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OPTIMIZATION OF THE IMPACT OF TECHNICAL SEISMICITY ON THE SURROUNDING, BUILDING AND THE POPULATION

OPTIMALIZÁCIA VPLYVU TECHNICKEJ SEIZMICITY NA OKOLITÚ ZÁSTAVBU, ŽIVOTNÉ PROSTREDIE A POPULÁCIU

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Abstract

Uncoupling of the rock massif by the energy of the explosion is a frequently used technology in mining operations. Environmental protection laws together with mining laws impose an obligation to protect the environment from the effects of mining activity. The application of blasting in quarries has both positive and negative impacts, mainly on the immediate surroundings. Technical seismicity is one of the fundamental problems in the disconnection of a rock massif, and intense vibrations can cause damage to the environment near the quarry. Therefore, it is necessary to constantly deal with the methodology of assessing the seismic effects of blasting works and their optimization in terms of the impact of technical seismicity on the surrounding buildings, the environment and the population.

The methodological procedure presented in the article was carried out with the aim of optimizing blasting operations in the quarry Záhradné in the Slovak Republic. Based on the propagation speed of seismic waves and the frequency of the rock environment in Záhradné quarry, the millisecond timing of operational blasting was determined so that the seismic effects of the blasting work would not cause any damage to residential buildings in the vicinity of the quarry and residents would not consider these vibrations dangerous. Based on the measured peak particle velocities in Záhradné quarry and in the monitored objects in the vicinity of Záhradné quarry, the law of seismic wave attenuation was established. Based on the law of attenuation of seismic waves, the maximum allowable charge weight for one timing stage during repeated bench blasting in Záhradné quarry was determined. The specified permissible charge will not cause damage to the surrounding buildings in the vicinity of Záhradné quarry, and residents of residential buildings will not be exposed to vibrations that they would feel as dangerous due to blasting. The methodological procedure presented in the article enables not only optimization, but also prediction of blasting works with the aim of reducing the adverse effects of blasting works in the vicinity of Záhradné quarry.

Abstrakt

Rozpojovanie horninového masívu energiou výbuchu je v banských prevádzkach často využívanou technológiou. Zákony o ochrane životného prostredia spolu s banskými zákonmi ukladajú povinnosť chrániť okolie pred účinkami banskej činnosti. Aplikácia trhacích prác v lomových prevádzkach má pozitívne, ale aj negatívne dopady hlavne na blízke okolie. Technická seizmicita je jedným zo základných problémov pri rozpojovaní horninového masívu a intenzívne vibrácie môžu spôsobiť poškodenie životného prostredia v blízkosti lomu. Preto je potrebné neustále sa zaoberať metodikou hodnotenia seizmických účinkov trhacích prác a ich optimalizáciou z hľadiska vplyvu technickej seizmicity na okolitú zástavbu, životné prostredie a populáciu.

Metodický postup prezentovaný v článku bol uskutočnený s cieľom optimalizácie trhacích prác v lome Záhradné v Slovenskej republike. Na základe rýchlosti šírenia seizmických vĺn a frekvencie horninového prostredia v lome Záhradné bolo stanovené milisekundové časovanie prevádzkového odstrelu tak, aby seizmické účinky trhacích prác nespôsobili žiadne poškodenia bytových objektov v blízkosti lomu a obyvatelia by tieto vibrácie nepovažovali za nebezpečné. Na základe nameraných rýchlosti kmitania v lome Záhradné a v monitorovaných objektoch v okolí lomu Záhradné bol stanovený zákon útlmu seizmických vĺn. Zo zákona útlmu seizmických vĺn bola stanovená maximálna dovolená nálož na jeden časovací stupeň pri opakovaných clonových odstreloch v lome Záhradné. Stanovená dovolená nálož nespôsobí poškodenie okolitej zástavby v blízkosti lomu Záhradné a obyvatelia bytových objektov nebudú pôsobením trhacích prác vystavení vibráciám, ktoré by pociťovali ako nebezpečné. Metodický postup, ktorý je prezentovaný v článku umožňuje nielen optimalizáciu, ale aj predikciu trhacích prác s cieľom zníženia nepriaznivých účinkov trhacích prác.

Keywords

blasting works in quarries, seismic effects, optimization of millisecond timing delay, law of seismic waves attenuation, impact the internal environment of buildings and population

Kľúčové slová

trhacie práce v lomoch, seizmické účinky, optimalizácia milisekundového časovania, zákon útlmu seizmických vĺn, vplyv na vnútorne prostredie budov a obyvateľov

1. INTRODUCTION

Extraction of minerals is one of the main activities of the world economy involved in creating social goods. However, this activity causes environmental damage. Experts (mining companies) around the world are addressing this issue and are looking for appropriate solutions and methods for environmental safety in extraction industries (Abbaspour et al., 2018; Sánchez-Sierra et al., 2018; Perminova and Lobanova, 2018; Végsöová et al., 2019).

Mining activity is mostly represented by these four main operations: drilling, blasting, loading and hauling. For a proper mine planning and design, all of these operations need to be carefully planned in such a manner that can prevent extra loads such as operating costs, environmental footprints, etc. Drilling and blasting are the two most significant operations in open pit mines that play a crucial role in downstream stages. Nowadays, the application of explosives to break rocks is a very common way of extracting rocks. The blasting technique has to have as minimal impact as possible on civil properties in the surrounding area. This is a crucial requirement how to reduce the damage to the buildings and citizens' health (Afeni, 2009; Coltrinari, 2016; Jacko et al., 2016; Zhang et al., 2020).

Blasting works are still the most effective and, at the same time, economically and time-optimal methods for breaking up the rock massif. The quantification of the harmful effects of blasting and the determination of seismic safety is currently a very topical problem. It is necessary to look for the most economically advantageous solution, which ensures the safety of the objects and ensures the effective technology of blasting works (Kondela and Pandula, 2012; Konček et al., 2020; Pandula and Kondela, 2020).

Blasting technology has seen great development since the invention of dynamite by Alfred Nobel in 1867, and blasting is still the most efficient and economical method for breaking up rock environments. On the other hand, breaking up rock environments also causes many problems caused by noise and vibrations. In particular, vibrations caused by blasting can cause damage to nearby buildings and discomfort for residents. Reducing or controlling the seismic effects of vibration is therefore a major concern for most quarry operations. Bench blasting is known as an effective way to reduce vibrations. In this method, individual boreholes are fired one after the other with a certain time delay. Seismic waves generated during blastings from boreholes cancel each other out and peak particle velocity (PPV) can be reduced using suitable time delays intervals. Despite the theoretical simplicity, it is usually difficult to predict the maximum peak particle velocities with sufficient accuracy due to timing delay error and the inhomogenity of the rock environment (Dojčár and Pandula, 1998; Ma et al., 2016; Soltys et al., 2017; Remli et al., 2019).

In blasting works, it is assumed that the method of calculating the timing delay will be determined according to the structural properties of the rock environment. The effect of interference by superposition of seismic waves is taken into account when calculating the timing delay. According to the theory of Langefors, two seismic waves can achieve maximum vibration interference when the delay time is half the period time of the seismic wave caused by the explosive explosion. Delay times are determined based on the rock environment uncoupling effect and the wave superposition effect (Langefors and Kihlström, 1978; Dojčár et al., 1996; Kondela and Pandula, 2012).

In order to reduce the seismic effects of blasting works, it is therefore necessary to know the structural properties of the rock environment in which the blasting works are carried out. Determining the structural properties of a rock massif is most often carried out using seismic methods. In this way, basic information is obtained about the spatial distribution and the intensity of damage of the rock environment in which the blasting works are carried out. The seismic wave passing through the rock environment from the blasting to the receptors carries information about the structural properties of the rock environment. Dynamic characteristics of seismic waves – speed and frequency – are important for optimizing the seismic effects of blasting. The article describes the method of determining the speed of propagation of seismic waves and the frequency of the rock massif and their use in reducing the seismic effects of blasting in quarries (Aldas, 2010; Wang et al., 2013; Pandula et al., 2018; Kudelas et al., 2019).

Research into the seismic effects of blasting shows that it is necessary to monitor these factors in particular work (Pandula et al., 2012; Kaláb et al., 2013; Leššo, 2018; Zhou et al., 2020; Fehér et al., 2020; Konček et al., 2020; Konček et al., 2021):

- recognition and characterization of natural objects around the quarry,
- permissible peak particle velocities (PPV) for natural objects,
- blasting technology and frequency of blasting in quarry.

The article presents the results of the research that was carried out in the quarry Záhradné and its surroundings. The aim of the research was to determine the law of attenuation of seismic waves from blasting to the receptors, based on the speed of propagation and frequency of seismic waves in the rock environment, to determine the optimal value of millisecond timing and using millisecond timing, to reduce the seismic effects of blasting (vibrations) to a minimum value. On the basis of the law of attenuation, determinid the maximum permissible charge weight for one timing stage during blastings so, that there is no damage to the surrounding buildings in the vicinity of the Záhradné quarry and the residents will not feel the vibrations as dangerous (Fig. 1).

Fig. 1 Location and view of the quarry Záhradné

2. GEOLOGICAL CHARACTERISTICS OF THE ROCK ENVIRONMENTS AROUND THE QUARRY ZÁHRADNÉ

The mining operation of the quarry Záhradné is located on the territory of the Slovak Republic, between the villages of Záhradné and Fintice in the Prešov region, Prešov district (Fig. 1). It is located approximately one kilometer south of the village of Záhradné. The deposit in the quarry Záhradné is located in the northern part of the Prešov Mountains. Genetically, this deposit is assigned to Sarmatian volcanism. The useful raw material is garnet pyroxenic-amphibole andesite, which can also be defined as diorite porphyrite. The deposit contains several types of andesites of different colors with different degrees of cracking and separation . The rock on the deposit is dark gray porphyritic, formed by a fine-grained base material with growths of feldspars, pyroxenes and amphiboles. It is also characterized by the widespread occurrence of grenades. The rock is whole without visible secondary veins. The texture of the rock is omnidirectional (Fig. 2) (Internal materials VSK MINERAL s.r.o. - Záhradné quarry).

From all sides except the NW, the bearing body is in contact with claystones and siltstones of the Central Carpathian Paleogene, which are pierced by andesites with significant contact and dynamic effects. In the lower part of the massif, an andesite flow is formed by propylitized, fine-grained andesite with growths of white plagioclase. Dark growths of amphiboles and, more rarely, pyroxenes are also sometimes visible. Rarely, garnet growths also occur in andesite. The upper part of the massif passes into a spherical blocks separation. Spherical blocks are formed of propylitized andesite (Fig. 3). Inside the andesite body there are several centimeter to decimeter positions of mylonitized zones linked to faults and tectonic discontinuities. The ratio of these overburdens to the mined raw material is negligible. The upper part of the quarry is intensively tectonically disturbed and weathered. As a rule, the overburden of andesites consists of Quaternary clays and clay-stone scree with a thickness of 1.0 - 4.6 meters (Internal materials VSK MINERAL s.r.o. – Záhradné quarry).

The deposit lies high above the local erosion base and is not waterlogged. In andesite or diorite porphyry can be considered with fracture permeability. The building stone deposit is surrounded on almost all sides by Paleogene sedimentary rocks, which we can consider impermeable or only weakly permeable. The thickness of the andesite body in Záhradné quarry is determined on the basis of a geological survey with a maximum lower depth limit at the level of 450 m above sea level. A significant tectonic line runs in the vicinity of the bearing body, but it does not interfere with the verified reserves. Secondary faults and contraction cracks are steeply inclined from 60° to 90°. Tectonic disturbances were also recorded. The basic parameters of the bearing are listed in Tab. 1 (Internal materials VSK MINERAL s.r.o. - Záhradné quarry).

