RESEARCH OF TECHNICAL SEISMICITY IN THE MAGLOVEC QUARRY

VÝSKUM TECHNICKEJ SEIZMICITY V LOME MAGLOVEC

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Abstract

Disintegration of the rock mass explosion is due to release energy blast, which changes the energy of seismic waves and causes distortion to the massif in the bulk elastic-plastic deformation. Blasting operations generate seismic waves with different maximum velocity amplitudes and wide spectrum of frequencies. The intensity of seismic waves' vibrations is proportional to the weight of the applied explosive. If the vibrations are sufficient in energy, surrounding buildings can be damaged or destroyed. Evaluating the negative effects of the blasting operations and quantification of the seismic safety is nowadays very actual and a challenging problem. Determine the impact of all factors on the nature of the deformation is very difficult. Identification of characteristics of rock at the moment when transition energy of explosion is changing in the mass energy of seismic waves is not possible for the recent state of knowledge of explosion process. Based on the large number of measured data (monitoring) is the best prediction of these effects. The article presents the results of monitoring of blasting in the Maglovec quarry. The results of the evaluation of seismic effects of blasting verified in a Maglovec quarry are the methodological base for evaluation of the seismic effects of blasting in all quarries in Slovakia.

Abstrakt

Rozpojovanie horninového masívu výbuchom sa deje v dôsledku uvoľnenia energie výbuchu, ktorá sa mení na energiu seizmických vĺn a spôsobuje narušenie rovnováhy v masíve pri jeho objemovej pružno-plastickej deformácii. Trhacie práce generujú seizmické vlny s rôznou maximálnou rýchlosťou kmitania a široké spektrum frekvencií. Intenzita vibrácií seizmických vĺn je úmerná hmotnosti použitej výbušniny. Ak majú vibrácie dostatočnú energiu môžu byť okolité objekty poškodené alebo zničené. Hodnotenie negatívnych účinkov trhacích prác a kvantifikácia seizmické bezpečnosti je v súčasnej dobe veľmi aktuálny a zároveň náročný problém Určenie vplyvu všetkých faktorov na charakter deformácie je veľmi ťažké. Identifikácia charakteristík horniny pri prechode energie výbuchu v horninovom masíve na energiu seizmických vĺn, nie je za súčasného stavu poznania výbuchového deja možná. Na základe väčšieho počtu nameraných údajov (monitoringu) je však možná predikcia týchto účinkov. Článok prezentuje výsledky monitorovania odstrelov v lome Maglovec. Hodnotenia seizmických účinkov trhacích prác overované v lome Maglovec je metodickým základom pre hodnotenie seizmických účinkov trhacích prác vo všetkých lomoch na Slovensku.

Keywords

technical seismicity, blasting operations, seismic waves

Kľúčové slová

technická seizmicita, trhacie práce, seizmické vlny

1 Introduction

Disintegration of the rock mass explosion is due to release energy blast, which changes the energy of seismic waves and causes distortion to the massif in the bulk elastic-plastic deformation. Determine the impact of all factors on the nature of the deformation is very difficult. Identification of characteristics of rock at the moment when transition energy of explosion is changing in the mass energy of seismic waves is not possible for the recent state of knowledge of explosion process. Based on the large number of measured data (monitoring) is the best prediction of these effects. Analyzed are the dangerous phenomena, which are accompanied by blasting. As well are known, the criteria and methodology destination zones, dangerous for speech seismic and pressure waves and also the flight of pieces of rock. Formulated the conditions and recommendations for organizational and technical measures have been completed in the conduct blasting permit prevent or significantly limit the adverse effects on civil buildings, structures, machinery, mining works and the environment. Known basic tasks seismic blasting, the principles formulated solutions are clear and yet so far this part of the engineering seismic not recovered from its empirical beginnings. The force, which arises at the point of explosion, raises the ambient medium stress elastic waves. Waves spread to the surrounding area and transmit power of the explosion at a greater distance. Stress wave is transmitted increased tension on the surrounding rocks. They are an explosion near the centre and at a distance of a few meters and the induced stress nature of compression waves. Compressive stress increases fast to a maximum and then slowly decreases to zero, so that oscillation occurs subdued environment (Mosinec, 1976).

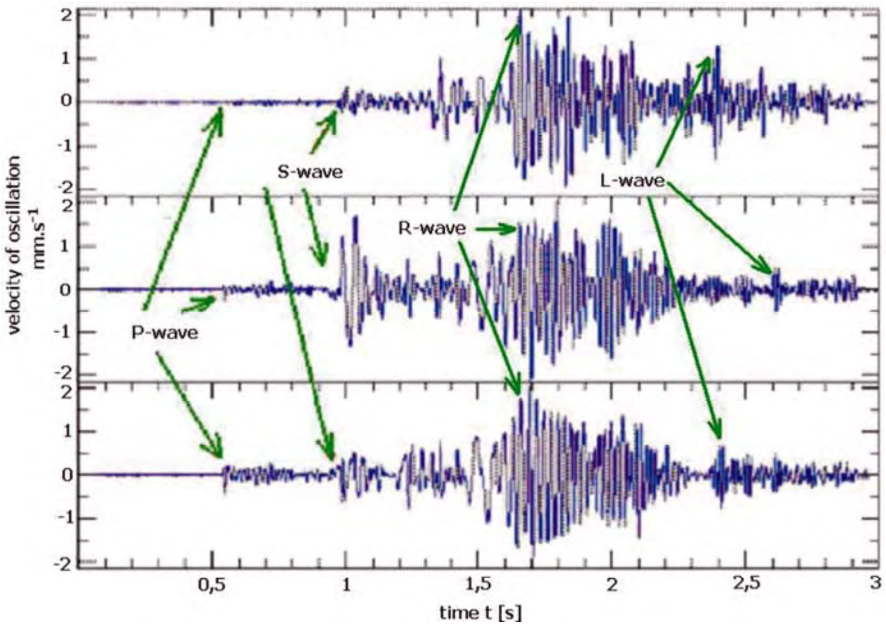
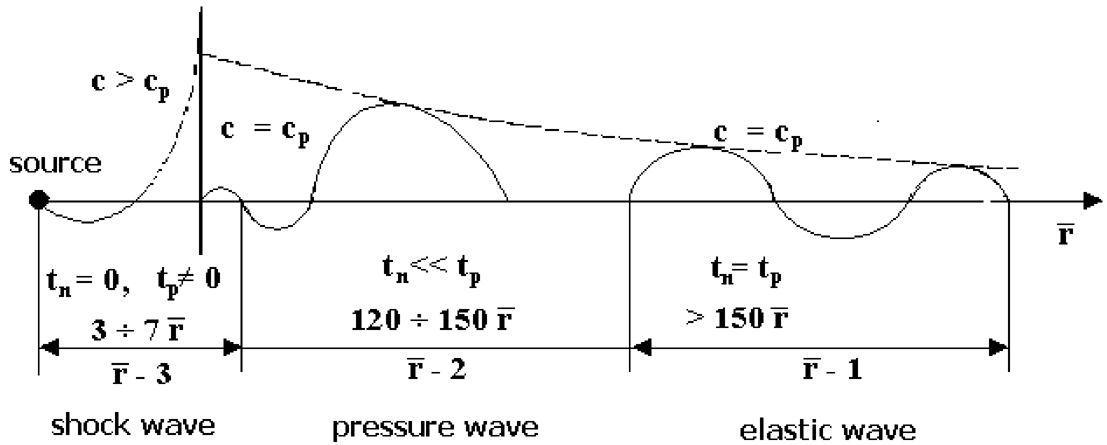


Fig.1 Example seismic record depicting the arrival of P- waves, S- waves, R- waves and L- waves. Can see the difference of time of arrival of the wave to sensor, while the difference in the size of the amplitude (Chen, 1982 in Pandula and Kondela, 2010).

