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TIMING OF QUARRY BLASTS AND ITS IMPACT ON SEISMIC EFFECTS

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ABSTRACT
The impact of blasting operations is accompanied by both positive and negative after-effects. Vibrations, activated by explosion, help to disintegrate the rocks representing a positive effect on one hand and a negative effect on the other and they endanger the surrounding buildings and other properties. If the vibrations are large enough, then the ambient objects could be damaged or destroyed. The negative effects depend on their range and strength. Vibration intensity of seismic waves is generally proportional to the weight of the explosive used. Recently, negative effects of the blasting operations and quantification of the seismic safety have been highly actual and stand for a challenging problem. The article highlights the results of the blasting operation monitoring in some quarry in Slovakia.

KEYWORDS: seismic effects, blasting operations, timing of blasting

INTRODUCTION

In blasting operations even applying the most proficient approaches we can´t rely on entire utilization of energy released by detonation impulse only for carrying out the intended work. It is necessary to take into consideration the fact that part of the energy will occur in the form having negative impact.

Blasting operations, carried out anywhere, have an impact on many different objects such as underground and overhead distribution, fauna, flora which have to be thoroughly protected in order not to cause more damage than benefit by utilizing the blasting energy.

Predominantly we have to deal with the following issues:

- projection of the material,
- air shock wave, resp. shock wave in water ,
- seismic effects.

The seismic effects of the intended blasting can be substantially reduced, e.g. by Don Leet (1960), Mosinec (1976), Dojčár (1981), Holub (2006), Pandula and Kondela (2010), Kaláb et al. (2011):

- Distribution of total charge capacity into partial ones. The final seismic impact can be efficiently reduced by millisecond rock blast timing as a consequence the delayed timing of particular blasts causes interference of seismic waves and as a result their undesirable effects are mutually eliminated. There is an evidence that if the vibration is weaker then the blast overcomes the resistance of blasting distance easier and therefore in some cases it is required to increase the weight of the charge by 30 – 40 %. As a result the amplitude increases but the particle velocity decreases and the projection of the blasted material will be smaller. We can achieve lower seismic effect considering increase of casting off and smashing of blasted material.

According to timing the blasting can be divided into:

- instantaneous (simultaneous initiation of a group of explosive charges),
- timed (the partial blasts explode in different time sequences).

In one time sequence more charges can explode simultaneously which are then considered one partial charge.

In timed blasting there are two time sequences Δt taken into consideration:

- $\boldsymbol{\Delta t \geq 250}$ **ms** (there is a seismic waves attenuation before explosion of the next charge component),
- $\boldsymbol{\Delta t < 250}$ **ms** (occurrence of effects interference of charge components).

The required length of boundary sequence timing depends on rock environment and it can decrease from value 250 ms up to Δt = 10 ms.

If it is an instantaneous blasting, the calculation will consider the total weight of explosive. In case of a delayed blasting the effect of timing, if shorter than 250 ms, can be only experimentally verified. If it is impossible then supposing approximately similar

Table 1 Values of exponents depending on massif characteristics (Mosinec, 1971).

c_p [m.s^{-1}]	τ [ms]	t
up to 1000	100	0.3
1000 ÷ 1500	70	0.45
1500 ÷ 2000	60	0.6
2000 ÷ 2500	50 ÷ 40	0.7
2500 ÷ 3000	40 ÷ 35	0.8
3000 ÷ 3500	35	0.9
3500 ÷ 4000	35	1.0
over 4000	20 ÷ 10	1.0

charge components we consider the doubled weight of partial charge component (the weight in one time step – equivalent weight of charge Q_{ev}), or considering charges of different sizes at maximum total weight of two biggest ones. If the weight of a charge is four times bigger than any one of the others then we can consider the weight of this biggest one. The normal projection and sealing of the charge are required.

The maximum reduction of particle velocity can be achieved at initiation sequence of the charge (e.g., Mosinec, 1971; Pandula and Kondela , 2010):

$$\boldsymbol{\tau} = \frac{\mathbf{10^5}}{\mathbf{c_p}}, \text{ [ms]} \tag{1}$$

where: c_p is transition velocity of longitudinal seismic waves in rock environment between blast and protected object [m.s^{-1}]. In accordance with chosen value τ, the total weight of charge can be:

$$\mathbf{Q_c = Q_{č}\, N^t}, \quad \text{resp. } \mathbf{Q_c = Q_p^{,}.N^t}, \text{ [kg]} \tag{2}$$

Where Q_C is the admissible charge of timed blasting (delay) [kg], N is the number of charges, resp. group of charges with weight Q_p blasted at time step τ, t is the exponent dependant on solid mass characteristics, see Table 1.

