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OPTIMIZATION OF THE FRESH ROCK FRAGMENTATION DURING BENCH BLASTINGS IN THE QUARRIES

OPTIMALIZÁCIA FRAGMENTÁCIE ROZPOJENEJ HORNINY PRI CLONOVÝCH ODSTRELOCH V LOMOCH

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Abstract

The rock fragmentation is one of the goals of the blasting operations. The economics of the blasting operations can be achieved merely by the fragmentation. The significance of the fragmentation optimization depends on the conditions of the operation. The goal is to reduce the average particle size of the fresh rock to the required level, in other words, the optimization of the fragmentation. The examination and the measurement of the fresh rock fragmentation is one of the first steps leading to the optimization. The analysis of the fragmentation due to the photographs, the monitoring of the vibration and the high-speed video provide a lot of useful data for the optimization of the blasting operations in the quarries. Modifying the parameters of the blasting operations enables not only achieving the appropriate fragmentation but also the seismic safety in the surroundings of the blasting operation. The article describes experiments that were performed in the conditions of the quarry Trebejov.

Abstrakt

Fragmentácia hornín je jedným zo základných cieľov trhacích prác. Ekonomika trhacích prác sa dá dosiahnuť jedine optimalizáciou fragmentácie. Význam optimalizovania fragmentácie závisí od podmienok prevádzky. Cieľom je znížiť priemernú veľkosť častíc rozpojenej horniny na požadovanú úroveň, inými slovami, optimalizácia fragmentácie. Pozorovanie a meranie fragmentácie rozpojenej horniny je jednou z prvých krokov k optimalizácii. Analýza fragmentácie z fotografií, monitorovanie vibrácií a vysokorýchlostné video poskytuje veľa užitočných údajov pre optimalizáciu trhacích prác v lomových prevádzkach. Zmenou parametrov trhacích prác je možné dosiahnuť nielen vhodnú fragmentáciu, ale aj seizmickú bezpečnosť okolia lomovej prevádzky. V článku sú popísané experimenty, ktoré boli uskutočnené v podmienkach lomu Trebejov.

Keywords

quarry blasting, fragmentation optimization, seismic safety, burden and spacing boreholes

Kľúčové slová

trhacie práce v lomoch, optimalizácia fragmentácie, seizmická bezpečnosť, záber a rozostup vrtov

1. Introduction

The fresh rock as a result of the shot blasting in the rock massive presents a polymorphic mixture of the fresh rock pieces of different sizes. The fragmentation or the lumpiness can be characterized as the granulometric composition of the fresh rock i.e. the proportional content of the different size pieces (Dojčár, 1980). The uniquely accredited criterion for the evaluation of the fragmentation has not been known so far. In the calculations of the blast planning and scheduling it is generally required to define the size of the pieces by one number. The lumpiness can be characterized by the criteria for the particular pieces /mostly in a maximum way/ or by the criteria defining the fresh rock as a whole.

The particular pieces are mostly defined by:

- maximum piece of the fresh rock, i.e. the biggest linear dimension l_{max} (mm), from the three reciprocally perpendicular dimensions;
- equivalent dimension of the biggest piece l (mm), which presents the block edge and is defined according to the piece volume.

The mutual relationship between the criteria 1 and 2 mainly depends on the structural- tectonic features of the fresh rock nevertheless it has not been known so far. The value l_{max} has to be specified under the particular conditions in the given quarry. The pieces bigger than l_{max} are oversize.

For the characterization of the fresh rock as a whole the following features are applied:

- The grain-size curves mostly cumulatively. The advantage is that according to the curve position on the graph we can figure out the portion of the oversize classes.
- The mean diameter of the pieces of the fresh rock d_s (mm), which quantitatively characterizes the pieces size or the whole fresh rock by one number.

The value d_s affects in a large extent the proportion of the big classes in the fresh rock. As there has not been a more appropriate criterion, the value d_s is most frequently applicable in the praxis. The mutual relation between the criteria l, l_{max} and d_s has not been known yet. Because of lack of more exact basic documents the classification by Rževsky is used in the practical applications (Rževsky, 1973), where the required fragmentation is presented by the rock pieces of the following dimensions $l_{max} \leq 600$ up to 1000 mm and $d_s \leq 150$ up to 200 mm (Dojčár, 1980).