With increasing distance from the center of the explosion and the resulting shape of the stress of the transmission environment changes movement by the acute increase of pressure, the decline is not stopped at zero, but the first part of the positive pressure followed by a second part of the negative pressure wave spreading. Deformation vibration environments acquire character. In any environment, flexible solid state is the formation of longitudinal stress P waves accompanied with a transverse wave, which occurs in the transition and the reflection of longitudinal waves at the interface of different environments (Mosinec, 1976).

If the environment is limited to the surface, which in practice is always present, formed by interaction of the transverse and longitudinal waves other types of waves. These waves propagate only near the surface and are called surface waves. By the nature of their dissemination can distinguish between Rayleigh waves R and Love waves L (Fig.1). Because of the spread in a relatively narrow strip, which adheres to the surface, their energy decreases with distance more slowly than waves vol. Rayleigh waves indicate soil particles elliptical motion, as the water particles in the surface waves. For the distribution of energy explosion imparted rock massif, on the energy of



Annotations:
t_n – time accretion voltage [s],
t_p – time the voltage drop [s],
$\bar{r}$ – relative distance from the source,
c – wave velocity [m×s^{-1}],
c_p – velocity of longitudinal waves [m×s^{-1}],
r_0 – radius of charge [m],
r – distance from the explosion [m].

Fig.2 Attenuation of seismic waves depended on the relative distance from the source (Mosinec, 1976).

individual types of seismic waves it will take some time. Therefore, the energy of waves stabilizes at a certain distance from the source of explosion. According to (Mosinec, 1976), the attenuation of seismic waves can be represented graphically, according to the relative distance $\bar{r} = r/r_0$, (r_0 - radius of charge) from the source wave (Fig. 2).

Distance, at which the energy of waves stabilizes, is for more explosive charge (450 ÷ 4500 kg) of about 150 m. It differs therefore changing energy transmitted by certain types of waves with distance. Within the first 150 m may change the way that energy is transferred to other types of waves. At a greater distance has no exchange of energy and a decrease in energy occurs only due to widening wave front and depression (Mosinec, 1976).

If it spreads seismic wave environment, resulting oscillations (waves), which are registered seismograph. The footage (earthquake records) can be subtracted maximum deflection of particles A. Registered waves is quite complex and consists of a number of sine waves of different frequencies. Usually between one frequency waves prevails. For the predominant frequency is determined by the maximum amplitude. Substituting in the formula, we can calculate the speed of oscillation (or particle velocity) v.

To determine the maximum particle velocities in practice uses an empirical relationship called Langefors or alternatively Koch (Bongiovanni et al., 1991; Dojčár et al., 1996; Mosinec, 1976; Siskind, 2001). This relationship, which is used for the evaluation of the seismic effect of blasting in surface quarries, often referred to in the following format:

$$v_{\max} = K \times Q^{m} \times l^{-n}, \qquad (1)$$

where v_{max} - maximum particle velocity [$mm \times s^{-1}$],

Q - weight of charge [kg],

l - distance from the source [m],

K, m and n are empirical parameters.

Charts are built either as dependence of the maximum particle velocity v_{max} at a distance, or so. reduced distance L_R, which is the ratio of the square root of the distance l weight detonations Q. If we leave the Czech standard CSN 73 0040 or Slovak standard STN EN 1998-1/NA/Z1, then the value of empirical constants in the exponent in the sizes we are considering m = 0.5 and n = 1 That relationship thus passes the form:

$$v_{\max} = K \times \frac{\sqrt{Q}}{l}. \qquad (2)$$

This relationship, called the law attenuation of seismic waves can be very useful for determining the seismic safety. For complex geological conditions, however, may have a very low correlation (Holub, 2006; Dojčár et al., 1996; Kalab et al., 2006). To construct the law attenuation of seismic waves is therefore necessary to use as many measuring opinion.

2 Experimental measurements

Experimental measurements were carried out in a Maglovec quarry (Pandula, Kondela, 2012). The diorite porphyrite quarry in Maglovec is located in the northern part of Slanské vrchy Mts., approximately 35 km to the NW from Košice. In the vicinity of the quarry (approx 800 m to the SW) Vyšná Šebastová and Severná villages (SW) are situated. Monitoring of blasting operations in Maglovec quarry, (Fig.3), as an example, enabled to describe seismic of blasting operations methodology (Kaličiak at al., 1991).

The semi – intruded body of diorite porphyrite in Maglovec quarry is of Neogene age (Middle Sarmatian, 12±0.3 Ma). The body intruded into the Neogene, Lower Miocene sediments. Intrusions of diorite porphyrite (laccoliths, sills) penetrated during Middle Sarmatian at the boundary of Lower Miocene and Lower Sarmatian volcanic complex. Rocks are dark gray and light gray with distinctive dark minerals’ phenocrysts (Fig.3). The phenocrysts most often compose of plagioclase (An34-36), hypersthene, augite and amphibole. The structure is porphyric with holocrystalline, micro-allotriomorphic to hypidiomorphic grainy ground substance. The final structure is then amphibolic – pyroxene to pyroxene – amphibolic diorite porphyrite (Kaličiak at al., 1991).

The thickness of mantle-rock varies from 5 m to 40 m. Progressing exploitation in the quarry revealed internal structure of diorite porphyrite body. The structure is much more difficult than it was expected during investigation based on borehole research. Current mined part of deposit in Vyšná Šebastová identified tectonic line with general trend NNE – SSW, with its origin genetically connected to consolidation of footwall clay sediments caused by load of solidified body. It is failure zone, which destroys part of the deposit and divides the deposit into two parts (Fig. 3).