Based on the evaluation of laboratory tests from surveys, it can be concluded that the technological parameters of the raw material of the deposit meet the requirements of harmonized standards and the specified standard governing the use of raw materials for the production of crushed aggregate for construction purposes (Internal materials VSK MINERAL s.r.o. - Záhradné quarry).

Tab. 1 Parameters of the mined mineral

Parameters	
Volumetric weight:	2.45 – 2.75 Mg.m^{-3}
Absorbency:	< 3.0 %
Resistance to fragmentation (Los Angeles factor)	LA20 (< 20 %)
Abrasion resistance (abrasion factor micro-Deval)	MDE25 (< 25 %)
Resistance to freezing and thawing	F1 (< 1 %)

Based on the results of the geological survey, three different quality classes were allocated to the deposit:

- the first class is represented by the raw material of the eastern wing of the transition zone, with the exception of the weathered part,
- the second class forms the largest part of the bearing filling and includes the near-contact, central and western wing of the transition zone,
- and the weathered parts of all zones are included in the third class (Internal materials VSK MINERAL s.r.o. - Záhradné quarry).

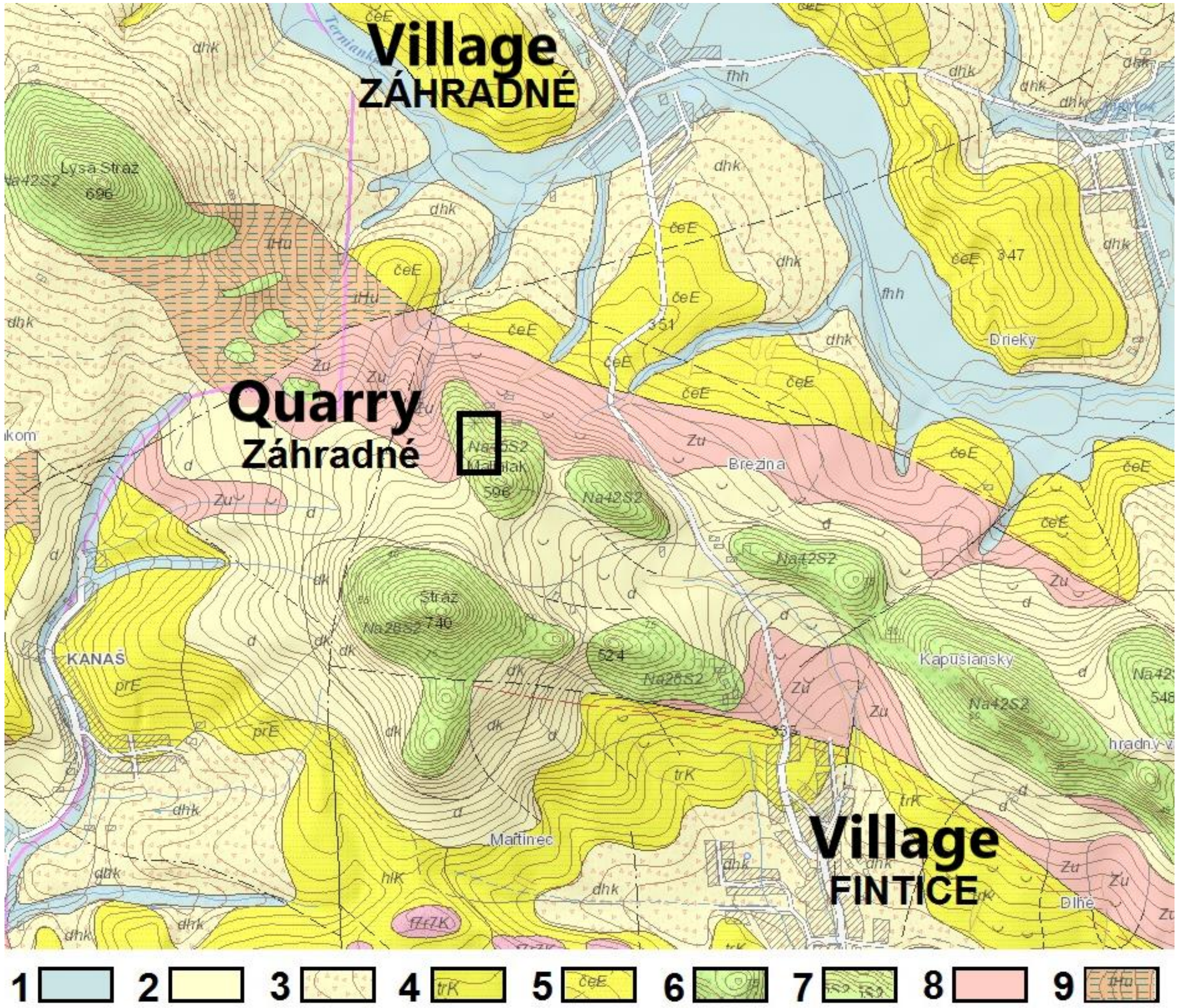


Fig. 2 Geological map of the vicinity of the quarry Záhradné

Description of the legend of Fig. 2:
QUATERNARY: 1 - fluvial sediments: lithofacies undivided floodplain clays, or sandy to gravelly clays of valley floodplains and mountain stream floodplains (Holocene), 2 - deluvial sediments as a whole: lithofacies undifferentiated slopes and rubble (Pleistocene - Holocene), 3 - deluvial sediments: predominantly clay-rocky (inferiorly sandy-rocky) slopes and rubble (Pleistocene-Holocene),
NEOGENE: 4 - Prešov Formation: silts, sandstones, tuffs, conglomerates (Miocene-Carpathian), 5 - Chelov Formation: sandstones, claystones, conglomerates, volcaniclastic rocks, coal seams (Miocene-egenburg), 6 - andesite volcanics of eastern Slovakia, formations: intrusive complex Lysá Stráž - Oblík, extrusive domes of augitic-hypersthenic andesites (Miocene-middle Sarmatian), 7 - andesite volcanics of eastern Slovakia, formations: intrusive complex Lysá Stráž - Oblík, extrusive domes of pyroxenic-amphibolic andesites with garnet,
PALEOGENE (subtatra group): 8 - Zubereck formation - normal flysch: claystones, siltstones and sandstones (Eocene-Oligocene), 9 - Hutian formation-claystones in absolute dominance over sandstones and conglomerates (Eocene-Oligocene) (Internal materials VSK MINERAL s.r.o. - Záhradné quarry; Mello et al., 1996).

Fig. 3 View of the upper weathered part of the quarry Záhradné with spherical blocks of propylitized andesite

3. METHODOLOGY OF MEASUREMENT AND VIBROGRAPHS USED FOR MEASURING TECHNICAL SEISMICITY

The basic threats during the performance of blasting work are the scattering of material, the action of an air pressure wave and the seismic effects of blasting work. Objects, machinery and electrical equipment will be protected from the effects of blasting by observing blasting parameters (blast, distance, weight of charges, timing of charges, etc.) and by rigorously determining and clearing the safety circle. Objects and equipment located in the safety perimeter, which cannot be moved (e.g. substation, operating building, etc.), and which may be endangered by the effects of blasting, will be covered, boarded up or secured, if necessary, such a way that the possible flying of material did not harm them. Protection against the seismic effects of blasting will be ensured by observing the maximum weight of the charge that can be fired in one timing stage and appropriate timing delay blasts individual boreholes (Pandula and Jelšovská, 2008; Kudelas et al., 2019; Konček et al., 2021).

In order to assess the impact of seismic effects, it is very important to establish a safe limit, at which the structure does not break or the rock is released. In both cases, the creation of new cracks or the opening of existing cracks, or the falling off of mortar or plaster in the case of construction objects or the falling off of small fragments in the case of rocks is considered a violation. Catastrophic breach, i.e. j. the collapse of the building or the sliding of the rock must be prevented under all circumstances. In some justified cases, however, it is possible to allow the occurrence of minor damages, as long as they do not threaten the safety of the building. For this, it is necessary to know the appropriate scale for assessing seismic effects, which can be measured on the given object and possibly extrapolated. Furthermore, it is necessary to distinguish more precisely the degree of violation and to predict a preliminary estimate of the effects on the environment (Dvořak and Osner, 1972; Pandula and Kondela, 2012).

The starting point for the forecast of the object's load is, in common practice, knowledge from constructions that were realized using a similar source of vibrations and in the same or similar geological environment. The second condition is necessary to be able to assess the influence of the environment on the magnitude of seismic effects at the monitored location. In this case, the most significant monitored physical parameter is the attenuation of seismic waves in the environment in which seismic waves propagate. For the most accurate determination of the amount of attenuation, it is best to place one measuring device near the source of vibrations and the other on the monitored object. As a general rule, we expect the magnitude of the seismic load to decrease with distance. In specific conditions, e.g. with the superposition of several types of waves, however, we can also encounter an increase in the maximum amplitude of the oscillation or a significant increase in the duration of the vibrations (Kaláb et al., 1997; Pandula et al., 2021).

When measuring technical seismicity, equipment is used with automatic data recording after the trigger conditions have been met, with recording of the signal history before and after the trigger. Vibration records (seismograms) are used to assess the impact of seismicity on building objects. Seismograms are either analog or digital, which record the movement of a mass point at the measurement location as a function of time during the passage of the seismic wave through the monitored location. The basic characteristics of a seismogram are the deflection amplitude and the frequency of individual waves or wave groups (Kaláb, 2018; Pandula et al., 2021).

The measuring sensors should be placed on the masonry of the lowest floor or on the foundations of the measured object (reference point of measurement). In other places, where a construction object may be damaged, the detected peak particle velocities may be greater than the values measured at the reference position (e.g. due to the effect of the object's response to seismic oscillations). Most often, the load on buildings is assessed according to the peak value of the amplitude of the peak particle velocities and the frequency of the peak oscillation (STN EN 1998-1/NA/Z1). Current seismic equipment can perform this initial interpretation automatically without operator intervention. The reliability of the automatic interpretation is almost one hundred percent (STN Eurokod 8, 2010; Kaláb, 2018).

A detailed interpretation should be carried out if the seismic measurement results indicate the possibility of damage to building objects. A necessary prerequisite for a detailed analysis is a recording (primarily in digital form) of the seismic manifestation in the evaluated location. Specialized seismological software allows not only a perfect display of the recorded wave image, but also the recalculation of the recording to other parameters (displacement or acceleration in the case of measurement of the peak particle velocities), conversion of the recording from the time domain to the frequency domain (discrete or fast Fourier transformation using signal adjustments using weighting windows). or determination of the character of the movement of the particle at the point of measurement. From these seismological characteristics, it is possible to determine what happens after the blast (gradual generation of seismic waves by individual time steps, formation of secondary, reflected, refracted and surface waves). This information can also be used for the project of blasting works, as from the point of view of the size of individual charges in individual time steps, or the total charge. The goal is the high efficiency of disconnecting the rock massif while simultaneously minimizing the impact of vibrations on building objects or people. When interpreting seismic manifestations in small distances and in a complex geological situation, it is not possible to start from simple dependencies, which are recommended for blasting work in surface quarries with large loads and large distances between the blasting site and the assessed object. It very often happens that the seismic load does not always decrease with increasing distance, for example due to the generation of subsequent wave groups or the formation of intense surface waves. For the evaluation of the seismic manifestation of blasting of explosives in the so-called a range of empirical dependencies can be used for the remote zone. There is an effort to construct a general relationship that will allow predicting the maximum value of the oscillation speed depending on the total size of the charge (or the size of the charge fired in one time step) and the distance. However, all relationships are based on the knowledge of empirically determined constants, which are characteristic for the given location and can only be obtained by parametric measurements. When processing the measured maximum values of the peak particle velocities, approximation by regression lines using the method of least squares with three variables is very often used in the bilogarithmic scale, namely: peak particle velocities values ($mm.s^{-1}$), distance (m) and weight of the partial charge (kg). The reliability of the approximation and the determination of the empirical parameters is possible only on the basis of the comparison of the resulting values of the correlation coefficients. Due to the three-dimensional task and with regard to simplifying the solution, the so-called parameter was introduced reduced distance. The use of this quantity does not have a fundamental effect on the course of the studied dependencies (Pandula and Kondela, 2010; Kondela and Pandula, 2013; Kaláb, 2018; Pandula et al., 2021).

