the vibration

The source of seismic waves were lined blasting in the Kučín quarry the deposit of zeolite tuff, before entering the Kučín village (Fig. 6).

Parameters of blasting operations:

1.) The total charge of the 1. blast was 105 kg, of which explosive EXAN G 85.5 kg, 12 kg of the SENATEL and 7.5 kg of explosives EURODYN. On disconnection of 3 wells were used. Non-electric ignitor, timing 42 ms.

2.) The total charge 2. blast was 113 kg, of which explosive EXAN G 58.5 kg, 12 kg of the SENATEL and 17.5 kg of explosives EURODYN. Dissociating the 8 boreholes were used, including 3 heeled boreholes. Non-electric ignitor, timing 42 ms.

Fig. 7a The EURODYN explosives

Fig. 7b The borehole charge

To optimize the timing of blasting operations was done the third line blast in the quarry Kučín.

3.) The total charge of the 3. blast was 25 kg of explosives EURODYN 2000. The disengagement was used 10 heeled boreholes. In one borehole was 2.5 kg explosives EURODYN 2000. The depth of the hole was 3.5 meters. Seal 3 m. Non-electric ignitor, timing 42 ms.

Due to the further optimization of the parameters was carried out by the fourth line blast.

4.) The total charge of the 4. blast was 25 kg of explosives EURODYN 2000. The disengagement was used 10 heeled wells. In one borehole was 2.5 kg explosives EURODYN 2000. The depth of the borehole was 3.5 meters. Seal 3 m. Non-electric ignitor, timing 9 ms.

Explosives and charging into wells is shown in Fig. 7a and Fig. 7b.

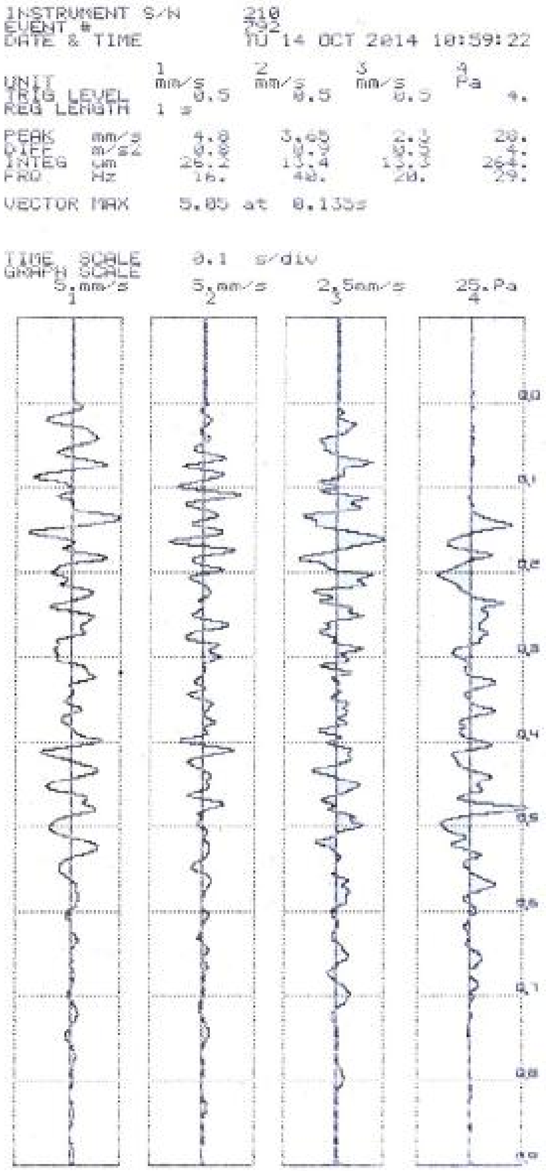

Fig. 8a The resulting record the particle vibration and sound waves on the position of one – residential house measured at the 3. blast

