INVESTIGATION ON SEISMIC SIGNALS FOR BLASTING IN QUARRIES

SKÚMANIE SEIZMICKÝCH SIGNALOV PRI ODSTRELOCH V LOMOCH

Blažej Pandula [1], Julián Kondela [2], Karel Holub [3]

Abstract

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. The article presents the results of the analysis as well as an evaluation method of seismic safety of the objects during blasting work held by the law of decrease of the seismic wave amplitudes in 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 effects of seismic blasting in all quarries in Slovakia.

Abstrakt

Odstrel generuje 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. Článok prezentuje výsledky analýzy stejne ako hodnotenie seizmické bezpečnosti objektov pri trhacích prácach v lome Maglovec. Hodnotenia seizmických účinkov trhacích prác overované v lome Maglovec sú metodickým základom pre hodnotenie účinkov trhacích prác vo všetkých lomoch na Slovensku.

Keywords

blasting operations, seismic safety, seismic waves

Kľúčové slová

trhací práce, seizmická bezpečnosť, seizmické vlny

1 Introduction

The rock blast seismics is part of seismic engineering. In practice the seismics of rock blasts is predominantly focused on solution of the following issues (Dojčár et al., 1996):

- measurement and evaluation of particular vibration effects rising from a defined source on a given receptor,
- prognostics of effects of a potential source on a given receptor,
- prediction of effects of a defined source on a potential receptor.

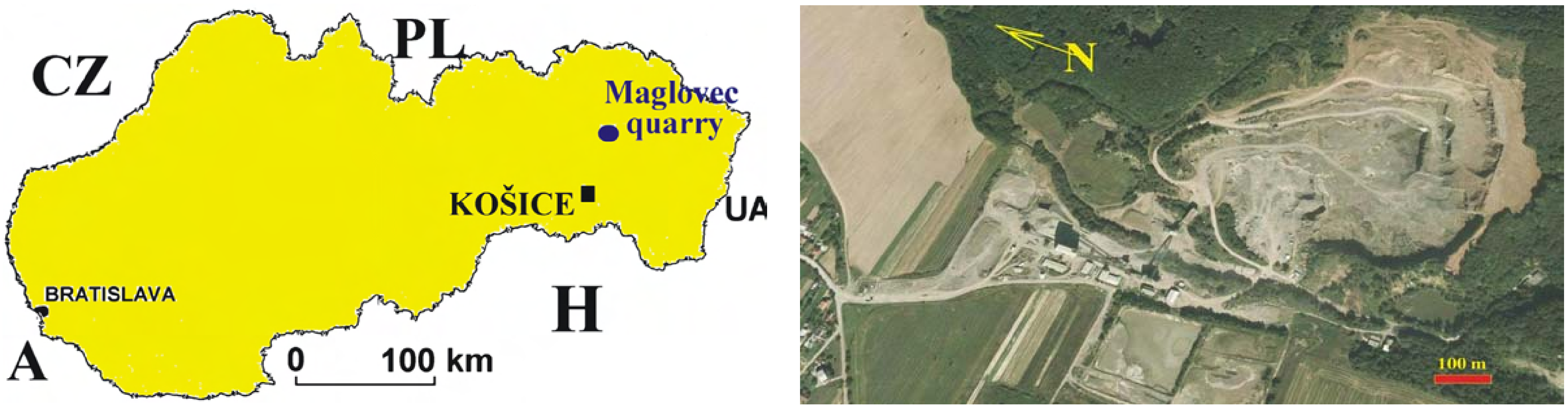


Fig. 1 Position of Maglovec quarry and its aerial view

In practice all tasks of rock blast seismics are given due to combination of three basic issues. Due to the previous statement it follows that there exist three components which are predominant for the rock blast seismics (Pandula and Kondela, 2010; Holub, 2006; Kaláb and Knejzlík, 2004; Kaláb and Lednická, 2006):

- source of vibration,
- transmitting medium,
- receptor.

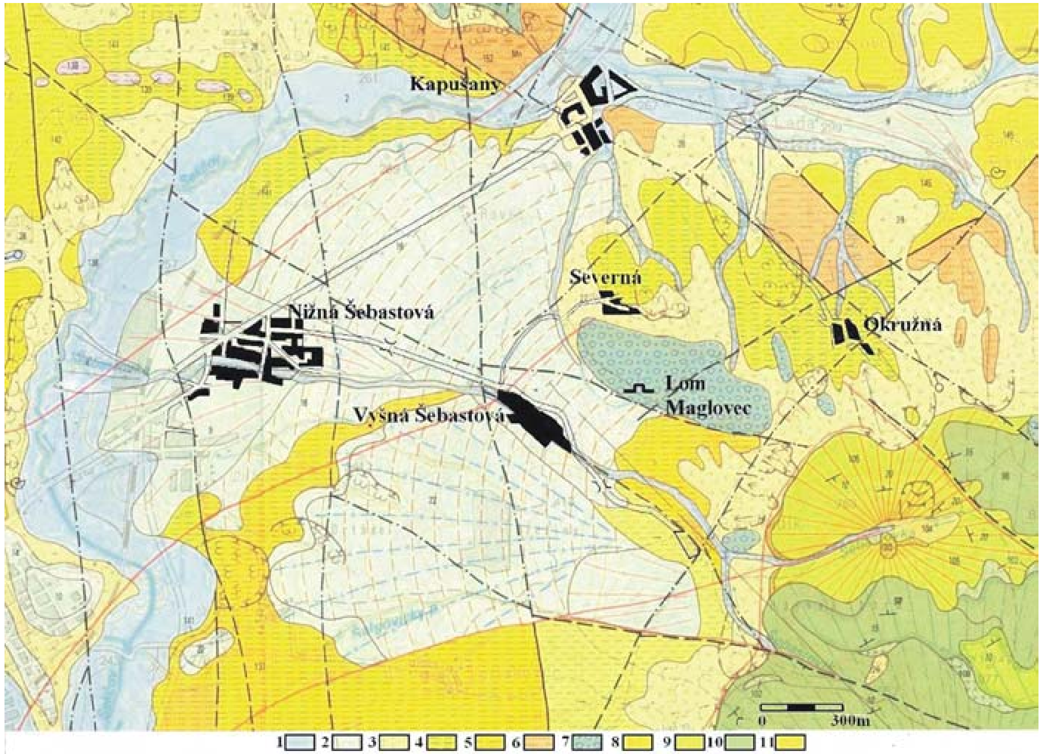


***Fig. 2** Geological map of Maglovec quarry with the nearest villages (Kaličiak et al., 1991) edited. 1 fluvial sediments: loams, sands, clays, 2 proluvial sediments: sandy gravels with loess loams regolith, 3 deluvial sediments: loamy rocky undivided sediments, 4 mirkovske formation: monotonous, grey 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.*

Due to experiments carried out in the quarry Maglovec applying the latest measurement techniques we measured the seismic effects of rock blasts in the surrounding area of the source and searched to analyze the different types of seismic waves arising at blasting. The analysis enables to evaluate the seismic effects of rock blasts in an appropriate way.