In order to determine the maximum values of the peak particle velocities, an empirical relationship is used in practice, the so-called Langefors or also Koch (Mosinec, 1976; Siskind, 1980; Bongiovanni et al., 1991; Dojčár et al., 1996). This relationship, which is used to assess the seismic effect of blasting operations in surface quarries, is often given in the form:

$$v_{max} = K \,.\, Q^{m} \,.\, L^{-n} \,, \tag{1}$$

where: v_{max} - peak value of particle velocity [$mm.s^{-1}$],
Q - charge weight [kg],
L - distance from the source [m],
K, m and n are empirical parameters.

The graphs are compiled either as a dependence of the peak particle velocities v_{max} on the distance, or on the so-called of the reduced distance L_R, which is the ratio of the distance L and the square root of the weight of the charge Q fired in one timing stage. If we start from the Czech standard ČSN 73 0040 or the Slovak standard STN EN 1998-1/NA/Z1, then we consider the values of empirical constants in exponents in the sizes $m = 0.5$ and $n = 1$. Thus, the given relationship takes the form (Dojčár et al., 1996; Kaláb et al., 2013).

In order to construct the law of attenuation of seismic waves, it is necessary to use not only the recording of the vibration manifestation as a whole, but also individual parts of the recording corresponding to individual time stage of blast.

When assessing technical seismicity, it is necessary to deal with three impacts (Kaláb, 2018):

- Impact of seismic shocks and vibrations on surface objects.
- Impact of seismic shocks and vibrations on underground works.

- The impact of seismic shocks and vibrations on the feelings and psyche of the population.
- Assessing the impact of seismicity on objects includes the following points (Kaláb, 2018):
- Determination of permissible load.
- Load forecast.
- Determination of risk, possibly safe distance and other parameters.
- Passporting (including photo documentation), especially for historical and damaged buildings.
- Seismic measurement of tremors.
- Assessment of safety at the detected load (correction of the current state).
- Monitoring the state of cracks.

Assessing the impact of vibrations on objects must always be based on local conditions.

3.1 Methodology and used vibrographs

The following digital vibrographs (Fig. 4) were used to measure and graphically record the seismic effects of blasting works at the measurement standpoints:

- vibrograph Minimate Pro 6 - Instantel and seismographs from the Canadian company Instantel (Fig. 4A),
- vibrograph Svantek 958 A - Class 1 and vibration sensors of the Polish company Svantek (Fig. 4B),
- vibrograph ABEM Vibraloc and seismographs of the Swedish company ABEM (Fig. 4C),
- seismograph ABEM Terraloc Mk 8 with accessories (Fig. 4D, 14).

Vibrographs provide a digital and graphic record of all three components of the vibration speed of environmental particles, horizontal longitudinal - v_x, horizontal transverse - v_y, vertical - v_z. Vibrographs Minimate Pro 6 – Instantel and ABEM Vibraloc work autonomously, they automatically perform channel tests without operator intervention and influence on the measured and registered vibration

Fig. 4 Instruments used to measure technical seismicity and propagation seismic waves in rock massif

characteristics. Seismograph ABEM Terraloc Mk 8 is a compact seismograph for measuring propagation seismic waves in rock massif (Kondela and Pandula, 2012; Konček et al., 2020;).

Vibrographs Minimate Pro 6 – Instantel and ABEM Vibraloc and Svantek 958 A - Class 1 have an AD converter with an automatic 14-bit dynamic range that corresponds to 0.05 ÷ 250 mm.s-1. The ABEM Terraloc Mk 8 seismograph has an A/D converter resolution of 21 bits (Kondela and Pandula, 2012; Konček et al., 2020;).

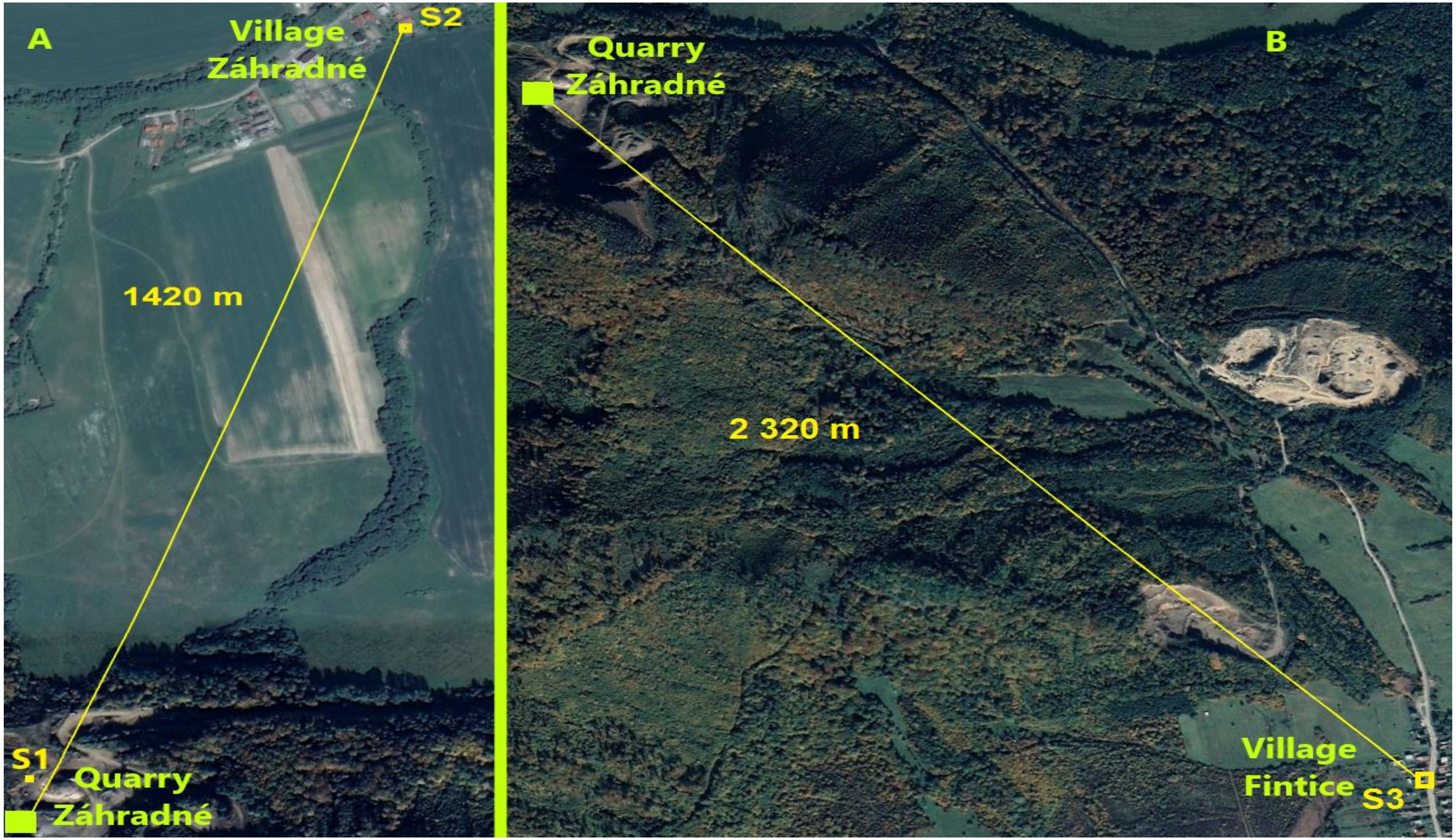


Fig. 5 Positions and distances from the bench blasts CO 34 and CO 35 in Zahradné quarry to the measuring standpoints (S1, S2, S3)

ABEM electrodynamic geophones with a frequency range of 2 ÷ 1000 Hz and a sensitivity of 20 mV/mm.s^{-1} were used for these measurements. Furthermore, a three-component geophone from Instantel with a frequency range of 2 ÷ 1000 Hz and a sensitivity of 10 mV/mm.s^{-1}. The geophones were placed on a special pad with sharp steel spikes, which ensured continuous contact with the ground. Vibrographs work autonomously, they automatically perform a channel test without operator intervention and influence on the measured and registered vibration characteristics (Kondela and Pandula, 2012; Konček et al., 2020).

Measuring positions for bench blasts no. 34 and no. 35 (hereinafter "CO 34 and CO 35") were located in such a way as to record the seismic effects on the nearest surrounding buildings in the villages of Záhradné and Fintice and their inhabitants. The standpoints were situated as follows:

- the first standpoint was in Záhradné quarry (S1) in order to measure the frequency of seismic waves caused by blasting and obtain PPV values for the precise determination of the law of attenuation of seismic waves in the transmission environment between the source and receptors,
- the second standpoint was a residential house in the village of Záhradné (S2),
- the third standpoint was in a residential house in the village of Fintice (S3).

Fig. 6 Measuring standpoint S1 and used ABEM Vibraloc vibrograph for measuring technical seismicity during CO 34 a nd CO 35 bench blasts

We can see all these standpoints (S1, S2, S3) on (Fig. 5 - 8).

To determine the law of attenuation seismic waves in the transmission environment between the source (bench blasts CO 34 and CO 35) and the receptors (residential buildings in the villages of Záhradné and Fintice), the measuring standpoint S1 was located 11 m from the initiation borehole in Záhradné quarry. A digital four-channel ABEM Vibraloc vibrograph (Fig. 6) was used to measure seismic effects on a standpoint S1.

For the assessment of seismic effects on residential buildings in the Záhradné village, the measuring standpoint S2 was located on the nearest apartment building (house no. 335/25A) in village Záhradné. A Minimate Pro 6 - Instantel vibrograph was placed on the S2 standpoint, which measured the effects of technical seismicity on the building. The sensors were placed on a concrete base at the entrance to the rear premises of the house and on the window sill of the building under consideration (Fig. 7A). On this building, a Svantek 958 A – Class 1 vibrograph was installed in the premises where the residents of the residential building stay. This vibrograph measured the effect of technical seismicity on the residents of the residential building. The sensor was located on the floor in the object's room (Fig. 7B).

Measuring standpoint S3 for the assessment of seismic effects on residential buildings in the Fintice village was located on the nearest apartment building (house no. 476) in village Fintice. The ABEM Vibraloc vibrograph was placed at standpoint S3, which was situated on a concrete base at the entrance to the rear premises of the residential building under consideration (Fig. 8).

