Exploration Geophysics, Remote Sensing and Environment XXVIII.2 (2021)

DOI: 10.26345/egrse-049-21-204

OPTIMIZATION MILLISECOND TIMING DELAY OF BLASTING IN MALA VIESKA QUARRY

OPTIMALIZÁCIA MILISEKUNDOVÉHO ČASOVANIA PRI TRHACÍCH PRÁCACH V LOME MALÁ VIESKA

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Abstract

The Environmental Protection Law together with Geological and Mining Law impose on a mining plant obligate a duty to protect its surroundings against the effects of mining operations. The negative effects of mining activities include vibrations with different particle oscillation velocities and a wide range of frequencies that are caused by blasting works. They are one of the basic problems in quarries. Intense vibrations can cause critical environmental damage near quarries. Therefore, it is necessary to constantly study how to regulate the vibrations caused by blasting work and to deal with the evaluation of the negative effects of blasting work, and their optimization in terms of blasting parameters. The research presented in the article was carried out with the aim of optimizing blasting works in the quarry Malá Vieska in the Slovak Republic. The aim of the research was to use millisecond timing delay to optimize the seismic effects of blasting (vibrations) and to determine the maximum allowable load per timing stage based on the law of attenuation of seismic waves, so that no damage is caused to objects near the quarry and residents would not consider these vibrations dangerous.

Abstrakt

Zákony o ochrane životného prostredia spolu s geologickým a banským zákonom ukladajú banskému závodu povinnosť chrániť jeho okolie pred účinkami banskej činnosti. K negatívnym účinkom banskej činnosti patria vibrácie s rôznymi rýchlosťami oscilácií častíc a širokým rozsahom frekvencií, ktoré sú spôsobené trhacími prácami. Sú jedným zo základných problémov lomov. Intenzívne vibrácie môžu v okolí lomov spôsobiť kritické škody na životnom prostredí. Preto je potrebné neustále študovať spôsob regulácie vibrácií spôsobených trhacími prácami a zaoberať sa hodnotením negatívnych účinkov trhacích prác a ich optimalizáciou z hľadiska parametrov trhacích prác. Výskum uvedený v článku bol vykonaný s cieľom optimalizácie trhacích prác v lome Malá Vieska v Slovenskej republike. Cieľom výskumu bolo využiť milisekundové časové oneskorenie na optimalizáciu seizmických účinkov trhacích prác (vibrácie) a na

základe zákona o útlme seizmických vĺn určiť maximálne prípustné zaťaženie pre každú časovaciu fázu, aby nedošlo k poškodeniu predmetov v blízkosti lomu a obyvatelia by tieto vibrácie nepovažovali za nebezpečné.

Keywords

mining, blasting works in quarries, optimization of millisecond timing delay, attenuation law of seismic waves

Kľúčová slová

ťažba, trhacie práce v lomoch, optimalizácia milisekundového časového, zákon útlmu seizmických vĺn

1 INTRODUCTION

One of the basic problems with blasting works is effective solution for the seizure and vibration arising during blasting within mining operations. The basic solutions of seismic effects arising from blasting works are clearly formulated and while so far the problems that blasting works cause are completely missing. Compared to underground mining works, blasting work in quarries is somewhat recommended (Kudelas et al., 2019).

Vibrations caused by blasting work are one of the main problems in surface mines and intense vibrations can cause great damage to structures and plants near surface mines, especially the stability of the final pit wall. It is very important to study how to regulate vibrations caused by blasting works while mitigating the negative effects of these works in quarries (Konček et al., 2020 and Zhang, Goh, 2016).

With the new advances in blasting technologies, many undesirable factors can now be avoided. Optimal explosion results are thus achieved much easier and faster. This study points to an experimental methodology for determining delay time by explosion monitoring. Blasting works were monitored by seismographs and evaluated using seismograph's software (Kondela, Pandula, 2012).

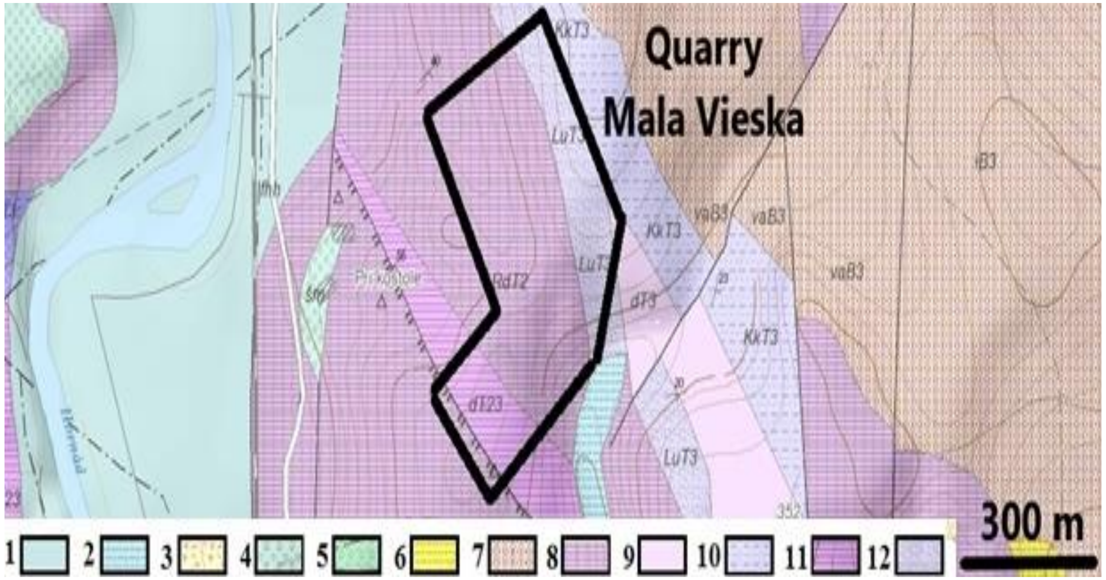
The basic idea of optimizing the seismic effects of blasting work is explained simply by the assumption of superposition of sinus seismic waves. When two identical seismic waves are superimposed with a certain delay, the amplitude of the superimposed wave may vary according to the phase delay. If the delay is half the period of the sine wave, the two waves interact with each other and, as a result, the amplitude of the superimposed wave is minimized. However, because the actual vibrations of the explosion have complex properties, it is not so easy to define optimal delay times (Pandula, Kondela, 2010 and Pandula, Kondela, Pachocka, 2012).