The diorite-porphyrite quarry in Maglovec is located in the northern part of Slanské vrchy Mts., approximately 45 km to the NW from Košice (Fig. 1). 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, as an example, enabled us to describe seismic of blasting operations methodology.

2 Transmitting medium

The semi – intruded body of diorite porphyrite in Maglovec quarry is of Neogénne age (Middle Sarmatian, 12+- 0.3 Ma). The body intruded into the Neogénne, 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. The phenocrysts most often compose of plagioclase (An_{34-36}), 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 et 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

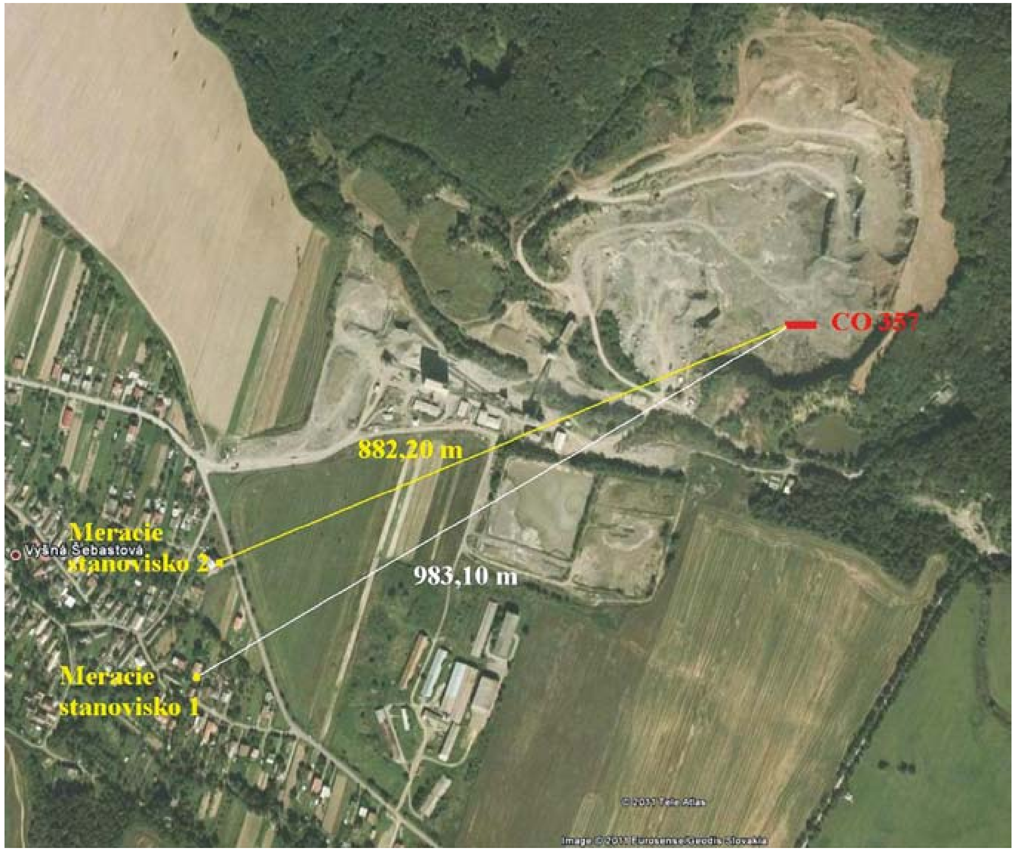


Fig. 3 Measuring position 1 and 2 family house No. 255 in the village Vyšná Šebastová and panel house No. 218 and their position to blasting

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. 2).

3 Receptors

The receptors were family houses in the village Vyšná Šebastová and an office building in the Maglovec quarry (Fig. 3). The measurements were carried out on both types of civil buildings – a block of flats and a family house - which were nearest to the source of seismic effects and moreover the seismic waves could have manifested most. To compare the obtained results we carried out measurements on the office buildings in the quarry Maglovec which were situated in imminent neighbourhood of activated blasting.

Fig. 4 Position of triplex drilling at bench blasting No. 357 and crown after blasting