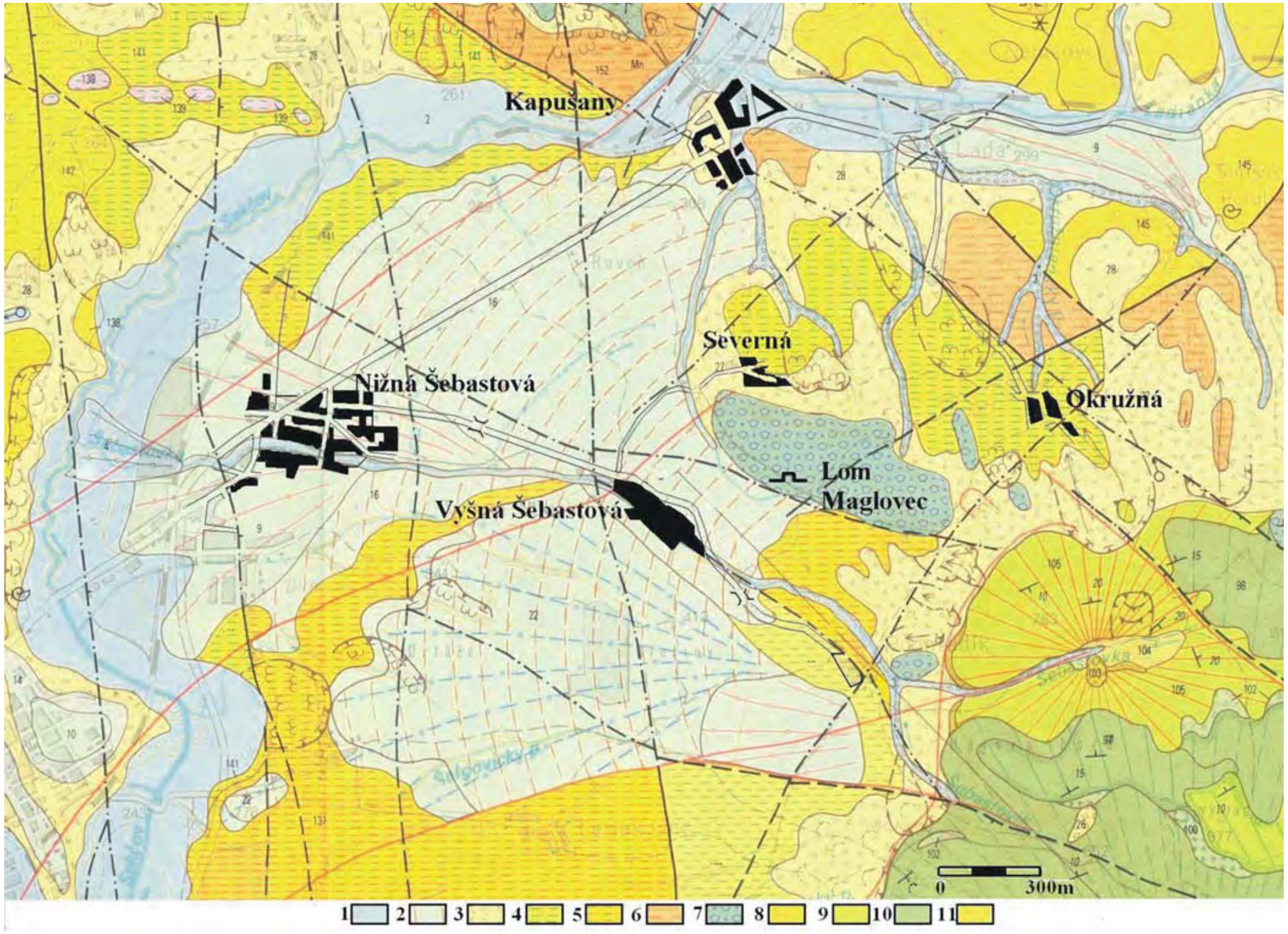


Fig.3 Geological map of Maglovec quarry with the nearest villages (Kaličiak, et. al., 1991) edited. 1 fluvial sediments: loams, sands, clays, 2 proluvial sediments: sandy gravels with loess loams regolith, 3 deluvial sediments: loamy rocky undivided sediments, 4 mirkovske formation: monotonous, grey calcareous claystones, 5 kladzianske formation: greenish grey claystones with beds of fine grained sandstones, 5 zuberecke formation: alternation of sandstones, siltstones with interformation conglomerates, Mn carbonate ore and varicolored claystones, 7 intrusions of amphibolic pyroxene diorite porphyrite, 8 Čelovské formation: light grey siltstones to fine grained sandstones, 9 Sebastovka formation: lava torrent of amphibolic pyroxene andesite, 10 Stavica formation: lava torrent of augite - hypesthenic andesite, hypesthenic augite andesite, pyroxene andesite with different ratio of augite and hypesthene 11 Čelovské formation: light grey greenish grey micaous claystones.

2. 1 Measuring positions and seismic devises used for measuring

The following digital seismic devises were used for measuring and graphic records of the seismic effects:

- digital blasting seismograph VMS 2000 MP and seismic receivers by Geospace (Fig. 4),
- digital blasting seismograph Minimate Pro 6 and seismic receivers by Instantel (Fig. 5),
- digital blasting seizmograph ABEM Vibraloc and seismic receivers by ABEM (Fig. 6),
- digital blasting seizmograph UVS 1504 and seismic receivers by Nitro Consult (Fig. 7),
- portable seizmograph ABEM Terraloc Mk 8 and seismic receivers by ABEM (Fig. 8).

Seismographs provide a digital and graphical record of all tree components of a velocity of particle oscillation of a medium: horizontal radial – $\mathbf{v_x}$, horizontal transverse – $\mathbf{v_y}$ and vertical – $\mathbf{v_z}$. Seismographs VMS 2000 MP, Minimate Pro 6, UVS 1504 and ABEM Vibraloc work autonomously and automatically perform testing of individual channels without influence of an operator into the measured and registered characteristics of oscillation. These seismographs have their own converter with automatic 14 bits dynamic range what respond to 0.05 ÷ 250 $mm \times s^{-1}$. For measurements were used the following geophones: The electrodynamics geophones Nitro Consult with frequency range 1 ÷ 1000 Hz and sensitivity 20 $mV/mm \times s^{-1}$, and tree-components geophones Geospace, Minimate Pro 6 and ABEM with frequency range 2 ÷ 250 Hz and sensitivity 10 $mV/mm \times s^{-1}$. The geophones were installed on a special board with sharp steel bits that ensured continual contact with the base.

Fig.4 Measuring position 1 the location of the seismograph VMS 2000 U.S. company Thomas Instruments and sensors company Geospace 8.5 m away from the blast.

Measuring positions were located so it would be possible to evaluate the influence of an artificially excite seismic effect by a bench blasting on the residential buildings. Measuring positions were located as to be able to assess and check also the law of attenuation of seismic waves. Distance among the receivers and the bench blasting are in Table 1. Position of the measuring site to the bench blasting is shown on Fig. 9. When measurements were also used seismograph ABEM Terraloc MK8 with 24 geophones for registration of a seismic wave on profile 8.5 to 250 m from the blast.