If Q_c, is defined using relation (2), then N is calculated. The relation (2) is valid for $N > 6 \div 12$, depending on solid mass characteristics. The stability of blasting concurrence and the entire reduction of seismic effects in solid mass can be achieved only for $N > 6 \div 8$, and in rocks with $c_p = 1000 \div 2000$ m.s^{-1}, for $N > 10 \div 12$.

EXPERIMENTAL MEASUREMENTS

Monitoring the rock blasting in quarries in Slovakia was focused on: size of charge, distance between source and receptor and, moreover we dealt with impact of timing on range of seismic effects (Mosinec, 1971; Dojčár and Pandula, 1998).

Due to measured blasts we completed grafical recordings, i.e. dependence of particle velocity of components v on time t, v = f (t), always for all components of particle velocity nevertheless the vertical component was registered twice, Figure 1.

For detailed analysis it is necessary to identify the time of blasting duration. It can be calculated as multiple of total electric delayed charges DeM (23) and of delay of t = 23 ms and adding the estimated time of dissipation caused by production technology, e.g. 30 %:

1. blasting: 3º ÷ 8º DeM: 5 x 23 = 115 ms ± 0.3 x 23 = 108 ÷ 122 ms,
2. blasting: 10º ÷ 18º DeM: 8 x 23 = 184 ms ± 0.3 x 23 = 177 ÷ 191 ms,
3. blasting: 0º ÷ 8º DeM: 8 x 23 = 184 ms ± 0.3 x 23 = 177 ÷ 191 ms,
4. blasting: 0º DeM: 0 x 23 = 0 ms ± 5 ms = 0 - 5 ms,

The last values introduced in previous chart present the approximate time of blasting termination, i.e.: 1. blasting duration was approximately 125 ms, after installing the electric current into electrical circuit, 2. and 3. blastings approximately up to 200 ms and 4. blasting approximately up to 5 ms.

The analysis of records of particular blastings shows that there were not registered significantly higher values of particle velocity in any blasting presented above in intervals listed above up to the time values 500 ms. On the contrary in blastings and particle velocity components of the records from the initial values up to the value 0.0 (it shows the recording of self-detonation at timing of rock blasting), there were the existing lowest values of particle velocity.

The recordings up to the value of 0.0 presents the so-called pre-history which exactly shows the graphical recording of self-detonation of blasting. It reflects the actual state in which the values of self-detonation vibrations–blasting of charges were so low that they fell under sensitivity limit of recording equipment. Only the next step of blasting which follows the detonation of charges initiated particle velocities higher than the sensitivity of seismograph,