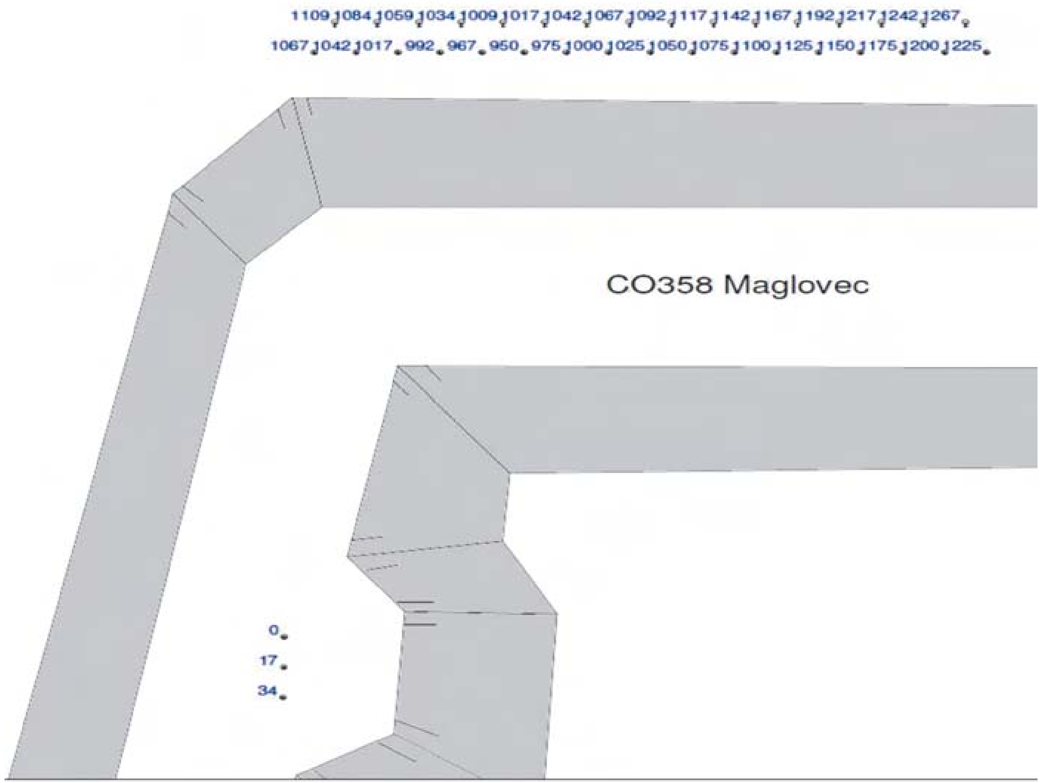


Fig. 6 Scheme of borehole distribution and millisecond timing scheme bench blasting Nr. 358

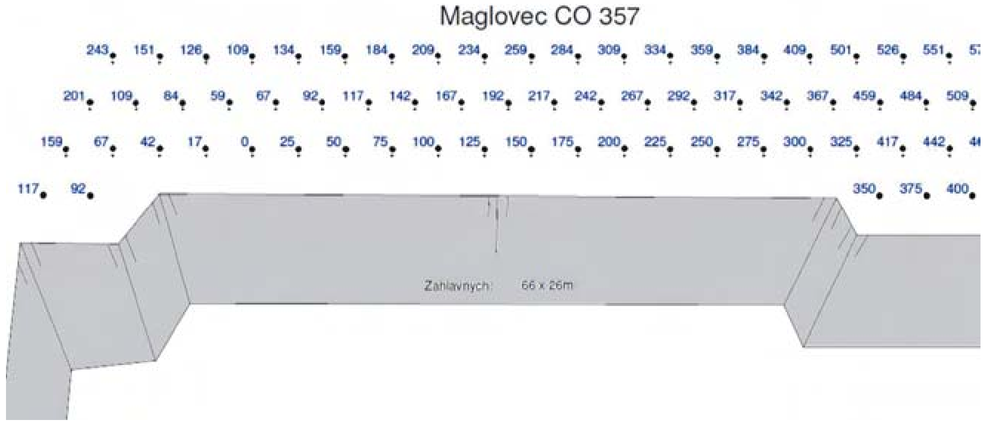


Fig. 5 Scheme of borehole distribution and millisecond timing scheme bench blasting No. 358

4 Source of vibrations

The sources of seismic waves were a tristichous bench blasting No. 357 (Fig. 4), double-row bench blasting No. 358 and a surface blasting No. 359. The first one was the bench blasting No. 357 with the following parameters:

There were 68 boreholes drilled with 26 m of length (Fig. 5). The maximum explosive charge in one borehole was 235 kg. For initiation the following explosives were applied: Senatel 192 kg and Eurodyn 400 kg and for shooting and blasting the explosive Centragold 100 – 14 415 kg was applied. The total weight of explosion charge in boreholes was 15 007 kg. The maximum weight of explosion charge set off in one time stage was 470 kg.

The parameters of tristichous bench blasting No. 358 are these:

There were 36 boreholes drilled with 26 m length (Fig. 6). The maximum weight of explosion charge in one borehole was 205 kg. For initiation the following explosives were applied Senatel and Eurodyn; and for shooting and