The structural properties of the rock environment in the Záhradné quarry were determined by measuring the speed and frequency of seismic wave propagation using the Terraloc Mk8 seismic apparatus. Based on the speed and frequency of seismic waves propagation, it was possible to determine the optimal millisecond timing delay value for bench blast CO 35 (Brixová et al., 2018; Pandula et al., 2018; Pandula and Kondela, 2020; Putiška et al., 2021) (Fig. 9).

***Fig. 7** Measuring station S2A - used Minimate Pro 6 measuring equipment to measure the effect of technical seismicity during CO 34 and CO 35 bench blasts on a residential building and S2B - used Svantek 958 measuring equipment to measure the effect of technical seismicity during CO 34 and CO 35 bench blasts on the residents of a residential building*

Fig. 8 Measuring standpoint S3 and used ABEM Vibraloc vibrograph for measuring technical seismicity during CO 34 and CO 35 bench blasts

Fig. 9 Measurement of the propagation speed and frequency of seismic waves of the rock massif during blasting operations in Záhradné quarry using the Terraloc Mk 8 seismic apparatus

4. SOURCES OF SHOCKS IN RESEARCH TECHNICAL SEISMICITY (CO 34, CO 35)

The source of the seismic effects were bench blasts CO 34 and CO 35 on the andesite deposit located 1420 meters from the residential building Záhradné and 2320 meters from the residential building Fintice. The positions and distances from CO 34 and CO 35 in Záhradné quarry to the measuring standpoints (S1, S2, S3) can be seen in Fig. 5 (Pandula and Kondela, 2020;).

Parameters of bench blast CO 34 in the quarry Záhradné: 11 vertical boreholes with a diameter of 105 millimeters, an inclination of 65 degrees and a length of 23.2 to 23.8 meters were drilled. The total blast charge was 1743 kg of explosives, of which the maximum charge per time stage was 160 kg. The explosives used were Andex M - 1525 kg, Senatel Powerfrag - 168 kg and Eurodyn 65 - 50 kg. 22 non-electric detonators - Indetshock MS 20/50 were used during the blasting and the timing delay was used - 17 ms (Fig. 10).

The bench blast CO 35 consisted of 28 boreholes with a diameter of 105 millimeters with the length of one borehol ranging from 15 to 17.5 m. The blasting was in three rows with a distance between individual rows of 3.5 m. The total charge of explosives in the boreholes was 2325 kg of ANDEX M and 75 kg of Ecodanubit 65/2500 explosive was used for ignition. The maximum charge in one borehole was 100.5 kg of explosives. The blast timing delay was used 17 ms, 25 ms and 50 ms (Fig. 11) (Pandula and Kondela, 2020).

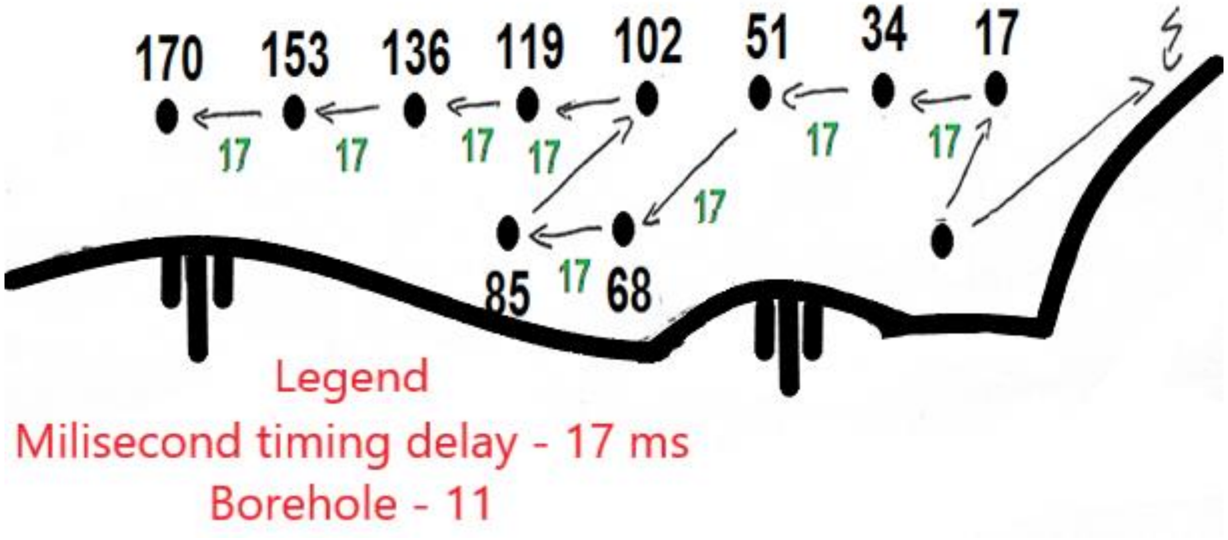


Fig. 10 Timing scheme and location of boreholes for bench blast CO 34 in Záhradné quarry

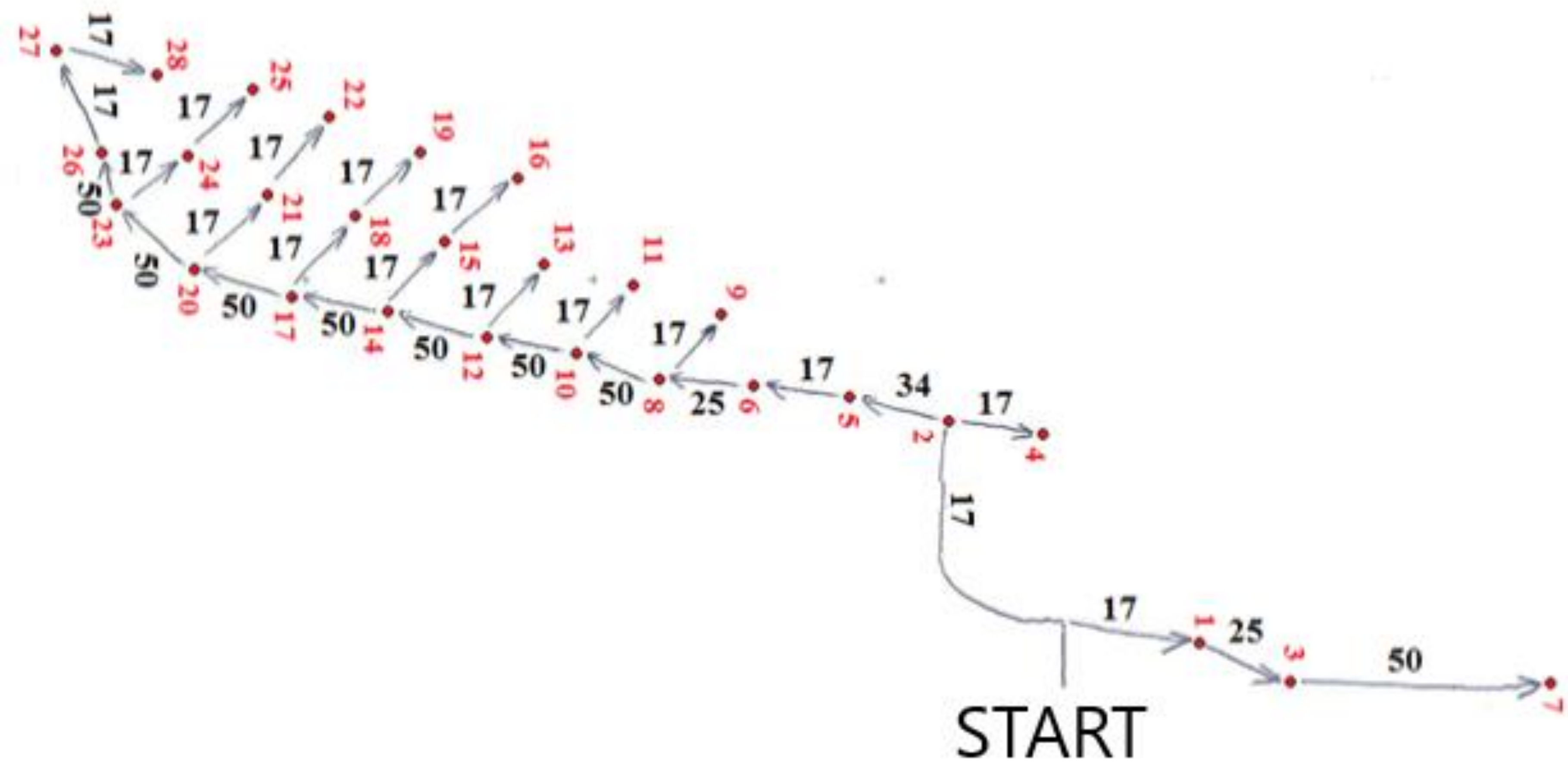


Fig. 11 Blast timing scheme and location of boreholes for bench blast CO 35. Timing delays are given in milliseconds. Boreholes are marked in red, timing delays in black

5. MEASURED VALUES AND RESULTS

The measurement of the speed of propagation of seismic waves with a Terraloc Mk 8 seismograph carried out in Záhradné quarry by bench blast CO 34 made it possible to set the optimal millisecond timing delay for CO 35. The measured speed of propagation of seismic waves in the part of rock massif in which the blasting work will take place was 3889 $m.s^{-1}$ (Fig. 12). The analysis of the seismic record showed that the predominant frequencies of the rock massif are 31 Hz. These propagation velocities and frequencies correspond to the degree of disturbance of the rock environment through which the seismic waves have passed. Based on the theory of seismic wave propagation and attenuation, the greatest vibration attenuation is achieved with millisecond timing if the waves generated by the next blast are in antiphase.

According to the theory, with a frequency of seismic waves of 31 Hz, we achieve this with a millisecond timing delay of 16.5 milliseconds. Therefore, a millisecond timing delay of 17 milliseconds was used in the blasting in order to achieve the maximum effect of seismic wave attenuation (Pandula and Kondela, 2010; Pandula and Kondela, 2020).

