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ASSESSMENT OF THE NEGATIVE EFFECTS OF BLASTING IN QUARRIES ON WATER RESOURCES

POSÚDENIE NEGATÍVNYCH VPLYVOV TRHACÍCH PRÁC V LOMOCH NA VODNÉ ZDROJE

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Abstract

Vibration is one of the basic problems in quarries because its effects can cause critical damage to the environment near the quarry. For this reason, it is necessary to constantly deal with the evaluation of the effects of blasting and the optimization of technical parameters of blasting. The article presents the results of experimental research aimed at optimizing blasting work in the quarries et Slovakia. Using the law of attenuation of seismic waves, the maximum mass charge weight explosives per timing stage was calculated in the quarries so that blasting works did not cause negative effects on the water resources. The results of the research presented in the article and the optimization of the technical parameters of the blasting works will make it possible to repeat the blasts in the quarries without negative effects on nearby natural phenomena and the entire near area.

Abstrakt

Vibrácie sú jedným zo základných problémov v lomoch, pretože ich účinky môžu spôsobiť kritické škody na životnom prostredí v blízkosti lomu. Z tohto dôvodu je potrebné neustále sa zaoberať vyhodnocovaním účinkov odstrelov a optimalizáciou technických parametrov odstrelov. Článok prezentuje výsledky experimentálneho výskumu zameraného na optimalizáciu trhacích prác v lomoch na Slovensku. Pomocou zákona útlmu seizmických vĺn bola v lomoch vypočítaná maximálna hmotnosť nálože výbušnín na časový stupeň tak, aby trhacie práce nespôsobili negatívne účinky na vodné zdroje. Výsledky výskumu prezentované v článku a optimalizácia technických parametrov trhacích prác umožnia opakovanie odstrelov v lomoch bez negatívnych vplyvov na blízke prírodné javy a celé blízke okolie.

Keywords

Blastings, seismic safety, quarries, water resources, the law of attenuation of seismic waves

Kľúčové slová

Trhacie práce, seizmická bezpečnosť, lomy, *vodné zdroje, zákon útlmu seizmických vĺn*

1. Introduction

Extraction of mineral raw materials is one of the basic parameters that have an impact on the development of industrial activities in society. The growing demand for raw materials has an impact on increasing mining. The consequence of this is an increase in negative environmental impacts in the immediate vicinity of mining operations. One of the main tasks of contemporary society is sustainable mining, with as little impact on the environment as possible. Therefore, it is necessary to look for methods and practical solutions for the maximum reduction of the negative impacts of mining activity on human society, infrastructure and the environment (Fehér et al., 2020)

One of the main problems is technical seismicity and the seismic effects of blasting on society, infrastructure, sources of drinking and mineral water (Konček et al., 2020).

Sources of drinking and mineral water located in the rock massif in the immediate vicinity of mining operations are problematic. It is assumed that their lifespan and quality will not be threatened by mining. The problem of assessing the effects of the seismic effects of blasting on sources of drinking and mineral water is in two aspects:

- assessment of the physical condition of the water management work,
- assessment of the rock environment that is a water collector.

The assessment of the impact of seismic effects on water management works is practically similar to the assessment of construction objects. The assessment of the impact of technical seismicity is thus defined by the norm. When assessing the collector of a water source, it is necessary to determine at which values of oscillation speeds no further faults occur even in a broken rock environment. Due to the variability of the lithology and structure of the rock environment in which underground water (drinking, mineral, healing) accumulates, there is no uniformly defined procedure for assessing the effects of technical seismicity.

We do not come with any recommendations for the assessment of surface and underground mining and engineering works built directly in the rock mass. These works are usually considered as buildings on the surface, which is far from capturing the real conditions, because the rock mass can withstand much higher vibration velocities compared to buildings (Soltys et al., 2017).

Ensuring the seismic safety of these works during blasting works consists in preventing the formation of residual deformations in the mass of rocks on which these works are built. Only such strain that does not cause permanent deformations is permissible in the rock mass. The evaluation of the rock stability of pits, adits, underground chambers, protective pillars, hydrotechnical tunnels, slopes, notches, quarry floors, heaps, etc., is therefore based on the deformation properties of rocks. The criterion is the relative deformation and the benchmark is again the particle velocity v_p. Some authors rely on the general deformation model of rocks as a continuous elastic-plastic environment. Under a certain amount of pressure, both the loading and the relief of the rock take place flexibly, while upon exceeding a certain limit, permanent residual deformations occur. Their accumulation due to periodic blasting can lead to loss of stability and rock collapse. Then, the relative deformations $\varepsilon_0 \leq 0.0002 \div 0.0003$ are still within the elasticity limits (Dojčár et al., 1996; Pandula and Kondela, 2010).

For works that must have a long lifespan (notches, etc.), the condition of seismic safety can be expressed depending on the velocity of longitudinal waves in the mass c_p:

$$\boldsymbol{v_p = 0.0001 c_p} \text{ [m.s}^{-1}\text{]}$$

For underground and other mining works, due to their different required lifespan, the boundary conditions of vibration may be different. It is recommended to classify works into four classes, in the vicinity of which, depending on the lifespan, relative deformations of 10-4 ÷ 5.10-4 are permissible.