Peak Measurements

	Vertical	Transverse	Radial
PPV (mm/s)	11,93	8,39	8,83
Freq (Hz)	11,4	10,7	28,4
Time (ms)	580	614	528
PPA (g)	0,09	0,06	0.15
PPD (mm)	0,16655	0,12480	0,04948
PVS (mm/s)	12.448 @ 580,1ms		
PSPL (PA)	61,35 (129,738 dB) @ 611,3ms		
PSPL Freq	19,7Hz		
Sensor Test	Passed	Passed	Passed

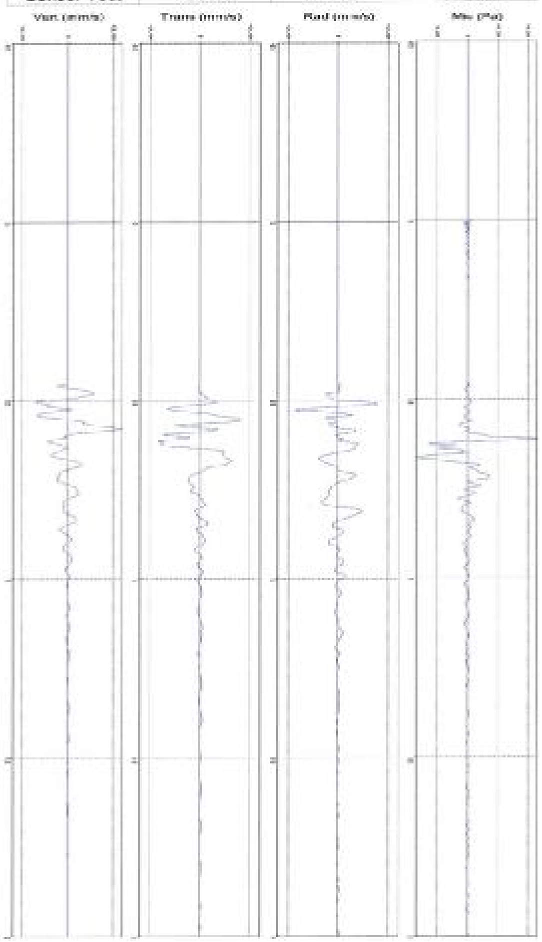

Fig. 8b The resulting record the particle vibration and sound waves on the position of one – residential house measured at the 1. blast