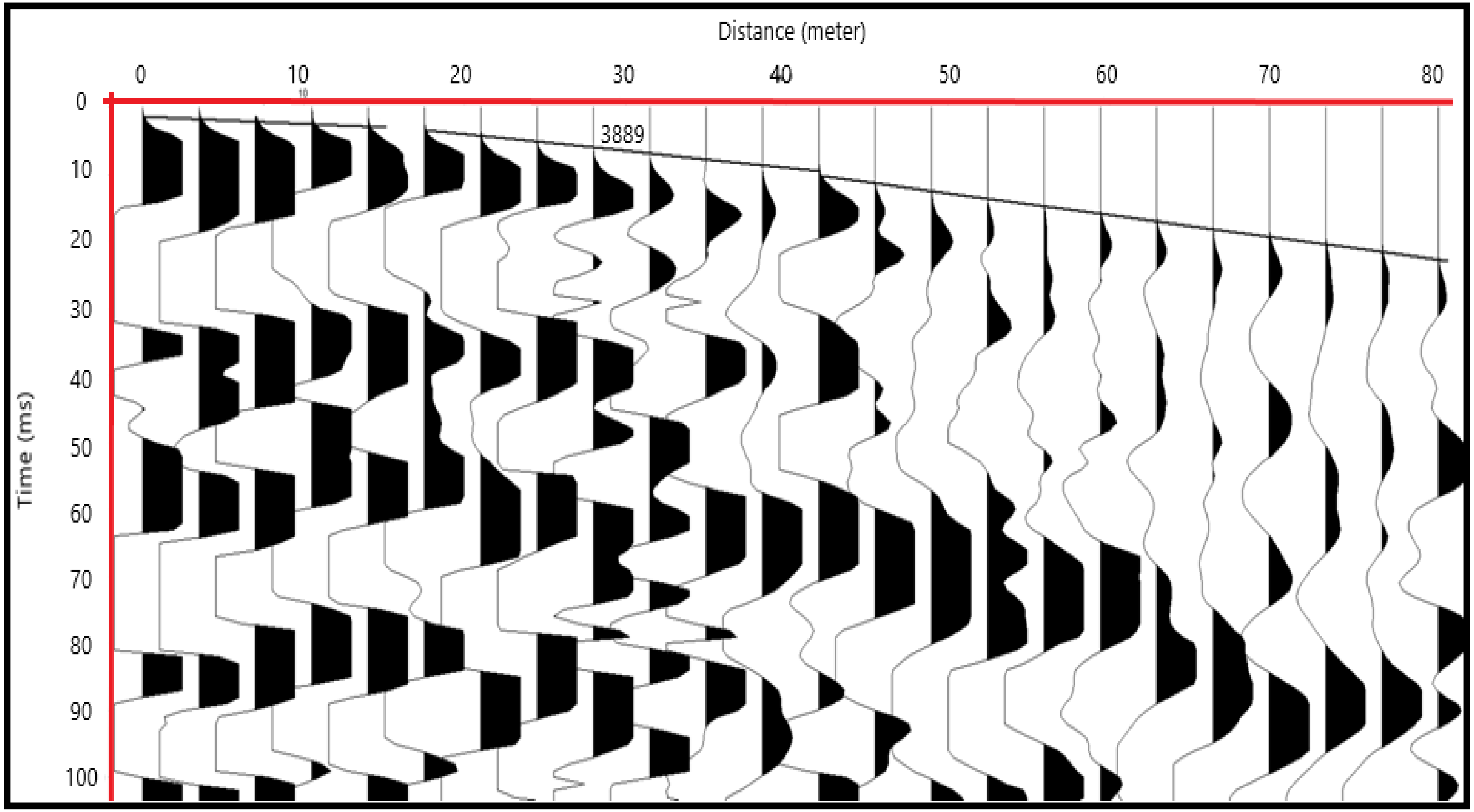
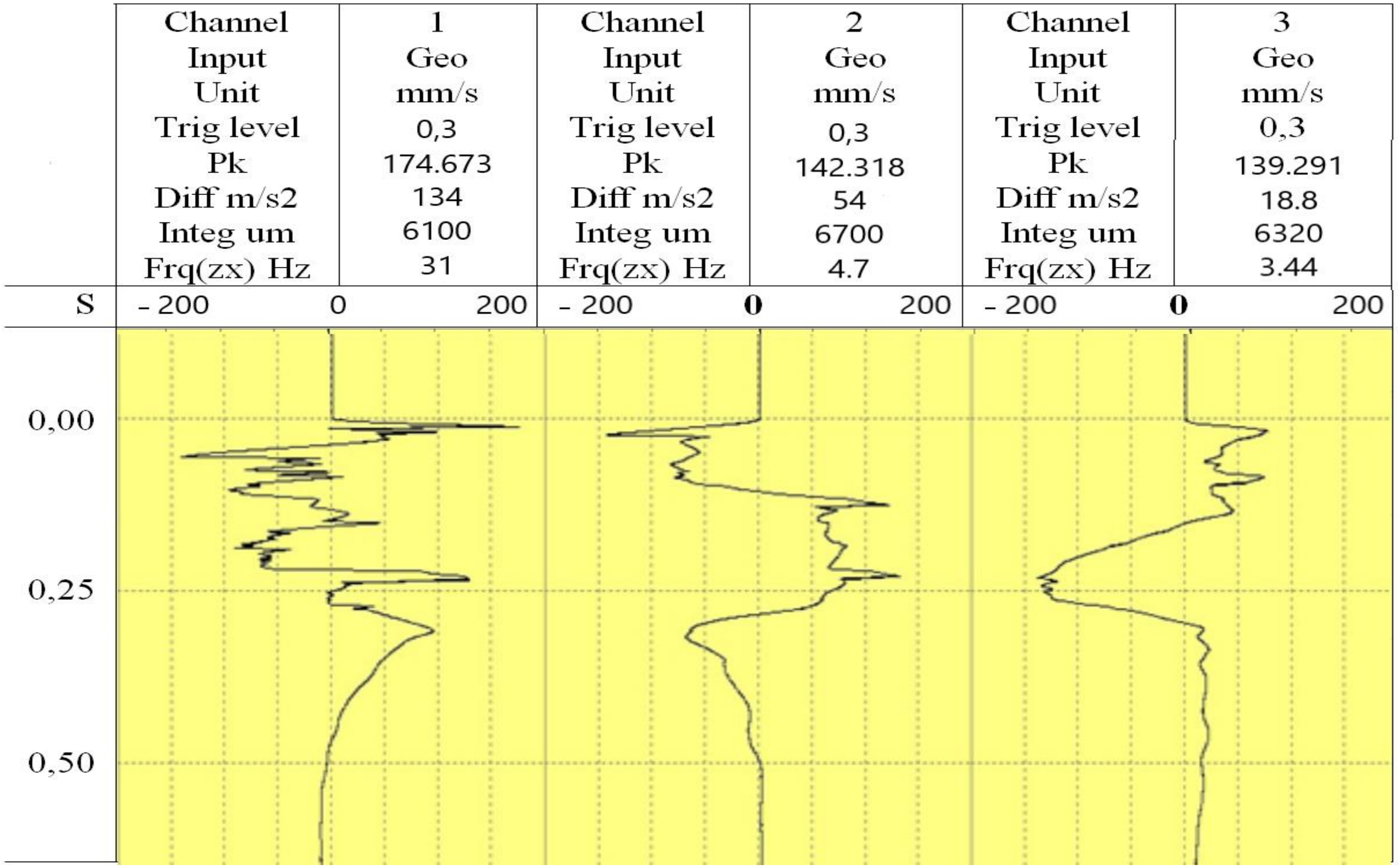


Fig. 12 Seismic recording from Terraloc Mk 8 seismograph at CO 34 with an identified seismic wave propagation speed of 3889 m.s^{-1} with a frequency of 31 Hz in the andesite rock environment in Záhradné quarry

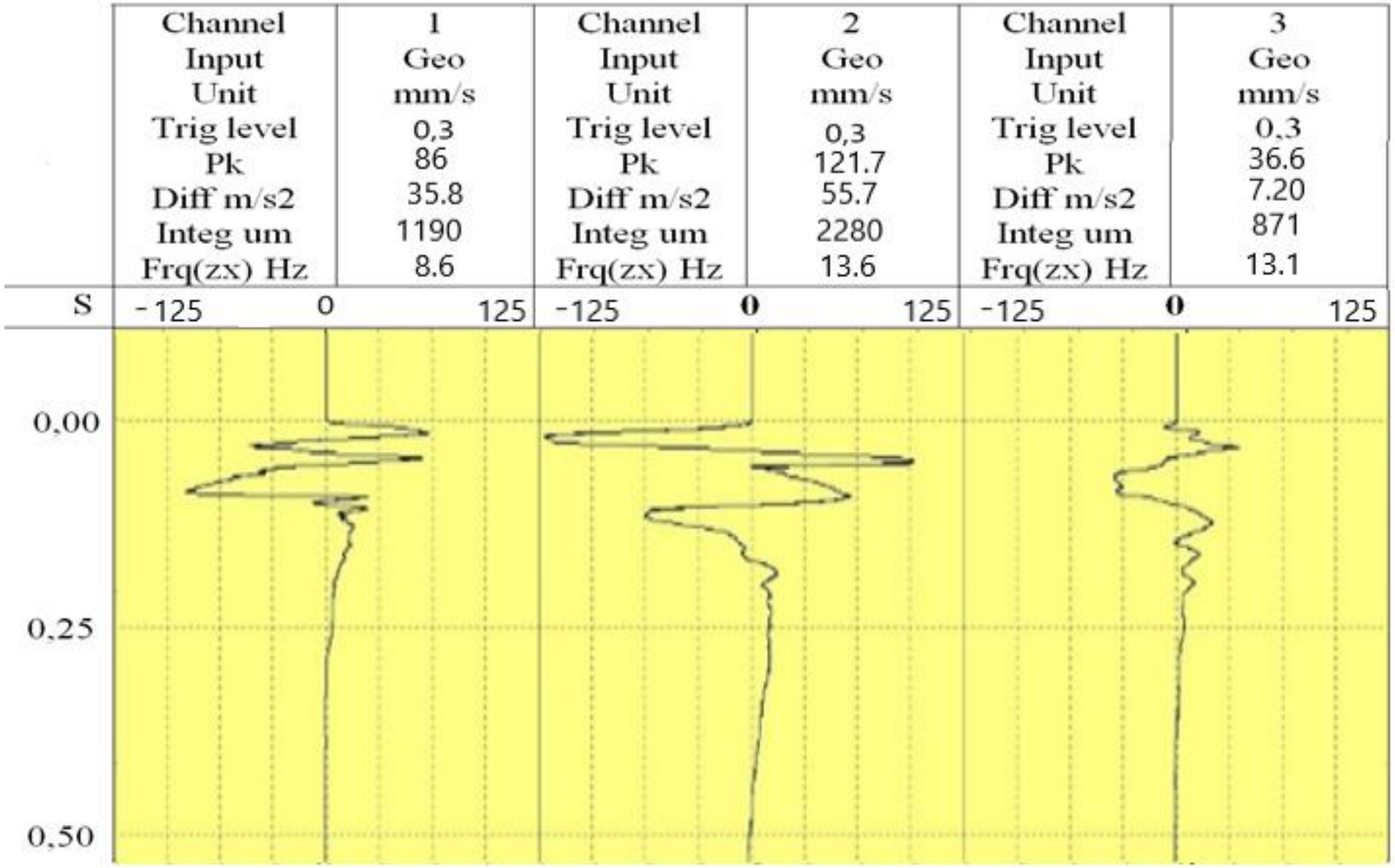
The vibrographs placed on the measuring standpoints were calibrated before the measurement and their sensitivity was checked. At the measuring standpoints, graphic courses of individual components of seismic waves at a bench blast CO 34 were recorded. Individual graphic records were four seconds long (Fig. 13). The vibrographs were placed on the measuring positions in such a way that it was possible to assess the effect of the induced technical seismicity on the assessed objects. In Fig. 13 we can see channel 1 (axis z). It can be seen from the course of the recording that there was a damping of the tension wave amplitudes during the blast of the second, third and fourth borehole. The fifth and sixth boreholes were out of row (Fig. 10) and there was no damping of the tension wave amplitudes. At other boreholes that were in a row, the amplitudes of the tension waves was dampened.



Channel	1	Channel	2	Channel	3
Input	Geo	Input	Geo	Input	Geo
Unit	mm/s	Unit	mm/s	Unit	mm/s
Trig level	0,3	Trig level	0,3	Trig level	0,3
Pk	174.673	Pk	142.318	Pk	139.291
Diff m/s2	134	Diff m/s2	54	Diff m/s2	18.8
Integ um	6100	Integ um	6700	Integ um	6320
Frq(zx) Hz	31	Frq(zx) Hz	4.7	Frq(zx) Hz	3.44

Fig. 13 Graphical record of individual wave components from measurement of bench blast CO 34 at measuring standpoint S1 in Záhradné quarry (first channel - z, second channel - x, third channel - y)

In Fig. 14 we can see the recording of CO 35 blasting. It can be seen from the course of the recording that during the blasting of the second and third boreholes there was no damping of the tension wave amplitudes. In other boreholes that were in the rows, the amplitudes of the stress waves were significantly attenuated.



