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# PREPARATION OF MINING IN DARGOV QUARRY FROM THE VIEW POINT OF SEISMIC EFFECTS OF BLASTING WORKS ON THE ROAD AND SUPPORTING WALL

# PRÍPRAVA ŤAŽBY V LOME DARGOV Z POHĽADU SEIZMICKÝCH ÚČINKOV TRHACÍCH PRÁC NA CESTU A OPORNÚ STENU

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## Abstract

Vibrations induced by blasting operations belong to fundamental problems in quarries because intense vibrations can cause critical damage in quarries vicinity. Blasting operations generate seismic waves with different particle velocities and a wide spectrum of frequencies. This process depends on rock properties, charge sizes and blasting technology. It is very important to study how to control vibrations induced by blasting operations while mitigating the negative effects of blasting operations in quarries. The aim of this work was to find the most suitable way to ensure the safety of a specific building located close to the mining area and to define the most efficient blasting technology. The paper presents a methodological procedure based on the latest knowledge on the reduction of vibration intensity in blasting operations in quarries. The results of the experiments were confirmed in practice blasting operations in various quarries in the Slovak Republic.

## Abstrakt

Vibrácie vyvolané trhacími prácami sú jedným zo základných problémov v lomoch a intenzívne vibrácie môžu spôsobiť kritické poškodenie prostredia v blízkosti lomov. Trhacie práce generujú seizmické vlny s rôznymi rýchlosťami častíc a širokým spektrom frekvencií. Tento proces závisí od vlastností hornín, veľkostí nálože a technológie trhacích prác. Je veľmi dôležité študovať, ako regulovať vibrácie vyvolané trhacími prácami pri zmierňovaní negatívnych účinkov trhacích prác v lomoch. Cieľom tejto práce bolo nájsť najvhodnejší spôsob, ako zabezpečiť neporušenie daného objektu v blízkosti dobývacieho priestoru a definovať najefektívnejšiu technológiu trhacích prác. V článku je uvedený metodologický postup založený na najnovších poznatkoch o znižovaní intenzity vibrácií pri trhacích prácach v lomoch. Výsledky experimentov boli potvrdené v praxi pri prevádzke trhacích prác v rôznych lomoch v Slovenskej republike.

**Keywords**

*Blasting operations in quarries, seismic safety, velocity and frequency of seismic waves, millisecond timing delay, attenuation law of seismic waves*

**Klíčová slova**

*Trhacie práce v lomoch, seizmická bezpečnosť, rýchlosť šírenia a frekvencia seizmických vĺn, milisekundové časovanie, zákon útlmu seizmických vĺn*

# 1 Introduction

Because of their explosive energy blasting works are very often applied within various technologies in construction industry. This is especially for stone and gravel quarrying, excavation of adits and tunnels, crushing of stones, making cuttings and embankments for roads, railways, canals, making irrigation channels, excavation of river and lake bottoms, consolidation of foundation soils, ploughing of compacted and frozen soils, construction of dams, ports, ponds, lake etc. In addition, different kind of protected buildings are designed like protective buildings in mines, which has to resist the shock wave generated during blasting works, or protective walls and cylinders of ammunitions and plants, which has to withstand the explosion in emergency state and other protective structures used in industry. The theory of calculations of structures loaded by explosive pressure waves has wide application in design of protective structures for civil defence and in military. Protective structures are considered as elastic and elastoplastic systems. It is necessary to respect the sensitivity of the materials to the deformation rate. The resistivity to the effect of explosive pressure waves has to be evaluated for every construction in vicinity of the projected or expected blast. Explosions as well as the constructions can be in the air, water and rocks. The most common case is the assessment of constructions to resist the effect of seismic waves generated through blasting works in open pits or during ground works etc. (Henrych, 1973; Mosinec, 1976). The research in Dargov open pit is focused to optimizing the seismic effects of blasting works in order to ensure their effectiveness and environmental safety. The Dargov open pit was chosen for realization due to its preparations to mining operations opening. The test measurements were performed at three standpoints within the open pit itself.

Different studies have been worked out on vibration regulation and moreover the following well-known practical methods were applied (Kaláb, 2018, Kaláb et al., 2015; Kaláb, 2004; Holub, 2006; Müncner, 2000; Persson et.al., 1994; Langefors and Kihlström; 1978), whose recommendations are as follows:

- Application of time delay between the boreholes;
- Reduction of borehole numbers in the same time delay;
- Application of multi-row blastings and appropriate time delay between rows;

- Application of charge distribution and appropriate timing between charges;
- Division of quarry wall into more benches and as a consequence it leads to charge capacity reduction for one borehole.

The reduction or the regulation of the vibration impact means a problem for most of quarries. Bench blastings are generally known as an effective way of vibration reduction. Applying this method, the particular charges in the boreholes are blasted one after another with a certain time delay. There is a mutual interference in the seismic waves activated during the blasting operations and the Peak Particle Velocity (PPV) can be reduced by means of appropriate timing.

In this paper there are presented the single-row blastings in boreholes in which the boreholes were initiated one after another from the boundary with predefined timing delay. We assume that the possibility of reproduction of single-row blasting is quite effective, in other words, the seismic waves propagation from each point of blasting proves the same procedure. At the same time each blasted borehole contains the different charge. The borehole length, the borehole distribution and the borehole size were the same as this principle is commonly applied in blasting operations and moreover it corresponds with current draft method of blasting operations. (Kou and Rustan, 1992).

# 2 Experimental measurements in the quarry Dargov

## 2.1 Geology of the quarry Dargov

The quarry Dargov can be found 3 km west from village Dargov close to road connecting two towns – Košice and Michalovce. It contains hypersthenic andesites originated as volcanic lava flows and volcanoclastics (Fig. 1, 2, Kaličiak et al., 1991).


