Impacts of noise and technical seismicity from blasting works during tunnel construction on the surrounding environment

Ján Fehér[1]***, Jozef Čambál***[1]***, Martin Cvoliga***[2]***, Ladislav Kačmár***[3]***, Vladimír Sulovec***[4]***, Martin Šuver***[4] *and* ***Ján Beca***[4]

The paper is focused on the measurement of adverse effects caused by blasting works in tunnels on the environment. The disintegration of the rock massif during tunnel construction is performed in most cases by explosions due to the release of the explosion energy, which is transformed into the energy of the seismic waves and causes disruption of the massif balance. Blasting works generate noise and seismic waves with different maximum vibration velocities and a wide range of frequencies. The intensity of the seismic waves is proportional to the massif of the explosives used. If the vibration has sufficient energy, the surrounding buildings may be damaged or destroyed. Assessing the negative effects of blasting and quantifying seismic security is currently a very challenging issue. However, based on periodic measurements, prediction of these effects is possible. The paper presents the results of monitoring of blasting works in tunnels in the Slovak Republic. The evaluation of noise and seismic effects of blasting works verified that in tunnels is a methodological basis for noise and seismic effects of blasting works not only on surrounding buildings but also on the surrounding environment.

Keywords: *tunnel, blasting works, technical seismicity, noise*

Introduction

Tunnel excavation affects the surrounding environment (Mishra and Mallick, 2012). Adverse effects include mainly noise and seismic effects (Jonson, 2012). The systematic measurement of noise and seismic effects in blasting operations is an essential part of determining the adverse effects on the environment (Fei et al., 2018). Based on the measured values, we are able, if necessary, to operatively carry out measures to optimize the performance of blasting operations (Mihalik and Pandula, 2008; Pandula and Kondela, 2010; Kalab et al., 2013). Based on the research activities, noise measurement and technical seismicity measurements were carried out in the construction of the tunnel, in the implementation of tunnel blasting (Murayama et al., 2014). Measurements were made in the residential area near the tunnel based on residents' complaints. The importance of the measurements has resulted from the need to detect adverse effects on the environment (Müncner, 2011; Kondela and Pandula, 2012; Lesso et al., 2013; Shin at al., 2018; Blistan, 2007; Kalab, 2018; Kalab and Štemon, 2017). Noise and seismic instruments were calibrated and sensitized prior to measurement (Nistov et al., 2012). The graphs of the individual components of seismic waves (França et al., 2011) were recorded in the measurement positions. Seismic apparatuses have been placed on the measuring positions to assess the impact of the seized technical seismicity on the objects under assessment (Pandula et al., 2012).

Measuring position and apparatus used for measurement

The measuring position or noise measurement was carried out about 200 m from the blasting works, which were carried out in the tunnel of residential buildings. A special instrument from SVANTEK - SVAN 958A was used to measure noise. SVAN 958A Class 1 Four-Channel Sound and Vibration Analyzer is designed for all applications requiring simultaneous Class 1 audio and vibration assessment. Each of the four input channels can be independently configured to detect sound or vibration with different filters and RMS detector time constants that give users great flexibility in measurement. The real advantage of the SVAN 958A is the ability to perform advanced analysis simultaneously with a level meter. In practice, this allows the user to obtain broadband results, such as L_{eq}, RMS, L_{Max}, L_{Min}, L_{Peak}, along with a four-channel analysis such as FFT or octave band analysis (Raisian et al., 2016).

[1] *Ján Fehér, Jozef Čambál,* Faculty of Mining, Ecology, Process Control and Geotechnologies, Technical University of Kosice, Department of Montaneous Sciences, Letná 9, 042 00 Košice, Slovak Republic, jan.feher@tuke.sk, jozef.cambal@tuke.sk
[2] *Martin Cvoliga,* NDS a.s., Dúbravská cesta 14, 841 04 Bratislava, Slovak Republic, martin.cvoliga@ndsas.sk
[3] *Ladislav Kačmár,* TUBAU, a.s., Pribylinská 12, 831 04 Bratislava, Slovak Republic, kacmar@tubau.sk
[4] *Vladimír Sulovec, Ján Beca,* EUROVIA - Kameňolomy, s.r.o. Osloboditeľov 66, 040 17 Košice, Slovak Republic, vladimir.sulovec@eurovia.sk, martin.suver@eurovia.sk, jan.beca@eurovia.sk

Fig. 1. Device SVAN 958A (Fehér et al., 2019)

Measured value

From the outputs of the special SVAN 958A instrument in case of noise measurement of blasting operations, it is necessary to use the permissible values of the maximum sound level A in the monitored time interval using the time weight function F. Value LAF_{max} (dB).