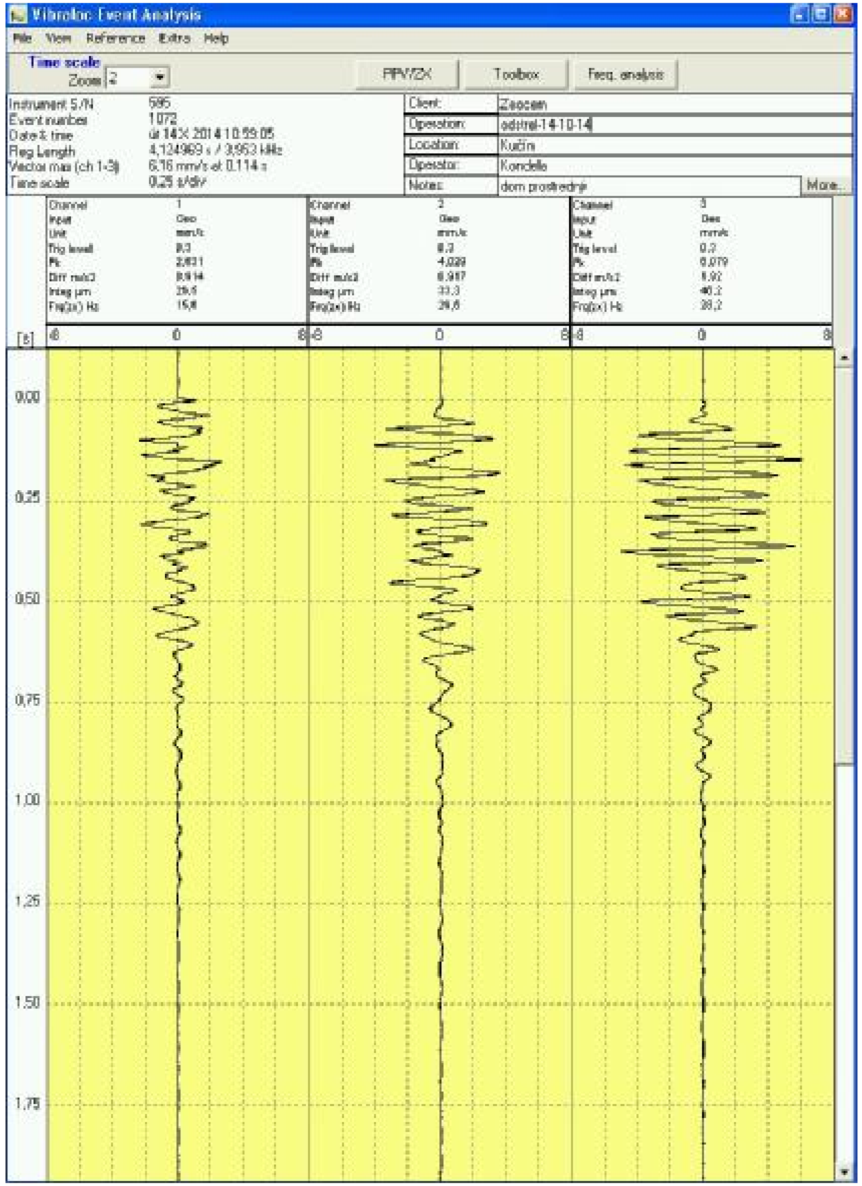

Fig. 9a The resulting record the particle velocity

6 Measured seismic effect blasting operations and analysis

Before measurements the apparatuses positioned at individual standpoints were calibrated and their responsiveness was checked. At the measuring standpoints there was recorded the graphical process of individual components of seismic vibration at bench blastings (Fig. 8a, Fig. 8b, Fig. 9a, Fig. 9b, Fig. 10, Fig. 11).