2.2 Source shocks

Sources of seismic events were bench blasting no. 361 (Fig.10) on the bearing diorite porphyrite situated about 8 km northeast of Prešov in the cadastral territory of Vyšná Šebastová and Podhradík. Blasting was realized by Ltd. company ORICA, Humenné. Where blasting was drilled 61 boreholes with a length of 26 m. Maximal load in one borehole – it is

Fig.5 Location of seismograph Minimate Pro 6 and sensors Instantel at a distance of 110 m

Fig.6 Measuring position 2 location of seismograph ABEM Vibraloc 250 m from the blast

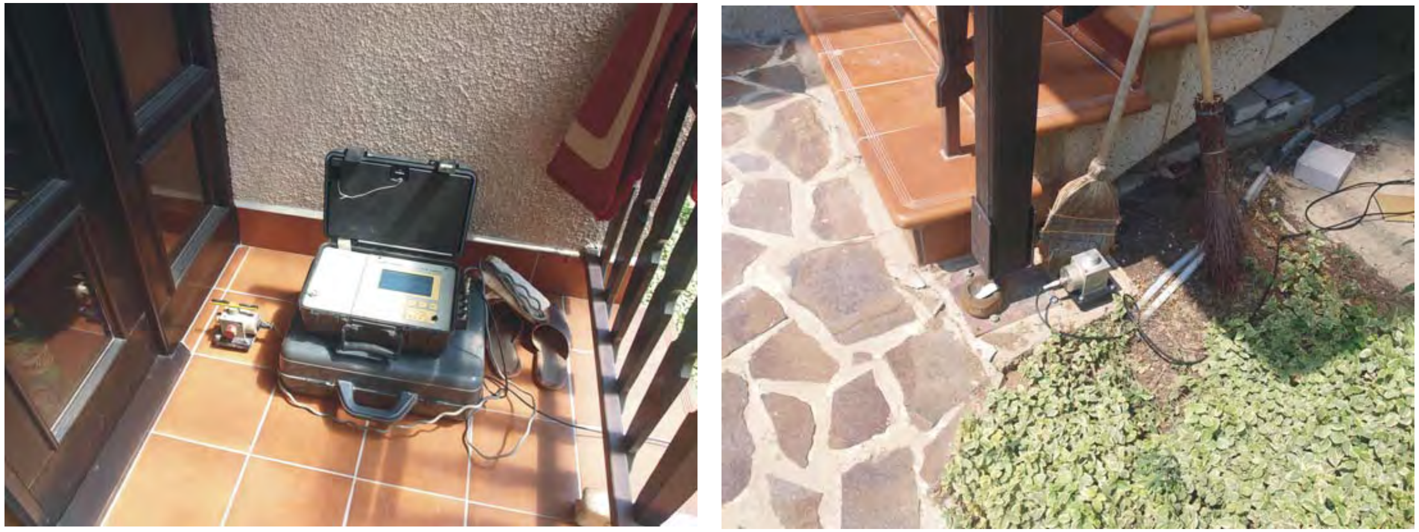


Fig.7 Measuring position 3 location seismograph UVS 1504 company Nitro Consult placed in the stairwell of the house no. 255 (left) and sensor location on the foundations of a dwelling house no. 255 (right).

Fig.8 Seismograph Abem Terralock Mk 8 locations and the location of the trigger geophon 8.5 m from the first borehole (right). Geophone was deployed to profile within 220 m from blast apart after 10 m. The first geophone was next on the startup geophon at 27.5 m from the source in the first borehole.

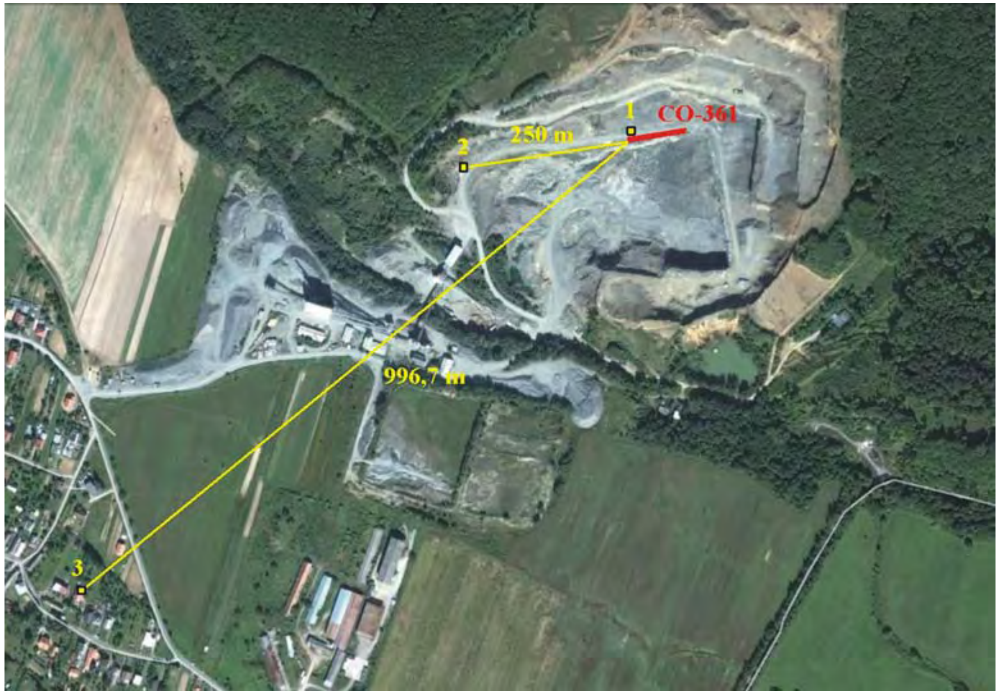


Fig.9 ***Position of measuring sites 1, 2*** *and 3 and their position* ***with bench blasting no. 361.***

Tab.1 Interdistance among measure positions and bench blasting

Position	Blasting seismograph	Interdistance [m]	
		sloping	horizontal
1	VMS 2000	27.5	8.5
	Minimate Pro 6		110
2	ABEM VIBRALOC		250
3	UVS 1504		996.7

223 kg of explosives. For priming explosive was used Centragold 100 13 462 kg and Eurodyn 2000 125 kg. Total explosive charge in boreholes was 13 587 kg. Per time step was used more than 446 kg of explosives. Used detonators are these: Nonel 122 pieces and 64 pieces of connectors (Fig. 11 and 12).

3 Measured seismic effects blasting operations and analysis

Seismograph VMS 2000 (Fig.13), he was placed on position 1. Before the measurements were calibrated and checked was his sensitivity. Readings in the blast on the position are listed in Table 2. On position 1 was recorded graph of the components of the seismic waves (Fig. 14). Channel no. 1 is a component of z, channel no. 2 is a component y and channel no. 3 is a component of x. Seismograph Minimate Pro 6 was deposited between the measurement position of 1 and 2 at a distance of 110 m from the first borehole. Before the measurements were calibrated and checked was his sensitivity. Readings in the blast on the position are listed in Table 3. On the position was recorded graph of the components of seismic waves (Fig. 15). Channel no. 1 is the measurement noise; channel no. 2 is a component of x, channel no. 3 - component of z and channel no. 4 – component of y.