Depending on the function of the elastic-plastic properties of the rocks and the permissible relative deformation, the following relation is recommended for the calculation of the permissible particle velocity (Dojčár et al., 1996):

$$\boldsymbol{v_p = \frac{375 \cdot \left(c_p^2 - \frac{4}{3} \cdot c_s^2\right) \cdot \left\{[1 + (1 - 2 \cdot \mu) \cdot \varepsilon_0]^{\frac{8}{3}} - 1\right\}}{c_p \cdot [1 + (1 - 2 \cdot \mu) \cdot \varepsilon_0]^4}}$$

where:

- v_p is the permissible particle velocity [mm.s^{-1}],
- c_p, c_s are the velocities of longitudinal and transverse waves in the mass [m.s^{-1}],
- μ is the Poisson's ratio,
- ε_0 is the permissible relative deformation.

The values of permissible particle velocity v_p calculated from the formula for individual classes of mining works are provided in Table 3. These correspond very well with the values of cp measured and determined for solid rocks in various underground mines (300 ÷ 500 m.s^{-1}). For periodic blasts, it is recommended to reduce the permissible particle velocities in Tables 2 and 3 by the safety coefficient q_s, (v_p/q_s), depending on the object class T:

Tab. 1 Safety coefficient for individual object classes

Object class T	1	2	3	4
Safety coefficient q_s	1.52	1.44	1.36	1.3

The quality of buildings (q) is provided in Table 2. The overall quality consists of four sub-values:

$$q = q1 + q2 + q3 + q4.$$

Tab. 2 Particle velocities during periodic blasts

Rock properties	**Strength coefficien t cs**	***c_p [km.s^{-1}]***	**Permissible particle velocities v_p [mm.s^{-1}]**			
			1*	**2***	**3***	**4***
Strongly cracked and porous	0.5 ÷ 1	1 ÷ 2	41	82	122	204
Strongly cracked and porous	1 ÷ 3	2 ÷ 3	68	136	203	340
Rocky, strongly cracked	3 ÷ 5	3 ÷ 4	95	190	284	475
Relatively solid, cracked	5 ÷ 9	4 ÷ 5	122	244	367	600
Solid, slightly cracked	9 ÷ 14	5 ÷ 6	149	298	445	745
Very strong, solid	14 ÷ 20	6 ÷ 7	178	356	533	890

Classes of engineering works:

1* Particularly important works with a lifespan of over 10 years, ε_0 = 0.0001 (hydrotechnical tunnels, pits, main mining works, drainage and other water management works).

2* Important works with a lifespan from 5 to 10 years, ε_0 = 0.0002 (shaft bottoms, headings, ceiling pillars, stable slopes of floors and heaps, etc.).

3* Works with a short lifespan from 1 to 5 years, ε_0 = 0.0003, (corridors, chambers, etc.).

4* Works with a lifespan of up to one year, ε_0 = 0.0004, (stopes, slopes of working floors, etc.).

Tab. 3 Particle velocities during periodic blasts

Object class T	**Permissible particle velocities v_p [mm.s^{-1}] for the quality q of the object**								
	0	1	2	3	4	5	6	7	8
1	46	27.6	16.5	10	6	3.7	2.2	1.3	-
2	75	46	27.6	16.5	10	6	3.7	2.2	1.3
3	120	75.6	46	27.6	16.5	10	6	3.7	2.2
4	198	120	75	46	27.6	16.5	10	6	3.7

2. Source of vibrations and measurement methodology

Source of seismic effects was three test blastings of small-scale in the quarry Trenčianske Mitice Skaličky.

Parameters of test blastings - total charge in individual test blasts 150.0 kg of Emulex explosive, charge per one borehole 50 kg of Emulex explosive, timing of individual boreholes 25 and 42 milliseconds, diameter of boreholes 90 mm, depth of boreholes 15 m. The burden/spacing ratio was 1.

Digital four-channel vibrographs ABEM Vibraloc, Vibracord Tellus and Svantek were used to measure the seismic effects of test blasting. The geophones were placed on a special pad with sharp steel spikes, which ensured continuous contact with the ground. Each test blast was recorded individually at each measuring position and its effects were evaluated separately.

The measuring standpoints during test blastings were sited in such a way that the attenuation of vibrations between the blasting and water sources could be determined. In Fig. 1 are the positions of test blastings and individual measuring standpoints in Trenčianské Mitice Skaličky quarry and on the water sources nearby the quarry.