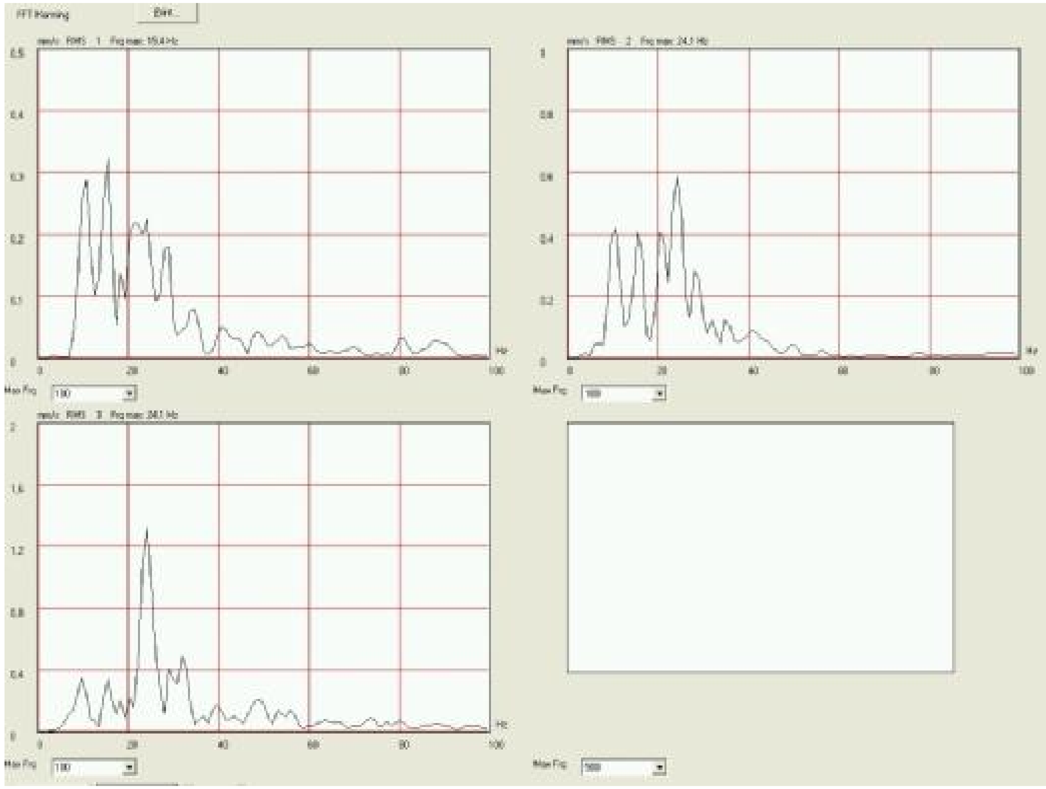

***Fig. 9b** The frequency analysis of the vibration of the components (in the longitudinal, transverse and vertical directions) on the measuring position 2 – residential building, on the 3. blast. The measured values are given in Table 3*

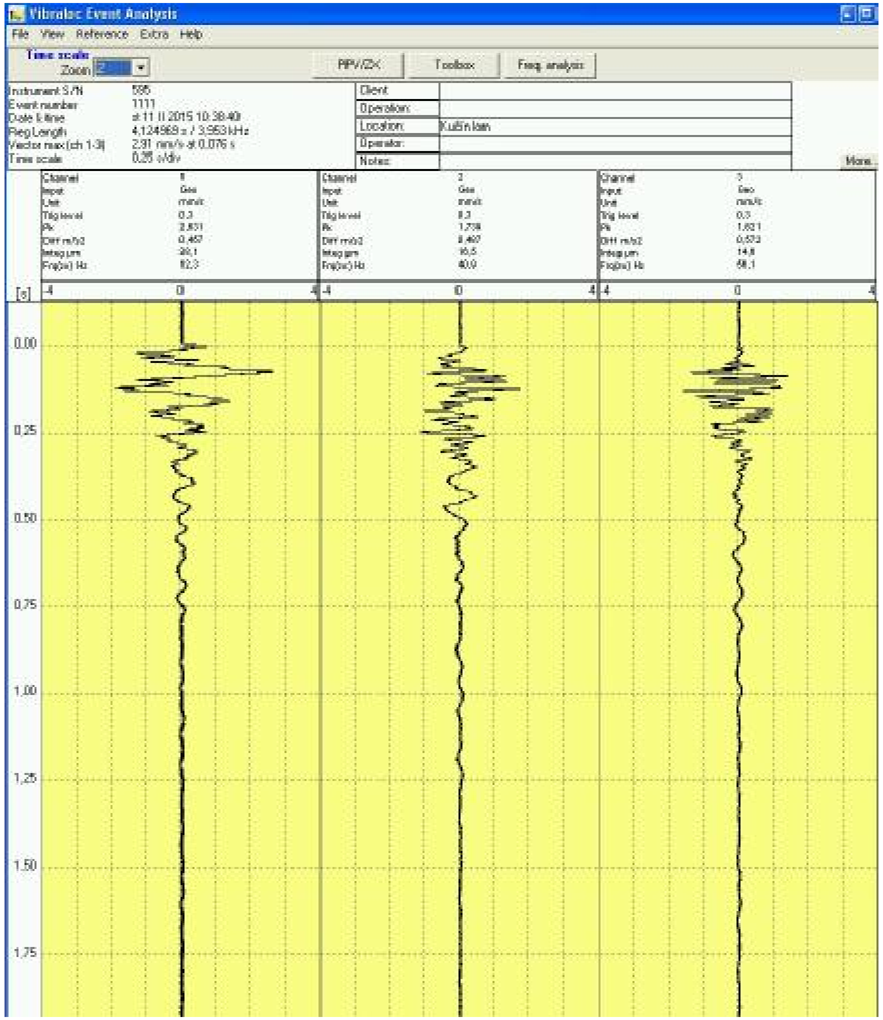

***Fig. 10** The resulting record the particle velocity of the components (in the longitudinal, transverse and vertical directions on the measuring position 1 – residential house, on the 4. blast. The measured values are given in Table 3*

