



**RESEARCH THE TECHNICAL SEISMICITY OF BLASTING OPERATIONS IN QUARRIES
AND THEIR IMPACT ON THE INDOOR ENVIRONMENT OF BUILDINGS**

**VÝSKUM TECHNICKEJ SEIZMICITY TRHACÍCH PRÁC V LOMOCH
A ICH VPLYV NA VNÚTORNÉ PROSTREDIE BUDOV**

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Abstract

The paper presents the results of research conducted in laboratory conditions and in quarry operations in the Slovak Republic. The research was focused on the assessment of vibrations induced by blasting operations on residential buildings and their residents. Experimental blasting carried out in Nižný Hrabovec quarry demonstrated that the reduction of vibration intensity below $2 \text{ mm}\cdot\text{s}^{-1}$ was not perceived as dangerous by residents, which allowed the continuation of mining operations.

Abstrakt

V príspevku sú prezentované výsledky výskumu realizovaného v laboratórnych podmienkach a v lomových prevádzkach Slovenskej republiky. Výskum bol zameraný na hodnotenie vibrácií vyvolaných trhacími prácami na bytové objekty a obyvateľov týchto objektov. Experimentálne odstrely uskutočnené v lome Nižný Hrabovec preukázali, že zníženie intenzity vibrácií pod hodnotu 2 mms^{-1} nepociťovali obyvatelia ako nebezpečné, čím sa umožnilo pokračovať v ťažobných prácach.

Keywords

quarry blasting, optimization of millisecond delay of quarry blasting, minimization of vibration impacts on buildings and residents

Kľúčové slová

trhacie práce v lomoch, optimalizácia milisekundového časovania trhacích prác v lomoch, minimalizácia vibračných vplyvov na budovy a obyvateľov

1. Introduction

Mineral extraction is currently carried out in both larger and smaller surface mining operations using blasting. Blasting works are the most technically and economically acceptable tool for breaking hard rocks and affects the entire mining operation. It affects the method and speed of loading, transporting, crushing and finalizing the product. Proper fragmentation affects the maintenance and repair of operating equipment in quarries. Despite its positive advantages, the population perceives it negatively. The reasons are associated with its undesirable effects, such as noise, dustiness and technical seismicity. From the point of view of safety, stability of buildings, infrastructure and preservation of natural resources (water sources, caves), the main problem is the negative seismic effects of blasting (Abbaspour et al., 2018; Dojčár et al., 1996; Langefors and Kihlström, 1978).

Environmental protection laws, together with geological and mining laws, oblige a mining plant to protect its surroundings from the effects of mining activities. Vibrations caused by blasting affect not only buildings, but also the interior of buildings. If these buildings are located near quarries, residents may perceive these vibrations negatively. For this reason, it is necessary to constantly work on optimizing blasting operations. By applying appropriate millisecond timing, it is possible to reduce the intensity of vibrations to a level that residents will not perceive as negative effects inside buildings. Limit values for this intensity of vibrations have not yet been defined. To protect buildings from vibrations, normative values for the maximum speed and frequency of vibrations have been set. Hygiene standards for residents of apartment buildings have been applied, which assessed the impact of vibrations on residents by measuring the maximum speeds and accelerations of vibrations in the apartment building. (Baulovič et al., 2016; Betuš et al., 2025; Feher et al., 2021; Kondela and Pandula, 2012; Kudelas et al., 2019; Pandula and Kondela, 2010; Sambuelli, 2009; Soltys et al., 2019).

2. Methodology for assessing seismic effects of blasting operations in quarries

Before the measurement, the equipments placed at the measuring stations was calibrated and its sensitivity was verified. The devices recorded the graphic course of the individual components of the seismic wave during the research blasting works. The vibrographs were placed in the places so as to allow the analysis of the impact of technical seismicity on the monitored objects and residents. During the measurement, the devices were placed in the quarry operations, near the investigated blasting works (measurement standpoint MS 1) and the monitored residential buildings (measurement standpoint MS 2). At the MS 1 measurement standpoint in the quarry, ABEM Vibracord and Tellus vibrographs were installed near the initiation borehole of the blasting works. Minimate Pro 6 and ABEM Vibracord vibrographs were installed on the foundation wall of the monitored residential building (measurement standpoint MS 2), and CESVA VC 431 and Svantek 958 A triaxial vibrometers were installed inside the residential building. Minimate Pro 6 and ABEM Vibracord vibrographs measured the impact of vibrations on the building, and CESVA VC 431 and Svantek 958 A triaxial vibrometers measured the impact of vibrations of blasting works on the residents inside of the building. Analysis of the vibration speed during blasting in quarry and on the monitored object enabled the prediction of the use of maximum values of explosive charges during blasting so that there was no damage to residential buildings and residents did not experience these vibrations negatively.