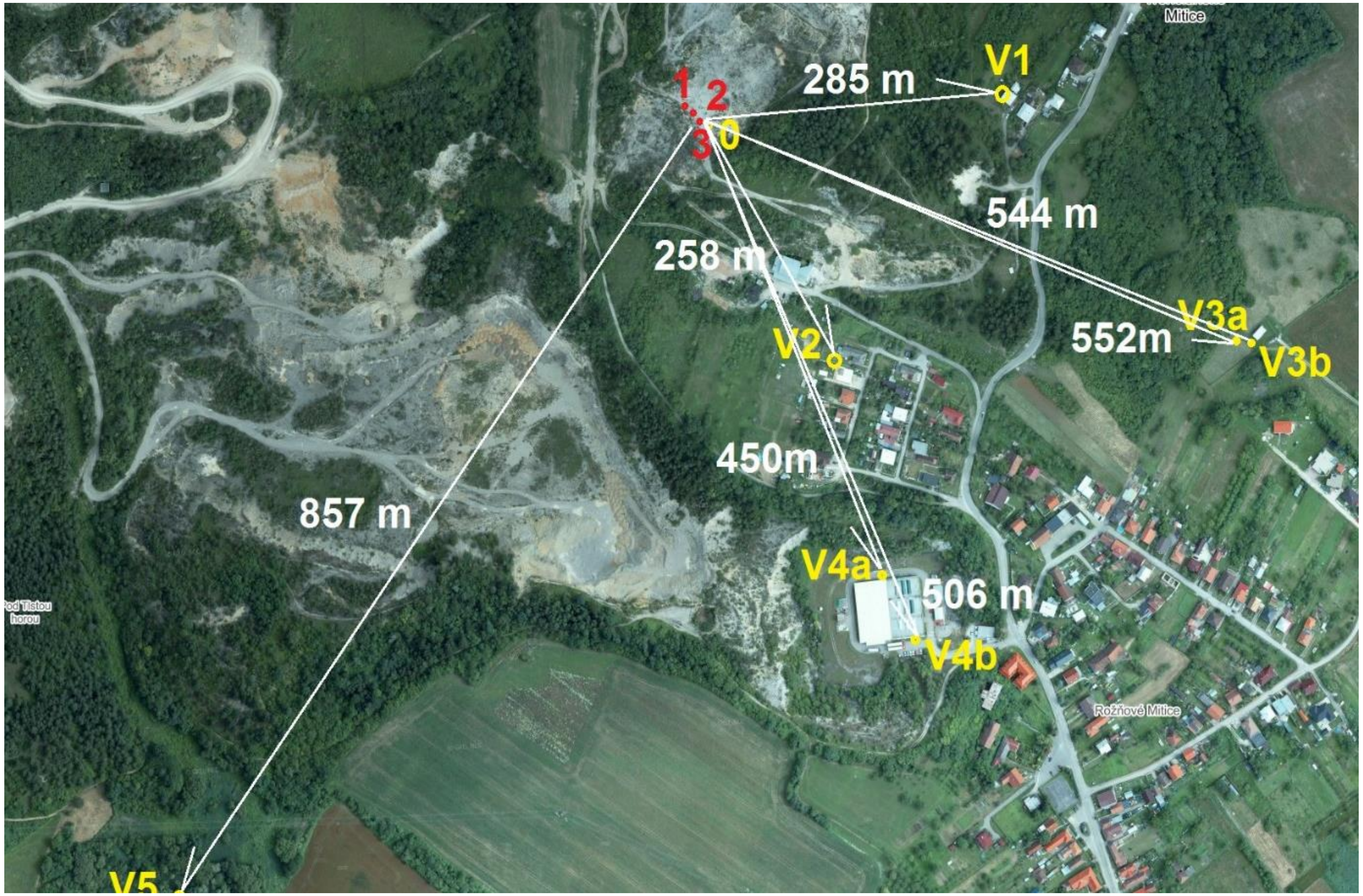


Fig. 1 The positions of test blasts 1, 2 and 3 in the quarry Trenčianske Mitice Skaličky in relation to measuring standpoints 0 to 7 located in the vicinity of the quarry

Measuring standpoint V0 quarry Trenčianske Mitice - Skaličky. The Vibracord measuring device with a three-component sensor was located on a rock base 15 m from the initiation borehole of blasting No. 3, 28 m from the initiation borehole of blasting No. 2 and 45 m from the initiation borehole of blasting No. 1 (Fig. 2).

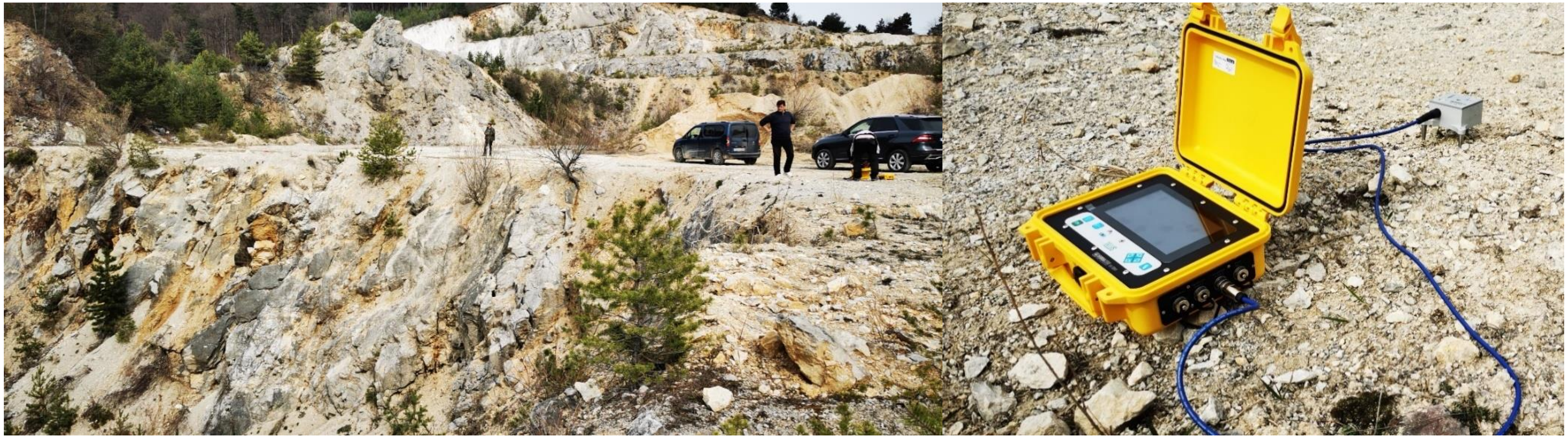


Fig. 2 Measuring standpoint V0 quarry Trenčianske Mitice - Skalničky and vibrograph Vibracord with a three-component geophon at a distance of 15 m from the initiation borehole of blast No. 3

Measuring standpoints V3a and V3b water source Zadná studňa spring and Zadná studňa pump. The sensors of the vibrographs Svantek were located on a concrete base (Fig. 3).