Langefors proposed a delay time $\Delta t = T / 2$ milliseconds (T is the period of seismic waves), which will allow the majority of vibrations to cancel each other out within a constant vibration cycle and the same vibrational shapes. In blasting work, it is assumed that the method of calculating the delay time is determined according to the structural conditions of the rock environment. Then, the effect of interference by superposition of seismic waves is taken into account when calculating the delay time. According to Langefor's theory developed by Leššo, two seismic waves could achieve maximum vibration interference when the delay time was half the period of the seismic wave period caused by an explosion of our explosive/s. The period of seismic wave propagation in blasting works is obtained by measuring the frequency of seismic waves in situ near the blast (Langefors, Kihlström, 1978 and Leššo, 2018). Experimental measurements were performed in the quarry Malá Vieska.

2 ENGINEERING GEOLOGY OF THE EXPERIMENTAL AREA

The quarry Malá Vieska (Carmeuse Slovakia s.r.o.) is located in the Slovak Republic in the cadastre of Kostoľany nad Hornádom in the Košice Region, Košice-okolie District, about 10 km north of the city of Košice (Fig.1).

Fig. 1 Position of Mala Vieska quarry



Description of the legend of picture no. 2:

Quaternary: 1- alluvial clays, sandy to gravelly clays of valley floodplains (Holocene),

2- proluvial sediments, clays to sandy clays with crumbs and rock fragments, 3 - deluvial sediments (unstructured) predominantly aluminous-stony, 4 - fluvial sediments-residual gravels of upper terraces, 5- proluvial sediments of sandy gravel with rock fragments in alluvial cones,

Neogene:6- Kladzian Formation-variegated claystones, sandstones, halls, anhydrites, 7-Klčov Formation - organ gravel, gravels, sands, clays

Mesozoic: 8 - Ramsau Dolomites (Ladin), 9 - main dolomites - light gray massive dolomites (young triassic), 10- Carpathian keuper - quartz sandstones, arkoses, conglomerates, clay shales, dolomites, 11 - gray layered dolomites in places breweries, 12 - Lunz layers - fine-grained sandstones, dark gray claystones and clayey-sandy shales

Fig. 2 Geological map of the vicinity of the quarry Malá Vieska (Internal materials Carmeuse Slovakia s.r.o.)

In the quarry Malá Vieska east of Družstevná pri Hornáde, layered, in some places massive dolomitic limestones and dolomites. Dolomites are light gray to gray in colour, rarely dark gray. The most important Ramsau dolomites are represented in the quarry and the Lunz strata are in their overburden.

Layers of the main dolomite appear in the overburden of the Lunz layers. The thickness of the layers of Ramsau dolomites in the quarry is from 10 to 100 cm. Sometimes they appear more like massive positions. As these are rheologically very hard rocks in the field, they form morphologically significant forms. These are mostly crystalline, sometimes microcrystalline dolomites with a small proportion of fossils, especially lamellibranchiata, dasycladaceae-probably diplopore. Crinoid residues are rare in dolomites. At several places in the quarry, dolomites are crimped along tectonic structures or form breccias. From a microstructural point of view, these are dolomicrites and dolopelmicrites, but sometimes the orthochemical component also consists of sparite (Fig. 2, Internal materials Carmeuse Slovakia s.r.o.)

***Fig. 3** Position of the vibrograph VMS 2000 standpoint S1 - at a distance of 17 m from the first initiated borehole CO 274 and a distance of 12 m at CO 277in the quarry Malá Vieska*

***Fig. 4** Vibrographs used for measuring technical seismicity at bench blasts CO 274, CO 275, CO 276 and CO 277 (A - UVS 1504, B – ABEM Vibraloc on standpoints S2 and S3 – church building*

3 METODOLOGY OF MEASUREMENT AND APPARATUS USED FOR MEASURING TECHNICAL SEISMICITY

For measuring and graphical recording of seismic effects of blasting works (bench blasts CO 274, CO 275, CO 276 and CO 277) the following digital vibrographs were used at the mentioned measuring stations:

- vibrograph VMS 2000 from the American company Thomas Instruments and sensors from the American company Geospace (Fig. 3).
- vibrograph UVS 1504 and sensors from a Swedish company Nitro Consult (Fig. 4),
- vibrograph ABEM Vibraloc and sensors from a Swedish company ABEM (Fig. 4).