Channel	1	Channel	2	Channel	3
Input	Geo	Input	Geo	Input	Geo
Unit	mm/s	Unit	mm/s	Unit	mm/s
Trig level	0,3	Trig level	0,3	Trig level	0,3
Pk	86	Pk	121.7	Pk	36.6
Diff m/s2	35.8	Diff m/s2	55.7	Diff m/s2	7.20
Integ um	1190	Integ um	2280	Integ um	871
Frq(zx) Hz	8.6	Frq(zx) Hz	13.6	Frq(zx) Hz	13.1

Fig. 14 Graphical record of individual wave components from measurement of bench blast CO 35 at measuring standpoint S1 in Záhradné quarry (first channel - z, second channel - x, third channel - y)

The measured values at the individual measuring standpoints are shown in Table 2. At the measuring standpoint S3, the peak particle velocities from the blast were not measured, because the values of the peak particle velocities at the nearest apartment building (house no. 476) in the village Fintice were below the set sensitivity level of the ABEM measuring equipment Vibraloc 0.1 mm.s^{-1}. For measuring standpoint S3 – apartment building (house number 476) in the village Fintice, the values of the peak particle velocities components (v_x, v_y, v_z) were determined to be 0.1 mm.s^{-1}. The actual values of the peak particle velocities on the apartment building were at CO 34 and CO 35 lower than the values of the set sensitivity of the ABEM Vibraloc vibrograph, placed on a concrete base at the entrance to the rear premises of the apartment building. Frequencies (f_x, f_y, f_z) could not be determined, therefore their values are not listed in Table 2. The peak particle velocities values measured at CO 35 show that the millisecond timing was set correctly (Tab. 2, Fig. 14).

Tab. 2 Measured peak values of peak particle velocities and frequencies of individual standpoints in bench blast CO 34

Measuring standpoints	**Distance from the source [m]**	**Bench blast**	**Total charge weight for timing stage [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]**
S1 - Záhradné quarry	11	CO 34	160	142	139	175	4.7	3.4	31
S1 - Záhradné quarry	36	CO 35	100.5	121.7	36.6	86	13.6	13.1	8.6
S2 – Záhradné village (Svantek)	1420	CO 34	160	0.129	0.193	0.211	11.1	10.2	13.1
S2 – Záhradné village (Sensor 1)	1420	CO 34	160	0.221	0.134	0.095	9.2	9.7	10.2
S2 – Záhradné village (Sensor 2)	1420 m	CO 34	160	0.268	0.181	0.102	7.8	8.2	9.1
S2 – Záhradné village (Svantek)	1425	CO 35	100.5	0.052	0.071	0.069	14.6	17-6	17.6
S2 – Záhradné village (Sensor 1)	1425	CO 35	100.5	0.13	0.16	0.2	10.2	10.2	9.2
S3 – Fintice village	2320 m	CO 34	160	≤ 0.1	≤ 0.1	≤ 0.1	-	-	-
S3 – Fintice village	2325 m	CO 35	100.5	≤ 0.1	≤ 0.1	≤ 0.1	-	-	-
Note: The values of the peak particle velocities at the S3 standpoint were below the sensitivity level of the Vibraloc measuring vibrograph 0.1 mm.s^{-1}.									

Description of the legend of Tab. 2: v_x *- peak particle velocities of environmental particles (horizontal/longitudinal),* v_y *- peak particle velocities of environmental particles (horizontal/transverse),* v_z *- peak particle velocities of environmental particles (vertical),* f_x *- maximum value of frequency (horizontal/longitudinal),* f_y *- maximum value of frequency (horizontal/transverse),* f_z *- maximum value of frequency (vertical).*

We used the relations (1) and (2) to process the peak measured values of the peak particle velocities in Záhradné quarry. The relationship (3) was used to calculate the maximum allowable charge for one timing stage depending on the distance during repeated blasts in the quarry Záhradné:

$$Q_{max} = L^2/L_R^2, \tag{3}$$

where: L – distance (m),
L_R – reduced distance ($m.kg^{-0.5}$) (Pandula et al., 2021; Konček et al., 2021).

Based on the recommendations of STN EN 1998-1/NA/Z1 Seismic loading of building structures, about charges used for bench blasting, which are tens of kilograms, where the oscillation frequencies are usually $f < 10$ Hz and based on the resistance of buildings to technical seismicity it is possible to classify buildings in the villages of Záhradné and Fintice into resistance class B (see Tab. 3) (STN Eurocode 8, 2010; Pandula et al., 2021).

Tab. 3 Resistance classes of building objects according to STN EN 1998-1/NA/Z1

Object resistance class	Residential, civil, industrial and agricultural buildings	Engineering objects	Underground facilities	Underground utility networks and cables
A	flimsy buildings that do not comply with regulations, ruins, historical buildings, monuments and fountains, buildings under personal monument care	-	-	-
B	brick buildings, houses up to 200 m^2 - at most three floors	-	-	-

As for the type and category of foundation soil of protected objects, due to the absence of more specific characteristics and data, we can classify it into category b, which is closest to reality - groundwater level is more than 3 m below the surface level (see Tab. 4) (STN Eurocode 8, 2010; Pandula et al., 2021).

Tab. 4 Dependence of the degree of damage on the peak particle velocities, type of object and foundation soil according to STN EN 1998-1/NA/Z1

Maximum permissible peak particle velocities for the frequency domain			Level of damage	Class of resistance of an object	Type of foundation
$f_k < 10$ Hz	10 Hz $< f_k < 50$ Hz	$f_k > 50$ Hz			
Up to 3	3 to 6	6 to 5	0	A	a
3 to 6	6 to 12	12 to 20	0	A	b, c
				B	a

Description of the legend of Tab. 4:

- *Legend class of building resistance: A - old buildings not conforming with regulations, ruins, historical buildings from unworked stone or bricks with arches cross-beams, girders and flat arches above the premise of the ground floor and basement: stone and brick monuments and fountains, buildings with extensive moulding decorations, buildings with special preservation and conservation status. B - conventional brick buildings detached or terraced houses with ground area up to 200 m three storeys at the most.*
- *Legend class of soil: Category a - includes rocks of all classes with the design strength $R_{dt} \leq 0.15$ MPa, underground water level at the constant depth of 1.0 to 3.0 m below the footing bottom. Category b - includes rocks of all classes with design strength $R_{dt} \leq 0.15$ MPa, underground water level at the constant depth of more than 3.0 m. This category also includes rocks of all classes with design strength $R_{dt} \leq 0.15$ MPa if the underground water level is constantly at the depth of 1.0 to 3.0 m below the footing bottom, Category c - includes rocks of all classes with the design strength $R_{dt} \geq 0.15$ MPa, underground water level at the constant depth of more than 3.0 m below the footing bottom. This category also includes rocks of all classes with design strength $R_{dt} \leq 0.6$ MPa if the underground water level is constantly at the depth of more than 1.0 m (STN Eurocode 8, 2010; Pandula et al., 2021).*

At standpoint S2, the Svantek 958A vibrograph was placed at a reference point (Decree of the Ministry of Health of the Slovak Republic No. 549/2007 and No. 237/2009) - in the place of the building where residents stay. She monitored the effects of vibrations on the residents of the building. According to Act no. 355/277 on the protection, support and development of public health, Decree of the Ministry of Health of the Slovak Republic no. 549/2007 and no. 237/2009 (Table 5) for apartment buildings, dormitories, retirement homes, for the reference time interval: day: $a_{wmax,p} = 0.11$ m.s^{-2}, measured maximum values of the vibration acceleration: $a_{wmax} = 0.007638$ m.s^{-2} (Fig. 15, Tab. 5).

Tab. 5 Allowed values of vibration quantities in the indoor environment of buildings

Description of the protected room in buildings	Reference time interval	Continuous or intermittent, periodic or steady-state random vibration	Shocks and vibrations with large dynamics occurring several times a day
		a_{weq} [m.s^{-2}]	a_{wmax} [m.s^{-2}]
Enhanced areas (such as hospital rooms, spa patients)	Time of occurrence for day, evening and night	0.004	0.008
Residential rooms, dormitories, retirement homes	Time of occurrence for day evening night	 0.008 0.008 0.005	 0.11 0.11 0.05
Nurseries, schools and libraries	Time of occurrence while using the room	0.008	0.11

The measured peak values of seismic effects, generated by the CO 34 and CO 35 bench blasts in the Záhradné quarry, are listed in Table 6. These values served us as a basis for determining the law of seismic wave attenuation in Záhradné quarry.

Device type	SVAN 958A		Standard	DIN 4150-3
	X	Y	Z	
Peak	0.052	0.071	0.069	mm/s
Dominant frequency	14.648	17.578	17.578	Hz
Peak Acceleration	4.775	7.816	7.638	mm/s^2
Peak Displacement	0.0006	0.0006	0.0006	mm
PPV	0.089 mm/s			

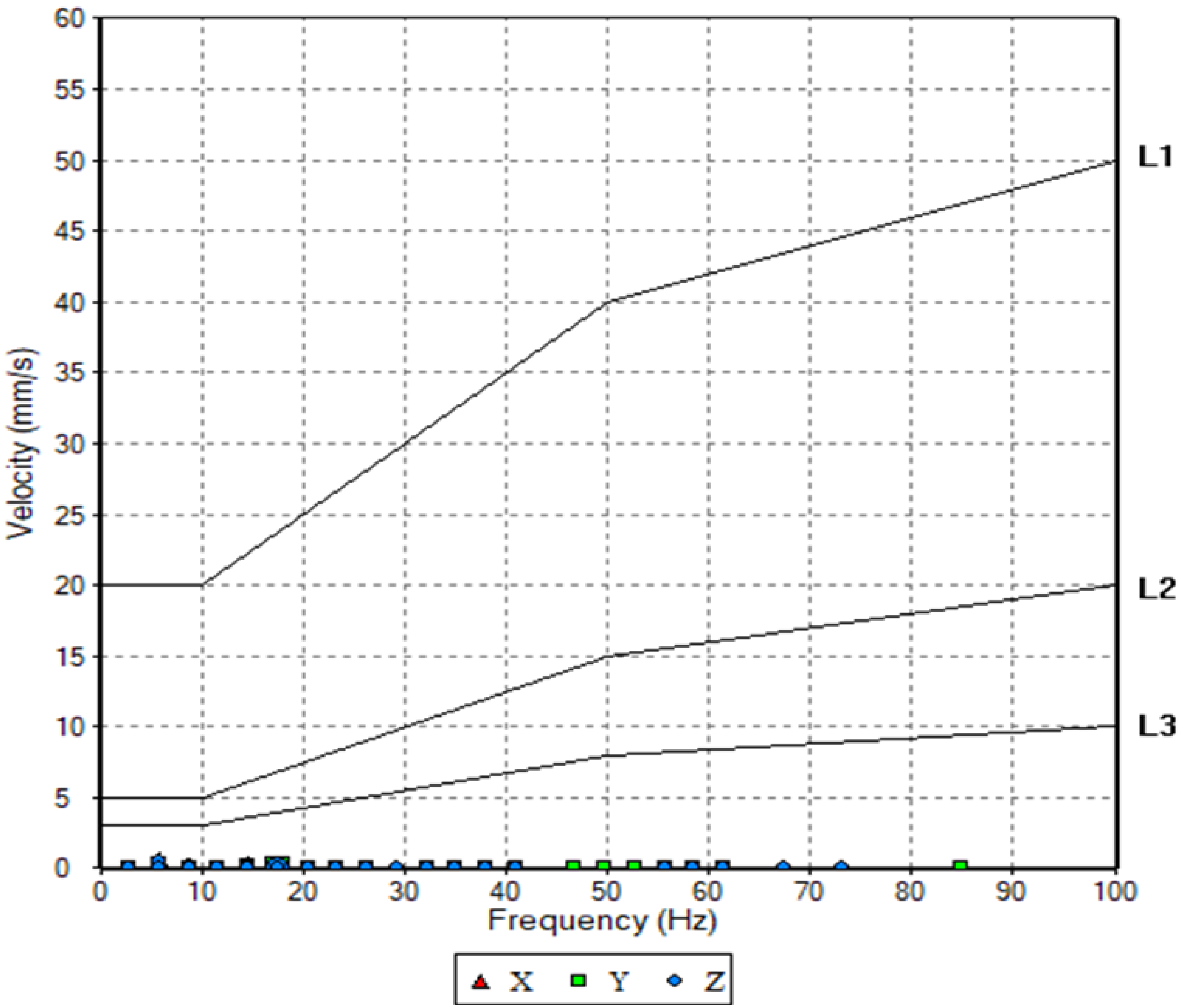


Fig. 15 Graphical recording and frequency analysis of individual wave components from the measurement at measuring standpoint S2 in village Záhradné – vibrograph Svantek. First channel-x, second channel-y, third channel-z at CO 35