Measuring standpoint V5 borehole of natural mineral water MP-1. The vibrograph Svantek with a three-component sensor was located in the object of the mineral water source MP-1 (Fig. 4).

3. Transmision environment

The quarry Trenčianske Mitice - Skaličky is situated in the Triassic carbonate sediments of the Choč mantle, mainly dolomites and Wetterstein limestones (Fig. 5). The rock environment of limestones and dolomites is significantly disturbed. The limestone massif is less disturbed than the massif formed by dolomites. In the south, the quarry is bounded by the Neogene sediments of the Bánovska highlands. On Quaternary sediments near

Fig. 3 Measuring standpoints V3a and V3b water source Zadná studňa spring and pump and vibrographs Svantek with sensors

Fig. 4 Measuring standpoint V5 water source MP-1 and vibrograph Svantek with positioning of the three-component geophon SVAN979A

the former natural springs of mineral waters, there is a protected natural formation - Mitická Slatina bog. There are several water sources in the vicinity of the quarry Trenčianske Mitice Skaličky. Among the protected by law since 2002 and used is the water source MP-1, intercepted by a borehole in 1992 (Melioris, Drexler, 1996). The hydrogeological structure in Trenčianske Mitice is an open hydrogeological structure with a semi-covered spring area (Fig. 5).

The collector is the rock environment of a different lithological and tectonic unit (Chočský nape) than the tectonic unit in which mining takes place (Krížňanský nape), the contact of the units is tectonic, which reduces the transmission of magnitudes of particle velocities to the rock environment of the collector (Brixová et al., 2018):

the rate of tectonic disruption of the rock environment of the collector is moderately high based on the analogy of the outcrop of marly, organodetritic and crinoid limestones of the Křižňany nape - (e.g. the outcrop of marly limestones at the Brestová saddle site on Orava, or in the Čebrát tunnel on Liptov, etc.) which increases attenuation velocities of oscillation into rocks environment of the collector,

it is a layered rock complex with layers up to 30 cm thick. These are predefined areas of discontinuity that increase the damping of particle velocities in the rocks environment of collector. The thickness of the rock environment of the collector rocks based on the drilling survey reaches about 50 m (Melioris and Drexler, 1996).

4. Results and discussion

Seismic effects were measured at individual measuring standpoins during test blastings. Maximum vibration values are given in Tables 4, 5 and 6.

A three-second graphic recording of the vibrations of the test blast from the measuring standpoint in the quarry Trenčianske Mitice Skaličky is shown in Figure 7.