Based on the measured values of vibration speeds and frequencies of individual components of seismic waves during research blasting, we had the opportunity to assess the effects of blasting in various quarries. We evaluated the seismic effects according to the STN EN 1998-1/NA/Z1 standard, which deals with seismic loads on building structures. We evaluated the effects on residents according to the ISO 2631-2 standard and the Decree of the Ministry of the Environment of the Slovak Republic No. 549/2007 Coll., which concerns protection against noise and vibration.

According to Eurocode 8, design of structures for seismic resistance STN EN 1998-1/NA/Z1, seismic loads and rules for buildings:

- limit value of vibration velocity $v = 3 \text{ mm}\cdot\text{s}^{-1}$, for frequencies less than 10 Hz. Frequencies less than 10 Hz are typical for blasting works in quarries.

At this value of vibration velocity, no damage to the building will occur.

According to the Decree of the Ministry of Health of the Slovak Republic No. 549/2007 for residential rooms, dormitories, retirement homes, for the reference time interval the permissible vibration acceleration values are:

- evening: $a_{w\max,p} = 0.11 \text{ m}\cdot\text{s}^{-2}$
- night: $a_{w\max,p} = 0.05 \text{ m}\cdot\text{s}^{-2}$
- day: $a_{w\max,p} = 0.11 \text{ m}\cdot\text{s}^{-2}$.

The maximum permissible vibration values are usually set in such a way as to minimize the disturbing effect on the human body. For residential environments, vibration acceleration values up to $0.3 \text{ m}\cdot\text{s}^{-2}$ are typical. If vibration values exceed these limits, this may cause inconveniences, such as reduced sleep quality or deterioration of the well-being of residents.

3. Measuring the impact of vibrations on humans in laboratory conditions

The measurement of the impact of vibrations on the monitored person was carried out in the laboratory of the Center for Research and Innovation in Civil Engineering of the Faculty of Civil Engineering of the Technical University of Košice. The aim of the measurement was to assess the impact of vibrations on a person at individual set frequencies using vibrations of a concrete beam induced by a hydraulic piston. We measured the vibrations of the beam in intervals from 1 Hz to 12 Hz. The vibrations were induced by the pressure of a single-axis hydraulic press AH160 on the concrete beam with an amplitude of $A = 0.5 \text{ mm}$ in two-minute intervals. The monitored person sat on the beam and recorded the sensations of vibrations at individual frequencies. The ABEM Vibraloc, CESVA VC 431 and Svantek 958 A instruments were used for the measurement (Fig. 1).

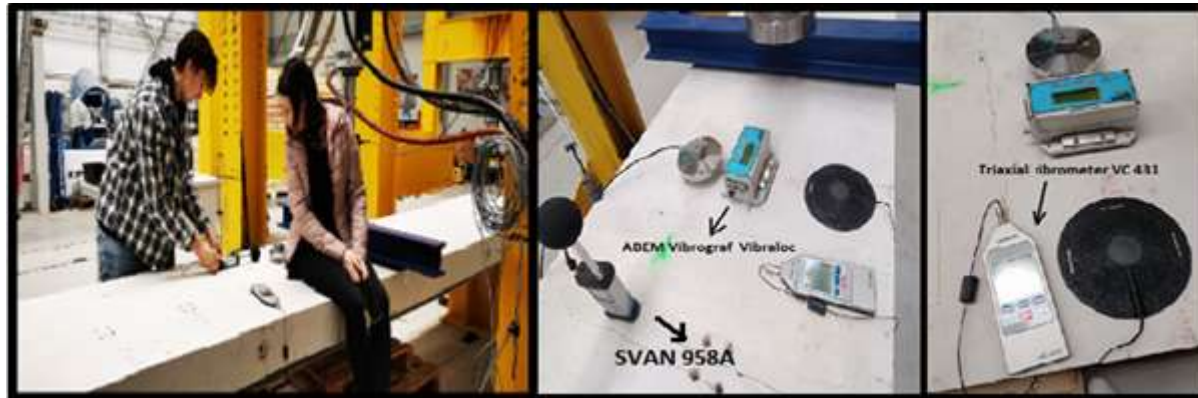


Fig. 1 Position of the instruments and the monitored person when measuring vibrations on a concrete beam