Time 16:28:24, LAF_{max} 66.7 dB

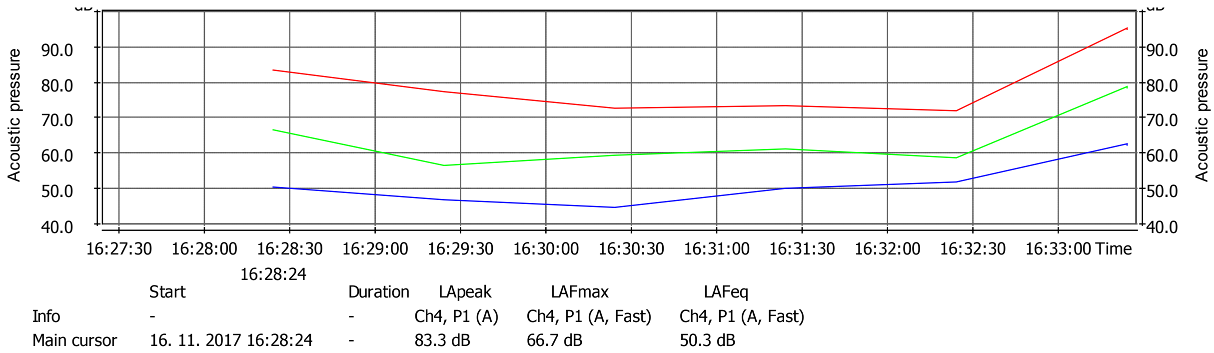


Fig. 2. Measured value, time 16:28:24 (Fehér et al., 2019)

Time 16:29:24 LAF_{max} 56.6 dB

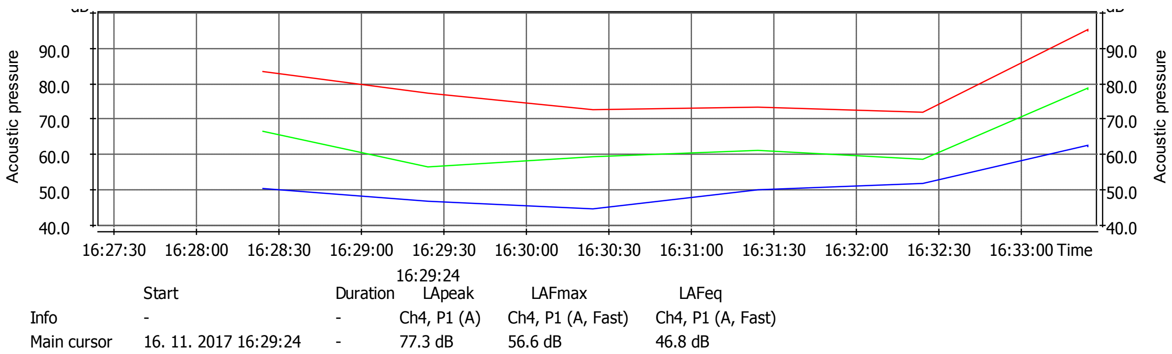
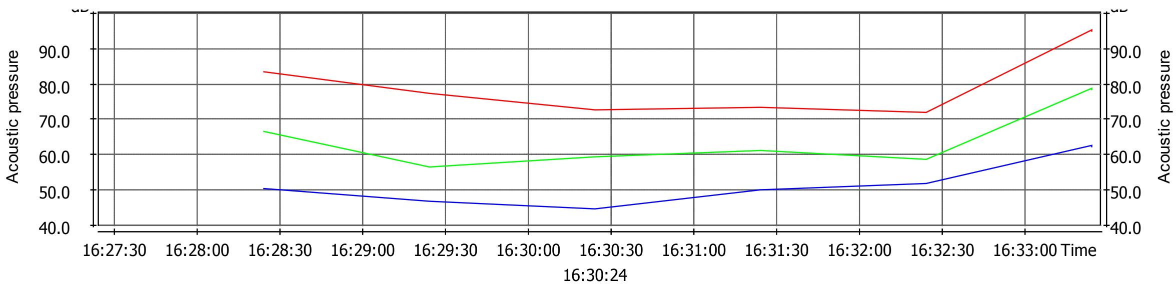


Fig. 3. Measured value, time 16:29:24 (Fehér et al., 2019)

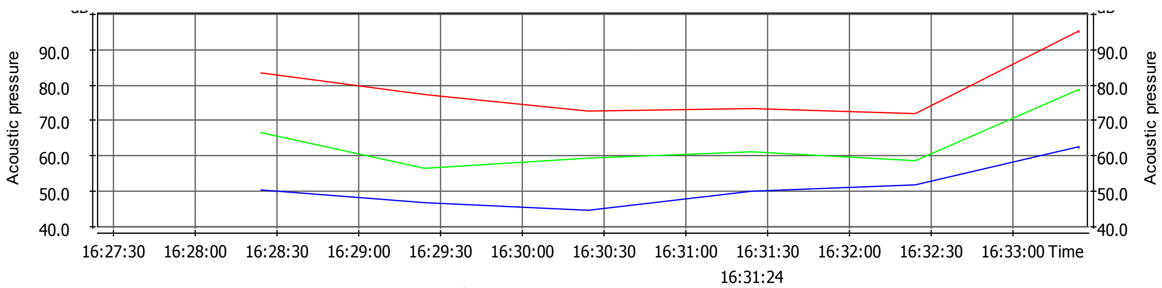
Time 16:30:24 LAF_{max} 59.4 dB



	Start	Duration	LApeak	LAFmax	LAFeq
Info	-	-	Ch4, P1 (A)	Ch4, P1 (A, Fast)	Ch4, P1 (A, Fast)
Main cursor	16. 11. 2017 16:30:24	-	72.6 dB	59.4 dB	44.6 dB