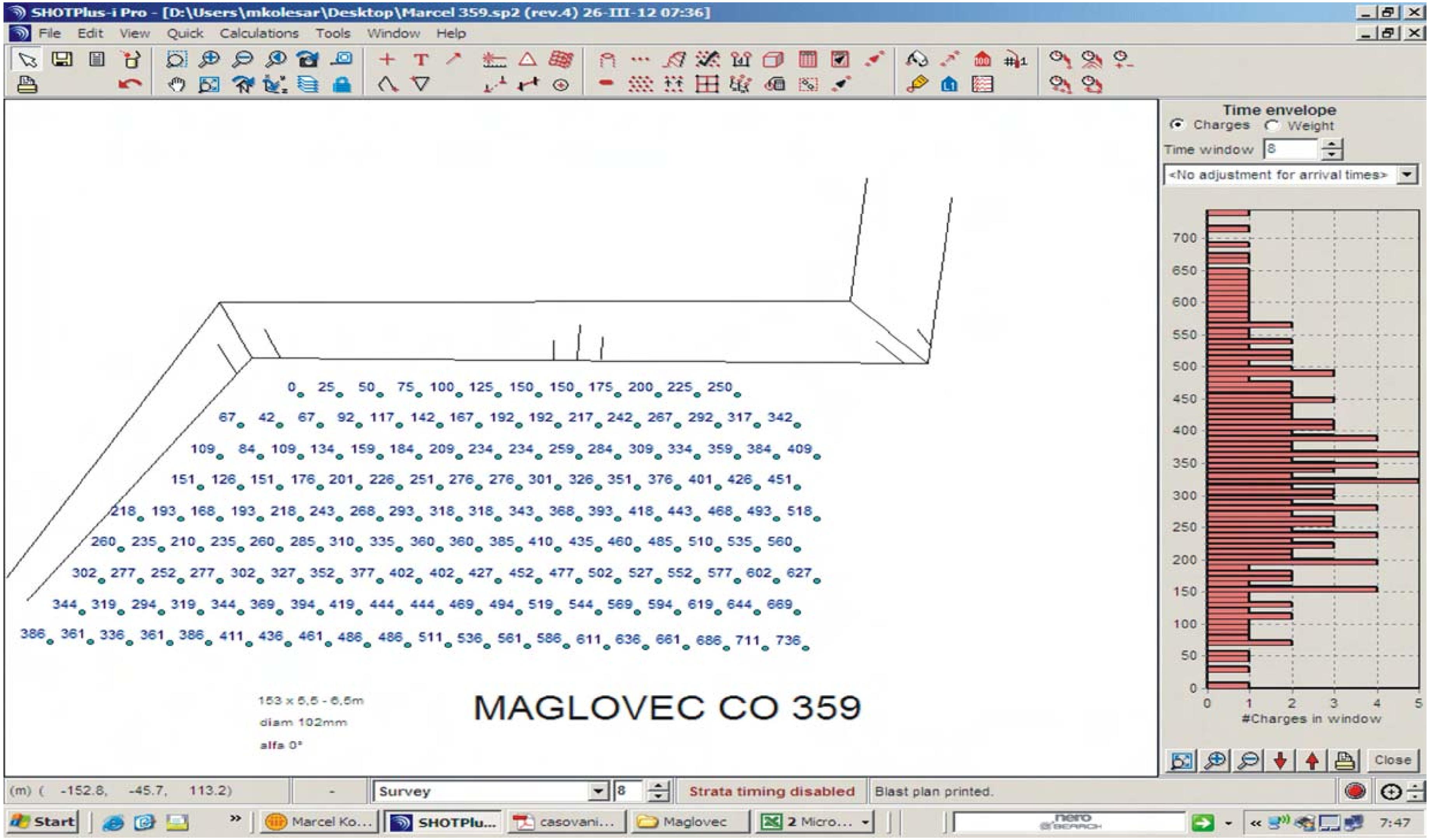


Fig. 7 Scheme of borehole distribution and parameters of explosive in bench blasting No. 359

blasting the explosive Centragold 100 was applied. The total weight of explosives in boreholes was 7374 kg. The maximum weight of explosion charge set off in one time stage was 410 kg.

The parameters of tristichous bench blasting No. 359 are following:

There were 153 boreholes drilled with 6 m length (Fig. 7). The maximum weight of applied explosive in one borehole was 16.7 kg. For initiation the following explosives were applied Senatel 2376 kg and Eurodyn 175 kg. The total weight of applied explosives in boreholes was 2 551 kg. The maximum weight of explosion charge set off in one time stage was 83.5 kg.

5 Equipment used and measurement methodology

Fig. 8 Measuring position in a I. storey, 20 m from the blast in the Maglovec quarry

For measurement and graphical recording of seismic effects the following digital equipments were used:

- the seismograph VMS 2000 MP by American company Thomas Instruments and the geophones by American company Geospace (Fig. 8 and 9),
- the seismograph ABEM Vibraloc and the geophones by Swedish company ABEM (Fig. 10),
- the seismograph UVS 1504 and the geophones by Swedish company Nitro Consult (Fig. 11).

The seismographs provide both digital and graphical records of all three components of vibration velocity of medium parts i.e. horizontal longitudinal – $\mathbf{v_x}$, horizontal transversal – $\mathbf{v_y}$, vertical – $\mathbf{v_z}$. The seismographs VMS 2000 MP, UVS 1504 and ABEM Vibraloc work autonomously and therefore they carry out tests of channels automatically and without any intervention or influence of operators on the measured and registered vibration characteristics. The seismographs VMS 2000 MP, UVS 1504 and ABEM Vibraloc have an automatic 14 bit dynamic convertor with 0.05 ÷ 250 $mm.s^{-1}$ dynamic range. For these measurements the electrodynamic geophones NitroConsult with frequency range 1 ÷ 1000 Hz were used and with sensitivity 20 $mV/mm.s^{-1}$. Further the three component geophone by company GeoSpace and the three component geophone by company ABEM with frequency range 1 ÷ 1000 Hz and sensitivity 10 $mV/mm.s^{-1}$ were applied. The geophones were set on a special support with sharp steel spikes which assured continual contact with foot.

The measuring standpoints were located in the way enabling effect evaluation of artificially activated blasting seismics on the family house No. 255 and the panel house No. 218. The distances between the recorders and the blasting are presented in Table 4.

Fig. 9 Measuring position in a 0. storey, 10 m from the blast in the Maglovec quarry

Fig. 10 Measuring position 2 family house No. 255 in the village Vyšná Šebastová

Fig. 11 Measuring position 2 panel house No. 218 in the village Vyšná Šebastová

6 Measured values and analysis

Tab. 1 Measured values of particle velocities and frequencies of blasting No. 357

Standpoint	**X [Hz]**	**Y [Hz]**	**Z [Hz]**	**X [mm. s^{-1}]**	**Y [mm. s^{-1}]**	**Z [mm. s^{-1}]**
Blasting III. storey	14.2	7.9	23.3	83.27	44.84	89.01
Family house No. 255 Vyš. Šebastová	4.54	9.74	54.9	0.867	0.541	0.965
Panel house No. 218 Vyš. Šebastová	6.9	1.5	17	1	1	0.75

Tab. 2 Measured values of particle velocities and frequencies of blasting No. 358

Standpoint	**X [Hz]**	**Y [Hz]**	**Z [Hz]**	**X [mm. s^{-1}]**	**Y [mm. s^{-1}]**	**Z [mm. s^{-1}]**
Blasting III. storey	12.5	13.8	12.5	80.29	47.38	139.59
Family house No. 255 Vyš. Šebastová	16.8	58.1	41.2	0.25	0.2	0.25
Panel house No. 218 Vyš. Šebastová	3	1	0.3	0.55	0.6	0.5

*Tab. 3 **Measured** values of particle velocities and frequencies of blasting No. 359.*

Standpoint	**X [Hz]**	**Y [Hz]**	**Z [Hz]**	**X [mm. s^{-1}]**	**Y [mm. s-^{1}]**	**Z [mm. s^{-1}]**
Blasting III. storey	**21.3**	**21.3**	**73.2**	**15.68**	**10.82**	**38.21**
Family house No. 255 Vyš. Šebastová	**62.7**	**52**	**54.9**	**0.535**	**0.515**	**1.066**
Office building Maglovec quarry	**17.9**	**30.9**	**15.1**	**3.304**	**2.837**	**6.013**

The measured maximum values of seismic effects generated by bench blasting carried out in the quarry Maglovec are demonstrated in Tables 1, 2 and 3 and in fig. 12. In case of blasting No. 357 the seismograph VMS

Fig. 12 Measuring position 3- office building in the Maglovec quarry

2000 MP was placed at the standpoint the first storey in the quarry, 20 m from the blasting and the seismograph Abem Vibraloc was placed in the family house No. 255 in the village Vyšná Šebastová; see fig. 13. The total weight of explosive in boreholes was 15 007 kg. The maximum weight of explosion charge set off in one time stage was 470 kg.