***Legend: 1 – hypersthenic andesite, 2 - augite – hypersthenic dacite, 3 - pyroxene andesite, 4 – sandy and claye gravels 5 - pyroxene – amphibole dacite with biotite, 6 - conglomerates of pyroxene andesites, 7 - breccias and sandstones, 8 – pyroclastics of pyroxene andesites, 9 – sandy and loamy gravels, 10 - augite-hyperstenic dacite ± amphibole, 11 – loamy gravels, 12 – sandy gravels – deluvium mostly loamy stones***

***Fig. 1 Geology of the Dargov quarry and its surroundings (Kaličiak et al., 1991)***

## 2.2 Methodology of the measurement and devices used during the blasting operations

The following digital seismic devices were used to measure and graphically record the seismic effects of blasting (Pandula and Kondela, 2017):

VMS 2000 MP seismograph from American company Thomas Instruments with seismic sensors from American company Geospace (Fig. 4),

ABEM Vibraloc seismograph and seismic sensors from Swedish company ABEM (Fig. 3, 5 a 6).

The measuring devices were prior to measurement calibrated and their sensitivity was checked. At the standpoints, the graphical record of individual elements of seismic waves was registered during experimental blasts.


***Fig. 2 The location of boreholes 1 and 2 in relation to the standpoints 1, 2 and 3, where the first and second blasts were realized***

Individual records are four second long. The location of seismic devices was chosen in order to evaluate the impact of generated technical seismicity on the selected object. Localization of individual standpoints were by Leica Zeno 20 device (Fig. 7). In this measurement we placed the VMS 2000 MP device within the Dargov quarry very close to boreholes 1 and 2, what allowed to obtain particle velocities (Fig. 2) for the very precise determination of the law of attenuation of seismic waves from blasts to the assessed object. The measured values at individual standpoints can be seen in Table 2.

***Fig. 3 The second standpoint in Dargov quarry. Vibrograf ABEM Vibraloc is located in 42 m distance from boreholes 1 a 2 at first and second blasts***


***Fig. 4 The first standpoint in Dargov quarry at third and fourth blasts. Vibrograf VMS 2000 is located 5.2 m from boreholes 1 a 2***

***Fig. 5 The second standpoint in Dargov quarry. Vibrograf ABEM Vibraloc is located in 90 m distance from boreholes 1 a 2 at third and fourth blasts***

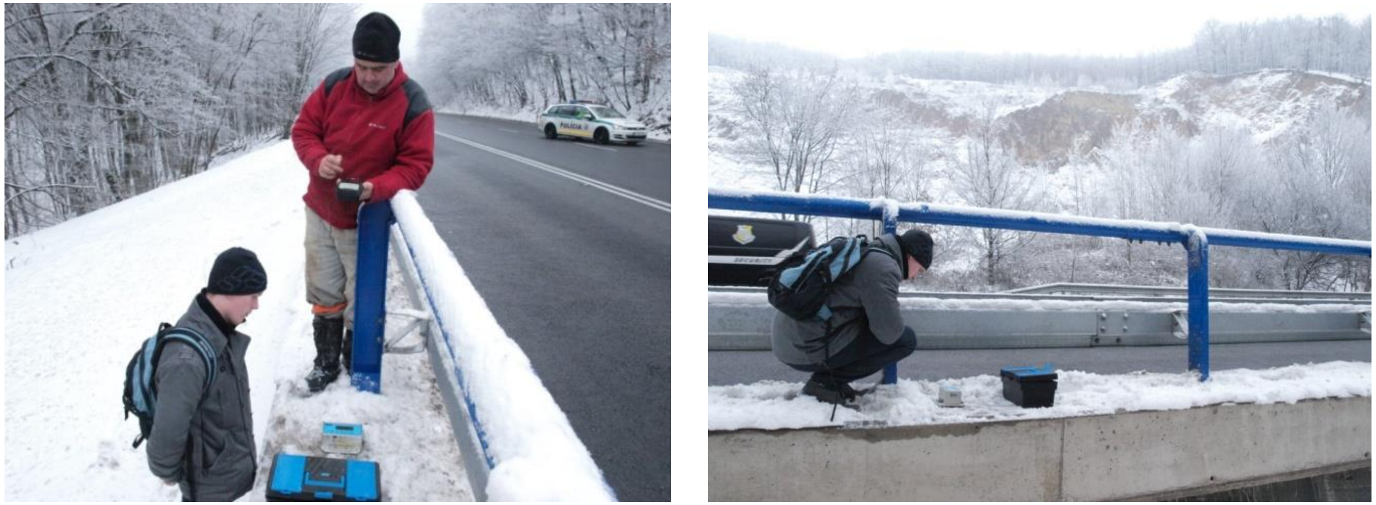

***Fig. 6 The third standpoint position on the supporting wall of road passing next to Dargov quarry. Vibrograf ABEM Vibraloc was located 126 m at third and fourth blast in the quarry Dargov***

***Fig. 7 Localization of individual standpoints by Leica Zeno 20 device***

Table 1 shows the distances between experimental blasts and measuring standpoints within the quarry Dargov. Data from four test blasts were recorded.

***Table 1 Distance of test blasts for the measuring standpoints in Dargov quarry***

| | Standpoint | Distance from the blast to the standpoints 1,2,3 [m] | |
|---|---|---|---|
| | | **oblique** | **horizontal** |
| **first blast** | 1 - Dargov quarry | 7.4 | 2.3 |
| | 2 - Dargov quarry | 40.6 | 40.0 |
| | 3 - supporting wall | 76.3 | 76.0 |
| **second blast** | 1 - Dargov quarry | 11.3 | 8.9 |
| | 2 - Dargov quarry | 42.6 | 42.0 |
| | 3 - supporting wall | 78.3 | 78.0 |
| **third blast** | 1 - Dargov quarry | 10.0 | 5.2 |
| | 2 - Dargov quarry | 89.5 | 90.0 |
| | 3 - supporting wall | 125.7 | 126.0 |
| **fourth blast** | 1 - Dargov quarry | 11.3 | 5.2 |
| | 2 - Dargov quarry | 89.0 | 90.0 |
| | 3 - supporting wall | 125.7 | 126.0 |

## 2.3 Source of vibrations

The sources of vibrations were test blasts within the quarry Dargov. For all blasts explosive EURODIN 2000 and non-electric ignition with millisecond delay 17 millisecond was used. The blasts differ in their weight: the weight of the first blast was 6.2 kg of explosive, the second blast used 10 kg, the third blast used also 10 kg of explosive and for the fourth blast 15 kg of explosive was projected.