Fig.10 Explosives used in the bench blasting the no. 361

Fig.11 Position bench blasting on the I. storey

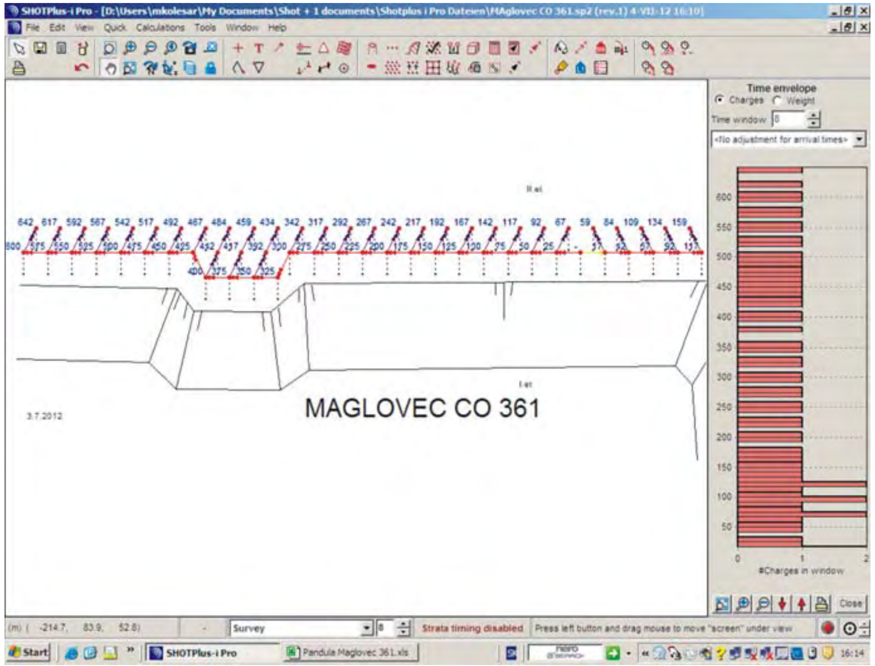


Fig.12 Position, timing of boreholes bench blasting on I. storey

Seismograph Abem Vibraloc was stored on position 2. Before the measurements were calibrated and checked was his sensitivity. Readings in the blast on the position are listed in Table 3. On the position 2 was recorded graph of the components of seismic waves (Fig.16). Channel no. 1 is a component of z, channel no. 2 is a component of x, and channel no. 3 is a component of y.

Seismograph UVS 1504 was stored on position 3. Before the measurements were calibrated and checked was his sensitivity. Readings in the blast on the position are listed in Table 2. On the measuring position 1 was recorded graph of the components of seismic waves (Fig.17). Channel no. 1 is a component of z, channel no. 2 is a component of y, and channel no. 3 is a component of x.

The wave record obtained by seismograph Terraloc ABEM Mk 8 (Fig. 18) it is possible to examine the shape of the waves emitted from the source at distances up to 250 m. In this way it was possible to determine when the wave packet separated on the basis of the speed of different types of waves - longitudinal wave, shear wave, Railegh waves and Love waves. From the record that was at a distance of 70 – 100 m from the source. At a distance of 107,5 m from the source at position geophone no. 9 can already be very well distinguish between different types of waves. Wave velocity determined from the record at that distance was 5000 ms^{-1}. In this way, experimental measurements confirmed the work (Mosinec, 1976). Based on the recommendations of STN EN 1998-1/NA/Z1 Seismic load structures and on the resistance of buildings to technical seismicity can be considered a family house in the village Vyšná Šebastová included in the resistance class B.

Fig.13 Position of the seismograph VMS 2000, first and trigger geophones seismograph of the Terralock Mk 8 and fracture wall after blast.

Tab. 2 Measured values on position 1

	Vertical	**Transverse**	**Radial**
PPV [mm/s]	178.46	112.09	87.35
Freq [Hz]	28.4	24.4	13.8
Times [ms]	499	668	689
PPA [g]	3.24	1.75	0.77
PPD [mm]	1.00010	0.73113	1.00740
PSV [mm/s]	193.360 @ 502.0 ms		
PSPL [PA]	0.15 (77.718 dB) @ 0.0 ms		
PSPL Freq	512. 0 Hz		
sensor test	passed	passed	passed

As regards the type and category of subsoil protected objects that in the absence of more specific characteristics and data can be classified into a category that is closest to reality (groundwater level was less than 3 m below the surface). On this basis, and given the long-term nature of on blasts bearing diorite quarry porphyrite Maglovec and given the nature of the buildings, the disintegration blasting on quarry deposit Maglovec and for building structures in the village Vyšná Šebastová may be the maximum permitted particle vibration (velocity component) set value $v_d \leq 3$ mm/s.

Tab.3 Measured values of bench blasting No.361 (speeds and frequencies)

Blasting seismograph	**X [Hz]**	**Y [Hz]**	**Z [Hz]**	**Z_1 [Hz]**	**X [$mm \times s^{-1}$]**	**Y [$mm \times s^{-1}$]**	**Z [$mm \times s^{-1}$]**	**Z_1 [$mm \times s^{-1}$]**
VMS 2000	13.8	24.4	28.4		87.35	112.1	178.5	
Minimate Pro 6	8.0	7.6	7.4		27.2	19.1	32.8	
ABEM Vibraloc	38.1	29.4	28.7		9.8	11.3	5.2	
UVS 1504	4.1	1.5	12	18	0.75	0.95	0.75	0.54

Measured peak values of blasting seismic effects generated are shown in Table 4. These values have served us as a basis for determining the law attenuation of seismic waves in a Maglovec quarry.
Based on data from Table 3 was constructed graphical dependence of the maximum vibration velocity components

on reduced distances at blasting. The graph in Fig. 19 is called. Law of attenuation of seismic waves to Maglovec quarry, 2, in which the value of Q, used in the form:

$$v = \left(\frac{L}{Q^{0,5}} \right) = K \times \left[\frac{L}{Q^{0,5}} \right]^n , \qquad (3)$$

where „v“is a measured maximal particle velocity (peak particle velocity components) generated by blasting, [mm×s^{-1}],

- L is the shortest distance of source of vibrations from their receptors, [m],
- $L/Q^{0,5}$ is reduced distance, [m/kg^{0,5}],
- Q is a weight of the charge for one time step, [kg],
- K is a coefficient depending on the conditions of blasting, characteristics of transfer environment, kind of a used explosive etc.
- n is indicator of attenuation of seismic waves.

The graph of the law attenuation of seismic waves for blasting in Maglovec quarry in Fig. 9 clearly shows that the limit of particle velocity 3 mm×s^{-1} for frequencies less than 10 Hz, will not be exceeded for the used permissible charge for one time step and for specific distances. The red line represents a limit of the maximal permitted particle velocities for Maglovec quarry.