Fig. 4. Measured value, time 16:30:24 (Fehér et al., 2019)

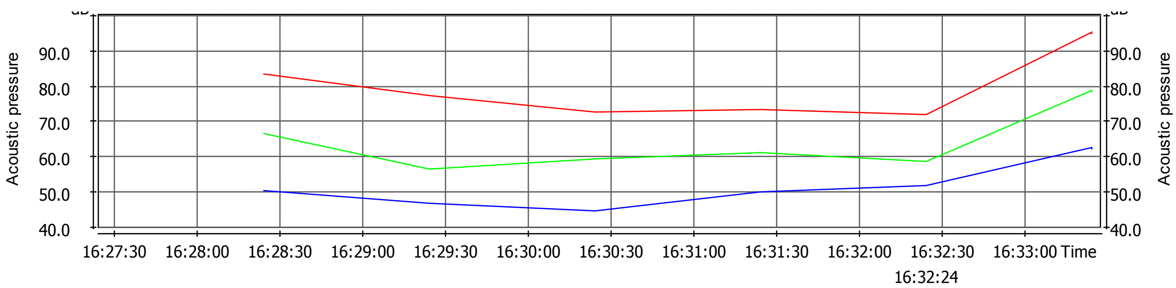
Time 16:31:24 LAF_{max} 61.1 dB



	Start	Duration	LApeak	LAFmax	LAFeq
Info	-	-	Ch4, P1 (A)	Ch4, P1 (A, Fast)	Ch4, P1 (A, Fast)
Main cursor	16. 11. 2017 16:31:24	-	73.3 dB	61.1 dB	50.1 dB

Fig. 5. Measured value, time 16:31:24 (Fehér et al., 2019)

Time 16:32:24 LAFmax 58.8 dB



	Start	Duration	LApeak	LAFmax	LAFeq
Info	-	-	Ch4, P1 (A)	Ch4, P1 (A, Fast)	Ch4, P1 (A, Fast)
Main cursor	16. 11. 2017 16:32:24	-	71.8 dB	58.8 dB	51.8 dB

Fig. 6. Measured value, time 16:32:24 (Fehér et al., 2019)

Time 16:33:24 LAF_{max} 78.8 dB

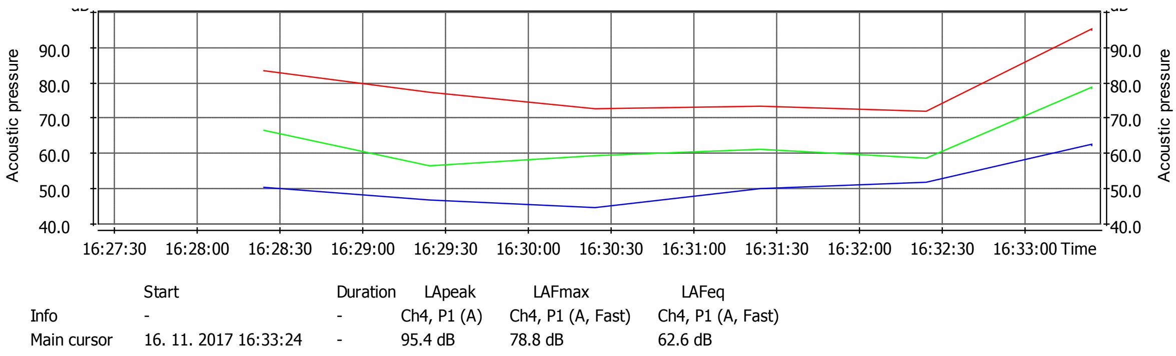


Fig. 7. Measured value, time 16:33:24 (Fehér et al., 2019)

Tab. 1. Measured value from blasting in the tunnel

Measurement time	Measured value LAF_{max} (dB)	Allowable value (dB)
16:28:24	66.7	118
16:29:24	56.6	118
16:30:24	59.4	118
16:31:24	61.1	118
16:32:24	58.8	118
16:33:24	78.8	118

Fig. 8. SVAN 958A installed near a residential building in Nimnica (Fehér et al., 2019)

Analysis and evaluation of noise measurements

Impulsive noise is the most subjective perceived by the population when measuring the noise level from blasting operations or the tunnel shot. Blasting works are, however, sporadic in time, and therefore these noise levels are not subject to permissible values according to the Ministry of Health Decree no. 549/2007. According to the decree, we use the maximum sound level A in the monitored time interval when using the time weight function F. LAF_{max} (dB) value according to MZSR no. 549/2007. The maximum A-level sound at a single occurrence may not exceed 118 dB in places and people's possible residence. From the above graphs, or the outputs from the measuring instrument SVAN 958A, it can be stated that the noise level generated by the blasting operations in the tunnel did not exceed the maximum value of LAF_{max} 118 dB.