Measuring standpoint at bench blasts CO 274, CO 275, CO 276, CO 277 were located on a listed building intended primarily for religious services (church, Fig. 5). This building required increased protection because cracks were identified in the walls after previous blasts. The measurement positions were situated as follows:

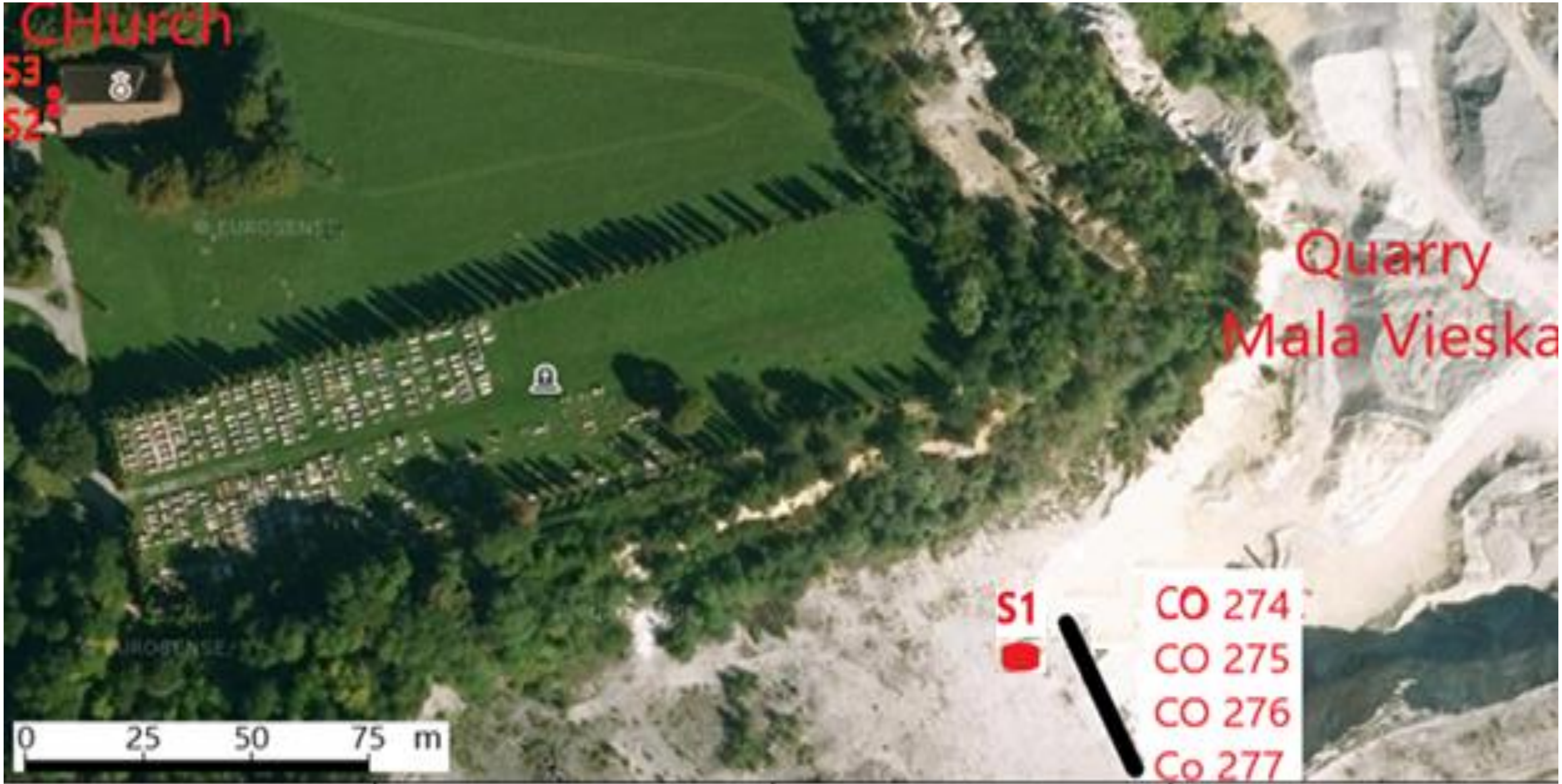
- the first standpoint was directly in the quarry Malá Vieska to measure the frequency of seismic waves caused by blasting and to obtain PPV (peak particle velocity) values for accurate determination of the law of attenuation of seismic waves in the transmission environment,
- the second standpoint was situated on a concrete base at the entrance to the assessed building,
- the third standpoint was on the window sill at the entrance to the assessed building.

The assessed object and cracks in the walls, we can see on Figure 5 (Pandula, Kondela, 2016, 2017, 2019 and 2021).