Mining on site Maglovec is performed by blasting operations. From the law of attenuation of seismic waves, it can be determined for a particular receptor the size of charge at a known distance so that the maximum values of the individual components of particle velocities do not exceed the maximal speed of vibration for Maglovec quarry. Based on measurements performed in Maglovec quarry to follow the blasting operation we establish the maximum charge per one time step as follows:

for distance 500 m $Q_{max} = L^2/L_R^2 = 500^2 / 30^2 =$ 278 kg,
for distance 600 m $Q_{max} = L^2/L_R^2 = 600^2 / 30^2 =$ 400 kg,
for distance 700 m $Q_{max} = L^2/L_R^2 = 700^2 / 30^2 =$ 544 kg,
for distance 800 m $Q_{max} = L^2/L_R^2 = 800^2 / 30^2 =$ 711 kg,
for distance 900 m $Q_{max} = L^2/L_R^2 = 900^2 / 30^2 =$ 900 kg,
for distance 1000 m $Q_{max} = L^2/L_R^2 = 1000^2/30^2 =$ 1111 kg and for distance 1100 m $Q_{max} = L^2/L_R^2 = 1100^2 / 30^2 =$ 1344 kg.

5 Conclusion

Seismic effects of blasting operations on building sites are judged by the particle velocities. The research, which was at the Institute of Geosciences F BERG TU Košice in recent years carried out, it was clear that the assessment of seismic safety of large-scale blasting operations is necessary to establish law attenuation of seismic waves for the monitored area. Number of necessary data for mathematical - statistical determination of the law attenuation of seismic waves is relatively high. Therefore it was necessary to evaluate on measurement several opinions as to obtain the necessary set of statistics, to determine the law attenuation of seismic waves. This information was used

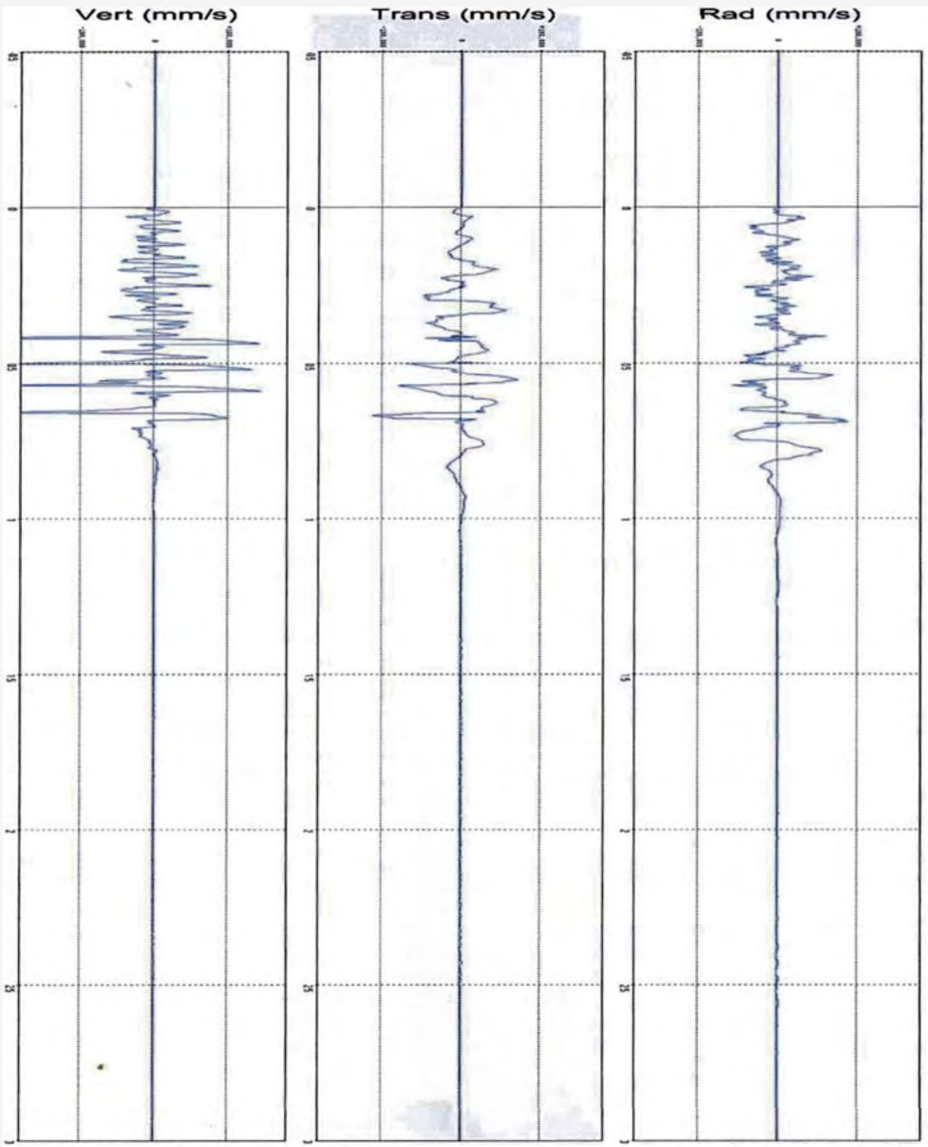


Fig.14 Graphic record of the individual components in the wave on the measuring position 1 (8.5 m from the blasting seismograph VMS 2000