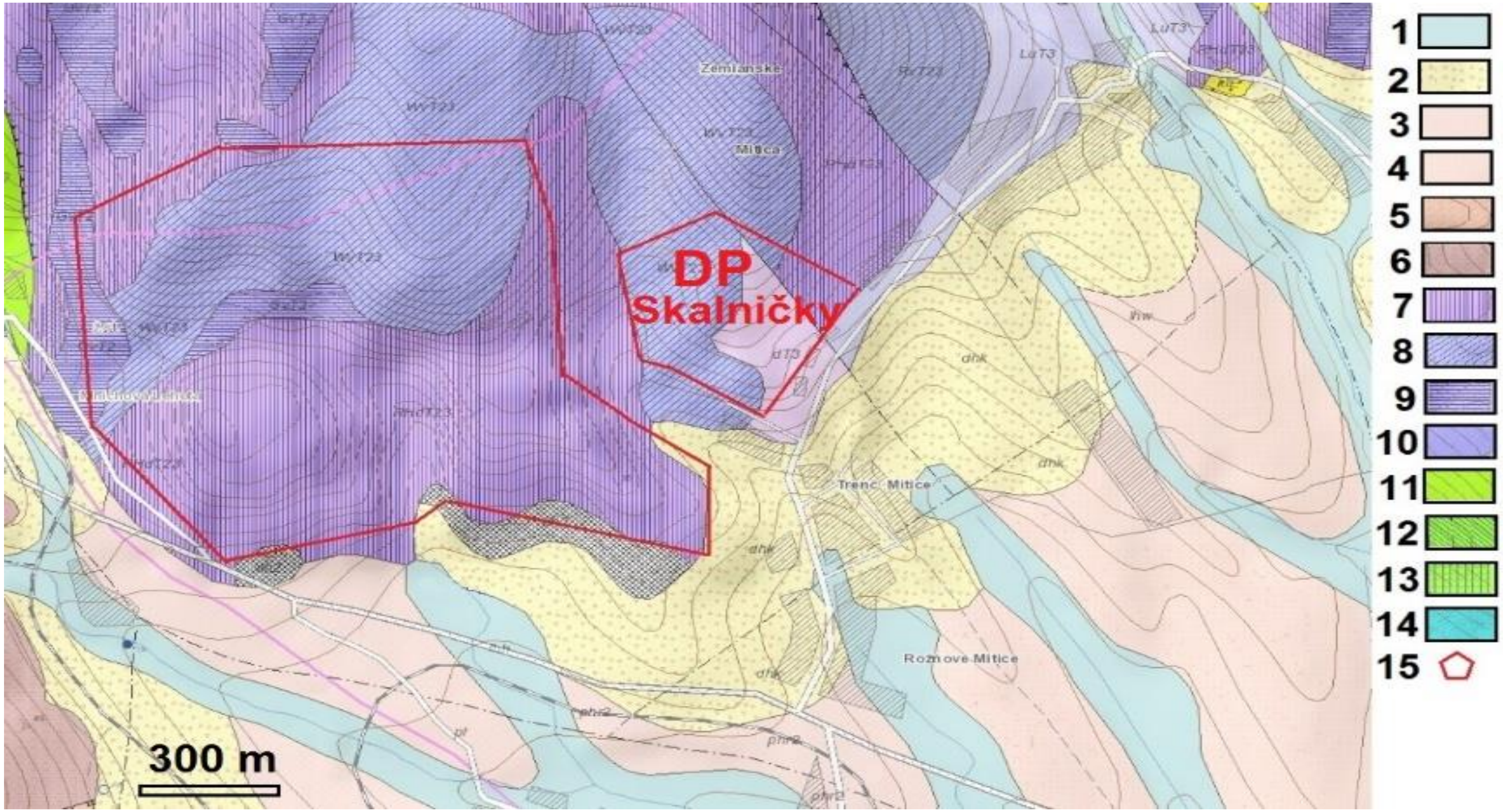


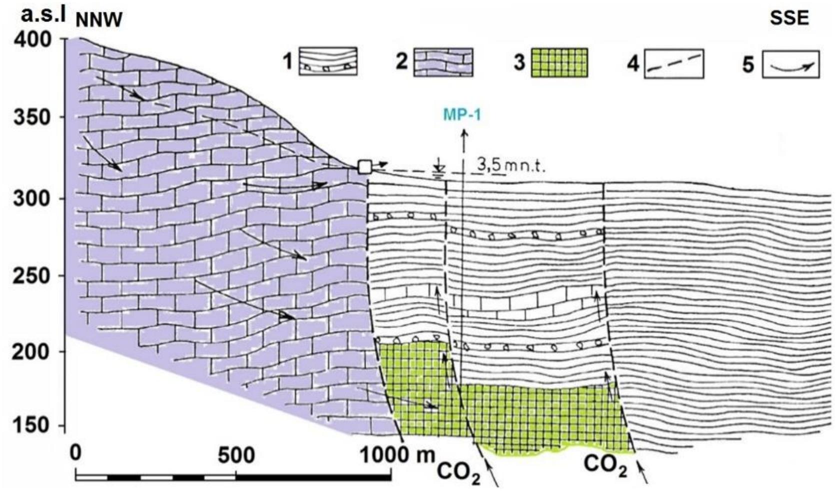
Fig. 5 Geological structure around the quarry Trenčianske Mitice - Skaličky (Maheľ, 1982)

Post Tertiary:1- clays, sandy clays, loams, clayey sand and gravels of river and stream bottom lands, 2- aluminium-stony (sporadically stony-sandy)down-slopes and debris, 3- loess loams with loess locality, 4- mainly clayey and sandy gravels, sands and sand clays with rock fragments in the lower intemediate alluvial cones with a loess loam cover and flushes;

Crystallinity of Považský Ínovec: 5- muscovite strips up to grained pararula with amphibolite of staurolite and /or garnet often diaftorized and chloritized, 6- krivosúdsky complex of strata – vulcanoclastic sedimentary rock, small-grained conglomerates largely light green fine-grained sandstones, locally violet siltstones;

Mesozoic of chočský overthrust:7- dolomites, 8- wettersteinské limestones, 9- dark grey limestones, 10- lúžňanské complex of strata – pink, off white and white fine -up to course grained quartzites (silicious sandstones), in a few isolated cases conglomerates;

Mezozoic of krížňanský overthrust:11- solid limestones and solid clays, 12- grey organodetritic limestones, 13- grey solid limestones, 14- sandy crinoid limestones, 15- border of the mining area - DP.



1 - Neogene sedimentary rocks (alternation of sandstones and claystones, possibly conglomerates),
2 - Chočský nape (dolomite, Wetterstein limestone, quartzite),
3 - Krížňanský nape (organodetritic limestones, sandy crinoid limestones, solid limestones and solid clays),
4 - faults,
5 - direction of groundwater flow

Fig. 6 Schematic hydrogeological section of the mineral water spring area MP-1 (Melioris and Drexler, 1996)

Based on the measured values of the velocities and frequencies of individual components of seismic waves during small-scale test blasting in the quarry Trenčianske Mitice Skaličky, we were able to evaluate the effects of individual blasting in accordance with Slovak technical norm EN 1998-1/NA/Z1 and assess their impact on water sources in the sanitary protection zone I. degree, and objects located nearby Trenčianske Mitice Skaličky quarry.

Tab. 4 Measured values of the peak particle velocities v_{peak}, of frequencies f and acoustic pressure L_C at the measuring standpoints during the blast No. 1

Measuring standpoint	Blast No. 1						
	v_{peakx} [mm.s^{-1}]	f_x [Hz]	v_{peaky} [mm.s^{-1}]	f_y [Hz]	v_{peakz} [mm.s^{-1}]	f_z [Hz]	L_{Cpeak} [dB]
V0	15.5	5.0	23.6	5.0	5.9	13.0	
HV1	1.02	5.89	1.01	5.89	0.46	5.89	92.4
HV2	1.91	5.89	0.59	11.72	0.79	5.89	99.0
V3a	0.68	4.0	0.72	4.0	0.39	4.0	
V3b	-	-	-	-	0.27	4.0	
V4a	0.55	5.9	0.93	5.5	0.26	4.2	
V4b	0.48	7.0	0.75	6.0	0.20	2.8	
V5	-	-	-	-	0.32	12.5	

Tab. 5 Measured values of the peak particle velocities v_{peak}, of frequencies f and acoustic pressure L_C at the measuring standpoints during the blast No. 2