Device type	SVAN 958A	Standard	DIN 4150-3
Serial No.	59114		
File name	Buffe_46		
Measurement time	10:28:08		
Measurement date	24. 3. 2025		
Logger step	5 s		
FFT band	175.000 Hz		

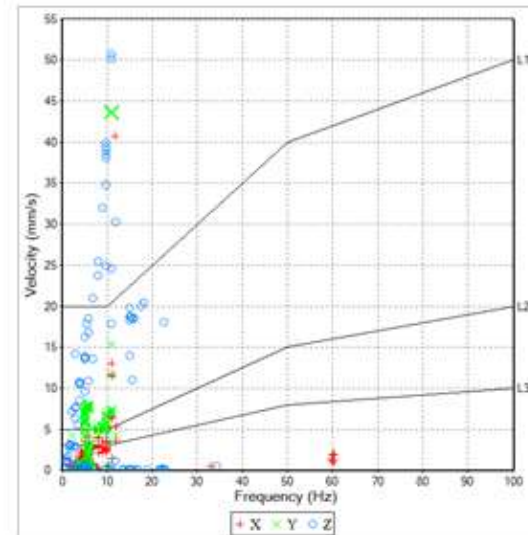


Fig. 2 Graphical recording of vibration speeds measured by the Svantek SVAN 958A vibrograph

Tab. 1 Measured values of vibration acceleration a_w in the laboratory using a CESVA VC 431 triaxial vibrometer, vibration velocity values v_z measured using an vibrometer SVAN 958 A and the feeling of the monitored person during the measurement

f (Hz)	a_{wx} ($m.s^{-2}$)	a_{wy} ($m.s^{-2}$)	a_{wz} ($m.s^{-2}$)	v_z ($mm.s^{-1}$)	Vibration sensations by the monitored person
1	0.20048	0.01638	1.13141	0.94	Insufficient perception
2	0.6331	0.01207	0.89642	2.09	Very weak vibrations
3	0.13104	0.01046	0.71056	3.08	Weak vibrations
4	0.12107	0.00960	0.64758	7.38	Slightly more intense vibrations
5	0.115430	0.00909	0.61332	10.7	Weak shaking
6	0.10198	0.01511	0.51861	13.5	Gentle shaking
7	0.09781	0.01797	0.51070	18.1	Slight body shaking
8	0.09536	0.01791	0.51737	26.8	More intense body shaking
9	0.09190	0.01801	0.56648	34.4	Intense body shaking - unpleasant vibrations
10	0.09132	0,02602	0,58342	40.6	Very strong body shaking - unpleasant vibrations
11	0.08791	0.01821	0.71690	50.4	Strong and intense body shaking – very unpleasant vibrations
12	0.08530	0.01825	0.81090	52.5	Very intense, strong and painful body shaking

When measuring the vibrations of a concrete beam in the laboratory of the Faculty of Civil Engineering - Center for Research and Innovation in Civil Engineering, where we investigated the impact of vibrations on a the monitored person, acceptable effects were recorded at vibration speeds of up to 2.09 mm.s^{-1} and frequencies of 1 - 2 Hz. The vibrations were clearly felt as gentle tremors. These vibrations caused a slight movement of the beam that was noticeable, but did not cause a feeling of significant disturbance. The feelings of the monitored person at vibration speeds of 2.03 to 3.08 mm.s^{-1} and frequencies of 3 Hz were perceived as weak vibrations. The feelings of the monitored person at vibration speeds of 3.08 to 7.38 mm.s^{-1} and frequencies of 4 Hz were perceived as intense and unpleasant vibrations. At higher frequencies (5 - 12 Hz), the vibration speed increased even more, which led to strong tremors in the body. The

sensations of the monitored person became very strong and intense. The sensations of the monitored person at vibration speeds above $26.8 \text{ mm}\cdot\text{s}^{-1}$ and frequencies of 8 - 12 Hz were perceived as unbearable during prolonged exposure.