Tab. 6 Measured peak values peak particle velocities of the bench blasts CO 34 and CO 35 at reduced L_R distance

Distance source - receptor L [m]	Charge weight for one timing stage Q [kg]	Reduced distance $L_R = L/Q^{0.5}$ [$m.kg^{-0.5}$]	v_x [$mm.s^{-1}$]	v_y [$mm.s^{-1}$]	v_z [$mm.s^{-1}$]
24.6	160	1.95	142	139	175
39	100.5	3.9	121.7	76.6	86
1425	100.5	142.5	0.052	0.071	0.069
1425	100.5	142.5	0.13	0.16	0.2
1420	160	112.3	0.268	0.181	0.102
1420	160	112.3	0.221	0.134	0.095
1420	160	112.3	0.129	0.193	0.211

Based on the data from Tab. 6, a graphical dependence of the maximum components of the peak particle velocities on the reduced L_R distance was constructed for bench blasts in the quarry Záhradné. The graph in Fig. 16 represents the law of seismic waves attenuation for the quarry Záhradné.

From the law of attenuation of seismic waves, it is possible to determine according to relation 3 for a specific receptor the size of the charge at a known distance so that the peak values of the individual components of the peak particle velocities do not exceed the permissible peak particle velocities.

The graph (Fig. 16) shows the values of peak particle velocities in Záhradné quarry (points on the upper left part of the graph) and the measured peak values of peak particle velocities on the assessed objects in the villages of Záhradné and Fintice (points in the lower right part of the graph). The red line represents the limit of permitted peak particle velocities for residential buildings in the villages of Záhradné and Fintice so that there are no negative changes on residential buildings. The green line represents the limit of permissible vibration rates for residents. Peak particle velocities of less than 2 $mm.s^{-1}$ are not considered dangerous by residents.

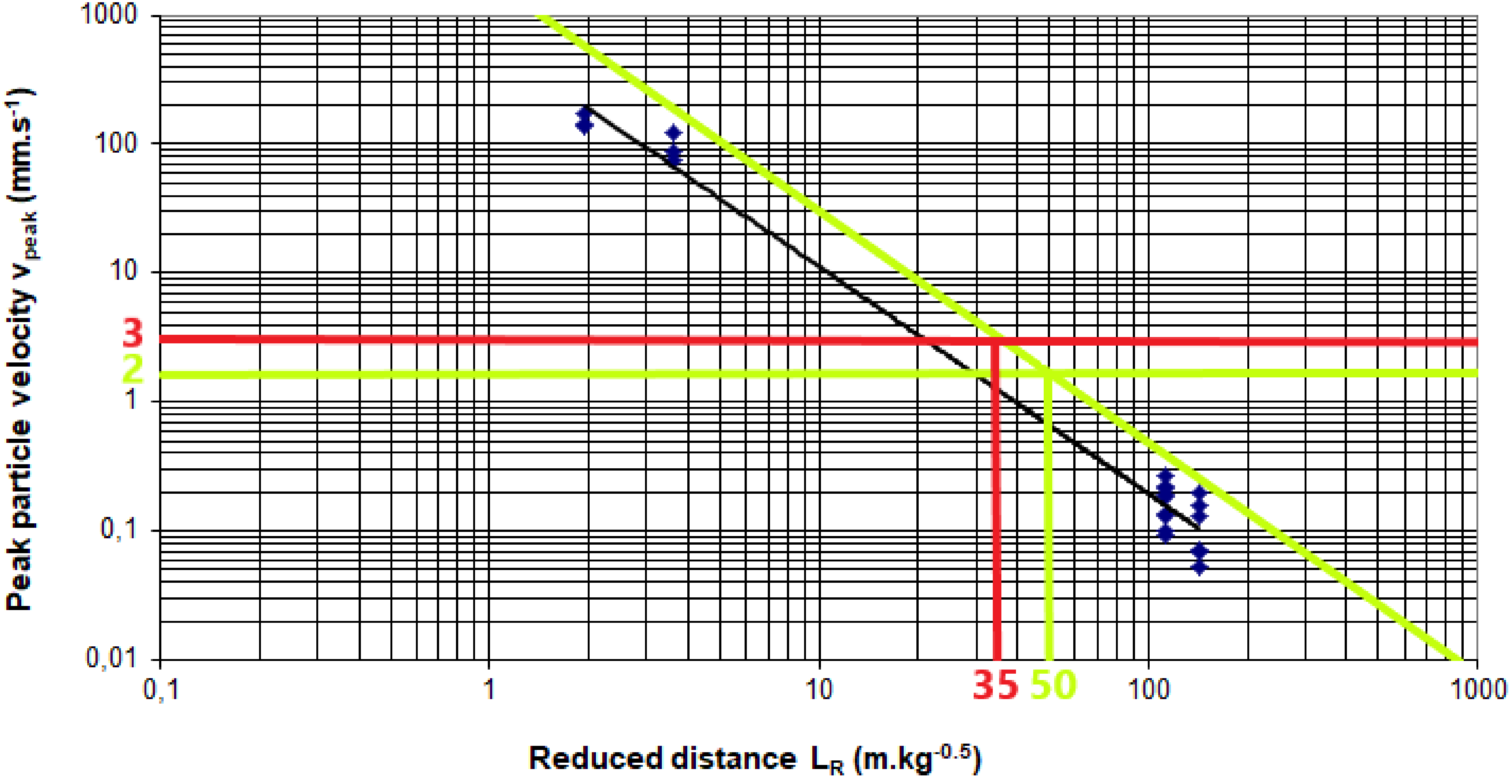


***Fig. 16* Graphical dependence of the peak components of the peak particle velocities on the reduced distance during bench blasts in Záhradné quarry - the law attenuation of seismic waves.**

The red line indicates the maximum safe permissible value of the peak particle velocities for building objects. The green line represents the limit of permissible vibration rates for residents. The points show the measured values of the peak particle velocities at the individual measuring standpoints during the CO 34 and CO 35 bench blasts in Záhradné quarry

On the basis of measured and calculated values during operational blasting in Záhradné quarry, the law attenuation of seismic waves was established, based on which it is possible to use the maximum permitted charge of explosive for one timing stage depending on the distance during repeated bench blasts in Záhradné quarry (Table 7) (Pandula and Kondela, 2010; STN Eurokod 8, 2010; Pandula et al., 2012; Pandula et al., 2021).

The results of measuring the seismic effects of the CO 34 and CO 35 bench blasts, which were carried out in the Záhradné quarry, confirmed that the measured values did not exceed the values set by the valid Slovak technical standard STN EN 1998-1/NA/Z1 Eurocode 8 Seismic load of structures $v_d < 3$ mm.s^{-1} for frequencies less than 10 Hz and for type b foundation soil (Pandula and Kondela, 2010; STN Eurocode 8, 2010; Pandula et al., 2021).

Mining at the location Záhradné is carried out by bench blasting. With this mining technology, when the maximum charge detonated in one timing stage does not exceed the Q_{max} values at the recommended distance from construction objects (Tab. 7), there will be no damage to residential buildings in the village of Záhradné and Fintice, nor will the residents perceive the blasting work as dangerous (Pandula and Kondela, 2010; STN Eurocode 8, 2010; Pandula et al., 2021).

Tab. 7 Recommended values of maximum charge for one timing stage depending on the distance source - receptor

Distance source – receptor L [m]	Reduced distance L_R [m.kg$^{-0.5}$]		Maximum permissible charge weight for one timing stage $Q_{max} = L^2/L_R^2$ [kg]	
	Buildings	Residents	Buildings	Residents
100	35	50	8	4
200	35	50	32.5	16
300	35	50	73.5	36
400	35	50	130.5	64
500	35	50	204	100
750	35	50	459	225
1000	35	50	816	400
1250	35	50	1275.5	625
1500	35	50	1836.5	900

6. CONCLUSION

Currently, blasting works are widely used in society. Many industries and spheres in human life have emerged where the use of blasting is an essential part. However, during this activity, it is necessary to think not only about the positive side, but also about the negative phenomena that are related to it. In order to prevent these undesirable phenomena, it is necessary to eliminate them. The aim of the article was to find a suitable methodology for reducing the impact of seismic effects of blasting operations carried out in quarry operations on the environment. The methodology used on the basis of test blasts during blasting works in Záhradné quarrie proved the suitability of its use to reduce the impact of seismic effects of blasting works in quarry operations on the environment and inhabitants.

In accordance with the established theses, it was found that appropriate timing of blasting significantly reduces the risk of adverse effects during blasting. The research and results achieved during test blasting in the Záhradné quarry allow the findings to be summarized in the following points:

1. if it is necessary to reduce the impact of the seismic effects of blasting on the environment during blasting in quarry operations, it is necessary to measure the propagation speed of seismic waves in the rock environment,
2. on the basis of the measured propagation speed and frequency of seismic waves, determine optimal millisecond blast timings,
3. on the basis of the measured peak particle velocities, determine the law of attenuation of seismic waves for blasting in quarry operation and potential receptors of the seismic effects of blasting,
4. carry out certification of potential receptors according to STN EN 1998-1/NA/Z1 Eurocode 8 Seismic load of buildings,
5. carry out an assessment of the foundation soil of potential receptors according to STN EN 1998-1/NA/Z1 Eurocode 8 Seismic load of buildings,
6. on the basis of STN EN 1998-1/NA/Z1 Eurocode 8 Seismic load of buildings, determine the maximum permissible peak particle velocity,
7. based on the law of attenuation of seismic waves, determine the reduced distance,
8. based on the reduced distance, calculate the maximum allowable charges for one timing stage for the expected distances between blasts in the quarry and potential receptors.

Adherence to this methodology will enable extraction of raw materials in quarries while observing the seismic safety of blasting works. During the measurements in the Záhradné quarry, using this methodology, the values of the vibration speed from the blastings and their impact on the environment were reduced to such an extent that even the residents did not perceive these effects as dangerous.

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References

ABBASPOUR, H., DREBENSTEDT, C., BADRODDIN, M., MAGHAMINIK, A. 2018. Optimized design of drilling and blasting operations in open pit mines under technical and economic uncertainties by system dynamic modeling, *International Journal of Mining Science and Technology*, Vol. 28 (6), pp. 839-848.