A very important regulating degree factor of the fresh rock massive at the blasting, which was monitored during the operation, is the round of the blast hole charge (burden). The research carried out by various researchers but first of all by Langefors (Langefors and Kihlström, 1963), proved that at constant specific charge and reducing the round of the blast hole charge (burden) the fragmentation is improving and vice versa. The round of the blast hole charge (burden) is also closely connected with the coefficient of the charge approximation which stands for the relation of two most important parameters of the blast: spacing of the charge in a row "a" to the round of the blast hole charge (burden) W, i.e. m = a/W. The correlation of W and "a", the value m characterizes the degree of the blasting energy distribution – the strain allocation and as follows the deformation and crash distribution in the fresh rock volume of the rock massive. Therefore, it is a significant regulation tool of the strain and deformation distribution at the blast in the rock massive and consequently of the final fragmentation. The research carried out in both laboratories and practical applications showed that the optimum value is $m \geq 2$ (Dojčár, 1980; Rustan, 1995; Adhikari, 2000).

Burden and spacing are the two most important variables in blast design (Ash, 1990). According to Ash (1990), the spacing/burden ratio should be between 1 and 2. It was suggested that blastholes initiated independent of one another will require this ratio to be between 1 and 1.5, where a value of 1.41 is the ideal geometric balance for breakage of massive material. The author further states that rocks with joint planes almost perpendicular to one another should have a ratio of 1.41, while rocks with joint planes oriented at close to 60° with one another and blastholes with long delay interval should have the ratio value at 1.15. Kojovic et al., (1995) did extensive research at the Mt. Coot-tha quarry in Brisbane, Queensland, Australia. Changes in blast design were done by adjusting the burden and spacing alone (Kecojevic and Komljenovic, 2006).

***Fig. 1* 3D scanning the fresh rock fragmentation during bench blast a drone in a quarry**

Beyond these factors the equality of the blast energy distribution in the blasting operations is also considerably affected by the drilling scheme, charge timing, initiation scheme and the charge composition. How does the charge timing affect the concurrence of the charges and the final fragmentation? At t = 0 ms (blast at the same time) is the concurrence of the charges at a maximum way, with the increase of the value t the concurrence of the charges reduces. There were carried out simulations of precision-guided fragmentation while the timing was taken into consideration. It demonstrated that the medium size of the fragment oscillated with increasing delay as a consequence of the phase fluctuation in interaction of the stress waves and crashes and the superpositions of the stress waves within the increasing delay. Langefors and Kihlström (Langefors and Kihlström, 1963) examined the impact of the blast model on the fragmentation during the experiments in the quarry. According to the monitoring and measurements the following relation has been developed among the average piece size in the fresh rock, type of the blasting operations and the specific charge weight. They also examined the impact of the