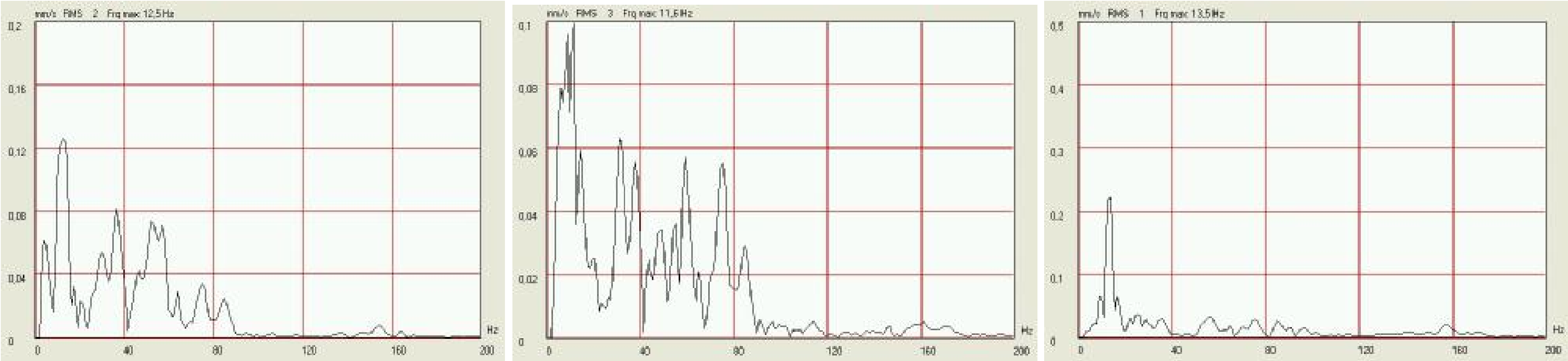

Fig. 11 Frequency analysis of the vibration record of the individual components (in the longitudinal, transverse and vertical directions) measured on the measuring position 2 – residential building, on the 4. blast

Effects of the so-called technical seismicity caused by rock blasting works are measured and assessed by particle velocity of the particiles of the medium (speed of amplitude) „v“, namely according to the maximum value of one of its three constituents x, y, z. The principle of seismic protection – seismic safety of building structures in relation to technical seismicity can be expressed as follows:

v £ $\mathbf{v_d}$

where „**v**” is maximum value of the component of particle velocity induced by the source of vibrations measured at the so-called reference standpoint of the projected (assessed) object; a reference standpoint is the foundation of the building’s ground floor; the value „**v**“ mainly depends on the maximum weight of the explosive charge blasted at one time stage **$Q_č$ [kg]**, on the maximum distance of the source from the receptor of vibrations **L [m]** and on the properties of the geological transmitting medium between the source and receptor of vibrations. In the light of the present day knowledge, the value „**v**“ cannot be reliably calculated either analytically and empirically in advance, the most reliable way to determine is by means of specific measurements as it is in this very case, **v_d** is the maximum permitted (boundary) particle velocity for the assessed (projected) object; at this particle velocity no damage to the object occurs – the damage level is 0; this value is determined intependently from the blasting (before blasting) based on practical experience as specified in various standards (in this country it is for instance EN 1998-1/NA/Z1), or on the basis of experts‘ assessments. EN 1998-1/NA/Z1 indicates the relation between oscillation intensity expressed by particle velocity of individual components and possibility of the damage of a building structure.