***Fig. 5** The assessed object (A) and during the section the crack found on which help as tertarget wasp (B)*

To determine the law of attenuation in the transmission environment between the source (bench blasts CO 274, CO 275, CO 276 and CO 277) and the receptor (church), the measuring position S1 (Fig. 3 and 6) was situated about 17 m (CO 274) and 12 m (CO 277) from the initiation borehole in the quarry Malá Vieska. A digital four-channel vibrograph VMS 2000 (CO 274) and ABEM Vibraloc (CO 277) were used to measure seismic effects at the standpoint S1.

Two S2, S3 measuring standpoint were located to assess the seismic effects on the church (Fig. 6) UVS 1504 and ABEM Vibraloc vibrographs (Fig. 4) were placed on the stands (S2, S3), which measured the effects of technical seismicity on the church building. The sensors were located on a concrete base at the entrance to the assessed object (S2) and on the window sill at the entrance to the assessed object (S3).



	S1	S2	S3
CO 274	17 m	231.65 m	236.86 m
CO 275	X	221.65 m	226.86 m
CO 276	X	266.2 m	273.3 m
CO 277	12 m	256	X

***Fig. 6** Position of opinions from bench blasting CO 274, CO 275, CO 276 and CO 277 in Malá Vieska quarry in relation to measuring standpoints (S1, S2 and S3) and distance of individual opinions*

4 SOURCES OF SHOCKS IN RESEARCH TECHNICAL SEISMICITY (CO 274, CO 275, CO 276 and CO 277)

The sources of seismic effects were bench blasts CO 274, CO 275, CO 276 and CO 277 in a deposit located from 231 to 273 meters from the church building. Positions and distances of CO 274, CO 275, CO 276 and CO 277 in relation to measuring positions (S2, S3), can be seen on Fig. 6 (Pandula, Kondela, 2016, 2017, 2019 and 2021).

Parameters of bench blasts CO 274, CO 275, CO 276 and CO 277 in the quarry Malá Vieska:

CO 274 - 7 vertical boreholes were drilled with a diameter of 105 mm, an inclination of 70º and a length of 26 m. The total charge was 770 kg of explosives. Total charge in the borehole 110 kg, of which the lower charge 93.25 kg (Ecodanubit 5 kg, Infernit 1.25 kg, DAP E 87 kg) and the upper charge 16.75 kg (Ecodanubit 2.5 kg, Infernit 1.25 kg, DAP E 13 kg). The maximum charge per delay was 93.25 kg. Interstemming was 4 m and stemming was 5m. Area of burden w = 4.5 m and spacing between boreholes a = 4.5 m. The explo-sives used were Ecodanubit 52.5 kg, Infernit 17.5 kg and DAP E 700 kg. Non-electric ignition - 15 pcs Indetshock MS 20/50. A millisecond delay time of 67 ms was used between boreholes (Fig. 7).

CO 275 - 12 vertical boreholes were drilled with a diameter of 105 mm, an inclination of 70º and a length of 28 m. The total charge was 1230 kg