## 2.4 Measured seismic effects of blastings and their analysis

Vibrographs recorded seismic waves registered by individual elements x (longitudinal), y (transversal) and z (vertical). The values measured during blastings at the standpoints are shown in the Table 2.

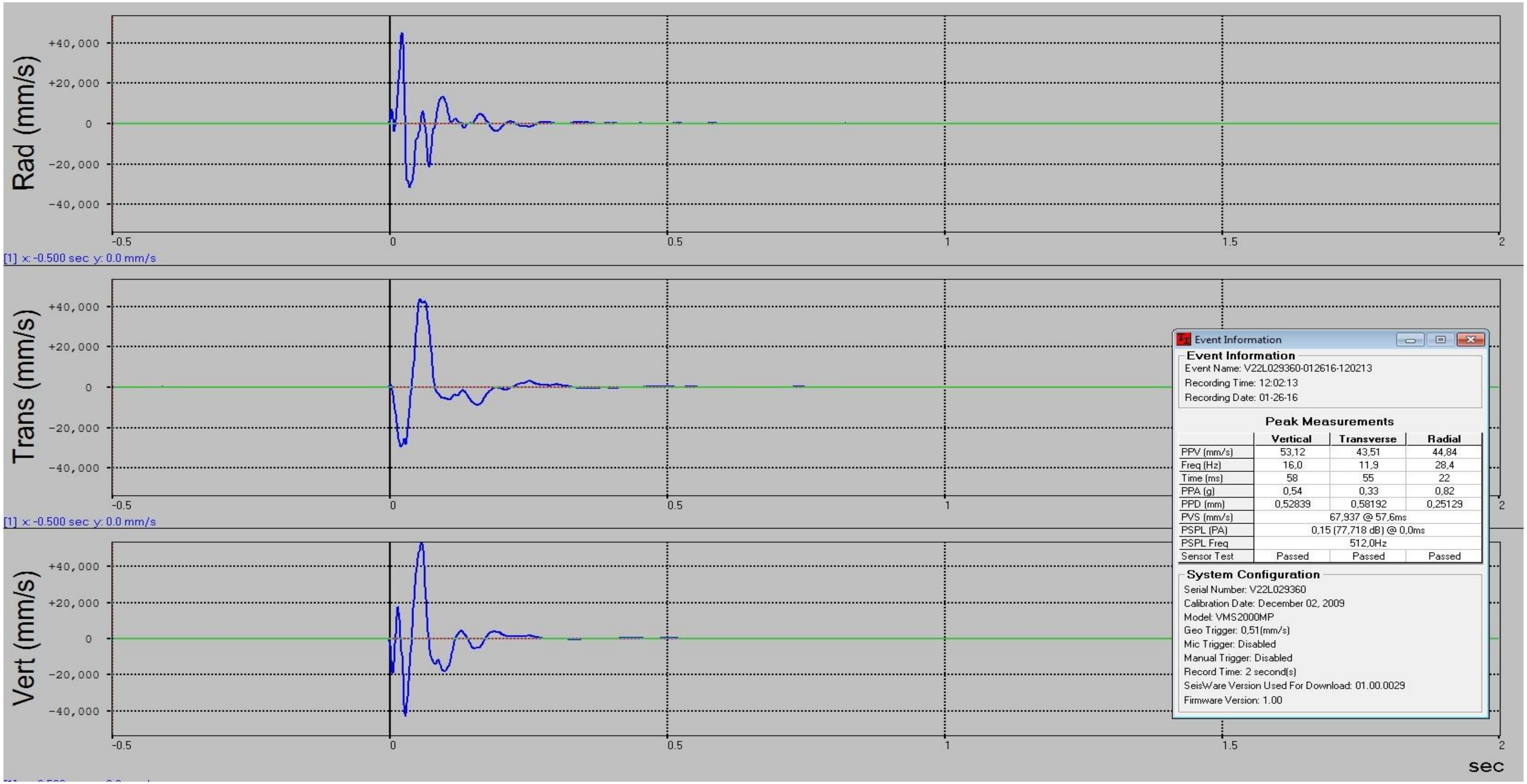


***Fig. 8 The record of particle velocities of wave elements in longitudinal, transverse and vertical direction measured at the stand-point 1 - after the third blast***