Measured maximum values of velocity components of vibration blasting in the quarry Kučín are shown in Table 4. If according to EN 1998-1/NA/Z1 is true:

$$v = K.\frac{\sqrt{Q_{ev}}}{L}$$

where **v** = the measured maximum particle velocity (maximum oscillation rate component) generated blast [mm.s^{-1}],
K = coefficient of transmission medium,
$\mathbf{Q_{ev}}$ = maximum charge per time step,
L = distance blast from measuring position.

Table 3 Measured values of speeds and frequencies of individual components for measuring wave positions in Kučín quarry

Measuring position	**x [mm. s^{-1}]**	**y [mm. s^{-1}]**	**z [mm. s^{-1}]**	**Sound [Pa]**	**x [Hz]**	**y [Hz]**	**z [Hz]**	**Sound [Pa]**
Kučín quarry 1. blast	-	-	-	-	-	-	-	-
1	8.83	8.39	11.93	61.35	28.4	10.7	11.4	19.7
2	1.75	1.4	0.95	6.5	7.6	7.4	4.5	0.9
Kučín quarry 2. blast	-	-	-	-	-	-	-	-
1	4.2	3.98	8.17	43.51	26.9	13.1	10.2	19
2	1.7	1.4	1.3	11	10	7.2	10	1.3
Kučín quarry 3. blast	26.39	12.81	32.36	-	20.5	8.4	36.6	-
1	2.3	3.65	4.8	28	20	40	16	29
2	4.029	6.079	2.631	-	29.6	28.2	15.6	-
3	1.361	1.417	0.863	-	25.3	25	22.2	-
Kučín quarry 4. blast	40.97	5.19	20.54	-	19.0	46.5	20.5	-
1	1.739	1.621	2.631	-	40.9	56.1	12.3	-
2	2.039	1.957	2.006	-	42.1	35.9	14.1	-
3	0.7	1.25	1	0.9	3.6	7.2	6.1	6.3

Then from that relationship coefficient transmission medium K for the vicinity of the Kučín quarry is worth:

$K_q = v \cdot L / \sqrt{Q_{ev}} = 40.97 \cdot 10.1 / \sqrt{2.5} = 261.7$
$K_1 = v \cdot L / \sqrt{Q_{ev}} = 2.631 \cdot 68.8 / \sqrt{2.5} = 114.48$
$K_2 = v \cdot L / \sqrt{Q_{ev}} = 2.039 \cdot 77.5 / \sqrt{2.5} = 99.94$
$K_3 = v \cdot L / \sqrt{Q_{ev}} = 1.25 \cdot 105.4 / \sqrt{2.5} = 83.32$

where K_q, K_1, K_2, K_3 are the values of the coefficients of the transmission environment for measuring standpoint **[q]**, 1, 2 and 3.

High values of coefficients transmission environment and frequency analysis of the components of oscillation shown that the transfer medium for the transmission of vibration is very good and significant attenuation of particle velocity rate was the interaction of charges based on the appropriate timing.

Measured maximum values of seismic effects generated in blasting operations that were conducted in a quarry Kučín, they served as a basis for determining the law of attenuation of seismic waves in the Kučín quarry.

Based on measured data was constructed graph of the maximum particle velocity components to reduce the distance where blasting operation. The graph in Fig. 12 is called Law attenuation of seismic waves for Kučín quarry.