Measuring position and devices used to measure seismic effects of blasting operations in Diel tunnel

The measuring position, or the measurement of technical seismicity, was carried out in residential buildings approximately 200 m from the blast. A special instrument from INSTANTEL - MINIMATE PRO 6 was used for seismic measurement. The MINIMATE PRO 6 offers 64 MB of memory, improved durability, metal housing, connectors and water resistance. It is possible to connect two standard ISEE or DIN triaxial geophones to monitor vibration sources from two different locations. Another option is to connect one ISEE or DIN triaxial geophone and one ISEE linear microphone, as well as the possibility to connect an audio microphone if air overpressure measurement is required.

Fig. 9. Device MINIMATE PRO 6 (Geonor, Inc., 2018)

The MINIMATE PRO 6 situated in the measured position was calibrated before the measurement, and its sensitivity was also checked. The graphs of the individual components of the seismic wave were recorded in the positions of measurement. Seismic apparatuses have been placed on the measuring positions so that the impact of technical seismicity on the objects under consideration can be assessed. On the basis of measured values of velocities and frequencies of individual components of the wave at the shot, we were able to evaluate according to STN EN 1998-1 / NA / Z1 seismic load of building constructions or effects on a housing development near the tunnel (Pandula and Kondela, 2010).

Criterion seismic effects

Effects of the technical seismicity induced by blasting are measured and assessed by the velocity of the environmental particles (particle velocity) "v" according to the maximum value of one of its three components x, y, z. The principle of seismic protection of seismic safety of building objects against technical seismicity can be expressed by the relationship

$$v \leq v_d \tag{1}$$

where v is the maximum value of the particle velocity component caused by the vibration source, measured at the so-called vibration rate. The reference position of the protected (assessed) object; the reference opinion is the ground floor of the building; the value of "v" depends mainly on the maximum mass of the explosive charge fired at one time point Q_{eq} [kg], further from the minimum source distance from the shock vibration receptor L [m] and the properties of the geological transfer environment between the source and the shock receptor. At the current knowledge level, the value of "v" cannot be calculated in advance either analytically or empirically; the most reliable is determined by a specific measurement, as in our case, v_d is the maximum allowable (limiting) particle velocity for the object (s) under consideration; there is no damage to the object at this vibration speed - the degree of damage is 0; this value is determined independently of the blast (before blast) based on practical experience. Different standards or on the basis of expert assessments by specialists. STN 73 0036: 1973-11 / STN EN 1998-1: 2005/NA shows the relationship between the vibration intensity expressed by the particle velocity of the individual components and the possibility of damage to the building. In accordance with the standard, the following criteria may be adopted for masonry civil buildings in an average building condition:

At particle velocity:

- v = 0 – 10 mm.s^{-1} – there is no damage to the building,
- v = 10 – 30 mm.s^{-1} - possibility of first signs of damage,
- v = 30 – 60 mm/s^{-1} – the possibility of minor damage.

Tab. 2 Dependence of the degree of damage from maximum particle velocity, type of object and ground soil according to STN EN 1998-1 / NA / Z1 (Pandula et al., 2010)

Maximum vibration rate for frequency range			Damage degree	Class of resistance	Type of soil
fk < 10 Hz	10 Hz<fk< 50 Hz	fk> 50 Hz			
less than 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
6 to 10	10 to 20	15 to 30	0	B	b,c
				C	a
			1	A	a
8 to 15	15 to 30	20 to 30	0	C	b
				B	c
			1	A	b,c
				B	a
10 to 20	20 to 30	30 to 50	0	C	c
				D	a
			1	B	b
				C	a
			2	A	a
15 to 25	25 to 40	40 to 70	0	D	b,c
				E	a
			1	C	b
				B	c
			2	A	b,c
				B	a
20 to 40	40 to 60	60 to 100	0	E	b,c
				F	a
			1	C	c
				D	a
			2	B	b,c
				C	a
30 to 50	50 to 100	100 to 150	0	F	b,c
			1	D	b,c
				E	a
			2	C	b

Tab. 3. Seismic effects depending on vibration velocity (Pandula et al., 2010)

Velocity of vibration (mm.s^{-1})	Characteristics of vibration and their effects
< 2	man does not perceive vibration, vibration can only be detected by devices
2 - 5	sensitive people perceive vibration
5 - 10	vibration is already a human perception
10 - 15	vibration is perceived by most people, the window pan shakes
15 - 30	first signs of very slight damage
30 - 75	light damage to buildings
75 - 100	possible damage to damaged buildings
100 - 200	serious damage to buildings, cracks in concrete
200 - 400	building disintegration, serious damage in reinforced concrete
> 400	possible demolition of buildings

In these blasting works in the Diel tunnel, explosives of the type AUSTROGEL and EMULEX 1 were used. The total weight of the blast in the tunnel was 110 kg per blast.