In case of blasting No. 358, fig. 14, the seismograph VMS 2000 MP was placed at the standpoint the third storey in the quarry, 20 m from blasting and the seismograph Abem Vibraloc was situated in the family house No. 255 in the village Vyšná Šebastová. The total weight of explosives in the boreholes was 7374 kg. The maximum weight of explosion charge set off in one time stage was 410 kg. The first three holes were set off individually. The weight of explosive set off in one time stage was 205 kg. They are registered as first ones in the record.

In Figure 14 on the right there is a record from the seismograph situated in the family house in the distance 1132.6 m from the source of seismic waves. At the beginning the record of first wave group can be seen from blasting of first three individual boreholes and in time of one second the record of the second wave group can be seen from the main blasting. In times 0.5 s and 1.5 s in both cases there can register different wave groups with lower frequency and in the first case with bigger amplitude.

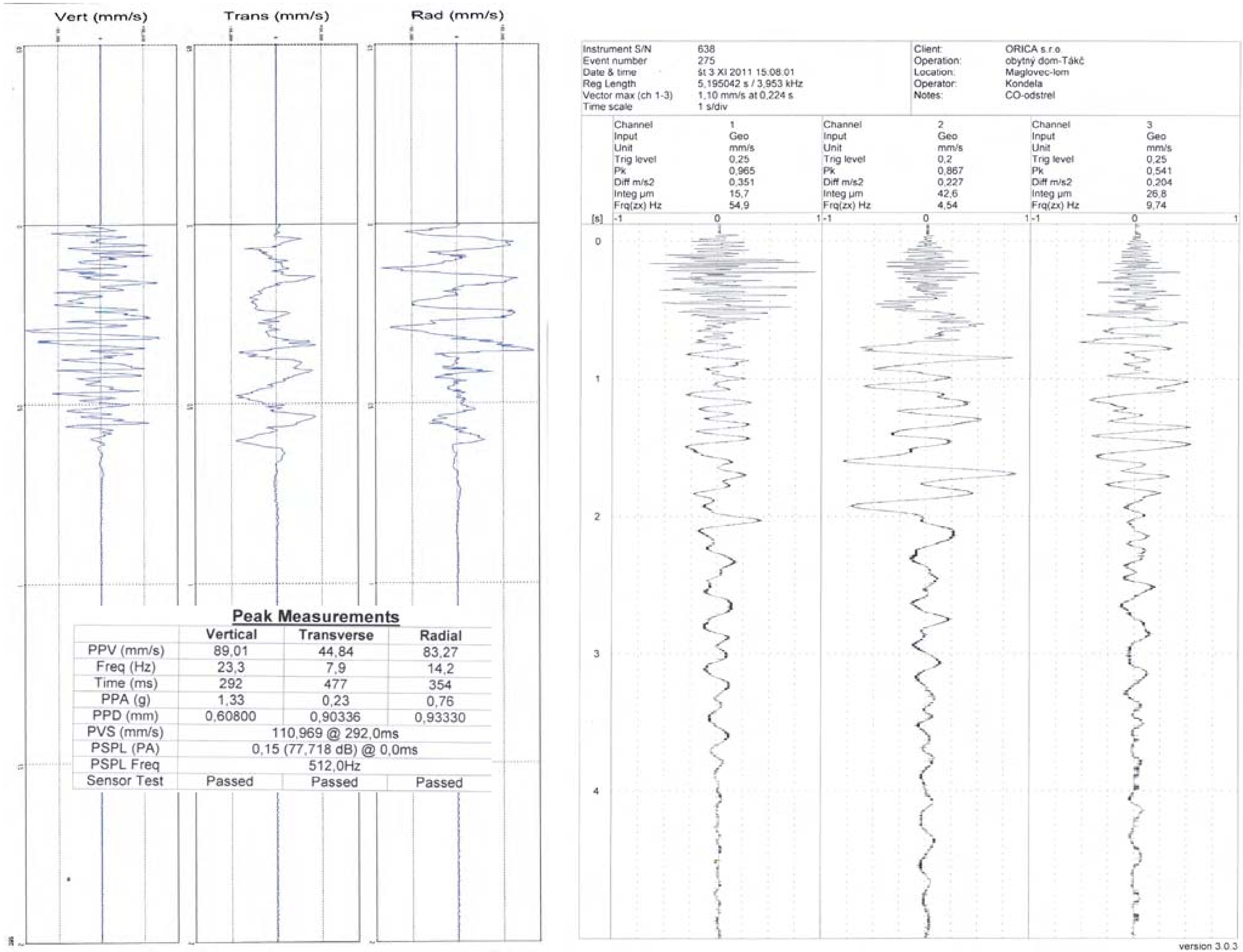
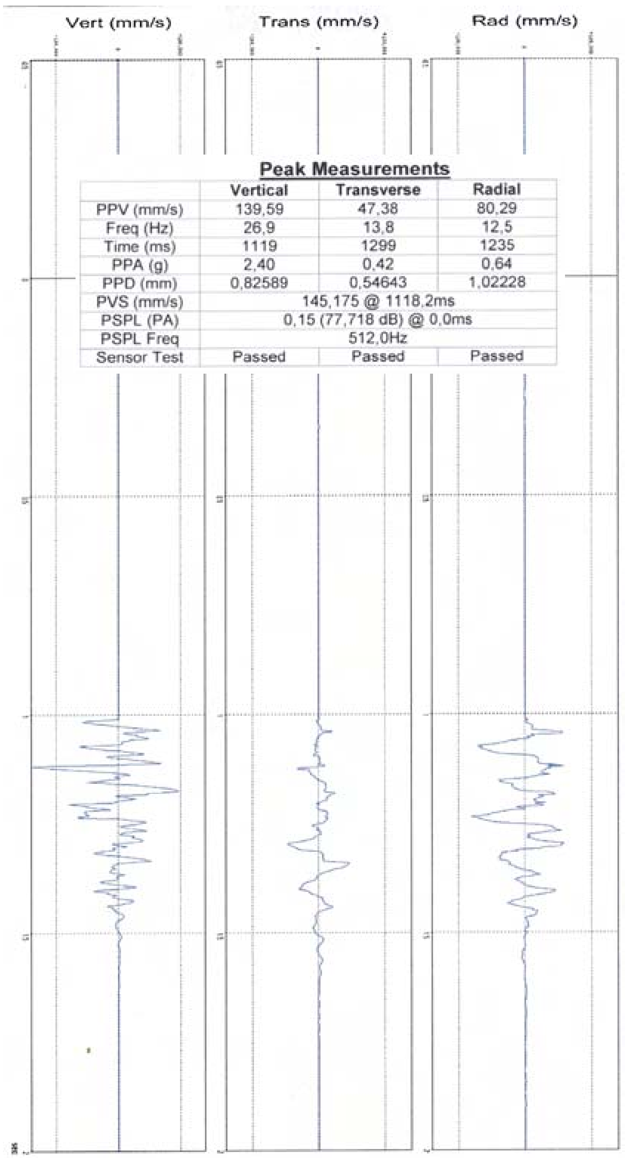