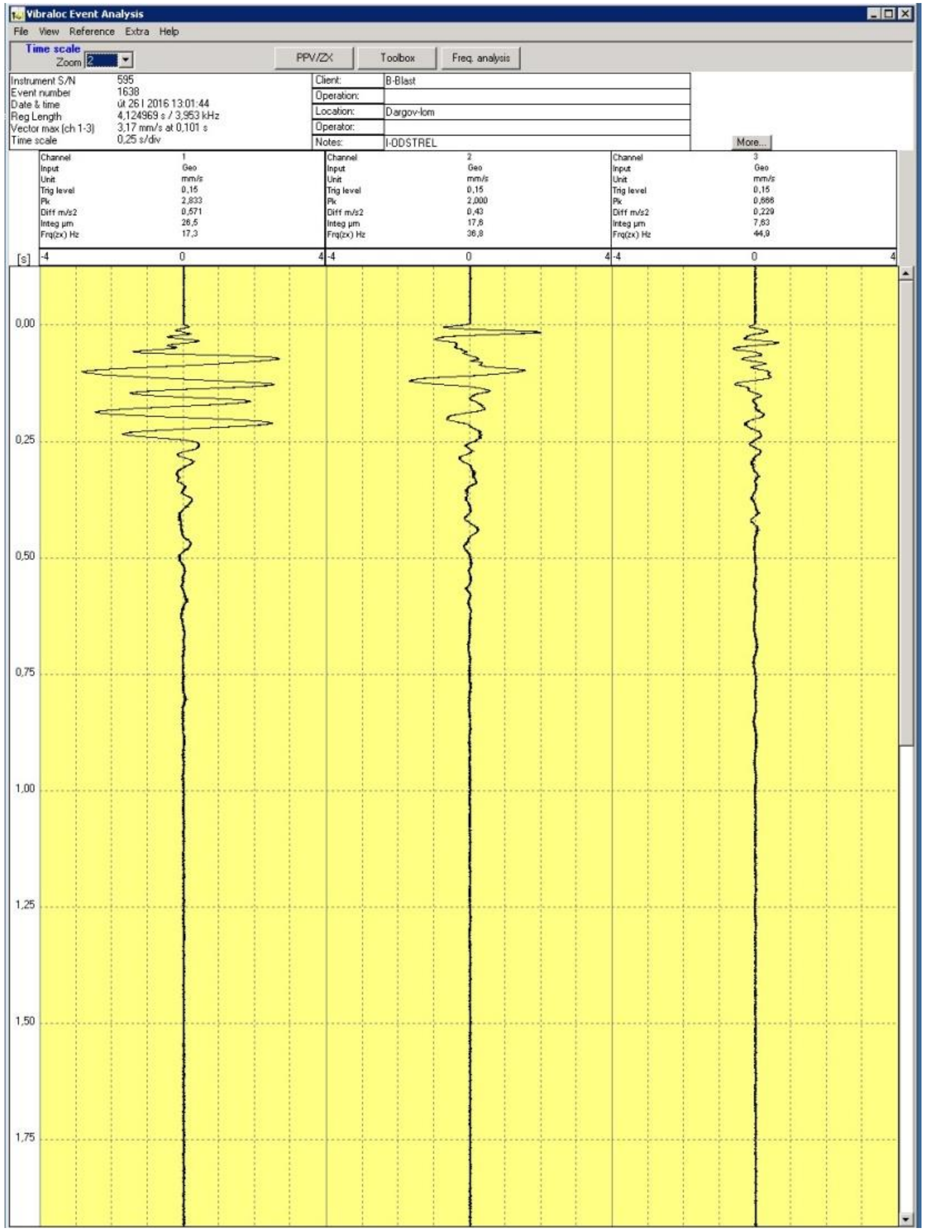


***Fig. 9 The record of particle velocities measured at the standpoint 2 - after the third blast. Channel 1 represents the z element, channel 2 represents the x element and y element is seen on the channel 3***

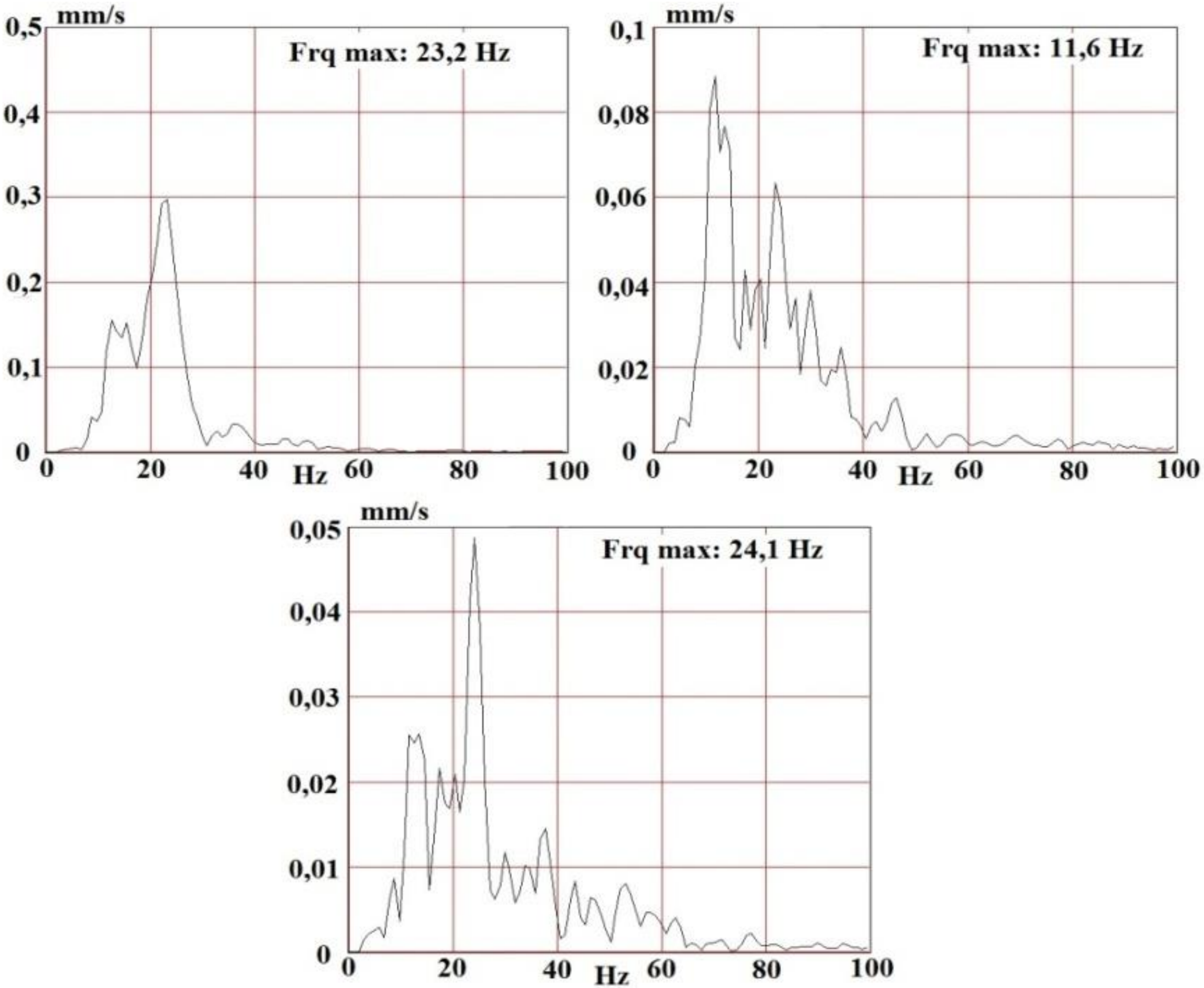


***Fig. 10 FFT analysis of the vibration record of wave in longitudinal, transverse and vertical direction measured at the standpoint 2 - after the third blast***