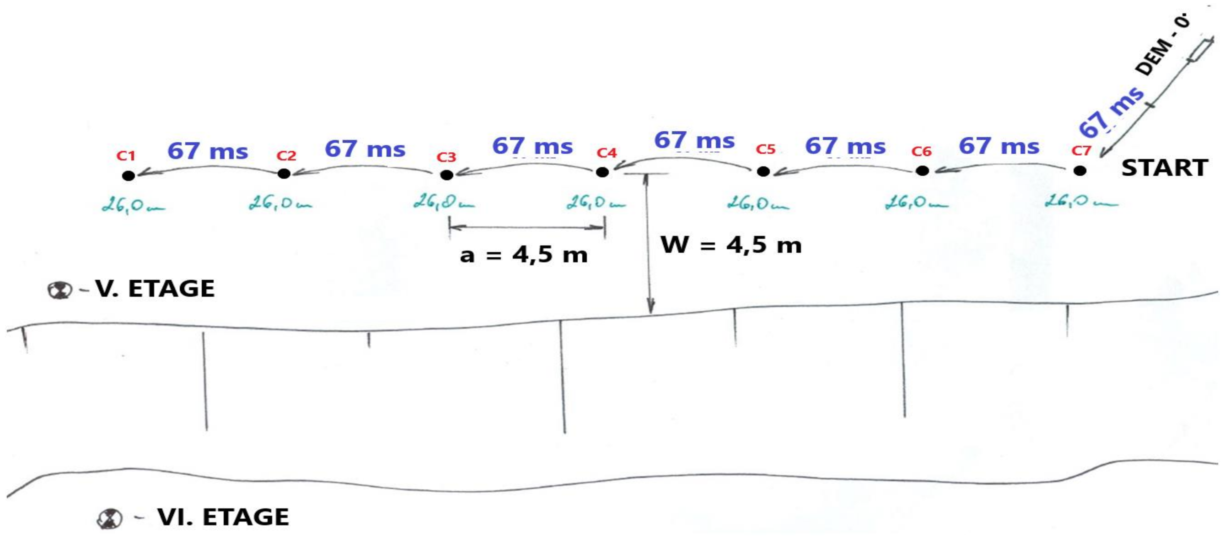


Fig. 7 Drilling and timing scheme CO 274

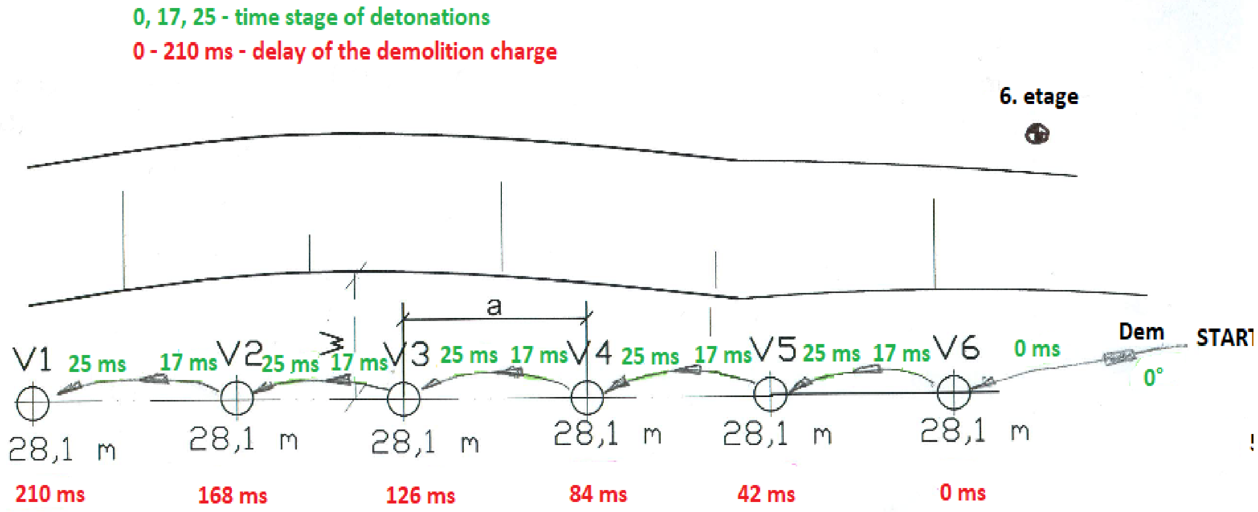


Fig. 8 Drilling and timing scheme CO 276

of explosives, of which the maximum charge per delay was 102.5 kg. Area of burden w = 4.2 m and spacing between boreholes a = 4.5 m. The explosives used were Perunit 30 kg and DAPMON 30 1200 kg. Non-electric detonator 36 pcs of Indetshock MS 20/50 detonators. A millisecond delay time of 9 ms was used between boreholes.

CO 276 - 6 vertical boreholes with a diameter of 105 mm, an inclination of 24° and a length of 28.1 m were drilled. The total blast charge was 630 kg of explosives. The maximum charge per delay was 111 kg. Area of burden w = 4.2 m and spacing between boreholes a = 4.5 m. The explosives used were Paladyn 3 Eco 30 kg and Dapmon Al 600 kg. Non-electric ignition – 18 pcs Exel. A millisecond delay time of 42 ms was used between boreholes (Fig. 8).

CO 277 - 6 vertical boreholes with a diameter of 105 mm, a slope of 60° and a length of 29.2 - 29.3 m and 54 heel boreholes with a length of 1.5 - 2.5 m were drilled. The total blast charge was 998.6 kg of explosives. The maximum charge per delay was 105 kg. Area of burden w = 4.5 m and spacing between boreholes a = 4.2 m. The explosives used were Eurodyn 2000 65/2500 and Andex A, Andex M and Senatel Powerfrag. Non-electric ignition – 77 pcs Exel, 25 pcs Exel connect adet 3 pcs and Dem-S. A millisecond delay time of 42 ms (header boreholes) and 25 ms heel boreholes were used between the individual boreholes (Fig. 9). (Pandula, Kondela, 2016, 2017, 2019 and 2021)