Fig. 13 The final grafical recording of blasting No. 357. Left a record of the seismograph in a I. storey, 20 m from the blasting, the right a record of the seismograph in a family house No. 255 in the village Vyšná Šebastová



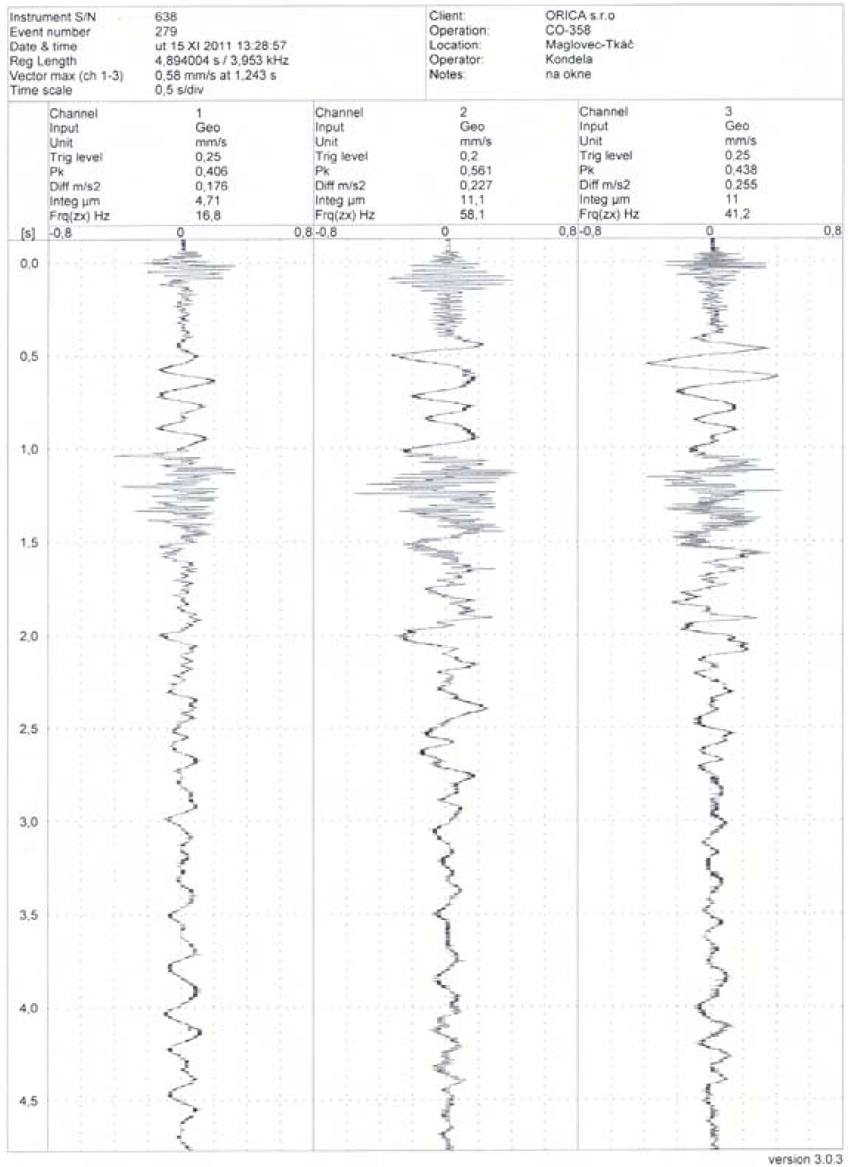


Fig. 14 ***The final grafical recording of blasting Nr. 358. Left a record of the seismograph in a III. storey, 20 m from the blasting, the right a record of the seismograph in a family house No. 255 in the village Vyšná Šebastová.***