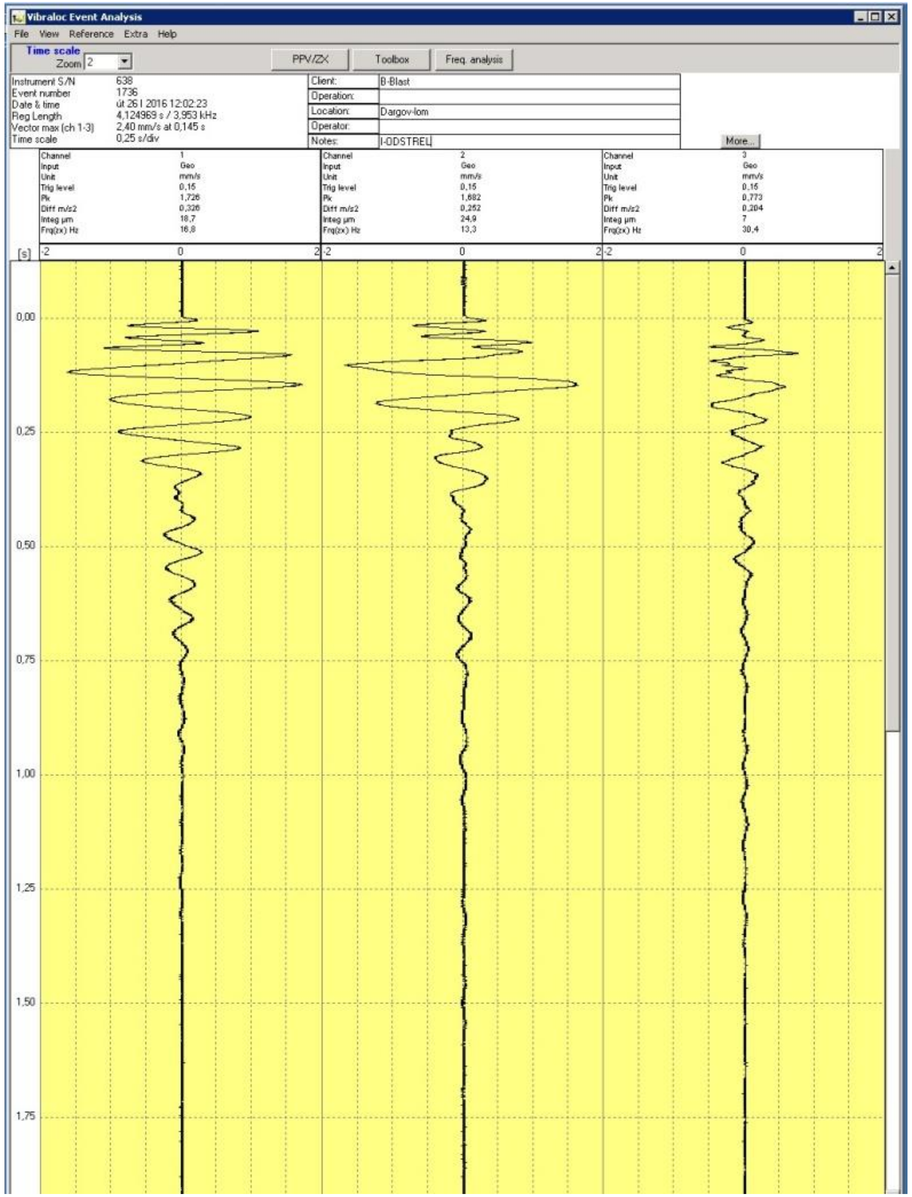


***Fig. 11 The record of particle velocities measured at the standpoint 3 - after the third blast. Channel 1 represents the z element, channel 2 represents the x element and y element is seen on the channel 3***