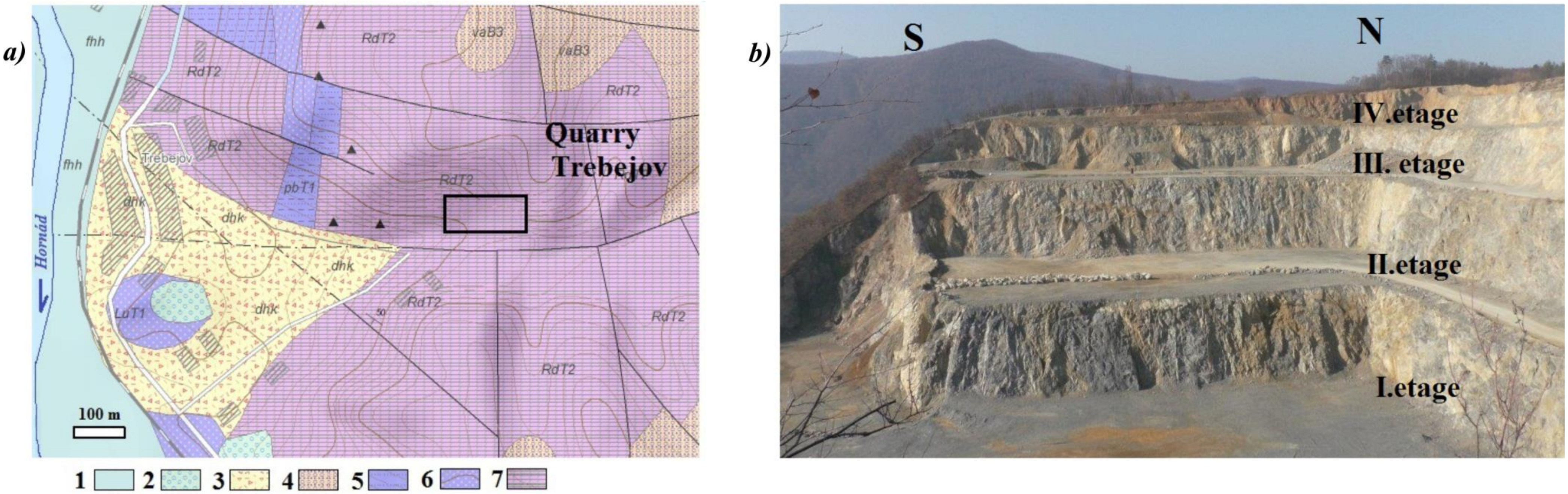


Fig. 2 Geological map of the surroundings of the quarry Trebejov (a) and the view in Quarry (b). Quaternary: 1 – clay, gravel, sand (Holocene), 2 – sandy gravel, gravel (Pleistocene), 3 – deluvium (unstructured) mainly loam stony, Neogene: 4 – klčovské formation varhaňovské gravel: polymict, weathered, without pebbles of carbonates (upper Baden-lower Sarmatian), Mesozoic: 5 – variegated clayey shales, clay sandy shales, with interbeds of quartzite (lower Trias), 6 – lúžňanské formation – quartzite, quartzite sandstone, locally with the interbed shales (lower Trias), 7 – Ramsau dolomites (ladin). (Mello at al., 1996)

time delay on the fragmentation of the rock and assigned that the fragmentation was optimized with the time delay 3–5 ms/m of the round of the blast hole charge. Gustafsson found out that the best time of delay was 5 ms/m in case of the large-scale blasting with 5 up to 8 m big round of the blast hole charge (Gustafsson, 1973; Hoshino and Mogi, 2000; Shi and Chen, 2011).

A lot of methods are available how to assess the blasting operations depending on the required results. The optimum fragmentation is the base for cost cutting of the shredder permeability, minimizing the deterioration of the apparatus, maximizing the velocity of the unloading of the fresh rock, decreasing the energy consumption etc. In the last years there were carried out a lot of research works aimed at creating a tool for the optimization of the blasts (Babaeian, 2019). The most effective blast is characterized by the difference of the grain-size distribution of the fragments in relation to the required parameters (Singh, 2000; Hettinger, 2015).

Currently 3D programs are applied for the fragmentation analysis where the necessary data are gained by the drones (Sereshki at all., 2016).

2. Geological structure of the rock environment around the Trebejov quarry

The experiments were carried out under the conditions in the quarry Trebejov. The quarry Trebejov is situated 13 km from Košíce and 17 km from Prešov. It is ca 800 meters far from the village Trebejov. There can be found a deposit of dolomite, namely the single sized dolomites, grey and dark grey. Furthermore, minerals such as brass, limonite, resin and silica are mined in the quarry. The deposit is located from 275 to 405 m.s.l /above the sea level (Fig. 2).

3. Measurement Methodology and evaluation of measured data

The project of the blasting operations and the analysis of the fragmentation are performed by applying 3D Metashape program, where the necessary data were obtained using a drone. The pictures from the drones provide a perfect way for the documentation of the blasting operations (Fig. 1, 8).

A VMS 2000 digital four-channel vibrograph was used to measure seismic effects at the S1 standpoint in the quarry Trebejov (Fig. 4). Measuring position S2, was situated in the entrance to the residential building no. 91 and measuring position S3 in the entrance to the basement of the assessed building - apartment house no. 91 in the village Trebejov. At S2 and S3 standpoint, digital four-channel vibrographs ABEM Vibraloc for measuring the particle velocity of the seismic waves, were used (Fig. 5). The position of blasting works in the Trebejov quarry in relation to measuring points in the village of Trebejov is shown in Fig. 3. Data on the blast position and the distance of the standpoints from the blast are given in Table 1.

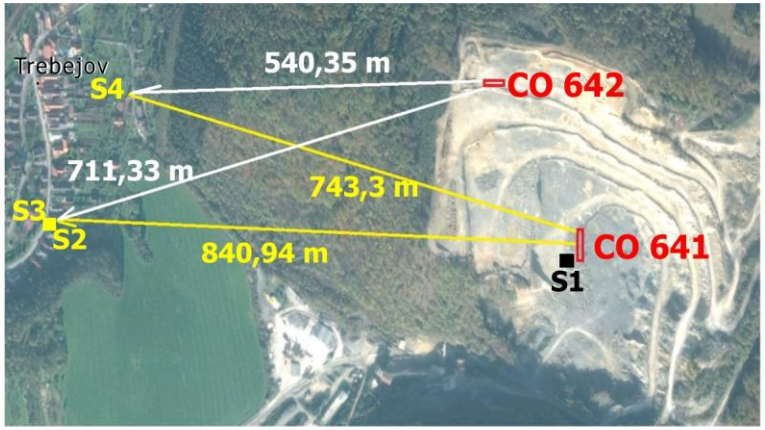


Fig. 3 Bench blast No. 641, position in the quarry Trebejov in relation to the measuring standpoints in the village Trebejov

Tab. 1 Data on the blast position and the distance of the standpoints from the bench blast No. 641