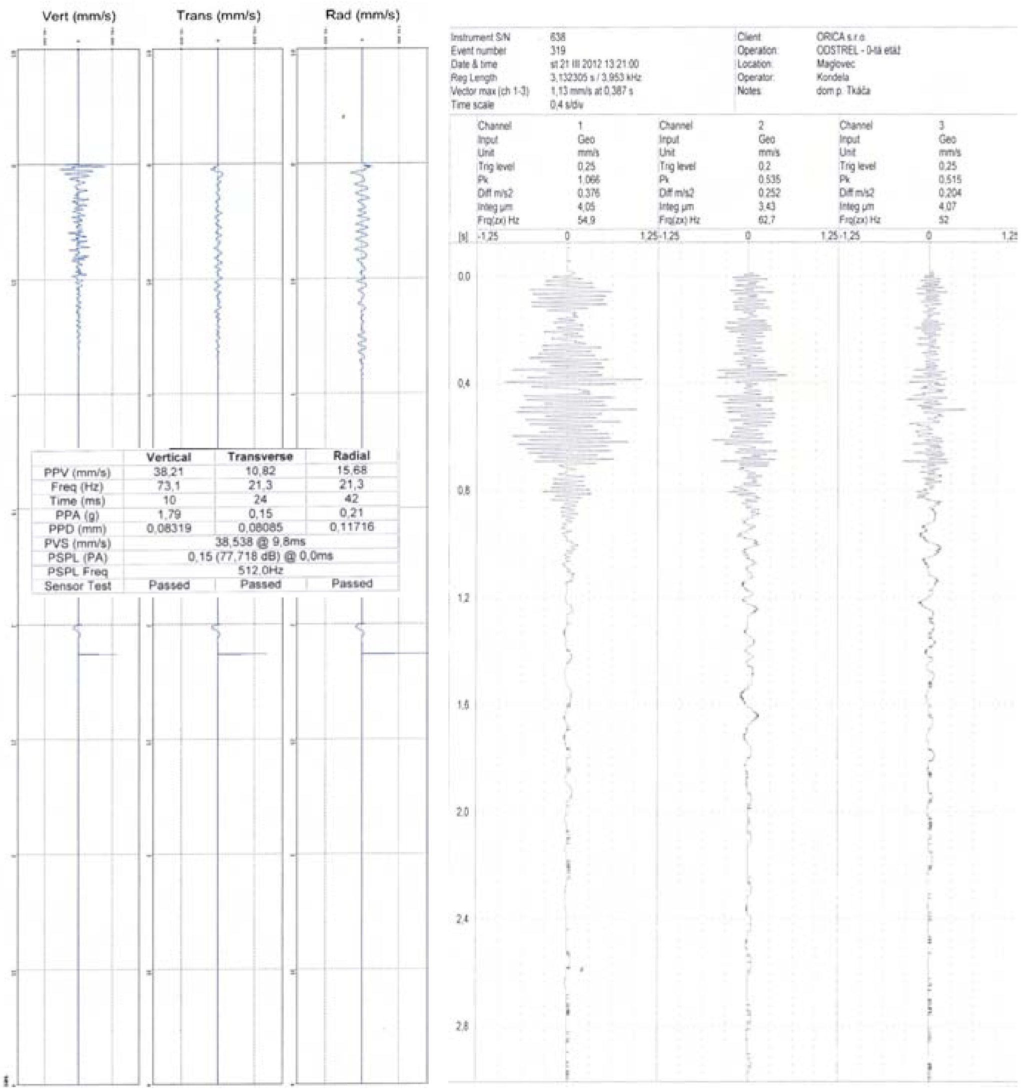


Fig. 15 The final grafical recording of blasting Nr. 359. Left a record of the seismograph in a 0. storey, 10 m from the blasting, the right a record of the seismograph in a family house Nr. 255 in the village Vyšná Šebastová

At blasting No. 359, fig. 15, the seismograph VMS 2000 MP was situated at the standpoint of the zero storey in the quarry, 20 m from blasting and the seismograph Abem Vibraloc was situated in the family house No. 255 in the village Vyšná Šebastová. The total weight of explosive in boreholes was 2 551 kg. The maximum weight of explosion charge set off in one time stage was 83.5 kg.

In Fig. 16 the decrease in the amplitude of vibration velocity of seismic waves between the source and the receptor is presented. As some sensors were close by the source, the principles of seismic wave's attenuation could have been defined in a very precise way. The sources of the seismic waves were the blasting in various geological media. The parameters of the source were gradually reduced (Table 4).

The transmitting medium and the distances between the source and the receptors were approximately the same. In the first case (bench blasting No. 357) the source (blasting) was situated in uneroded and slightly violated medium of diorite porphyrite (I. storey).

In the second case (bench blasting No. 358) the source (blasting) was situated in the identical rock medium. Only the distance between the source and the receptor was changed, the maximum weight of explosion charge was reduced and the explosion charge was reduced