Measuring standpoint	Blast No. 2						
	v_{peakx} [mm.s^{-1}]	f_x [Hz]	v_{peaky} [mm.s^{-1}]	f_y [Hz]	v_{peakz} [mm.s^{-1}]	f_z [Hz]	L_{Cpeak} [dB]
V0	24.83	8.0	27.63	6.0	9.1	9.0	
HV1	2.06	5.89	0.99	8.89	0.58	5.89	93.2
HV2	2.04	5.89	0.94	5.89	0.77	5.89	94.4
V3a	0.81	5.0	0.72	5.0	0.38	5.0	
V3b	-	-	-	-	0.29	4.0	
V4a	0.84	6.6	1.38	5.7	0.35	5.8	
V4b	0.71	8.3	1.37	6.7	0.41	5.8	
V5	-	-	-	-	0.40	10.0	

Tab. 6 Measured values of the peak particle velocities v_{peak}, of frequencies f and acoustic pressure L_C at the measuring standpoints during the blast No. 3

Measuring standpoint	Blast No. 3						
	v_{peakx} [mm.s^{-1}]	f_x [Hz]	v_{peaky} [mm.s^{-1}]	f_y [Hz]	v_{peakz} [mm.s^{-1}]	f_z [Hz]	L_{Cpeak} [dB]
V0	231.5	54	80.0	5.0	224.64	4.0	
HV1	1.02	5.89	1.01	5.89	0.46	8.89	94.6
HV2	3.39	5.89	1.97	8.79	1.53	5.86	95.3
V3a	1.08	4.0	1.12	5.0	0.56	4.0	
V3b	-	-	-	-	0.48	4.0	
V4a	1.54	7.02	2.0	5.52	0.55	5.2	
V4b	1.94	8.77	2.96	7.3	0.46	5.2	
V5	-	-	-	-	0.48	6.3	

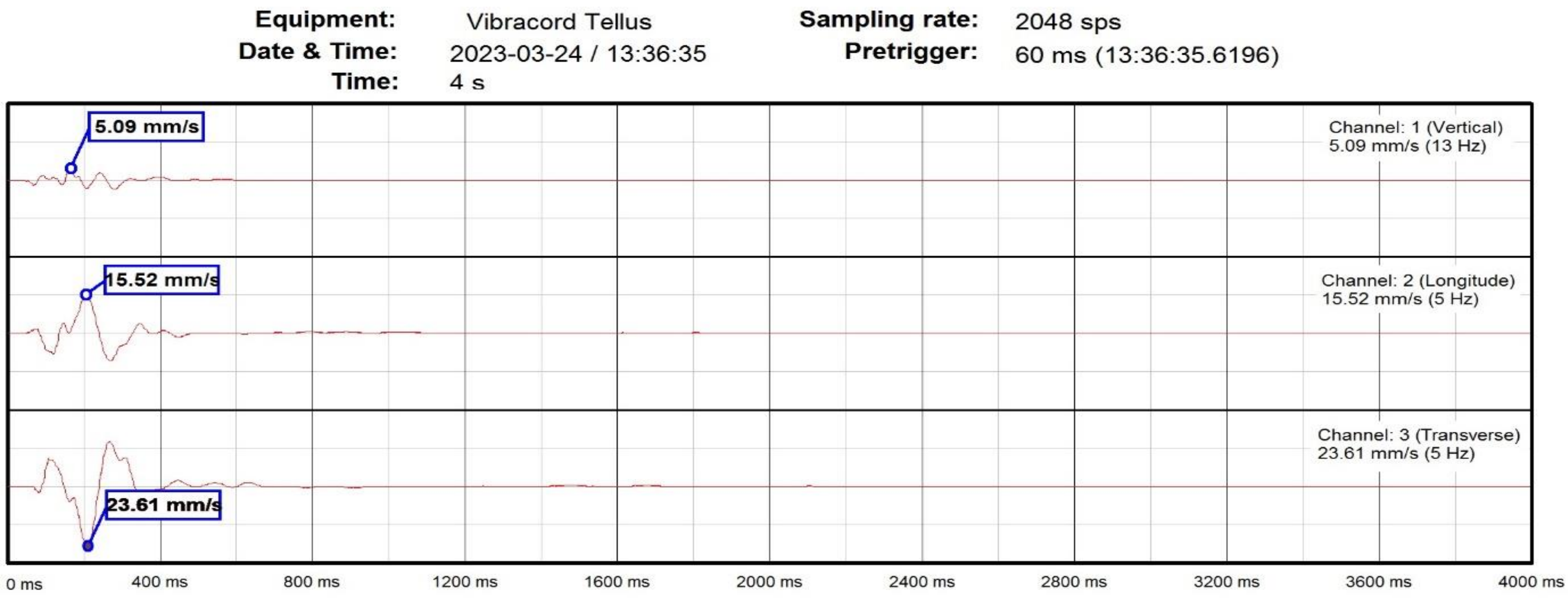


Fig. 7 Graphic record of the individual components of seismic waves in the quarry Trenčianske Mitice Skaličky. The recording is from the vibrograph Vibracord at the measuring standpoint V0, 45 m from the initiation borehole of blast No. 1.

Sources of drinking water are situated in the rock mass and their lifespan is expected to be several decades. We consider the blasts carried out in the quarry Trenčianske Mitice Skaličky to be periodic, given that this is a permanent mining operation in the quarry. We place the class of the assessed object, sources of drinking water, among the particularly important works with a lifespan of more than 10 years T-1. The assessment of the quality of an object depends on several factors. It is based on the method of its foundation, construction, used material and physical condition of the object at the time of measurement. In the case of assessing the seismic effects of blasting works on drinking water sources, it is not only an assessment of the physical condition of the water management work, but mainly an assessment of the rock environment, which is the collector. For the above reasons, we set a value of 6 for the quality parameter q of the object, where the permissible vibration velocity of the individual components is 2.2 $mm.s^{-1}$ (Table 2). At values of vibration velocities less than 2.2 $mm.s^{-1}$, no further disturbances occur even in the disturbed rock environment.