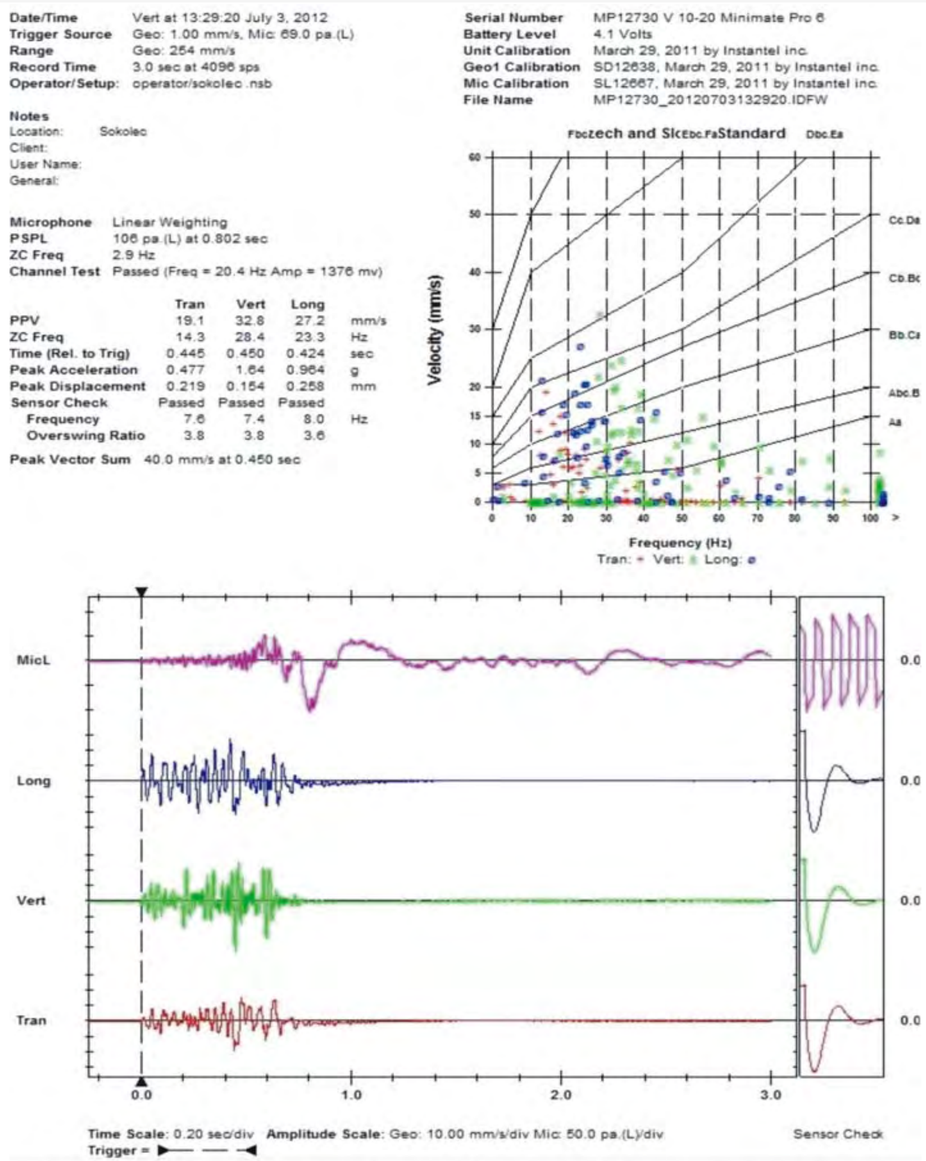


Fig.15 Graphic record of the individual components of seismic waves on measuring station. Distance of 110 m from the blast - seismograph Minimate Pro 6 and measured values.

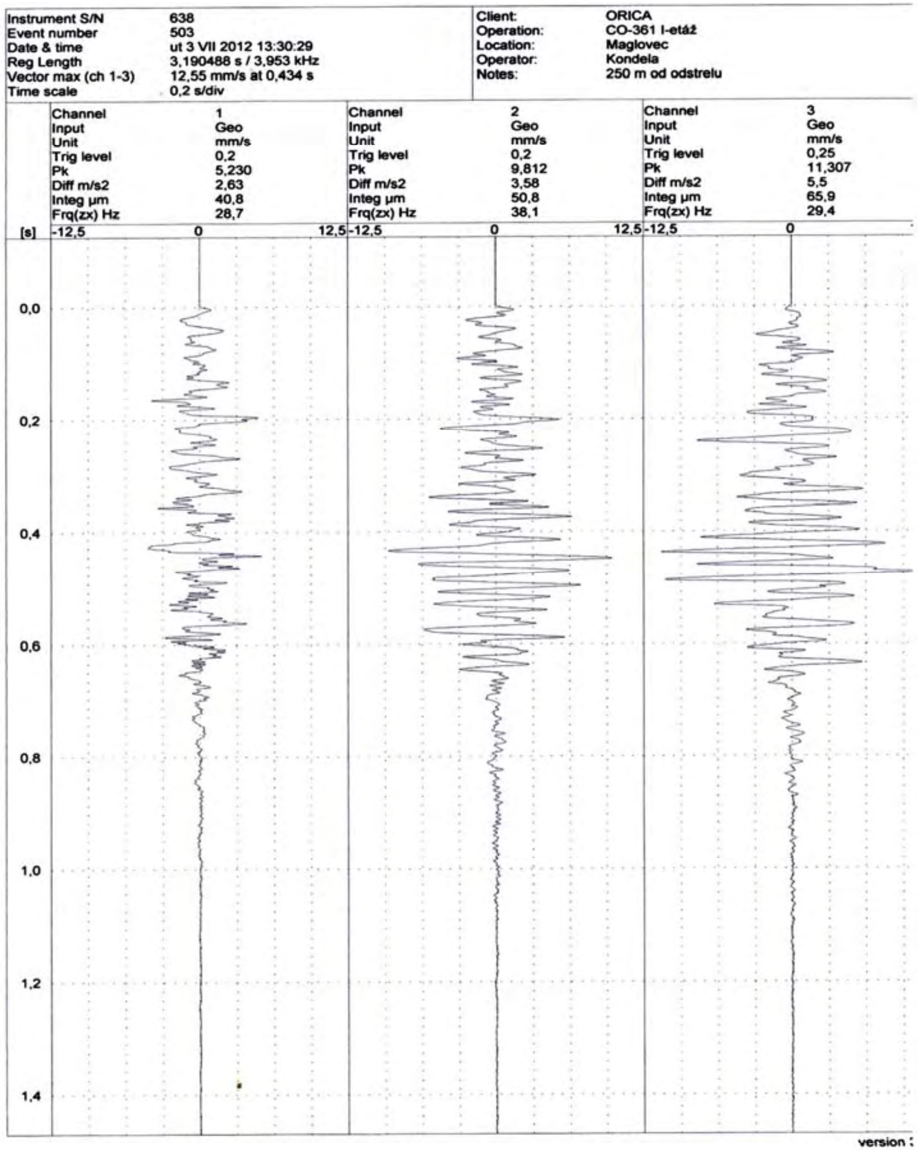


Fig.16 Graphic record of the individual components of waves on the measuring position 2 (250 m from the blast) and measured values on position 2.

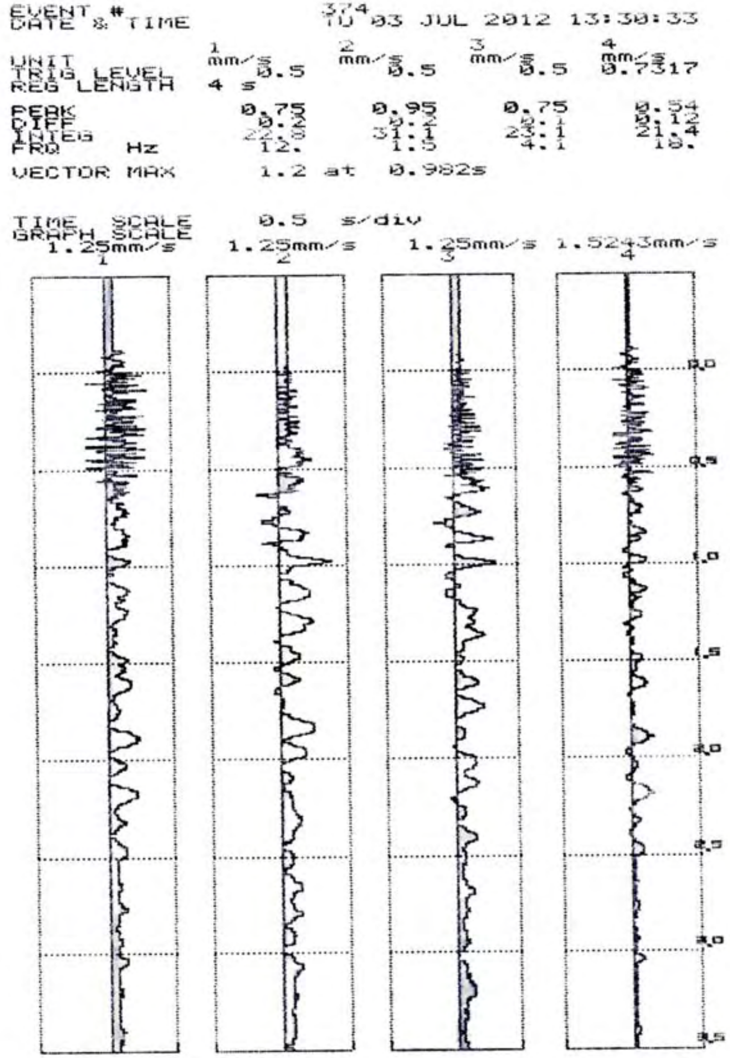


Fig.17 Graphic record of the individual components of waves on the measuring position 3 (house no. 255 - Vyšná Šebastová) and measured values on the position 3.