Standpoint	Blast	Coordinates of geophones and blast			Distance from blast to standpoint [m]		note
		x	y	z	Slant	Horizontal	
S1	**BB 641**	-	-	-	-	11.18	I. blast
S2	**BB 641**	-	-	-	-	840.94	
S3	**BB 641**	-	-	-	-	847.94	

Fig. 4 Position of the seismic apparatus MS 2000 MP at measuring the blasts, standpoint S1 in Trebejov quarry

Fig. 5 Apparatus ABEM Vibraloc for measuring the particle velocity of the seismic waves, placed in the front part of the house - entrance to the housing object No. 21 in the village Trebejov - standpoint S2. The standpoint S3 position was at the entrance to the back of the house

3.1 Parameters of the bench blasts in Trebejov quarry

The sources of the seismic effects were the bench blasts No. 641, No. 675, No. 690, No. 716 and No. 718 at the deposit of limestone situated cca 0.5 km in the East from the village Trebejov. For comparison there were chosen particular blasts with millisecond timing delay 9 ms, 17 ms and 25 ms (Pandula and Kondela, 2015, 2017, 2018).

Bench blast No. 641

At bench blast No. 641, which was performed at the 2nd etage, there were drilled 21 vertical drills with diameter 105 mm, under the angle 65° and length from 24.5 to 25.3 m. The distance between the boreholes (hole spacing) was 3.5 m and the round of the blast hole charge was 3.3–3.5 m. The total charge weight was 3490 kg of explosives, from which the maximum charge for 1. time stage was 168 kg. The applied explosives were Ekodanubit – 157.5 kg and Infernit – 52.5 kg and Austinit Al – 3280 kg. The non-electric initiation scheme consisted of – 42 pieces of Indetshock MS 20/50. The millisecond timing delay was 17 ms.

Bench blast No. 675

At bench blast No. 675, which was performed at the 1st etage, there were drilled 24 vertical drills with diameter 105 mm, under the angle 65° and length from 24.8 to 26.6 m. The distance between the boreholes (hole spacing) was 3.5 m and the round of the blast hole charge was 3.0–4.0 m. The total charge weight was 3515.0 kg of explosives, from which the maximum charge for one-time stage was 158.0 kg. The applied explosives were as follows: Dapmon – 2450 kg, Dapmon 30–650 kg and Emonit – 240 kg. The non-electric initiation scheme– 80 pieces of Indetshock MS 20/50. The millisecond timing delay was 25 ms.