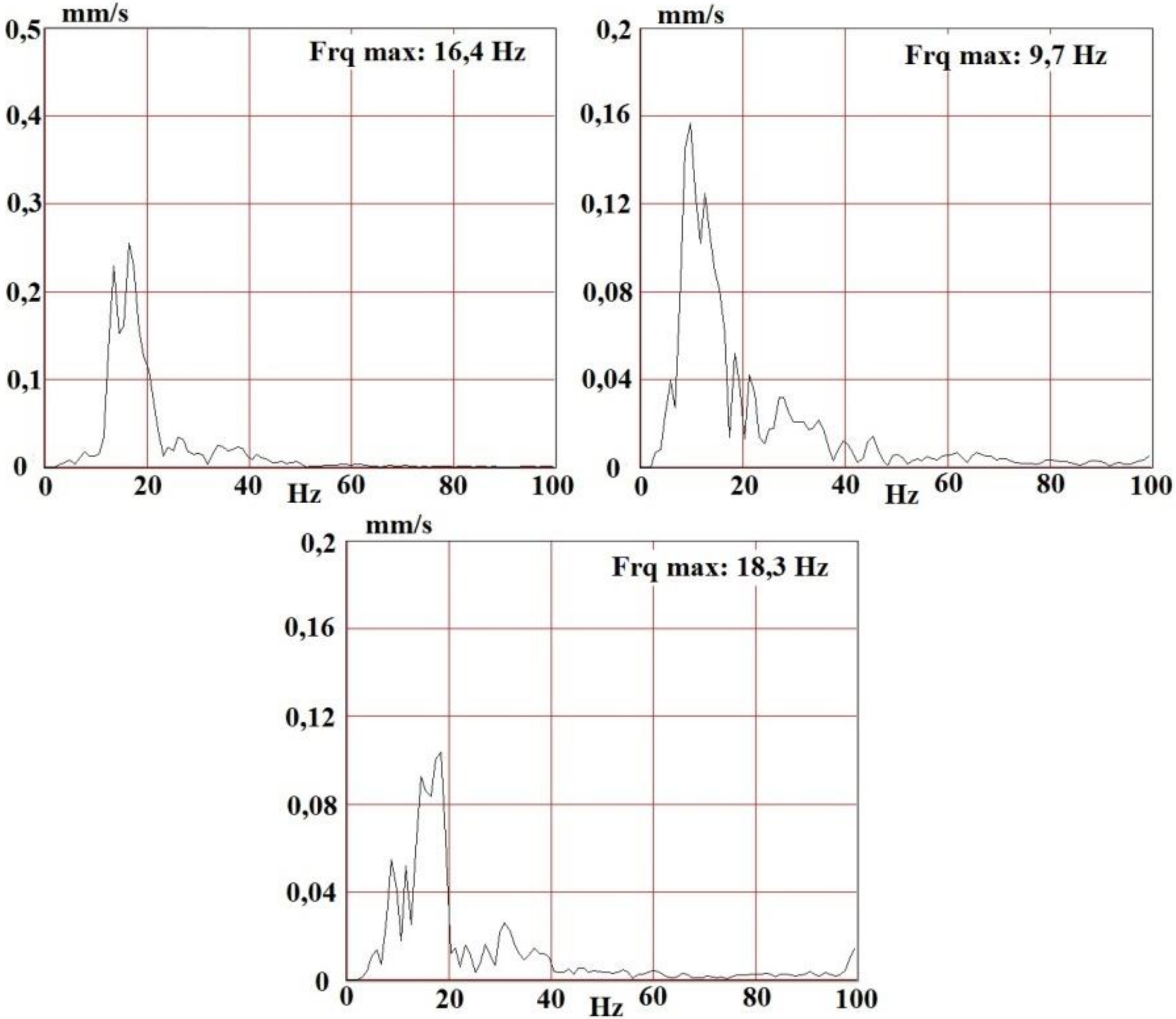


***Fig. 12 FFT analysis of the vibration record of wave in longitudinal, transverse and vertical direction measured at the standpoint 3 - after the third blast***

***Table 2 Maximum values of particle velocities at his frequencies in longitudinal, transverse and vertical direction at standpoints 1, 2 and 3 in Dargov quarry***

| Blast | Standpoint | x [mm.s$^{-1}$] | y [mm.s$^{-1}$] | z [mm.s$^{-1}$] | x [Hz] | y [Hz] | z [Hz] |
|---|---|---|---|---|---|---|---|
| **First blast** | 1 | 114.85 | 101.05 | 178.46 | 8.1 | 17.7 | 85.3 |
| | 2 | 17.507 | 21.276 | 17.490 | 33.6 | 29.3 | 53.9 |
| | 3 | 5.174 | 4.018 | 2.998 | 19.6 | 48.6 | 15.3 |
| **Second blast** | 1 | 74.38 | 46.93 | 142.25 | 36.6 | 20.5 | 22.3 |
| | 2 | 25.33 | 17.802 | 16.507 | 31.8 | 32.9 | 19.3 |
| | 3 | 7.901 | 6.928 | 4.545 | 19.9 | 41.5 | 42.8 |
| **Third blast** | 1 | 44.84 | 43.51 | 53.12 | 28.4 | 11.9 | 16.0 |
| | 2 | 2.0 | 0.66 | 2.83 | 36. | 44.9 | 17.3 |
| | 3 | 1.68 | 0.77 | 1.73 | 13.3 | 30.4 | 18.6 |
| **Fourth blast** | 1 | 45.2 | 48.81 | 83.6 | 14.6 | 11.1 | 30.1 |
| | 2 | 3.1 | 1.53 | 4.3 | 32.1 | 30.6 | 18.6 |
| | 3 | 2.65 | 1.11 | 2.61 | 13.6 | 13.7 | 17.4 |

Values of vibration velocities and his frequencies of individual elements during the experimental blasts in Dargov quarry (Table 2) were the basis for assessment of the seismic effects of blasting works according STN EN 1998-1/NA/Z1 Eurocode 8 on the road communication next to the Dargov quarry.

## 2.5 Permitted vibration velocity for infrastructure and selected protected objects in Dargov quarry vicinity

Permitted vibration velocity for the infrastructure is determined according to STN EN 1998-1/NA/Z1 Eurocode 8 Seismic loading of buildings.

With respect to the presumed character of blasts at the andesite deposit of Dargov quarry, it is possible to determine the maximal permitted particle velocity as:

$v_d \leq 20$ mm.s$^{-1}$.

According STN EN 1998-1/NA/Z1 Eurocode 8:

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

where v – maximum particle velocity generated by blast [mm.s$^{-1}$], K – factor dependent from the features of the transmission environment and blastings conditions [-],

$Q_{ev}$ – maximum charge weight for one time stage, [kg],

L – shortest distance of blasts from the assessed objects [m].