The pressure force generated at the point of the explosion causes a pressure wave in the surrounding environment. Waves spread to the environment and transmit part of the blast energy to a greater distance. The pressure wave propagates increased tension and rock movement. Near the centre of the blast and at a distance of a few meters, the induced tension is a compression wave. The pressure tension rapidly rises to a certain maximum and then slowly decreases to zero so that damped environmental vibration occurs. As the distance from the center of the explosion increases, the shape of the tension and the resulting movement of the transmission environment change so that after a sudden rise in pressure, its drop does not stop at zero, but the first portion of the overpressure is followed by the second portion of the vacuum propagating wave. Environmental distortions take on the character of vibration. In any flexible solid state, the formation of a longitudinal wave P is accompanied by a transverse wave S, which arises from the passage and reflection of the longitudinal wave at the interface of different environments (Pandula and Kondela, 2010).

Especially the graphical dependence of the maximum particle velocity components on the reduced distance in the tunnel, which depends on the amount and type of explosive used and the timing stages of the detonators used in the blast or timing of the blast itself (Pandula et al., 2012; Kondela and Pandula, 2012), is important when evaluating the results.

Tab. 4. The measured values of seismic effects caused by blasting works in tunnel (Fehér et al., 2019)

Date of measurement	Y mm.s^{-1}	Z mm.s^{-1}	X mm.s^{-1}
16.11.2017	0.268	0.686	0.252
16.11.2017	0.260	0.946	0.418
14.12.2017	0.126	0.985	0.260
14.12.2017	0.260	0.796	0.213
16.05.2018	0,283	0,178	0,127

Based on the measured values of the seismic effects at the blast in the Diel tunnel, the graphical dependence of the maximum particle velocity components on the reduced distance was sharpened - the red line represents the maximum permissible values of the particle velocity for the primary tunnel lining, the residential buildings in the village of Nimnica and the water sources in the Nimnica (Pandula et al., 2012).