These results provide an overview of how vibrations affect the sensations of the monitored person at different frequencies. At frequencies up to 3 Hz and vibration speed values up to $2.09 \text{ mm}\cdot\text{s}^{-1}$, the vibrations felt by the monitored person were described as very weak vibrations and indistinct. These vibrations were not felt negatively by the monitored person.

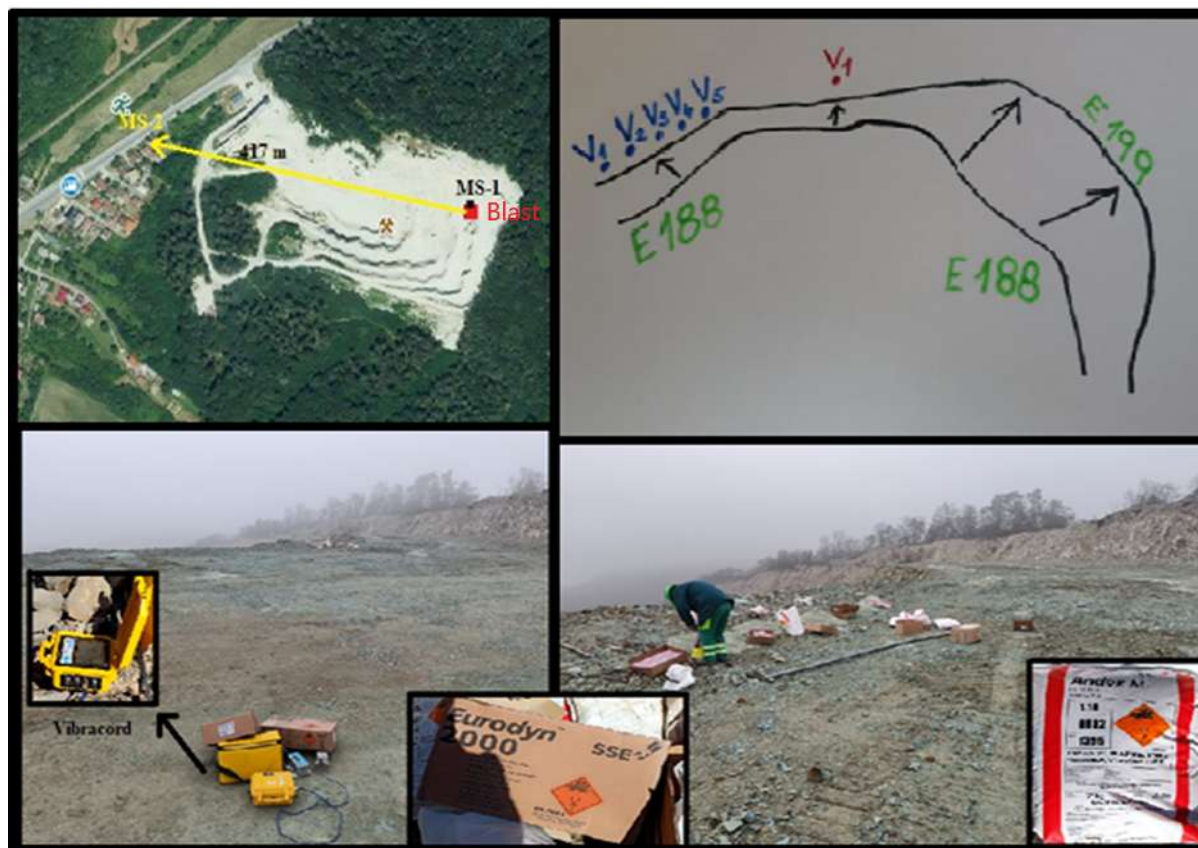


Fig. 3 Position of measuring standpoint MS 1 of research blastings in the quarry Nižný Hrabovec. Measuring standpoint MS1, measuring instruments Vibracord Tellus and ABEM Vibracord at a distance of 17.5 m from the separate borehole of the first blasting, 31.5 m from the boreholes of the second blasting and 417 m from the monitored residential building MS 2

4. Measuring the impact of seismic effects of blasting on buildings and the indoor environment of buildings in situ

Research into the impact of seismic effects of blasting was carried out while measuring the technical seismicity during zeolite mining in the quarry Nižný Hrabovec, during andezite mining in the quarry Slanec and during limestone mining in the quarry Trebejov.