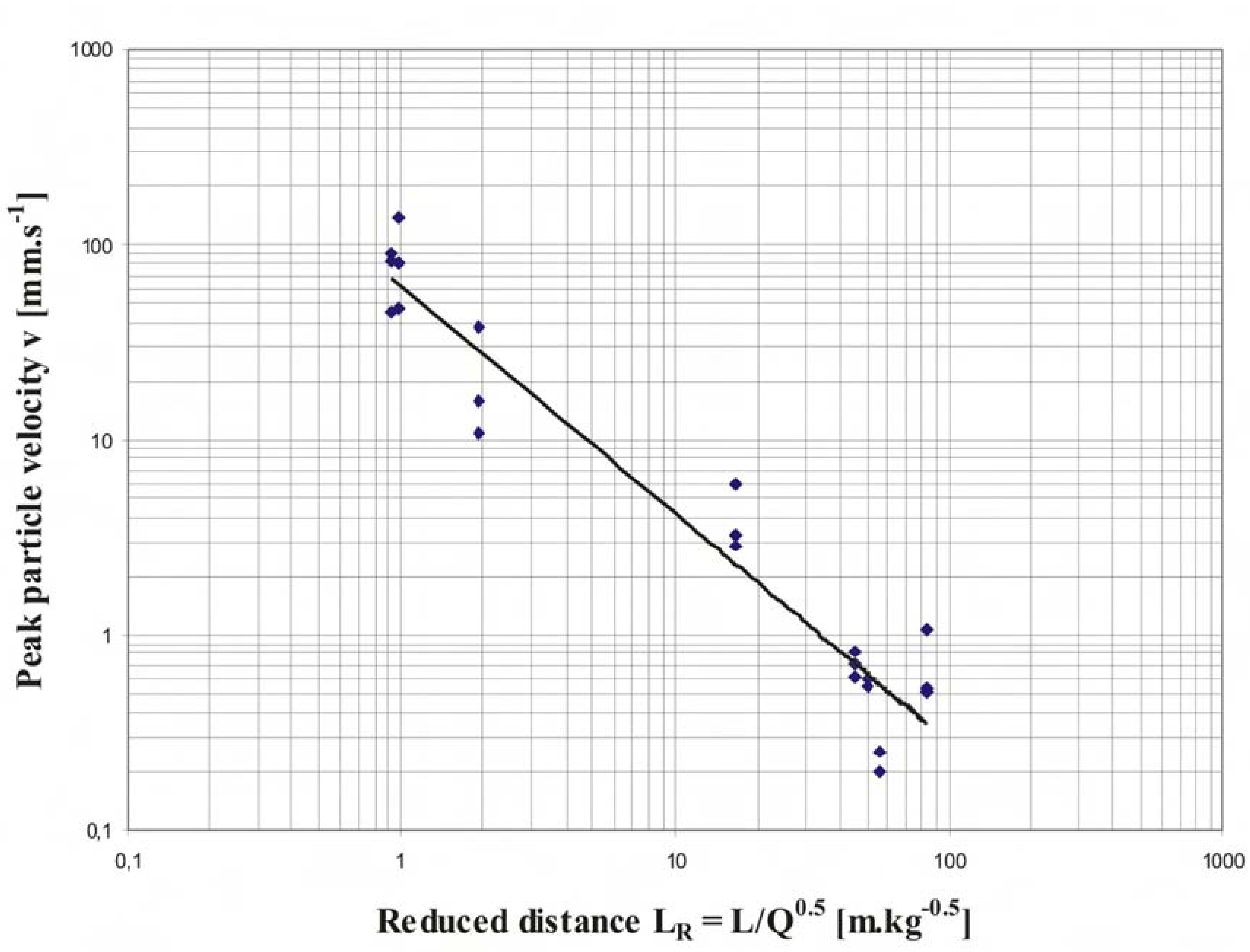


Fig. 16 Graphic relation of maximum vibration velocity components at reduced distance during bench blasting in Maglovec quarry

and the explosion charge in one time stage. The bench blasting No. 358 was situated on the III. storey so the seismic waves arriving to the receptor were attenuated by tectonic failure. As a consequence the receptor proved low vibration velocity despite the fact that the vibration velocity of the source was bigger than at bench blasting No. 357. In the third case (surface blasting No. 359) the source was situated in slightly weathered and violated diorite porphyrite at the zero storey. The surface blasting was at the level of underground water. In this case the seismic waves were attenuated only in a small range. Due to evaluation of surface blasting No. 359 we found out that despite much lower values of vibration velocity of the source compared with previous measurements the maximum vibration velocity of the receptor was 1 $mm.s^{-1}$ (Table 3). The reason for this was the high level of underground water in both the quarry and the measured object (Fig. 17), which enabled appropriate transmission of the seismic wave's energy from the source to the receptor. Nevertheless the vibration velocity of the receptor did not exceed the values according to standard STN 730036 and in the object of the family house the window cracked after the bench blasting No. 357. Due to frequency analysis we found out that the frequency of the source was 23.3 Hz at maximum vibration velocity but the

Tab. 4 Measured maximum value of vibration velocity blasting components

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}]
20	470	0.92	83.27	44.84	89.01
983.1	470	45.35	0.824	0.612	0.711
882.2	470	40.69	0.55	0.66	0.55
20	410	0.988	80, 29	47.38	139.59
1132.60	410	55.94	0.25	0.2	0.25
1017.80	410	50.27	0.55	0.6	0.5
10	83.5	1.94	15.68	10.82	38.21
776	83.5	83.8	0.535	0.515	1.066
152	83.5	16.63	3.304	2.837	6.013

***Fig. 17** The amount of ground water in its standpoint 1 was 1.6 m below ground level and in its standpoint Maglovec quarry the amount of ground water levels at the surface blasting*

frequency of the receptor of the family house was 54.9 Hz. Similarly at bench blasting No. 358 the maximum registered frequency of the source was 26.9 Hz and the frequency of receptor was 41.2 Hz. In the case of surface blasting No. 359 the mentioned maximum measured frequency of the source was 73.19 Hz and the frequency of the receptor was 54.9 Hz. Due to these measurements it follows that the family house under seismic waves effects, which source is the blasting, vibrates with its own frequency. The range of vibration amplitude depends on size of set off explosion charge activated in blasting. As the explosion charge at bench blasting No. 357 was the biggest as a consequence the size of vibration amplitude was the biggest as well and therefore the window cracked. In the object of the panel house this phenomenon was not registered however this object was situated nearer to the blasting. Its weight was much bigger and the energy of seismic waves activated by blasting was not enough for vibration of the object.

Evaluating the seismic waves records registered during the particular blasting we can conclude that in each case there were registered waves activated by blasting at the source in different time stages but on the receptor there were registered some further waves with low frequencies from 2 - 4 Hz and having big amplitude. As these waves were registered also in other quarries at the similar blasting the above mentioned measurements had to solve the following issue whether the source of these waves is the rock-fall or they are waves reflected from the geological boundary in the foot. As the waves were registered at surface blasting No. 359 their source is not the rock fall. At bench blasting No. 358 these waves were registered also in the case of individual blasting of three boreholes and of complete blasting immediately after the main wave group, it follows that they cannot be considered as reflected waves because they would be registered with a certain time lag (Leššo et al., 2007, 2010). Time lag is dependent on both depth of geological interface and velocity of seismic wave's diffusion in massive rock medium. One way to clarify the nature of the wavelength of maximum velocity amplitude of oscillation is that it is likely to surface waves that propagate in the subsurface layers carried out bearing the blast.

7 Conclusion

The measurements of different blasting such as bench blasting No. 357, bench blasting No. 358, surface blasting No. 359 highlighted the importance of effect of violation level and weathering of massive rock on attenuation of seismic waves radiated by blasting. These measurements proved that underground water level also influences the range of seismic wave's attenuation from the source to the receptor. These measurements entirely proved that seismic waves registered on blasting record after the main wave groups are surface waves which diffusion velocity is lower than the velocity of longitudinal and transversal waves radiated by blasting.

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Authors

[1] doc. RNDr. Blažej Pandula, CSc., Faculty of Mining, Ecology, Process Control and Geotechnology, Institute of Geo-sciences.,Letná 9, 040 01 Košice, Slovak Republic, blazej.pandula@tuke.sk, +421 905 769 615

[2] Mgr. Julián Kondela, PhD., Faculty of Mining, Ecology, Process Control and Geotechnology, Institute of Geo-sciences.,Letná 9, 040 01 Košice, Slovak Republic, julian.kondela@tuke.sk, +421 55 602 3139

[3] RNDr. Karel Holub, DrSC., Institute of Geonics AS CR, Ostrava, Czech Republic, holub@ugn.cas.cz