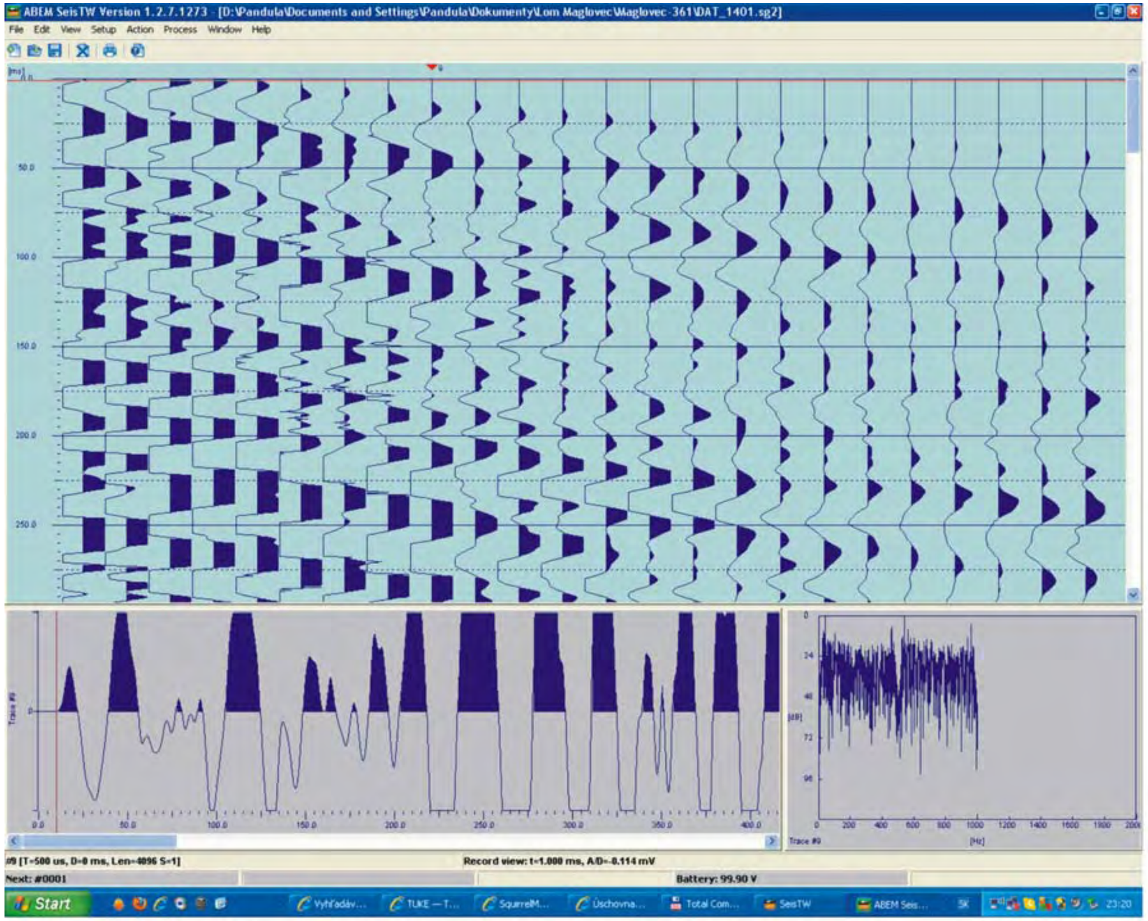


Fig.18 Record the measurement propagation of seismic waves from the blast using a seismograph Terraloc ABEM Mk 8. The first geophone was at a distance of 27.5 m from the source wave in the first borehole of the blasting. Geophone spacing was 10 m. The bottom picture shows the waveform record of the 9 geophon, which was at a distance of 107.5 m from the source of waves.

Tab.4 Measured maximum value of vibration velocity components at blast

L [m]	Q [kg]	$L_R = L/Q^{0,5}$ [$m/kg^{0,5}$]	v_x [mm/s]	v_y [mm/s]	v_z [mm/s]
996.7	446	47.19	0.75	0.95	0.75
220	446	10.4	9.8	11.3	5.2
110	446	5.21	27.2	19.1	32.8
8.5	446	0.4	87.35	112.1	178.5

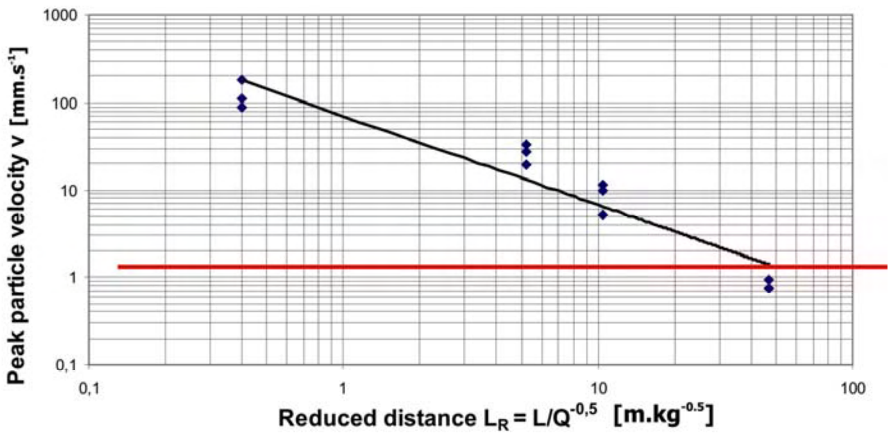


Fig.19 Graphical dependence of the peak particle velocities components at reduced distances for blasting in Maglovec quarry. The red line indicates the maximum safe limit of the particle vibration to building Vyšná Šebestová

to determine the permissible particle velocities observed for receptors, accurate assessment and determination of permissible explosives at blasting operations and to determine the law attenuation of seismic waves.

By law attenuation of seismic waves is necessary in the design of blasting operations set for a particular receptor maximum quantity of explosives per time step at a known distance source - receptor so that the maximum value of particle velocities components does not exceed the maximum permissible particle velocities. Experimental measurements have confirmed that the different types of waves registered by a blast at the speed of propagation in rock environment separated from the wave packet at a distance of a few tens of meters from the source.

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