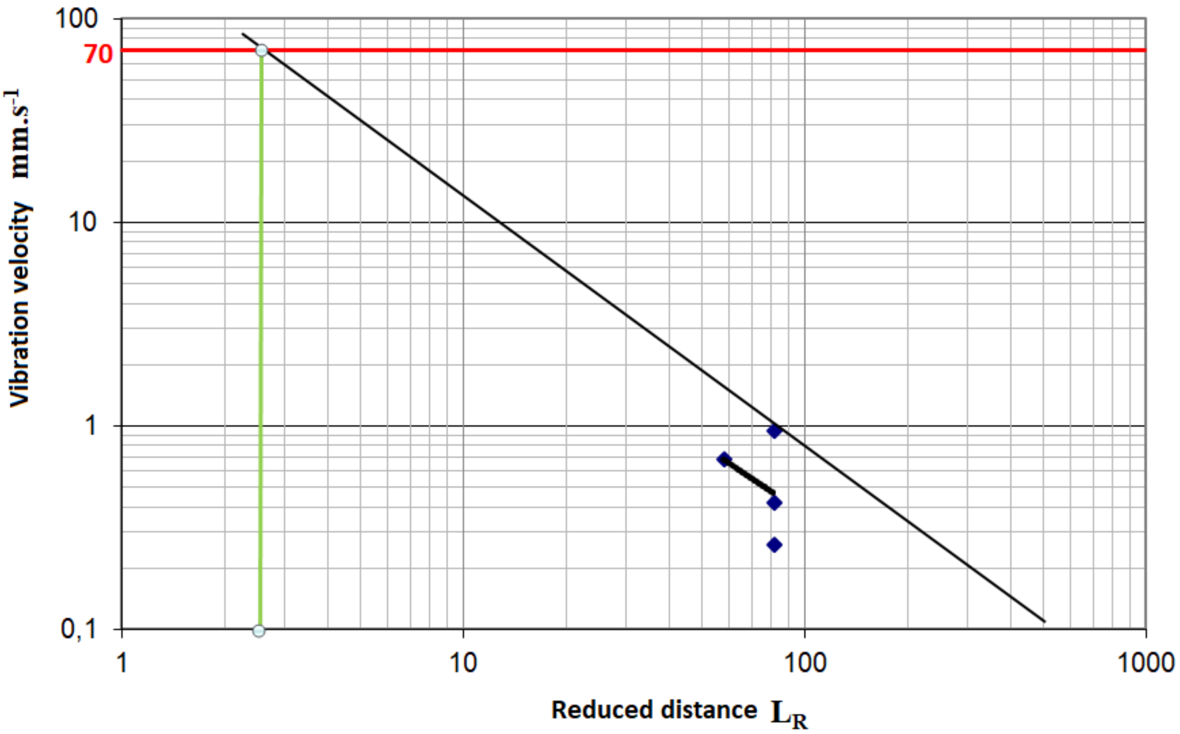


Fig. 10. Graphical dependence of particle velocity at the reduced distance on primary tunnel lining. The red line represents the maximum allowable particle velocity values for the primary tunnel lining (Fehér et al., 2019)

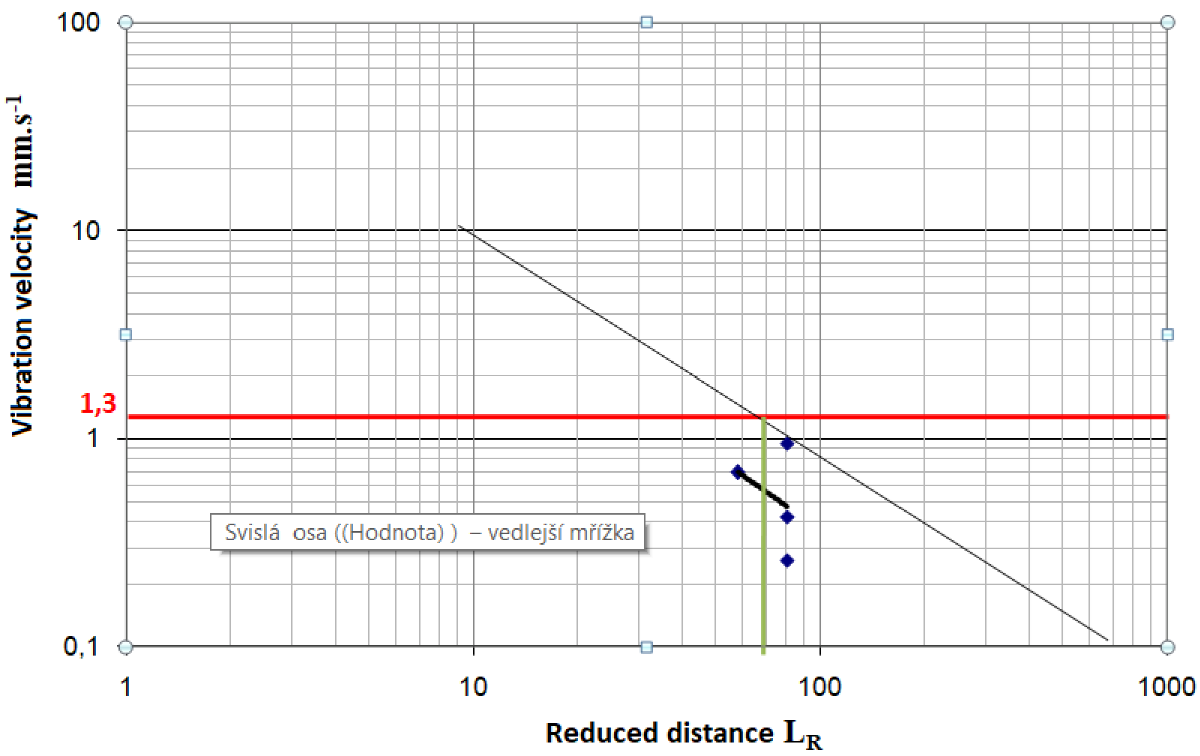


Fig. 11. Graphical dependence of particle velocity on reduced distance acting on Nimnica spa. The red line represents the maximum permissible particle velocity values for water sources at Nimnica Spa (Fehér et al., 2019)