From the measured data it is possible to calculate the value of K for the assessed surroundings of Dargov quarry:

$K_{11} = v_{max}.\ L / \sqrt{Q_{ev}} = 178{,}46\ .\ 7{,}4 / \sqrt{6{,}2} = 530{,}4$

$K_{12} = v_{max}.\ L / \sqrt{Q_{ev}} = 142{,}25\ .\ 11{,}3 / \sqrt{10} = 508{,}3$

$K_{21} = v_{max}.\ L / \sqrt{Q_{ev}} = 21{,}276\ .\ 40{,}6 / \sqrt{6{,}2} = 346{,}9$

$K_{22} = v_{max}.\ L / \sqrt{Q_{ev}} = 25{,}33\ .\ 42{,}6 / \sqrt{10} = 341{,}2$

$K_{31} = v_{max}.\ L / \sqrt{Q_{ev}} = 5{,}174\ .\ 76{,}3 / \sqrt{6{,}2} = 158{,}5$

$K_{32} = v_{max}.\ L / \sqrt{Q_{ev}} = 7{,}901\ .\ 78{,}3 / \sqrt{10} = 195{,}6$

$K_{13} = v_{max}.\ L / \sqrt{Q_{ev}} = 53{,}12\ .\ 10{,}4 / \sqrt{10} = 174{,}7$

$K_{14} = v_{max}.\ L / \sqrt{Q_{ev}} = 83{,}16\ .\ 11{,}3 / \sqrt{15} = 242{,}6$

$K_{23} = v_{max}.\ L / \sqrt{Q_{ev}} = 2{,}83\ .\ 89{,}5 / \sqrt{10} = 80{,}1$

$K_{24} = v_{max}.\ L / \sqrt{Q_{ev}} = 4{,}3\ .\ 89{,}5 / \sqrt{15} = 99{,}4$

$K_{33} = v_{max}.\ L / \sqrt{Q_{ev}} = 1{,}73\ .\ 125{,}7 / \sqrt{10} = 68{,}8$

$K_{34} = v_{max}.\ L / \sqrt{Q_{ev}} = 2{,}65\ .\ 125{,}7 / \sqrt{15} = 86{,}0.$

$K_{11}$, $K_{12}$, $K_{21}$, $K_{22}$, $K_{31}$, $K_{32}$, $K_{13,}$ $K_{14,}$ $K_{23}$ $K_{24,}$ $K_{33,}$ $K_{34}$ are values of coefficient for standpoints 1, 2 and 3 for the first, second, third and fourth blast.

Frequency analysis of the vibration components and calculated values of transmission coefficient showed, that transmission of vibrations in geological environment of Dargov quarry is very good and during mining operations there would not occur the necessary attenuation of explosion energy (Fig. 10 and 12) (Viskup et al., 2005).

The maximum vibration energy generated by experimental blasts was in the low frequency range of 10 to 40 Hz (Fig. 10 and 12). Therefore, it is necessary to adjust the millisecond timing of blasting works to a value that would through interaction of charges attenuate the vibrations to allowed values. The vibrations can be reduced by applying the principle of superposition of waves in the phase or in the opposite phase (Leššo, 2018). The key factor leading to the vibration reduction is the appropriate timing delay. Furthermore, the calculation of the timing delay takes into consideration the effect of attenuation by means of the superposition of seismic waves. Two seismic waves can achieve the maximum reduction of vibration when the timing delay is the half-period of waves propagation. In the literature (Tripathy et al., 2016; Dojčár et al., 1996; Kondela and Pandula, 2012) the timing delay is stated according to the experience of many projects. Langefors and Kihlstrom (1978) proposed the interval of millisecond timing delay as follows $\Delta t = T/2$ (T is the period of seismic waves), which enables the mutual interference of the most of vibrations under the condition of the constant vibration cycle and the same vibration types. Due to the calculations made by Leššo, at the frequency 40 Hz of the seismic waves it can be achieved by applying the millisecond timing value12.5 ms (Leššo, I., 2018).

The measured maximum values for seismic effects generated by test blasts at Dargov quarry are shown in Table 2. These data were used to determine the law of seismic wave attenuation not only in Dargov quarry, but also in its surroundings (Banerjee and Kumar, 2016; Kaláb et al., 2013; Pandula and Kondela, 2010; Barton, 2007).

***Table 3 Measured maximum values of components of particle velocity for test blasts in Dargov quarry***

| **L [m]** | **Q [kg]** | **$L_R = L/Q^{0,5}$ [$m/kg^{0,5}$]** | **$v_x$ [$mm.s^{-1}$]** | **$v_y$ [$mm.s^{-1}$]** | **$v_z$ [$mm.s^{-1}$]** |
|---|---|---|---|---|---|
| 7.4 | 6.2 | 2.97 | 114.85 | 101.05 | 178.46 |
| 40.6 | 6.2 | 16.3 | 17.507 | 21.276 | 17.49 |
| 76.3 | 6.2 | 30.6 | 5.174 | 4.018 | 2.99 |
| 11.3 | 10 | 3.57 | 74.38 | 46.93 | 142.25 |
| 42.6 | 10 | 13.47 | 25.33 | 17.802 | 16.51 |
| 78.3 | 10 | 24.76 | 7.901 | 6.928 | 4,54 |
| 10.4 | 15 | 2.68 | 44.84 | 43.51 | 53.12 |
| 89.5 | 15 | 23.1 | 2.0 | 0.66 | 2.83 |
| 125.7 | 15 | 32.45 | 1.68 | 0.77 | 1.73 |
| 11.3 | 10 | 3.57 | 45.72 | 48.81 | 83.6 |
| 89.5 | 10 | 28.3 | 3.1 | 1.53 | 4.3 |
| 125.7 | 10 | 39.75 | 2.65 | 1.11 | 2.61 |

Based on measured data a trend of maximum components of the vibration velocity at reduced distance during blasts were derived. The plot (Fig. 13) represent so called attenuation law of seismic waves for the Dargov quarry.