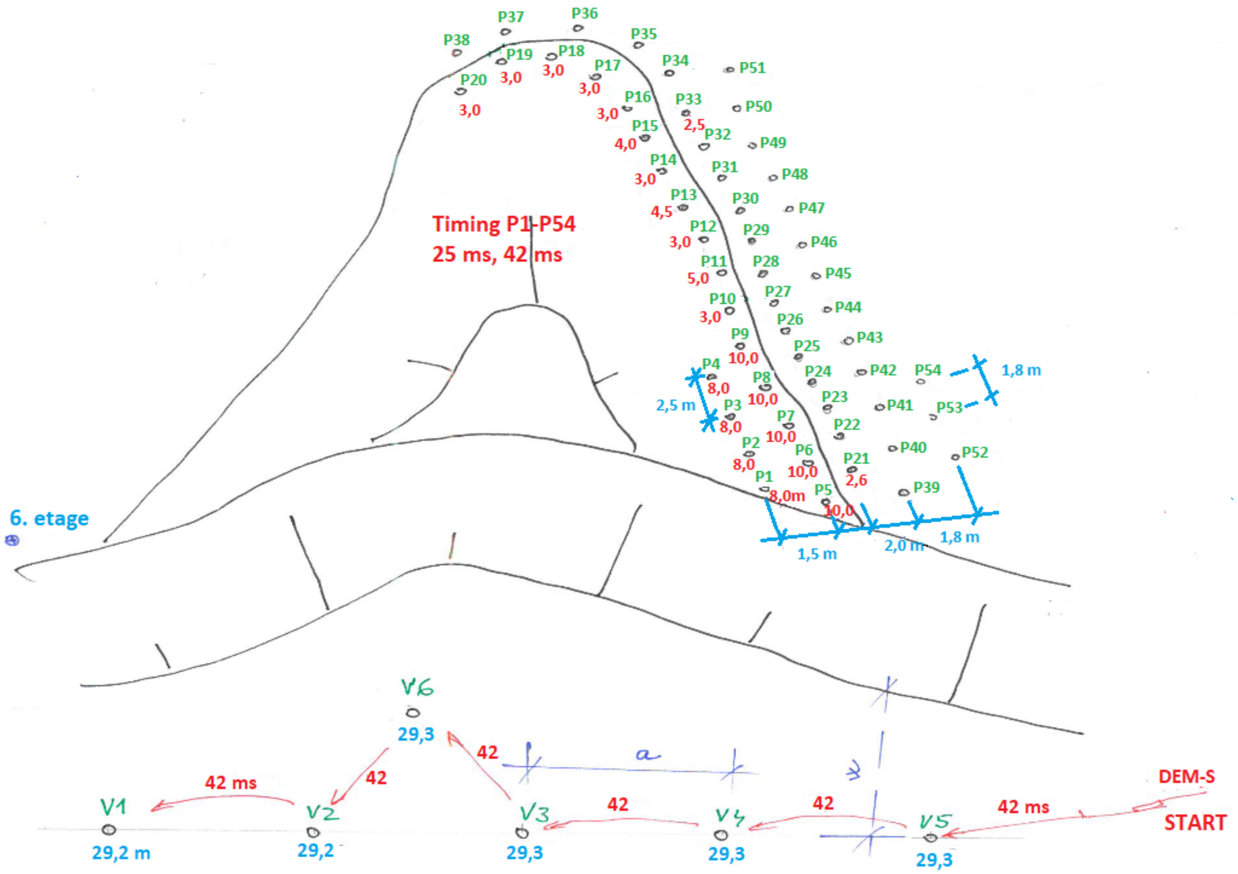


Fig. 9 Drilling and timing scheme CO 277

5 MEASURED VALUES AND RESULTS

The instruments stored on the stands were calibrated before their measurement and their sensitivity was checked. Graphical waveforms of individual components of seismic waves at bench blasts CO 274, CO 276, CO 276, CO 277 were recorded at the measuring stations. The individual graphical recordings were four-second (Fig. 10). The measured values at the individual measuring stations are given in the table 1.