AFENI, T. B. 2009. Optimization of drilling and blasting operations in an open pit mine-the SOMAIR experience. *Mining Science and Technology* (China), Vol. 19 (6), pp. 736-739.

ALDAS, G. G. U. 2010. Explosive charge mass and peak particle velocity (PPV) - frequency relation in mining blast. *Journal of Geophysics and Engineering*, Vol. 7 (3), pp. 223-231.

BONGIOVANNI, G., GORELLI, V., RIENZO, G., RINALDIS, D. 1991. Experimental Studies of Vibrations Caused by Blasting for Tunnel Excavations. *Blast and Impacts: Measurements and Effects of Vibration*, pp. 201-210.

BRIXOVÁ, B., MOSNA, A., PUTISKA, R. 2018. Applications of shallow seismic refraction measurements in the Western Carpathians (Slovakia). Case studies. *Contribution to Geophysics and Geodesy*, Vol. 48 (1), pp. 1 – 21.

COLTRINARI, G. 2016. Detecting seismic waves induced by blast operations at a limestone quarry by means of different transducer mounting. *International Journal of Sustainable Development and Planning*, Vol. 11 (6), pp. 959-969.

DOJČÁR, O., HORKY, J., KORINEK, R. 1996. *Blasting technology*. Montanex, a.s., Ostrava, p. 421.

DOJČÁR, O., PANDULA, B. 1998. *Výskum technickej seizmicity v lome Včeláre, Výskumná správa clonového odstrelu*. FBERG TU Košice, 1, pp. 7–10.

DVOŘÁK, A.,- OSNER, Z. 1972. Trhací technika a seizmické projevy při stavbě metra v Praze. *Rudy*, Vol. 5.

FEHÉR, J., ČAMBAL, J., PANDULA, B., KONDELA, J., ŠOFRANKO, M., MUDARRI, T., BUCHLA, I. 2020. Research of the Technical Seismicity due to Blasting works in Quarries and Their Impact on the Environment and Population, *Applied sciencies*, Vol. 11 (5), pp. 1-21.

Internal materials VSK MINERAL s.r.o. - Záhradné quarry [online]. Dostupné na internete: http://www.vskmineral.sk/lomy/zahradne/

Internal materials VSK MINERAL s.r.o. - *Záhradné quarry - Zvýšenie kapacity ťažby a spracovania stavebného kameňa - andezitu v dobývacom priestore Záhradné*.

Internal materials VSK MINERAL s.r.o. – Záhradné quarry

JACKO, S., FARKAŠOVSKÝ, R., DIRNEROVÁ, D., KONDELA, J., RZEPA, G., ZAKRŠMÍDOVÁ, B. 2016. The late cretaceous conditions of the Gombasek beds sedimentation (silica nappe, western carpathians). *Acta Montanistica Slovaca*, Vol. 21 (4), pp. 259-271.

KALÁB, Z., KNEJZLÍK, J., KOŘÍNEK, R., ŽŮREK, P., DOLEŽAL, J., NEUMAN, M. 1997. Analysis of seismic events induced by blasting operations in the opencast mine. *Mine Planning and Equipment Selection*, 1st Edition.

KALÁB, Z., PANDULA, B., STOLÁRIK, M., KONDELA, J. 2013. Examples of law of seismic wave attenuation, *Metalurgija*, No. 52/3, pp. 387-390.

KALAB, Z. 2018. Influence of vibrations on structures. Acta Montanistica Slovaca, Vol. 23 (3), pp. 293–311.

KONČEK, M., ŠOFRANKO, M., ČAMBÁL, J., FEHÉR, J., ŠUVER, M. 2020. Optimalization blasting operations in the quarry Sedlice in terms of meeting quality and safety requirements. *Exploration Geophysics, Remote Sensing and Environment,* Vol. 27(2), pp. 47-54.

KONČEK, M., ŠOFRANKO, M., ČAMBÁL, J., FEHÉR, J., ŠUVER, M. 2020. Optimalization of blasting works in Sedlice quarry. *Blasting Technique* 2020, Vol. 2020, pp. 167-174.

KONČEK, M., PANDULA, B., KONDELA, J., ŠOFRANKO, M., ČAMBAL, J., FEHÉR, J. 2021. Optimization of the impact of technical seismicity on the road bridge. *Transport & Logistics: The International Journal*, Vol. 21 (51), pp. 1-12.

KONDELA, J., PANDULA, B. 2012. Timing of quarry blasts and its impact on seismic effects. *Acta Geodynamica et Geomaterialia,* Vol. 9 (2), pp. 155-163.

KONDELA, J., PANDULA, B. 2013. Výskum účinkov technickej seizmicity na krasové útvary v karbonátových horninových masívoch, *Nové technológie pre vyhľadávanie geotermálnych zdrojov*: Medzinárodná vedecká konferencia, Vol. 2013, pp. 49-61.

KUDELAS, D., PANDULA, B., CEHLÁR, M., TAUŠOVA, M., KOŠČO, J. 2019. Critical Distance of the Seismic Waves' Impact in Disintegration of Rock Blasting. *Shock and Vibration*, pp. 1-8.

LANGEFORS, U., KIHLSTRÖM, B. 1978. *The modern technique of Rock Blasting*. A Halsted Press Book, pp. 281-288.

LEŠŠO, I. 2018. *Optimalizácia milisekundového časovania pri trhacích prácach v lomoch*. Manuskript, Košice, pp. 2.

MA, L., LI, K., XIAO, S., DING, X., CHINYANTA, S. 2016. Research on Effects of Blast Casting Vibration and Vibration Absorption of Presplitting Blasting in Open Cast Mine. *Shock and Vibration,* Vol. 2016, pp. 1-10.

MELLO, J., ELEČKO, M., PRISTAŠ, J., REICHWALDER, P., SNOPKO, L., VASS, D., VOZÁROVÁ, A. 1996. *Geologická mapa slovenského krasu*, MŽP-GSSR, Bratislava.

MOSINEC, V. N. 1976. Drobjaščee i sejsmičeskoje dejstvije vzryva v gornych porodach. Nedra.

PANDULA, B. - JELŠOVSKÁ, K. 2008. New criterion for estimate of ground vibrations during blasting operations in quarries. *Acta Geodynamica et Geomaterialia*. Vol. 5 (2), pp.147-152.

PANDULA, B., KONDELA, J. 2010. *Methodology of seismic blasting works*. Publisher: SSTVP DEKI Design, Ltd., Banská Bystrica, Slovakia, (in Slovak). p. 154.

PANDULA, B., KONDELA, J., PACHOCKA, K. 2012. Attenuation law of seismic waves in technical seismicity. *Metalurgija,* Vol. 51 (3), pp. 427-431.

PANDULA, B., KONDELA, J. 2012. Zhodnotenie účinkov technickej seizmicity na Brekovskú jaskyňu v Humenských vrchoch, *Aragonit*, Vol. 17 (1-2), pp. 18 - 24.

PANDULA, B., KONDELA, J., BUDINSKÝ, V., PREKOPOVÁ, M., BAULOVIČ, J., FEHÉR, J., ČAMBÁL, J. 2018. Optimatization of seismic effect during blasting operations by velocities of seismic wave´s propagation in quarries. *Exploration Geophysics, Remote Sensing and Environment*, Vol. 25 (2), pp. 41-52.

PANDULA, B., KONDELA, J. 2020. *Meranie vplyvu technickej seizmicity v lome Záhradné na okolitú zástavbu obce Záhradné a Fintice*. Expert opinion of the bench blast no. 34, Košice, 2020, TU FBERG. pp. 24.

PANDULA, B., KONDELA, J. 2020. *Meranie vplyvu technickej seizmicity v lome Záhradné na okolitú zástavbu obce Záhradné a Fintice.* Expert opinion of the bench blast no. 35, Košice, 2020, TU FBERG. pp. 23.

PANDULA, B., KONDELA, J., KONČEK, M., FEHÉR, J. 2021. Optimization of seismic effects of blasting works in Lietavská Lúčka quarry. *Exploration Geophysics, Remote Sensing and Environment*, Vol. 28 (2), pp. 29-48.

PANDULA, B., KONDELA, J., KONČEK, M., ŠOFRANKO, M., BUCHLA, I. 2021. Optimization millisecond timing delay of blasting in Malá Vieska quarry. *Exploration Geophysics, Remote Sensing and Environment*, Vol. 28 (2), pp. 49-62.

PANDULA, B., KONDELA, J., KONČEK, M., FARKAŠOVSKÝ, R. 2021. Optimalizácia vplyvu trhacích prác v lome Gombasek na Gombaseckú jaskynu. *Aragonit*, Vol. 26 (2), pp. 18 - 24.

PERMINOVA, O. M., LOBANOVA, G. A. 2018. A logistic approach to establishing balanced scorecard of Russian oil-producing service organizations. *Acta logistica*, Vol. 5(1), pp. 1-6.

PUTIŠKA, R., BRIXOVÁ, B., BEDNÁRIK, M., TORNYAI, R., DOSTÁL, I., BUDINSKÝ, V. 2021. Shallow gephysical survey as a tool for compactness verification of the underground sealing wall. *Acta Geologica Slovaka*, Vol 13 (2), pp. 199-204.

REMLI, S., BENSELHOUB, A., ROUAIGUIA, I. 2019. Optimization of blasting parameters in open cast quarries of el hassa-bouira (Northern Algeria). *GeoScience Engineering*, Vol. 2019 (1), pp. 53-62.

SOLTYS, A., TWARDOSZ, M., WINZER, J. 2017. Control and documentation studies of the impact of blasting on buildings in the surroundings of open pit mines. *Journal of Sustainable Mining*, Vol. 16(4), pp. 179-188.

SÁNCHEZ-SIERRA, S.T., CABALLERO-MORALES, S.O., SÁNCHEZ-PARTIDA, D., MARTÍNEZ-FLORES, J.L. 2018. Facility location model with inventory transportation and management costs. *Acta Logistica*,Vol. 5 (3), pp. 79-86.

SISKIND, D. E., STAGG, M. S., KOPP, J. W., DOWDING, C. H. 1980. *Structure Response and Damage Produced by Ground Vibration From Surface Mine Blasting*. Bureu of Mines RI 8507, p. 74.

STN Eurocode 8, 2010, *Design of structures for seismic resistance*. Part 1, National Annex, Amendment 1 (STN EN 1998-1 / NA / Z1), Bratislava, Slovakia, 2010. (in Slovak)

VÉGSÖOVÁ, O., STRAKA, M., ROSOVÁ, A. 2019. Protecting and Securing an Environment Affected by Industrial Activity for Future Utilization. *Rocznik Ochrona Środowiska*, Vol. 21, pp. 98-111.

WANG, Z., CHENG, F., CHEN, Y., CHENG, W. 2013. A comparative study of delay time identification by vibration energy analysis in millisecond blasting, *International Journal of Rock Mechanics and Mining Sciences*, Vol. 60, pp. 389–400.

ZHANG, W., GOH, A.T.C. 2016. Evaluating seismic liquefaction potential using multivariate adaptive regression splines and logistic regression. *Geomechanics and Engineering*, Vol. 10(3), pp. 269-284.

ZHOU, J., LI, C.H., KOOPIALIPOOR, M., ARMAGHANI, D. J., PHAM, B.T. 2020. Development of a new methodology for estimating the amount of PPV in surface mines based on prediction and probabilistic models (GEP-MC), *International Journal of Mining, Reclamation and Environment*, Vol. 35, pp. 48–68.

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