Based on Eurocode 8 Slovak technical norm EN 1998-1 /NA/Z1 Seismic loading of building structures, with regard to the charges used for bench blasting in the quarry Trenčianske Mitice Skaličky, which represent hundreds of kilograms, where the vibration frequencies are usually f < 10 Hz, and on the basis of the resistance of water management works to technical seismicity, the water source in the vicinity of the quarry Trenčianske Mitice Skaličky can be included among the particularly important works with a lifespan of more than 10 years T-1.

As for the quality of the object, due to the absence of more specific characteristics and data, we can classify it as the quality of the object q-6.

Based on the above and due to the longer-term nature of blasting at the Trenčianske Mitice Skaličky limestone deposit and with regard to the nature of the transmission environment, for disconnection by bench blasting at the Trenčianske Mitice Skaličky deposit and for water management works near the quarry, the maximum permissible particle velocity (velocity component) can be set to: $v_d \leq 2$ mm.s^{-1}.

The measured maximum values of seismic effects generated by test blasts that were carried out in the quarry Trenčianske

Tab. 7 Measured peak particle velocities of test blastings in the quarry Trenčianske Mitice Skaličky and at the water source Zadná studňa spring in the village Trenčianske Mitice

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}]
45	50	6.36	15.5	23.6	5.09
28	50	3.96	24.83	27.63	9.1
15	50	2.12	231.5	80.0	224.64
589	50	83.31	1.08	1.12	0.56
572	50	80.90	0.81	0.72	0.38
559	50	79.86	0.68	0.72	0.39
597	50	84.44	-	-	0.27
580	50	82.04	-	-	0.29

Tab. 8 Measured peak particle velocities of test blasts in the quarry Trenčianske Mitice - Skaličky and at the mineral water source MP – 1 nearby the village Trenčianske Mitice

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}]
45	50	6.36	15.5	23.6	5.09
28	50	3.96	24.83	27.63	9.1
15	50	2.12	231.5	80.0	224.64
857	50	121.2	-	-	0.32
857	50	121.2	-	-	0.40
857	50	121.2	-	-	0.48

Mitice Skaličky are in Table 7 and 8. These values served us as a basis for determining the law of attenuation of seismic waves in the quarry Trenčianske Mitice Skaličky (Pandula and Kondela, 2010; Pandula et al., 2012).

Based on the data from Tables 7 and 8 and the value of the coefficient of the non-flooded transmission environment, a graphical dependence of the components of the peak particle velocities on the reduced distance when test blasts was constructed. The graph in Fig. 8 and 9 represents the so-called law of attenuation of seismic waves for the quarry Trenčianske Mitice Skaličky (Kaláb et al., 2013), in which the value of the explosive charge Q was used in the form

$$v = \left(\frac{L}{Q^{0.5}}\right) = K\left[\frac{L}{Q^{0.5}}\right]^n,$$

where

- "v" is the maximum particle velocity (maximum particle velocity component) generated by blasting, [mm.s^{-1}],
- L.Q$^{-0.5}$ is the so-called reduced distance, [m.kg$^{-0.5}$],
- L is the shortest distance of the vibration source from the receptor [m],
- Q is the weight of the time stage charge [kg],
- K is the coefficient depending on the blasting conditions, the properties of the transmission environment, type of explosive, etc.,
- n is an indicator of seismic wave attenuation (Pandula and Kondela, 2010).

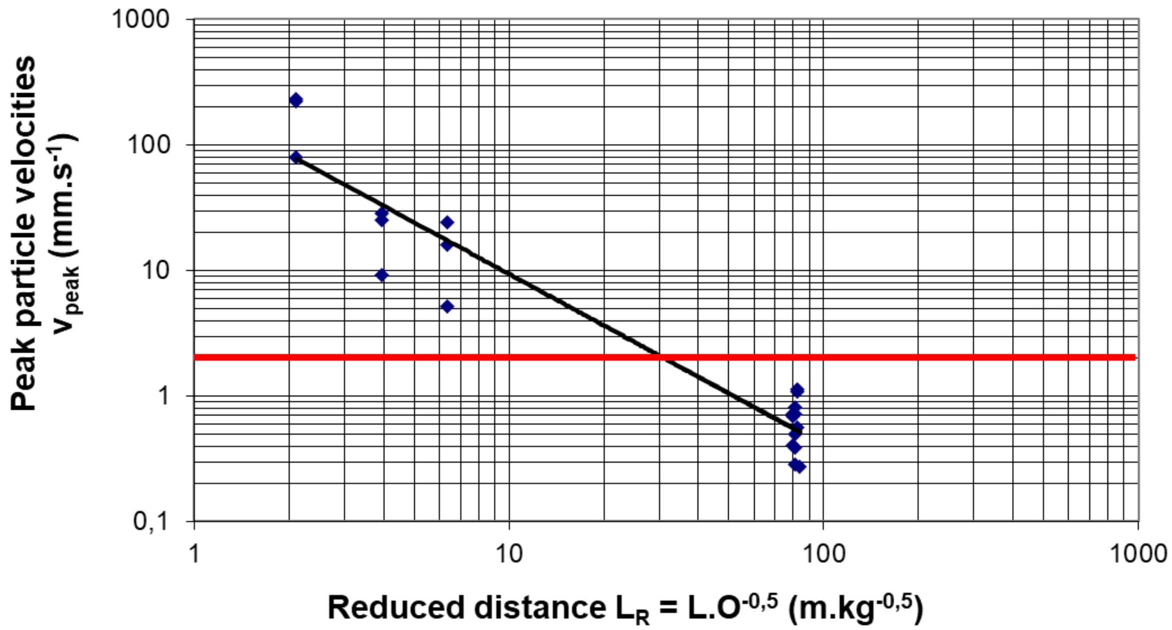


Fig. 8 Seismic waves attenuation law for the quarry Trenčianske Mitice Skalničky and water source Zadná studňa spring in the village Trenčianske Mitice.