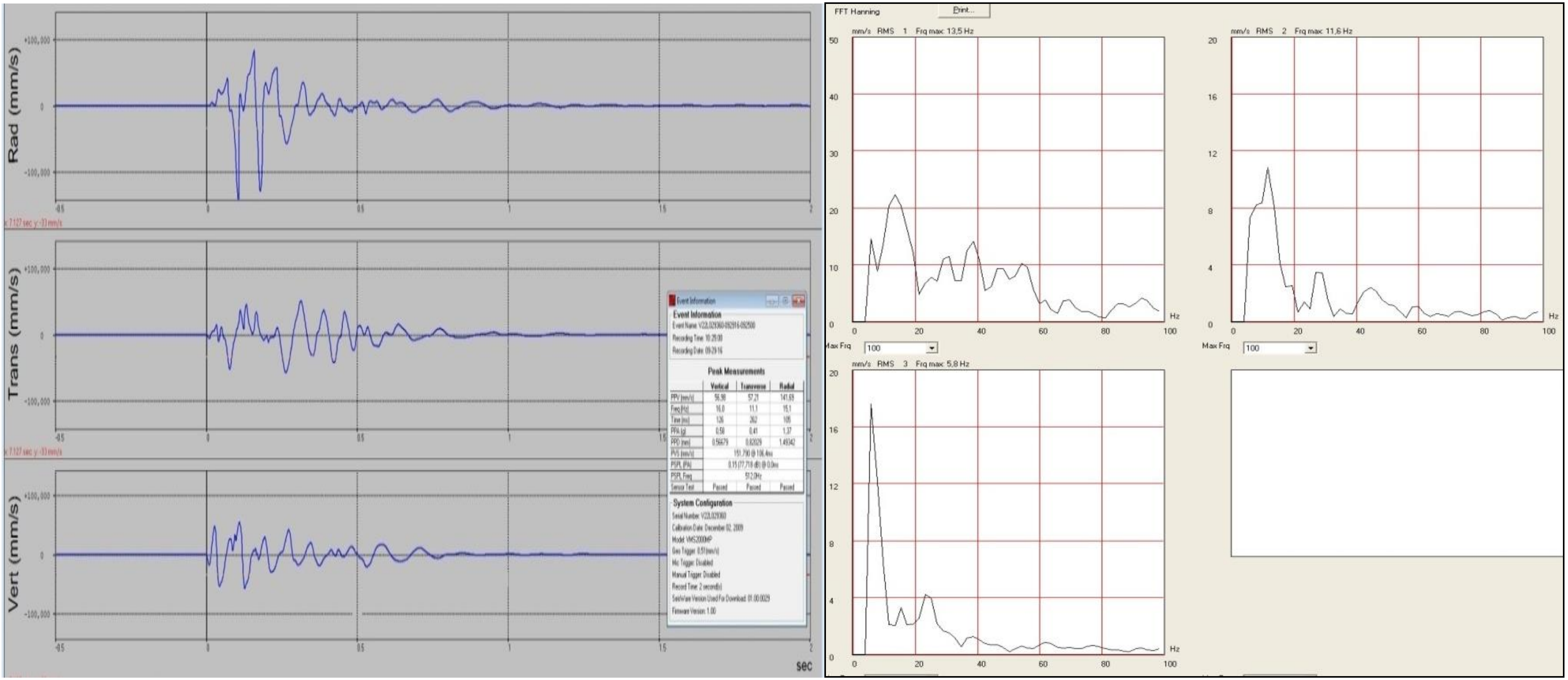


Fig. 10 Graphic recording of individual components of vertical-z, transverse-y, radial-x waves at CO 274 at a distance of 17 m from the first initiated borehole CO 274 in the quarry Malá Vieska (left) and Frequency analysis of vertical, radial and transverse components of vibration velocity at standpoint S1 - Malá Vieska quarry at bench blast CO 277 (right)

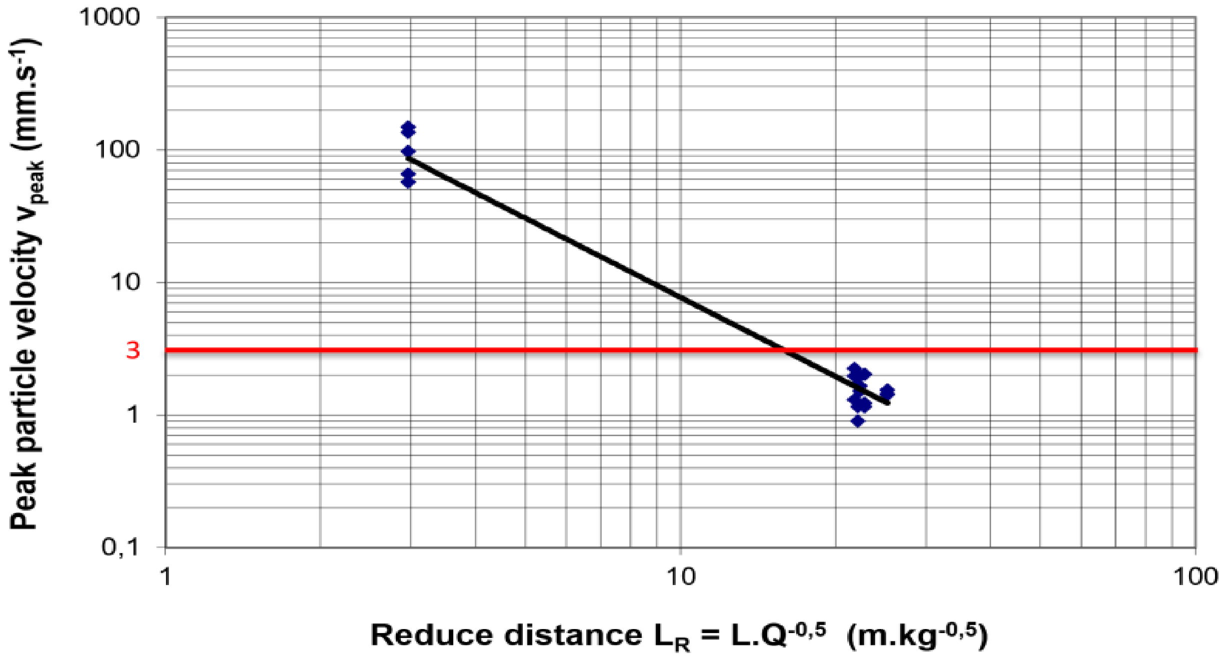
Tab. 1 Measured maximum values of vibration velocities and frequency of individual stations in aperture bench blasts CO 274, CO 275, CO 276 and CO 277.

Position	**Distance [m]**	**Timingdelay [ms]**	**Total charge weight per delay [kg]**	**v_x [mm. s^{-1}]**	**v_y [mm. s^{-1}]**	**v_z [mm. s^{-1}]**	**f_x [Hz]**	**f_y [Hz]**	**f_z [Hz]**
CO 274									
MaláVieska Quarry (S1)	17	67	110	147.69	57.21	56.98	15.1	11.1	16.0
Church (S2)	231.65			0.904	1.159	1.676	8.86	9.74	11.7
Church(S3)	236.86			1.159	1.216	2.024	7.49	7.84	10
CO 275									
Church (S2)	221.65	9	102,5	1.3	2.25	1.95	7.2	2.9	7.6
Church (S3)	226.86			1.52	1.96	1.65	5.9	3.4	4.5
CO 276									
Church (S2)	266.2	42	111	0.734	0.824	1.092	8.07	7.14	8.13
Church (S3)	273.3			0.986	1.013	1.127	5.99	7.42	9.48
CO 277									
MaláVieska Quarry (S1)	12	42	105	97.67	65.94	136.49	2.7	4.97	8.13
Church (S2)	256			1.54	1.45	1.42	7.7	3.6	9.96