Bench blast No. 690

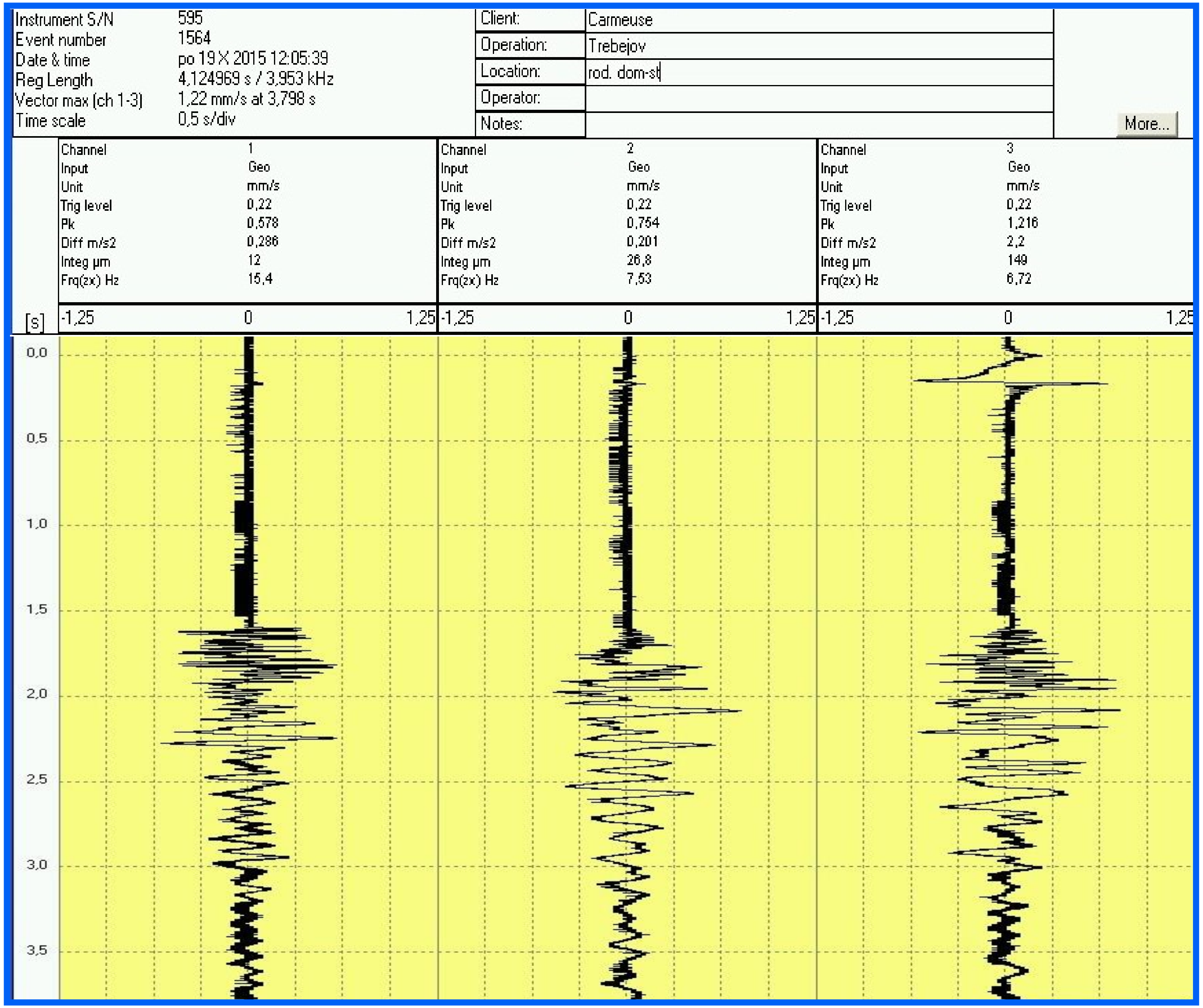
At bench blast No. 690, which was performed at the 3rd. etage, there were drilled 30 boreholes (15 main, 15 heel), with diameter 105 mm, under the angle 65° and length from 22.9 to 23.8 m. The distance between the boreholes (hole spacing) was 3.5–4.0 m and the round of the blast hole charge was 4.5 m. The following explosives were applied Dapmon 30–1650 kg. Emonit1 – 100 kg. Paladyn 30 and ECO 65 in total 100 kg. The total charge weight was 1850 kg. For one-time stage there was applied the maximum charge of 154.2 kg. The following detonators were applied – DeM – S 1piece Exel 475 ms, 500 ms 43 pieces of Exel connectadet 0; 9; 25 ms, Exel starter 41 pieces. The millisecond timing delay was 9 ms.

Bench blast No. 716

At bench blast No. 716, which was performed at the 1st etage there were drilled 22 main boreholes with diameter 105 mm, under the angle 65° and length from 25.5 to 27.7 m. The distance between the boreholes (hole spacing) was 4 m and the round of blast hole charge was 4 m. The blasting enabled the rock dismantling of 22 000 t of raw materials. The applied explosives were as follows: Perunit DE – 150 kg, Dapmon Al – 2100 kg. Senatel Powerfrag – 264 kg. The total charge weight – 2514 kg. For one-time stage there was applied the maximum charge of 165.0 kg. The following detonators were applied: Exel – 53 pieces, Exel connectadet – 22 pieces, DeM–S – 1 piece. The millisecond timing delay was 17 ms.

Bench blast No. 718

At bench blast No. 718, which was performed at the 3rd. etage, there were drilled in one row 20 main boreholes with diameter 105 mm, under the angle 65° and length from 24.8 to 26.6 m. For undercutting the bench blasting there were 8 boreholes drilled. The total length of boreholes was 485.8 m with diameter 105 mm. The distance between the boreholes (hole spacing) was 3.5–4.2 m and the round of the blast hole charge was 4.2 m. The blasting enabled the dismantling of 25 000 t of raw materials. The following explosives were applied: Perunit DE – 25 kg, Dapmon Al – 2675 kg, Senatel Powerfrag – 24 kg, Paladyn 31 Eco – 75 kg. The total charge weight was – 2799 kg. For one-time stage there was applied the maximum charge of 145.5 kg. The applied detonators were as follows: Exel – 48 pieces, Exel connectadet 33 pieces, Exel Starter – 1 piece, DeM – S – 1piece. The millisecond timing delay was 25 ms.