For the research blasting in the quarry Nižný Hrabovec, 5 vertical boreholes with a length of 12 m and one separate vertical borehole of the same length were drilled. The maximum charge in one borehole during the first blasting was 40 kg. The total weight of explosives used during the second blasting was 100 kg of Andex M explosive and 100 kg of Eurodyn 2000 explosive. The maximum charge per time stage was 40 kg. A non-electric detonator with a millisecond timing delay of 9 milliseconds was used for initiation. During the first research blasting, one separate borehole was fired, and during the second research blasting, 5 boreholes were fired with a millisecond timing delay of 9 milliseconds. The position of these research blastings and the monitored residential building in the village of Nižný Hrabovec is shown in Figure 3 and 4.



Fig. 4 Measuring standpoint MS 2 and position of measuring instruments in the monitored residential building No. 218 in the village of Nižný Hrabovec at a distance of 417 m from the research blastings

Tab. 2 Measured vibration values during the first blasting of one borehole and the second blasting of five boreholes and the impact of vibrations on the monitored person

Measuring standpoint/ Instrument	V_x (mm.s ⁻¹)	V_y (mm.s ⁻¹)	V_z (mm.s ⁻¹)		
MS1/Vibracord Tellus - first blasting	95.87	125.36	59.52		
MS1/Vibracord Tellus - second blasting	80.44	79.70	43.61		
MS1/ABEM Vibracord - first blasting	97.66	41.96	145.43		
MS1/ABEM Vibracord - second blasting	55.87	35.01	82.66		
MS2/Minimate PRO6 - first blasting	0.318	0.536	0.457		
MS2/Minimate PRO6 - second blasting	0.560	1.11	0.780		
MS2/ABEM Vibracord - first blasting	0.348	0.434	0.209		
MS2/ABEM Vibracord - second blasting	0.696	1.274	0.520		

MS2/Svantek – first blasting	0.955	0.266	0.6		
MS2/Svantek – second blasting	1.928	0.676	0.911		
Measuring standpoint/ Instrument	a_x (m.s ⁻²)	a_y (m.s ⁻²)	a_z (m.s ⁻²)	Feelings of monitored person	Impact on monitored person
MS2/CESVA – first blasting	0.01018	0.2088	0.04394	Insufficient perception	No impact on the person's comfort
MS2/CESVA – second blasting	0.00226	0.05247	0.01350	Insufficient perception	No impact on the person's comfort

The source of seismic effects in the quarry Slanec was mining blasting on a hypersthene-augitic andesite deposit located approximately 700 m northeast of the village of Slanec in the cadastral territory of the village of Slanec in eastern Slovakia.

On the second stage of the Slanec quarry, mining explosion No. 125/2024 was carried out. For the mining explosion, 42 boreholes were drilled with borehole lengths from 17 m to 19.6 m. For disconnecting the rock massif, 3050 kg of Andex M explosive, 125 kg of Eurodyn 65/2500 explosive and 360 kg of Senatl 72/2400 explosive were used. The total explosive charge in the boreholes was 3535 kg. The maximum charge in one borehole was 87.5 kg of explosive. Millisecond timing 25 ms, 42 ms, 67 ms. Non-electric ignition. The position of the mining blast and the monitored residential house at a distance of 1872 m in the village of Slanec is shown in Figures 5 and 6.

The source of seismic effects in the quarry Trebejov was mining blasting on a dolomite deposit in the northeastern cadastre of the Trebejov municipality. The Trebejov quarry is located 800 meters east of the Trebejov municipality, 13.5 km north of Košice and 17 kilometers from Prešov in eastern Slovakia.