6 CONCLUSION

After analysing and evaluating the records of technical seismicity of four aperture blasts, we found from the frequency analysis of individual components of vibration that the energy of all blasts acting on the listed building of the church repeatedly had a frequency less than 10 Hz. This information was used to determine the optimal millisecond delay between boreholes, the allowable peak particle velocity, to refine the evaluation and to determine the allowable maximum charge per timing stage. From the analysis of individual measured values, it can be clearly stated that the best results of seismic safety of large-scale blasting works in the quarry Malá Vieska were achieved using a time delay of 42 milliseconds. The optimization of the millisecond timing delay was determined on the basis of frequency analysis of blast records in the quarry Malá Vieska in close proximity to the initiation borehole. At CO 274, a frequency of 16 Hz was measured in the z-axis direction, and at CO 277, a frequency of 13.5 Hz (see Fig. 10 - Right) was detected in the z-axis direction from frequency analysis. In the direction of the z-axis, the wave passes from the initiation charge in the borehole to the sensor on the surface and best characterizes the rock environment in the quarry. According to the theory, two seismic waves could achieve maximum vibration interference if the delay time was half the time of the seismic wave period caused by the explosion. The optimal delay is $\Delta t = T/2 = 1/2f$, where f is the wave frequency. Then in the case of CO 274 the optimal delay time is 1/32 = 31 milliseconds and in the case of CO 277 the optimal delay time is 1/2f = 1/27 = 37 milliseconds. Since 9, 17, 25, 33, 42 and 67 millisecond timings are used for non-electric ignition, we chose a delay of 42 milliseconds. In order to optimize the maximum charge that can be used in blasting work to ensure seismic safety, it is absolutely necessary to precisely determine the law of attenuation of seismic waves for the monitored area.

The number of data required for the mathematical - statistical determination of the law of attenuation of seismic waves is relatively high. Therefore, it was necessary to evaluate the measurements of several blasts in order to obtain the necessary statistical file needed to determine the law of attenuation of seismic waves (Fig. 11).



The red line indicates the maximum safe per missible peak particle velocity for the church. The points show the measured values of peak particle velocity at individual measuring standpoints in the quarry Malá Vieska and the assessed church building (points marked on the axis Reduce distances in the graph are assigned according to the formula $L_R = L / \sqrt{Q}$*).*

Fig. 11** **Graphical dependence of the maximum components of the peak particle velocity on the reduced distance in aperture bench blasts 274 - 277 in the quarry Malá Vieska - The law of attenuation of seismic waves

Mining at the Malá Vieska site is carried out by using blasting. The measured values of the oscillation speed generated by the aperture blasting did not exceed the lowest values specified by the valid Slovak Technical Standard STN EN 1998-1 / NA / Z1, namely: v_d = 3 mm.s^{-1}. These measured values are safe from the point of view of seismic safety for buildings and inhabitants. On the basis of measured and calculated values during operational blasting in Malá Vieska quarry, the law of seismic wave attenuation was determined, on the basis of which it is possible to use the maximum permissible charge per time step depending on the distance for repeated aperture blasts in the Malá Vieska quarry (see Tab. 2).

Tab. 2 Use of the maximum permissible charge for one timing step depending on the distance for repeated aperture blasting in the quarry Malá Vieska.

Distance	**Calculation**	**Maximum charge weight per delay [kg]**
150 m	$Q_{vmax} = L^2/L_R^2 = 150^2 / 20^2 =$	56 kg
200 m	$Q_{vmax} = L^2/L_R^2 = 200^2 / 20^2 =$	100 kg
250 m	$Q_{vmax} = L^2/L_R^2 = 250^2 / 20^2 =$	156 kg
Based on the increase of blasting safety, we chose the value L_R = 20 to the law of seismic wave attenuation (see Fig. 11).		

The results of measuring the seismic effects of bench blasts CO 274, CO 275, CO 276 and CO 277, which were performed in the quarry Malá Vieska showed an increased attenuation of seismic waves induced by technical seismicity in the quarry Malá Vieska using a millisecond delay of 42 milliseconds. The delay value was determined based on frequency analysis.

Low frequencies, measured on the assessed church building, are more risk for buildings from the point of view of seismic safety. Therefore, the lowest value of the allowed vibration speed was determined according to the valid STN EN 1998-1 / NA / Z1 v_d<3 mm.s^{-1} for frequencies less than 10 Hz and for foundation soil type "b"(STN Eurokod 8, 2010).

Acknowledgment

This work is supported by the Scientific Grant Agency of the Ministry of Education, Science, Research, and Sport of the Slovak Republic and the Slovak Academy Sciences as part of the research project VEGA 1/0585/20 “Application of millisecond timing to decrease the negative effects of seismic waves generated by blasts” and VEGA 1/0588/21 “The research and development of new methods based on the principles of modelling, logistics and simulation in managing the interaction of mining and backfilling processes with regard to economic efficiency and the safety of raw materials extraction“, and is supported by the project of the Cultural and Educational Grant Agency of the Ministry of Education, Science, Research and Sport of the Slovak Republic and the Slovak Academy of Sciences project KEGA 006TUKE-4/2019, and is supported by the project of the EIT RM (European Institute of Innovation and Technology RawMaterials) project MineTALC – Backfill Mining Optimisation for Low- and Medium- Strength Deposits.

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