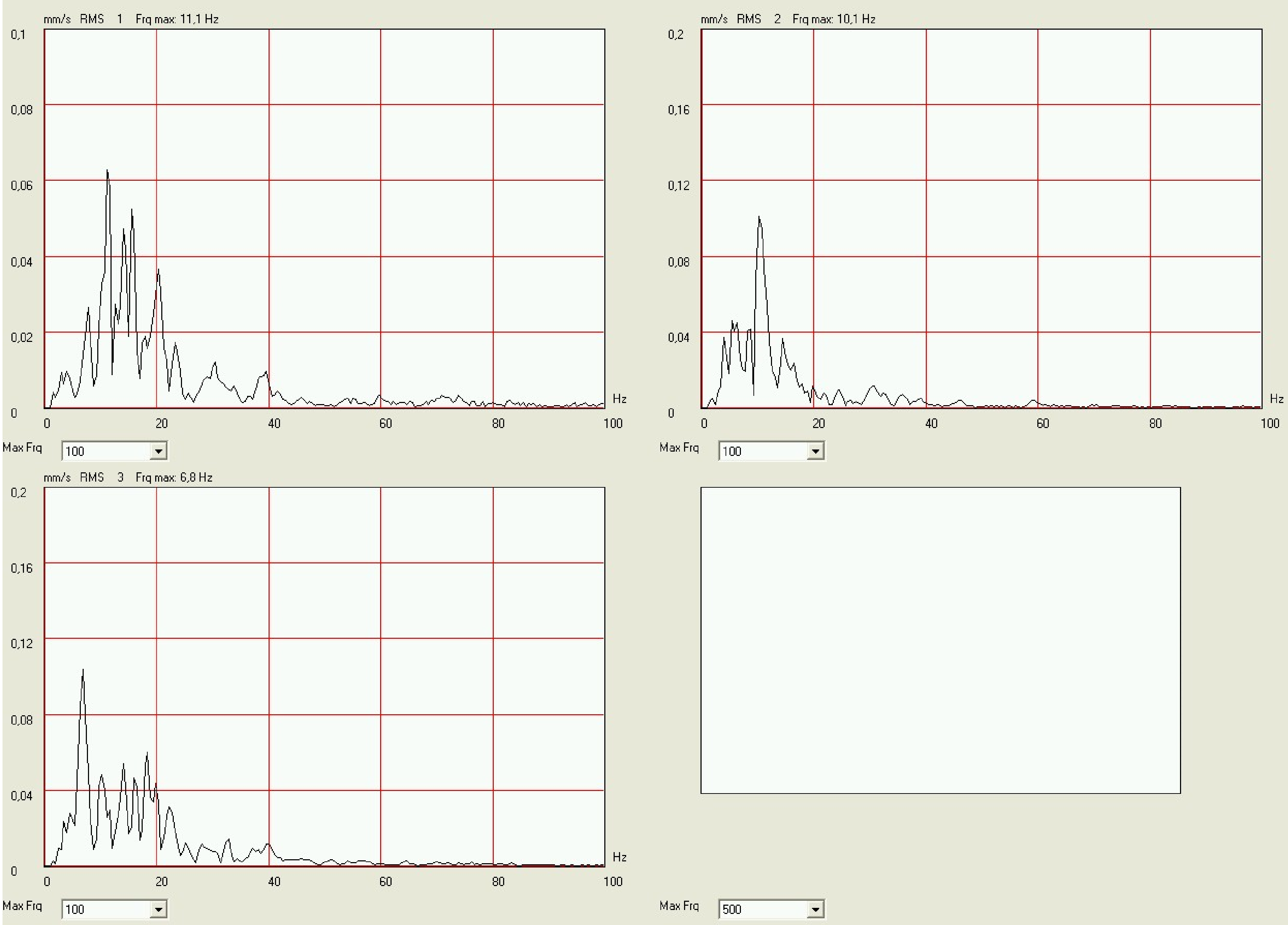


Instrument S/N 595
Event number 1564
Date & time po 19 X 2015 12:05:39
Reg Length 4,124969 s / 3,953 kHz
Vector max (ch 1-3) 1,22 mm/s at 3,798 s
Time scale 0,5 s/div

Client: Carmeuse
Operation: Trebejov
Location: rod. dom-st
Operator:
Notes:

Channel	1	2	3
Input	Geo	Geo	Geo
Unit	mm/s	mm/s	mm/s
Trig level	0,22	0,22	0,22
Pk	0,578	0,754	1,216
Diff m/s2	0,286	0,201	2,2
Integ µm	12	26,8	149
Frq(zx) Hz	15,4	7,53	6,72

Fig. 6 Graphic record of the measured vibration components from the standpoint 2 – housing object in Trebejov Seismic apparatus Vibraloc. The first channel – z, the second one – x, the third channel – y at bench blast No. 641



Max Frq 100

Max Frq 100

Max Frq 100

Max Frq 500

Fig. 7 Frequency characteristics of ther particular components of particle velocity at the measuring standpoint 3 – housing object No. 21 in the village Trebejov at bench blast No. 641