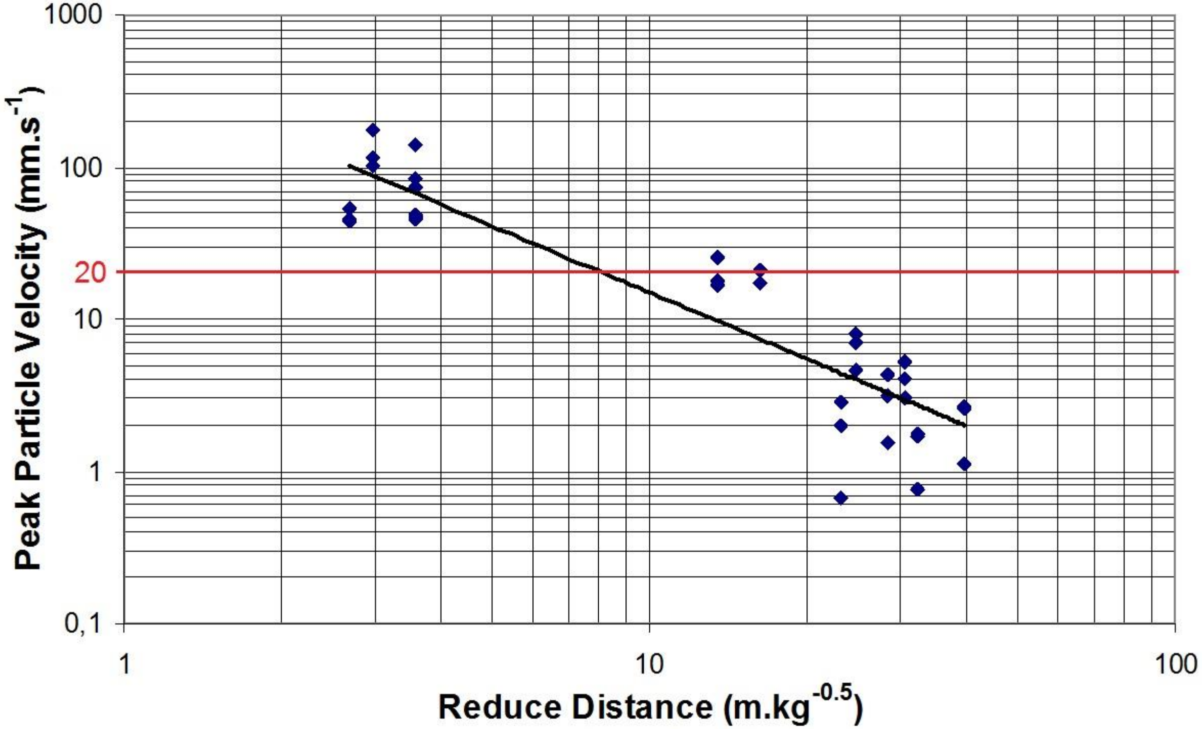


***Fig. 13 Derived trend of maximum components of particle velocity at reduced distance during test blasts in Dargov quarry – attenuation law of seismic waves. Blue dots show the maximum particle velocity measured during experimental blasts at standpoints 1, 2 and 3***

Reduced distance determined from the trend of attenuation law of seismic waves in Dargov quarry is $L_R$ = 20. By reducing the distance, it is possible to determine the charge weight at known distance of receptor so that the maximum values of individual components of vibration velocity do not exceed the allowed maximum values:

For distance 100 m $Q_{vmax} = (L/L_R)^2 = (100/20)^2$ = 25 kg,

For distance 200 m $Q_{vmax} = (L/L_R)^2 = (200/20)^2$ = 100 kg,

For distance 300 m $Q_{vmax} = (L/L_R)^2 = (300/20)^2$ = 225 kg,

For distance 400 m $Q_{vmax} = (L/L_R)^2 = (400/20)^2$ = 400 kg,

For distance 500 m $Q_{vmax} = (L/L_R)^2 = (500/20)^2$ = 625 kg.

## 3 Discussion

The aim of the experimental blasts was to evaluate the influence of the seismic effects resulting from blasting works on the supporting concrete wall and on the road. The blasting works in Dargov quarry will be carried out by bench blasts. For this blasting technology the maximum charge weight at one time stage should not exceed the maximum allowed charge weight determined on the base of the law of seismic wave attenuation in Dargov quarry. Then neither the damage of the supporting wall, nor the road will occur. This corresponds also with the expected intensity of seismic effects of blasting works. The particle velocity cannot, in accordance with the Slovak Technical Norm STN EN 1998-1/NA/Z1, exceed the maximum allowed particle velocity of 20 $mm.s^{-1}$.

The individual results of seismic effects measurements from experimental blastings in Dargov quarry proved, that the present transmission environment is suitable for the transmission of seismic waves. Peak particle velocity depend among others also from the maximum charge weight fired at one time stage. While the Dargov quarry is close to road, the allowed values of maximum charges according the test blasts are very low. For the first test blast, the charge weight on the one time stage was 6.2 kg, it means very low and therefore it could not disrupt the rock mass for further mining.

From the above we can conclude that the measured values during this blast would not allow the mine operation. On the base of the law of seismic waves attenuation in Dargov quarry, it was recommended to set a maximum 25 kg of charge at a distance 100 m from the blast. Dargov quarry is located close to road and therefore the maximum allowed charge weight on one time stage has to be respected. In this case the millisecond timing of the blasts is very important. The velocity of seismic waves propagation in andesite measured on the rock samples was 4883 $m.s^{-1}$ thus suggesting the good quality of the rock from the blasting works point of view. To decrease the seismic effects of blasting works in Dargov quarry we recommend using millisecond timing delay of 10 to 20 milliseconds (Mosinec, 1976; Pandula and Kondela, 2010). The solution for practical use in mining at the Dargov Quarry is a millisecond delay of 9 and 17 milliseconds.

Nowadays blasting works have a wide use. Many sectors and spheres have emerged in human life where the use of blasting is an essential part. However, in this activity it is necessary to think not only of the positive side but also of the negative phenomena related to it. To avoid these undesirable phenomena, it is necessary to eliminate them. The aim was to find a suitable methodology for reducing the environmental impact of seismic effects of blasting operations carried out in quarry operations. The methodology used on the basis of test blasts in quarry Dargov proved its suitability for optimizing the impact of the seismic effects of blasting operations in quarries on the environment.

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