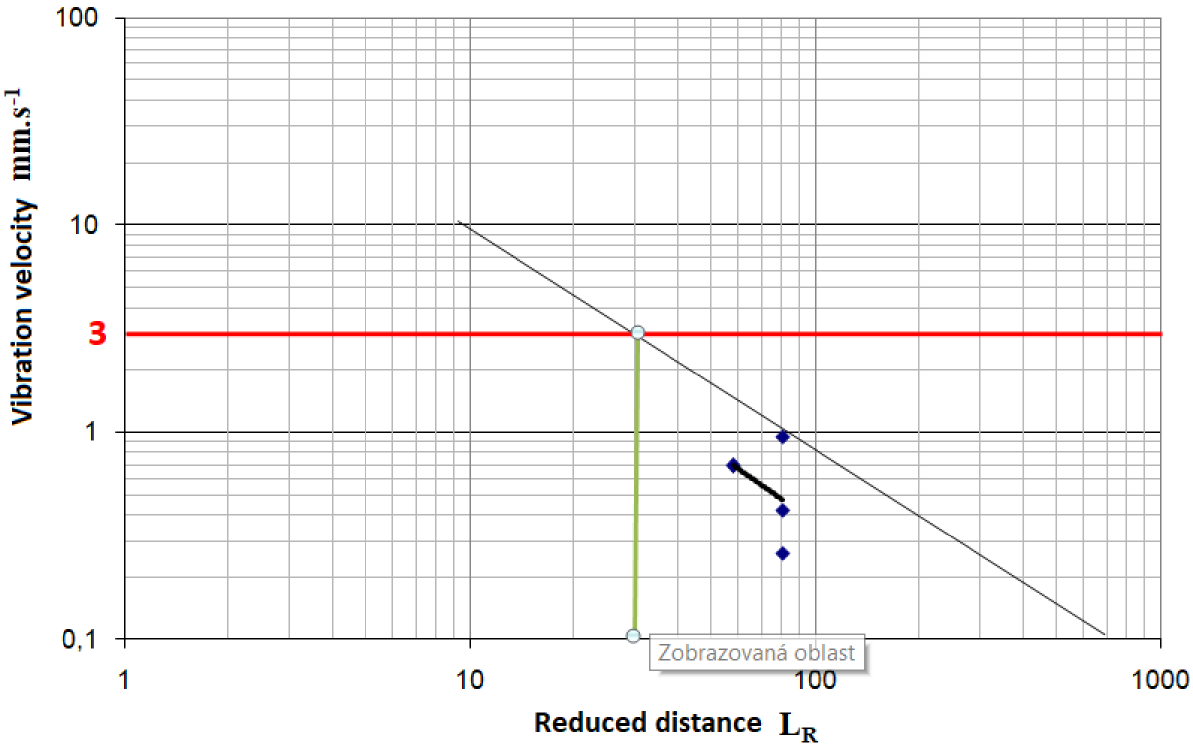


Fig. 12. The graphical dependence of the particle velocity at a reduced distance on residential buildings near the Diel Tunnel. The red line represents the maximum permissible particle velocity values for residential buildings in Nimnica (Fehér et al., 2019)

Fig. 13. Location of MINIMATE PRO 6 on the foundations of a residential building (Fehér et al., 2019)

Analysis and evaluation of seismic measurements

In the measurement of technical seismicity caused by blasting from tunnel blasts, vibrations were applied to residential buildings in accordance with Slovak technical standard STN EN 1998-1: 2005/NA (Fig. 10). Depending on the outputs of the MINIMATE PRO 6, the highest value measured (0.946 mm.s^{-1}) did not exceed 1 mm.s^{-1}, which is a non-perceptible figure (Fig. 11). Residents most perceive impulsive noise rather than shocks or vibrations caused by blasting. Measurements have confirmed that vibrations do not adversely affect residential buildings near the Diel Tunnel and citizens:

- v_d = 0 – 3 mm.s^{-1} – there is no damage to the building, nor do the inhabitants feel the vibration negative.

Conclusion

Noise levels from tunnel blasting do not exceed the maximum allowable noise for the reference time interval - a rare occurrence per day. The results show that blasting in the tunnel will not affect the current acoustic parameters in the nearest residential zone and will not endanger the environmental parameters in terms of noise.

From the seismic measurements and the graphical dependence of the vibration velocity on the reduced distance, or from the outputs of the MINIMATE PRO 6, we can conclude that the blasting works carried out at the tunnel excavation do not exceed the values that would lead to damage to the environment around the tunnel. The measured values did not exceed the values stipulated by the valid Slovak technical standard STN EN 1998-1 / NA/Z1 Seismic load of buildings.

As a result of the continuous tunnelling process, the distance between blasting operations and the residential area increases every day, which will only reduce the noise level and the effects of the season, which has a positive impact on the residential area and the surroundings of the tunnel.

The law of attenuation for the surrounding tunnel implies that the seismic effects caused by the blasting work will not cause such voltage changes that would break the bedrock in the living area and the nearby spa.

References

Blistan, P (2007). Presentation of geological date in geographic information systems. *Acta Montanistica Slovaca, Vol. 12, no. 3, (2007), pp. 329–334.*

Fei H., Liu M., Qu G., Gao Y. (2018) A method for blasting vibration signal denoising based on ensemble empirical mode decomposition-wavelet threshold, Baozha Yu Chongji/Explosion and Shock Waves, Volume 38, Issue 1, January 2018, pp. 112-118.

França G.S., Vasconcelos M.A.R., Chimpliganond C.N., Tomás, S.S. (*2012)* Study of vibrations generated by explosions made in the work of civil Tucuru? Locks 2 (PA), Revista Brasileira de GeofisicaVolume 29, Issue 1, January 2011, pp. 57-70.