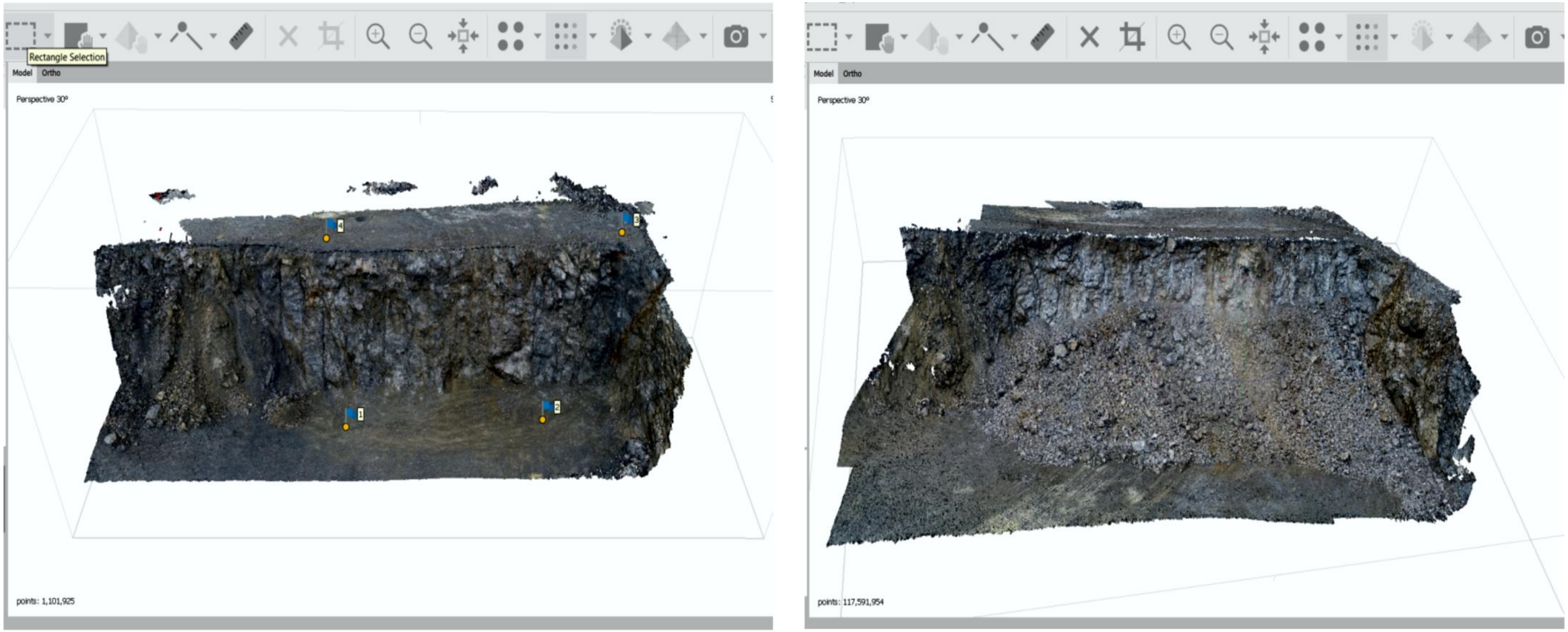


Fig. 8 3D model of the quarry walls and fragmentation of bench blasting No. 641 using the Metashape program

The frequency analysis of particle velocity proved that the energy having impact on the particular objects had a frequency lower than 10 Hz. Therefore, the admissible particle velocity, according to STN EN 1998-1/NA/Z1, was defined as 3 mm.s^{-1} (Fig. 6, 7).

At the bench blasting No. 641 the fragmentation concerning the quarry was adequate. Neither oversize pieces arose nor a lot of minor fractions (Fig. 8).

For collecting pictures, we are using dron of brand DJI Inspire2 with high resolution camera (Fig. 1). The photogrammetry software needs to have enough similar pixels within the set of pictures to produce the point cloud. For a precise reconstruction it is recommended to have minimum 70 % overlap between pictures in X axis and 60 % in Y axis. It is optimal to fly and collect pictures in two different altitude. We usually fly 50 m and then 30 m above the crest of the wall (as horizontal flight).