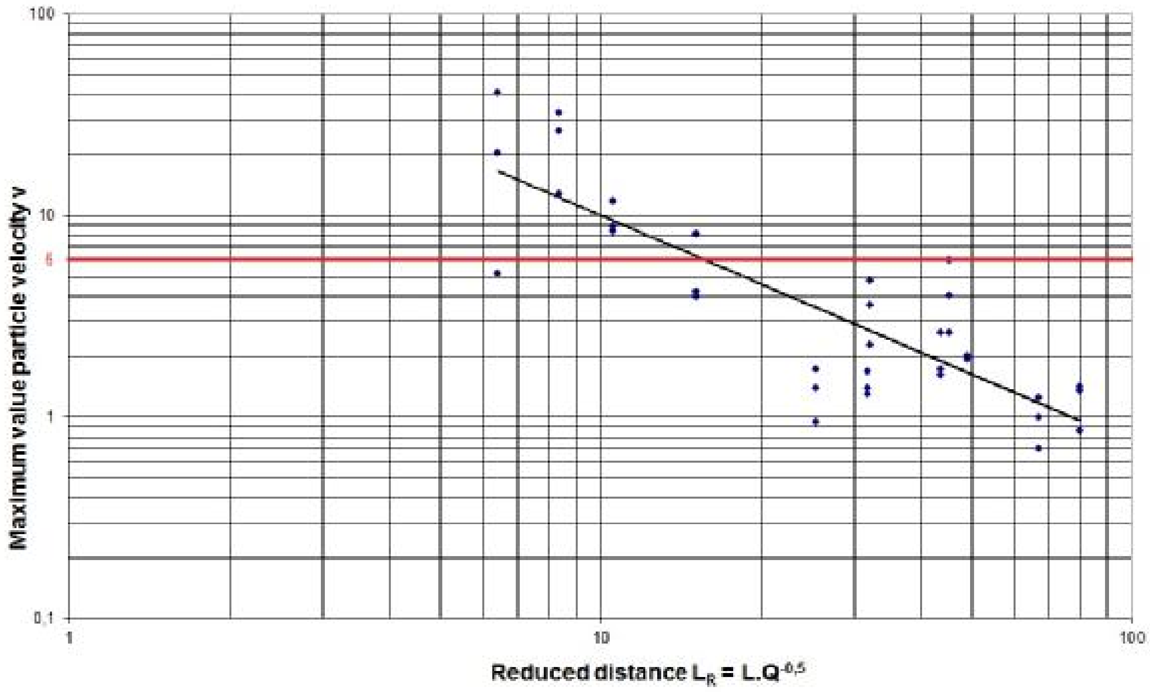

Fig. 12 Plot of the maximum particle velocity components to reduce the distances at line blasted in the Kučín quarry – law attenuation of seismic waves

7 Conclusion

Mining in the quarry Kučín is performed in line blasting operations. This technology quarrying maximum charge batting in one time step does not exceed 35 kg. Corresponding to this is that, depending on the distance of the source – receptor and intensity of seismic effects.

Table 4 Parameters source and receptor and the measured maximum value of the components particle velocity monitored blasting operation

L [m]	**Q [kg]**	**$L_R = L.Q^{-0.5}$ [m.kg$^{-0.5}$]**	**v_x [mm.s^{-1}]**	**v_y [mm.s^{-1}]**	**v_z [mm.s^{-1}]**
62.11	35	10.5	8.83	8.39	11.93
150.25	35	25.4	1.75	1.4	0.95
70.05	21.5	15.1	4.2	3.98	8.17
147.43	21.5	31.79	1.7	1.4	1.3
13.2	2.5	8.35	26.39	12.81	32.36
50.7	2.5	32.06	2.3	3.65	4.8
71.6	2.5	45.28	4.029	6.079	2.631
125.8	2.5	79.56	1.361	1.417	0.863
10.1	2.5	6.39	40.97	5.19	20.54
68.8	2.5	43.51	1.739	1.621	2.631
77.5	2.5	49.01	2.039	1.957	2.006
105.4	2.5	66.66	0.7	1.25	1

Optimizing the timing of blasting operations that were made in the Kučín quarry been achieved, that the measured values do not exceed the values laid down by applicable Slovak technical standard STN EN 1998-1/NA/Z1 Seismic structures $v_d < 6$ mm.s^{-1} and cause no harm monitored residential buildings in the Kučín village.

Given that the measured particle velocity at the objects were well below 6 mm.s^{-1}, the maximum size load one time step to 2.5 kg of explosives was set correctly. Used timing 9 ms significantly contribute to reducing the effects of seismic blast in the Kučín quarry.

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