Fig. 5 Position of measuring standpoint MS 1 and MS 2 of blasting in the quarry Slanec



Fig. 6 Measuring standpoint MS 2 and position of measuring instruments in the monitored residential building in the village of Slanec at a distance of 1872 m from the blasting in the quarry Slanec

Tab. 3 Measured vibration values during blasting in the quarry Slanec and the impact of vibrations on the monitored person

Measuring standpoint/ Instrument	v_x (mm.s ⁻¹)	v_y (mm.s ⁻¹)	v_z (mm.s ⁻¹)		
MS1/Vibracord Tellus	231	126	110		
MS2/Minimate PRO6 1	0.363	0.599	0.544		
MS2/Minimate PRO6 2	0.370	0.583	0.575		
MS2/Svantek	1.31826	0.36728	0.01660		
	a_{wx} (m.s ⁻²)	a_{wy} (m.s ⁻²)	a_{wz} (m.s ⁻²)	Feelings of monitored person	Impact on monitored person
MS2/CESVA	0.03715	0.00347	0.00622	Insufficient perception	No impact on the person's comfort

During the mining blasting operation number 3087, 22 boreholes were drilled with a depth of 30.2 - 30.7 m. The total weight of explosives used in the blasting operation was 4066.0 kg. The explosives used included Andex A - 2950 kg, Andex M, 80/2500 - 250 kg, Andex 2.70/1500 - 816 kg and Eurodyn 2000, 65/ 2500 - 50.00 kg. The maximum charge in the borehole was 197.5 kg. The millisecond timing of 17 ms and 25 ms was used. The monitored residential building was 669 m from the blasting operation (Fig. 7, 8).

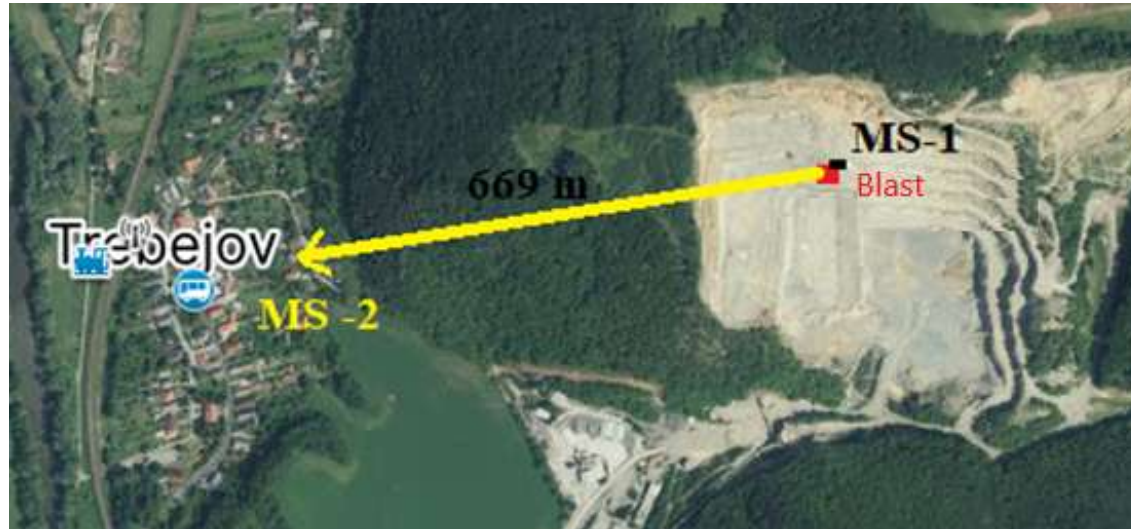


Fig. 7 Position of measuring standpoint MS 1 and MS 2 of blasting in the quarry Trebejov



Fig. 8. Measuring standpoint MS 1 and MS 2. Position of measuring instruments in Trebejov quarry and the monitored residential building in the village of Trebejov at a distance of 669 m from the blasting

Tab. 4 Measured vibration values during blasting in the quarry Trebejov and the impact of vibrations on the monitored person

Measuring standpoint/ Instrument	v_x (mm.s ⁻¹)	v_y (mm.s ⁻¹)	v_z (mm.s ⁻¹)		
MS1/Vibraloc	178.2	180.3	296.9		
MS2/Vibraloc	2.087	3.300	1.301		
MS2/Svantek	6.531	5.248	1.641		
	a_{wx} (m.s ⁻²)	a_{wy} (m.s ⁻²)	a_{wz} (m.s ⁻²)	Feelings of monitored person	Impact on monitored person
MS2/CESVA	0.07136	0.00408	0.00500	More intense vibrations	Comfort was disturbed

The source of the seismic effects was mining blasting No. 621 on a diorite porphyry deposit, which is located approximately 8 km northeast of Prešov in the cadastral territory of the municipalities of Vyšná Šebastová and Podhradík in eastern Slovakia.