Tab. 2 Measured values of frequency and particle velocity at examined bench blastings in the quarry Trebejov

Bench blasting No.	**Measuring standpoint**	**Velocity [mm/s]**			**Frequency [Hz]**			**Timing delay [ms]**	**Hole spacing [m]**	**Hole burden [m]**	**Fragmentation quality**
		X	**Y**	**Z**	**X**	**Y**	**Z**				
641	**Quarry Trebejov S1**	182	166	178	28	73	51	17	a=3.5	$W_1=3.5$ $W_2=3.3$	lesser adequate
	Village Trebejov S2	0.7	0.5	0.5	9.7	1.5	3.1				
	Village Trebejov S3	0.7	1.2	0.6	7.5	6.7	15				
675	**Village Trebejov S2**	1,3	0.8	0.7	14	8.0	24	25	a=3.5	W=3÷4	adequate
	Village Trebejov S3	0,8	0,9	0,4	9.2	14	25				
690	**Village Trebejov S2**	1.7	3.3	0.7	5,9	5,9	5,9	9	$a_1=4.0$ $a_2=3.5$	W=4.5	lesser adequate
	Village Trebejov S3	5.1	2.9	1.3	6.5	6.9	6.3				
716	**Village Trebejov S2**	1.2	0.9	0.5	11	8.4	27	17	a=4.2	W= 4.0	very good
718	**Village Trebejov S2**	0.7	0,7	0,8	12	10	26	25	$a_1=4.2$ $a_2=3.5$	W=4.2	very good
	Village Trebejov S3	0.9	0.7	0,5	12	10	14				

3.2 Assessment of the blasting fragmentation in the quarry Trebejov

At bench blast No. 641, which was performed at the 2nd. etage the fragmentation was adequate concerning the requirements of the quarry (Fig. 8). Neither oversize pieces arose nor a lot of minor fractions. The distance between the boreholes (hole spacing) was 3.5 m and the round of the blast hole charge was 3.3–3.5 m. The coefficient of the charge approximation was m = 1 to 1.06. The millisecond timing was 17 ms. The optimum timing by Gustafsson was 16.5 up to 17.5 ms.

The fragmentation of the bench blast No. 675, which was performed at the 1st etage was adequate, there can be found oversize pieces of the aggregates of stones, but a large amount of minor fractions did not occur there. The distance between the boreholes (hole spacing) was 3,5 m and the round of the blast hole charge 3.0–4.0 m. The coefficient of the charge approximation was m = 0.875 up to 1.17. The millisecond timing was 25 ms. The optimum timing by Gustafsson was 15 up to 20 ms.

The fragmentation at the bench blast No. 690, which was performed at the 3rd. etage was lesser appropriate, there cannot be found any oversize pieces of aggregate of stones but in the fresh rock there occurred a large amount of minor fraction. The distance between the boreholes (hole spacing) was 3.5–4.0 m and the round of the blast hole charge was 4.5 m. The coefficient of the charge approximation was m 0.78 up to 0.89. The millisecond timing was 9 ms. The optimum timing by Gustafsson was 22.5 ms.

Fig. 9 View on the quarry wall in front of the bench blasting No.718

Fig. 10 Fresh rock after blasting of the quarry wall at the 3rd etage at bench blast No.718

At bench blast No. 716, which was performed at the 1st etage the fragmentation was adequate concerning the requirements of the quarry. There did not occur any oversize pieces and there can be found only a few minor fractions. The distance between the boreholes (hole spacing) was 4.2 m and the round of the blast hole charge was 4 m. The coefficient of the charge approximation was m = 1.05. The millisecond timing was 17 ms. The optimum timing by Gustafsson was 20 ms.

The fragmentation at the bench blast No. 718, which was performed at the 3rd. etage was adequate concerning the requirements of the quarry, after the blasting there were neither a lot of minor fractions nor oversize pieces (Fig. 9, 10). The distance between the boreholes (hole spacing) was 3.5–4.2 m and the round of the blast hole charge was 4.2 m. The coefficient of the charge approximation was m = 0.83 up to 1. The millisecond timing was 25 ms. The optimum timing by Gustafsson was 21 ms.

4. Conclusion

The measurements were carried out in the quarry Trebejov and namely at bench blast No. 641 of the October 2015, bench blast No. 675 of the October 2017, bench blast No. 690 of the September 2018, bench blast No. 716 of the December 2019, bench blast No. 718 of the February 2020. The aim of this work was to consider the fragmentation of the particular blastings and moreover to define the impact of the timing of the particular blastings on the fragmentation. Furthermore there were considered the values of the particle velocity taking into consideration the impact on the environment. The fragmentation had to be assigned from the point of view of the particular quarry, namely the quarry Trebejov. At bench blasting No. 641, where the timing was 17 milliseconds, the fragmentation was qualified as an adequate one. At further bench blasting No. 675 with 25 milliseconds timing the fragmentation was adequate considering the quarry. On the contrary at blasting No. 690 with 9 milliseconds timing the fragmentation was lesser appropriate as in the fresh rock there was found a large amount of minor aggregate of stones. The bench blasts No. 716 and 718 with 17 and 25 millisecond timing proved a very good fragmentation. It follows that the optimum timing at these blastings were 17 ms and 25 milliseconds.

Thanks

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