Jonson D. (2012) Controlling shock waves and vibrations during large and intensive *blasting* operations under Stockholm City, Tunnelling in Rock by Drilling and Blasting: Workshop Hosted by FRAGBLAST 10 - The 10th International Symposium on Rock Fragmentation by Blasting2013, November 2012, pp. 49-58.

Kalab Z. (2018) Influence of vibrations on structures. *Acta Montanistica Slovaca, Volume 23, Issue 3, 2018, Pages 293-311.*

Kalab, Z., Štemon, P. (2017) Influence of seismic events on shallow geotechnical structures. *Acta Montanistica Slovaca Volume 22 (2017), number 4, 412-421*

Kalab Z., Pandula B., Stolárik M., Kondela J. (2013) Examples of law of seismic wave attenuation. Metalurgija Vol. 52, no. 3 (2013), pp. 387-390.

Kondela, J., Pandula, B. (2012) Timing of quarry blasts and its impact on seismic effects. Acta Geodynamica and geomaterialia Vol. 9, no. 2. (2012), pp. 155 – 163.

Leššo I., Flegner P., Pandula B., Horovčak P. (2007) New principles of process control in geotechnics by acoustic methods. *Metalurgija Vol. 46, no. 3 (2007), pp. 165-168.*

Mihalik R., Pandula B. (2008) The influances undesirable seismic effct of blasting by driving of Borik tunnel. In: Sborník vědeckých prací Vysoké školy báňské - Technické univerzity Ostrava. Vol. 8, no. 2 (2008), pp. 135-149.

Mishra A.K., Mallick, D.K. (2012) Analysis of blasting related accidents with emphasis on flyrock and its mitigation in surface mine, Rock Fragmentation by Blasting, FRAGBLAST 10 - Proceedings of the 10th International Symposium on Rock Fragmentation by Blasting 2013, November 2012, pp. 555-561.

Murayama H., Niwa H., Shimizu N., Higashinaka M., Noda K. (2014) Use of seismic interferometry for geological surveying ahead of the tunnel face, ISRM International Symposium - 8th Asian Rock Mechanics Symposium, October 2014, pp. 1353-1361.

Müncner E. (2011) Príručka pre strelmajstrov a technických vedúcich odstrelov. Banská Bystrica : SSTVP, 2011. ISBN 80-968748-4-5.

Nistov A., Klovning R., Lemstad F., Risberg J., Ognedal T.A., Haver P.A. Skogesal A.J. (2012) Noise reduction interventions in the Norwegian Petroleum Industry, Society of Petroleum Engineers - SPE/APPEA Int. Conference on Health, Safety and Environment in Oil and Gas Exploration and Production 2012: Protecting People and the Environment - Evolving ChallengesVolume 2, 2012, pp. 1278-1285.

Pandula B., Kondela J. (2010) Metodológia seizmiky trhacích prác, SSTVP Banská Bystrica, 2010, p. 156. ISBN 978-80-970265-0-9.

Pandula B., Kondela J., Pachocka K. (2012) Attenuation law of seismic waves. Metalurgija Vol. 51, no. 2 (2012), pp. 249-252.

Geonor, Inc. (2018): Minimate Pro6, http://geonor.com/live/products/vibration-monitors/minimate-pro6/

Raisian K., Yahaya J., Deraman A., Hamdan A.R., Rais I.A.I, Yahaya N.Z. (2016) A model for environmental quarry system based on particles, vibration and *noise* components, Journal of Environmental Management and Tourism, Volume 7, Issue 2, 2016, pp. 186-194.

Shin E.C., Park J.J., Kang J.K. (2018) Stability Analysis of Underground Tunnel for 2nd Perimeter Highway Construction *Work* in Incheon, *Indian Geotechnical Journal, Volume 48, Issue 2, 1 June 2018, pp. 235-250.*

Zákon Národnej rady Slovenskej republiky č. 355 z 21. júna 2007 o ochrane, podpore a rozvoji verejného zdravia a o zmene a doplnení niektorých zákonov

Vyhláška Ministerstva zdravotníctva Slovenskej republiky č. 549 z 16. augusta 2007, ktorou sa ustanovujú podrobnosti o prípustných hodnotách hluku, infrazvuku a vibrácií a o požiadavkách na objektivizáciu hluku, infrazvuku a vibrácií v životnom prostredí

Vyhláška Ministerstva zdravotníctva Slovenskej republiky č. 237 z 15. januára 2009, ktorou sa mení a dopĺňa vyhláška Ministerstva zdravotníctva Slovenskej republiky č. 549/2007 Z. z., ktorou sa ustanovujú podrobnosti o prípustných hodnotách hluku, infrazvuku a vibrácií a o požiadavkách na objektivizáciu hluku, infrazvuku a vibrácií v životnom prostredí

STN Eurokód 8, Navrhovanie konštrukcií na seizmickú odolnosť. Časť 1, Národná príloha, zmena 1 (STN EN 1998-1/NA/Z1).