During the blasting work, 21 boreholes were drilled with a borehole diameter of 89 mm and a depth of 25 m. The explosives used were Andex M 2275 kg, Senatel 96 kg and Riodin 50 kg. A total of 2421 kg of explosives and 40 detonators were used. Timing 25 ms. 124 kg of explosives were used per one borehole. The monitored residential building was 445 m from the blasting site (Fig. 9, 10, 11).



Fig. 9 Position of measuring standpoint MS 1 and MS 2 of blasting in the quarry Maglovec



Fig. 10 Measuring standpoint MS 1 and MS 2. Position of measuring instruments at the monitored residential building in the village of Seveřná at a distance of 445 m from the bench blasting in Maglovec quarry

Tab. 5 Measured vibration values during blasting in the quarry Maglovec and the impact of vibrations on the monitored person

Measuring standpoint/ Instrument	v_x (mm.s ⁻¹)	v_y (mm.s ⁻¹)	v_z (mm.s ⁻¹)		
MS1/Vibriloc	48.4	104.5	104.9		
MS2/Vibriloc	0.55	1.4	0.98		
MS2/Svantek	2.541	2.951	2.679		
	a_{wx} (m.s ⁻²)	a_{wy} (m.s ⁻²)	a_{wz} (m.s ⁻²)	Feelings of monitored person	Impact on monitored person
MS2/CESVA	0.00187	0.05558	0.00961	Weak vibrations	Comfort was disturbed

5. Analysis and evaluation of measured data

By analyzing the measured vibration values during research blasting in the quarry Nižný Hrabovec, we found that the maximum vibration speed in the monitored residential building when one borehole was fired was 0.955 mm.s⁻¹ and when five boreholes were fired it reached a value of 1.928 mm.s⁻¹. The monitored person felt the vibrations as very weak without feeling any discomfort. When analyzing the millisecond timing of the blasting, we found that the blasting work with a timing of 9 ms caused vibrations on the foundations of the residential building with a maximum value of $v_y = 0.536$ mm.s⁻¹ when one borehole was fired and $v_y = 1.27$ mm.s⁻¹ when five boreholes were fired. According to the STN EN 1998-1/NA/ZI standard, these values are safe for residential buildings.

By analyzing the measured vibration values during mining blasting in the quarry Slanec, we found that the maximum vibration speed in the monitored residential building during blasting was 1.3 mm.s⁻¹. The monitored person did not feel the vibrations. When analyzing the millisecond timing of the blasting, we found that blasting work with timings of 25 ms, 42 ms, 67 ms caused vibrations on the foundations of the residential building with a maximum value of $v_y = 0.599$ mm.s⁻¹. According to the STN EN 1998-1/NA/ZI standard, these values are safe for residential buildings.

By analyzing the measured vibration values during mining blasting in the quarry Trebejov, we found that the maximum vibration speed in the monitored object during blasting was 6.5 mm.s⁻¹. The monitored person noted weak to moderate vibrations with a feeling of discomfort. When analyzing the millisecond timing of the blasting, we found that blasting work with timings of 17 ms and 25 caused vibrations on the foundations of the residential building with a maximum value of $v_y = 3.3$ mm.s⁻¹. According to the STN EN 1998-1/NA/ZI standard, these values are safe for residential buildings.

By analyzing the measured vibration values during mining blasting in the quarry Maglovec, we found that the maximum vibration speed in the monitored residential building during blasting was 2.95 mm.s^{-1} . The monitored person felt weak vibrations. Comfort was briefly disturbed. When analyzing the millisecond timing of the blasting, we found that blasting work with a timing of 25 ms caused vibrations on the foundations of the residential building with a maximum value of $v_y = 1.4 \text{ mm.s}^{-1}$. According to the STN EN 1998-1/NA/ZI standard, these values are safe for residential buildings.

6. Conclusion

Research in the quarries Nižný Hrábovec, Slanec, Trebejov and Maglovec focused on the correlation of vibration speeds of monitored residential and indoor environments of residential buildings. Laboratory measurements of the effects of vibrations on the monitored person, research blasting carried out in the Nižný Hrábovec quarry and mining blasting in the Slanec, Trebejov and Maglovec quarries demonstrated that by reducing the vibration intensity below 2 mm.s^{-1} , the vibrations felt by the monitored person were described as very weak vibrations with no impact on the comfort of the residents.

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