5. Conclusion

From the law of seismic waves attenuation, it is possible to determine the charge size for a particular receptor at a known distance so that the maximum values of individual components of the vibration velocity do not exceed the specified maximum permitted vibration velocities.

According to the law of seismic waves attenuation in the quarry Trenčianske Mitice Skaličky, for the maximum permissible particle velocities for water resources nearby the village of Trenčianske Mitice, vmax = 2 mm.s-1, the reduced distance is expressed by the value L_R = 50. Using the reduced distance L_R = 50, it is possible to calculate the maximum permissible charge weight per borehole depending on the specific distance during repeated blastings in Trenčianske Mitice Skaličky quarry and mineral water source MP-1: for a distance 400 m $Q_{evmax} = (L/L_R)^2 = (400/50)^2 = 64.0$ kg.

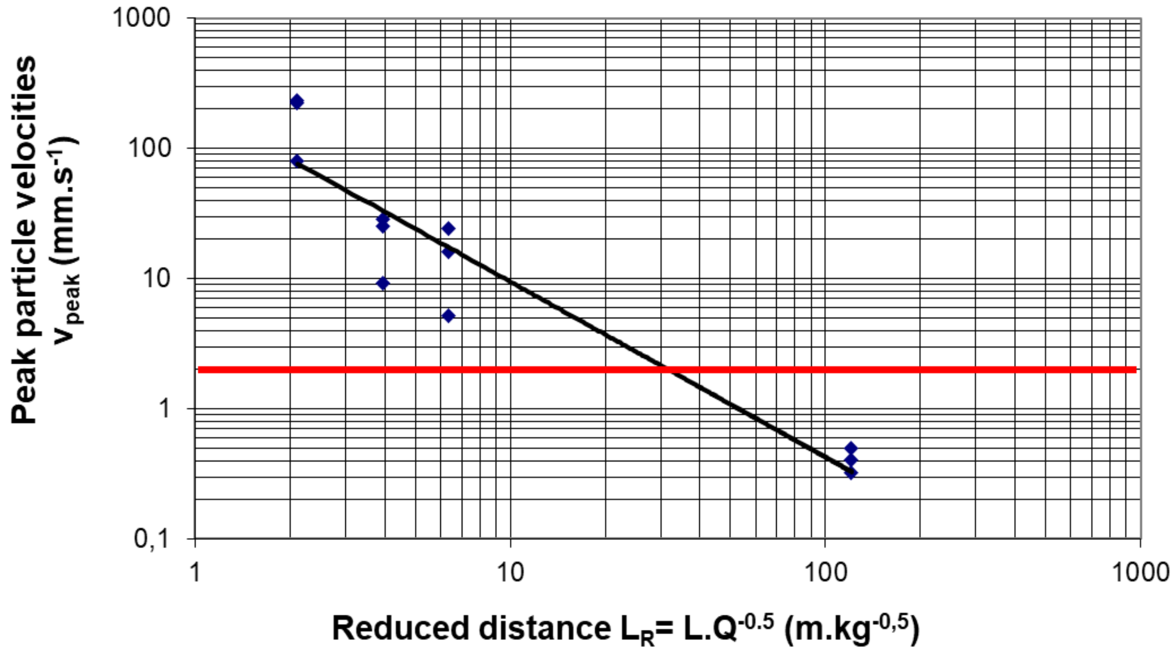


***Fig. 9** Seismic waves attenuation law for the quarry Trenčianske Mitice Skalničky and mineral water source MP – 1 nearby the village Trenčianske Mitice.*

According to the law attenuation of seismic waves in the quarry Trenčianske Mitice Skaličky, for the maximum permissible particle velocities for water resources in the village of Trenčianske Mitice, vmax = 2 mm.s^{-1}, the reduced distance is expressed by the value L_R = 60. Using the reduced distance L_R = 60, it is possible to calculate the maximum permissible charge weight per borehole Qevmax depending on the specific distance during repeated blastings in Trenčianske Mitice Skaličky quarry and water source Zadná studňa spring: for a distance 400 m $Q_{evmax} = (L/L_R)^2 = (400/60)^2 = 44.5$ kg.

The reduction of seismic effects of blasting can also be achieved by optimizing the timing delay of individual blasting (Kondela and Pandula, 2012). With the optimization of the timing scheme, spacing and blast range, it is likely that the charge weight per borehole will be able to be higher than what is currently set. During test blasts, it was demonstrated that the size of the burden/spacing ratio significantly influenced the seismic effects on the monitored objects. Recommendations to reduce the effects of vibration from blasting: reduce the height of the etage in the quarry to 10 m for blasting, the distance of which from water sources or permanently inhabited buildings (family houses) is less than 400 m, if the blasting is situated at a distance of up to 400 m from construction objects and water sources, monitor the effects of vibrations of operational blasting, when designing a blasting drill scheme, keep the burden/spacing ratio to be less than 1.

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