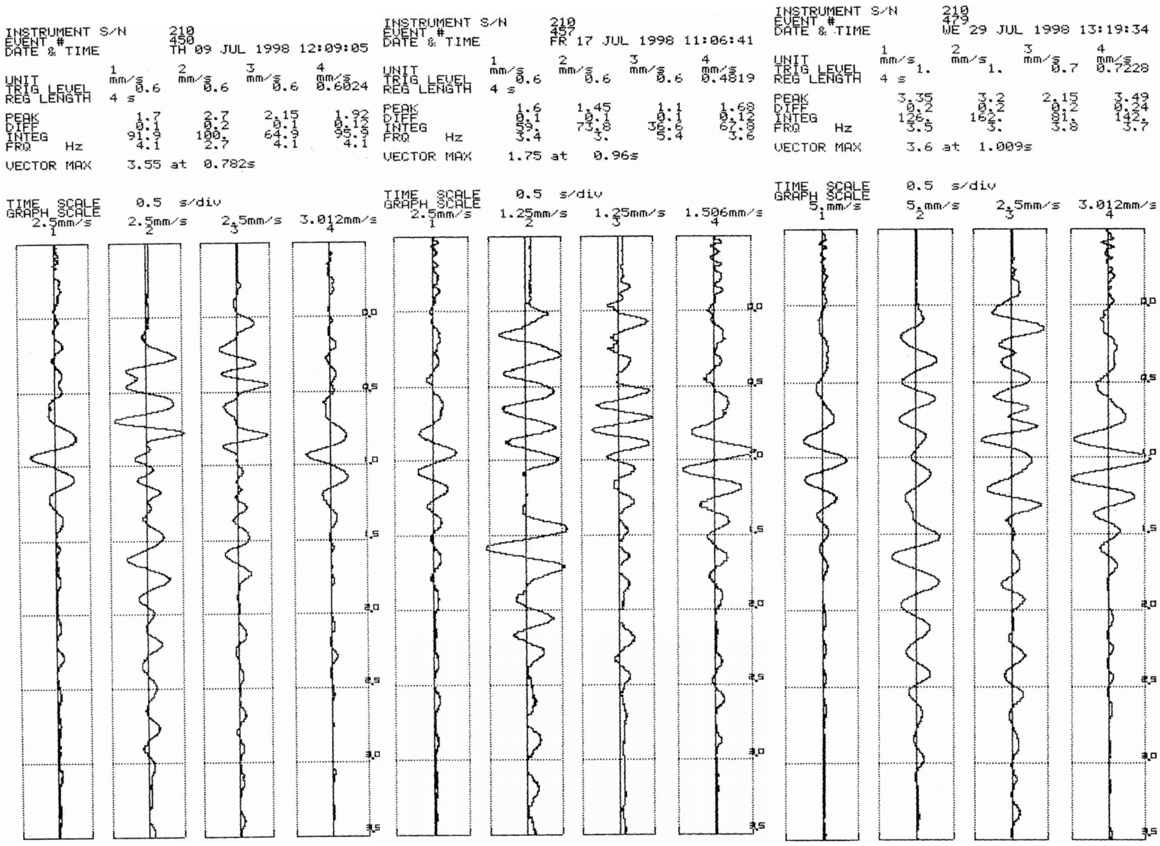

Fig. 1 Graphical recordings 1. blasting, v = f (t) – bench blasting Nr. 2278, 2. blasting, v = f (t) – bench blasting Nr. 2279, and 3. blasting, v = f (t) – bench blasting Nr. 2281 in the Včeláre quarry (Dojčár and Pandula, 1998).

as a consequence it started the recording and the so-called pre-history is displayed also in the respective record.

All vibrograms show that higher values particle velocity were recorded exclusively within the interval of value longer than 0.0 ÷ 0.5 s, i.e. in interval when the reflection from interface occurs which again has its time duration according to increasing time step of charges. The maximum values of particle velocities of particular blasting components were recorded within the following approximate intervals.:

1. 1. blasting, v = 2.70 mm.s^{-1} approximate interval 1.3 s,
2. 2. blasting, v = 1.70 mm.s^{-1} approximate interval 1.45 s,
3. 3. blasting, v = 3.50 mm.s^{-1} approximate interval 1.5 s,
5. blasting, v = 0.95 mm.s^{-1} approximate interval 1.25 s.

For demonstration of these issues in detail was introduced Figure 2 showing recordings of millisecond blasting at drilling boreholes in small-scale blasting (d = 36 mm, drill length 1 ÷ 1.5 m, low weight and quantity of blasted rock), applying time stages 0º, 1º, 2º, 3º, 4º DeM-S. In this case the individual components of particle velocity are determined and recorded and determined in graphical recording immediately after the first blasting and consequently as individual charges in accordance with timing activate correspondent vibrations. We can observe noticeable differences comparing this graphical recording with those from the Včeláre quarry. In this case the charges are small and the reflection of seismic waves do not generate measurable vibrations.

SIMILAR MEASUREMENT WERE CARRIED OUT IN OTHER QUARRIES IN SLOVAKIA

The source of seismic vibrations in the Maglovec quarry near Prešov was tristichous bench blasting Nr. 315 (Pandula et al., 2009). There were 100 boreholes drilled each of 26 m depth (see Fig. 3), one borehole contained 225 kg of Titan 7000 explosive.. The total charge of explosives in boreholes was 22 500 kg. For ignition the following media were used: 367.5 kg of Austrogel explosive, 100 pieces of detonators M_s 475/27$_M$, 100 pieces of detonators M_s 500/78$_M$,

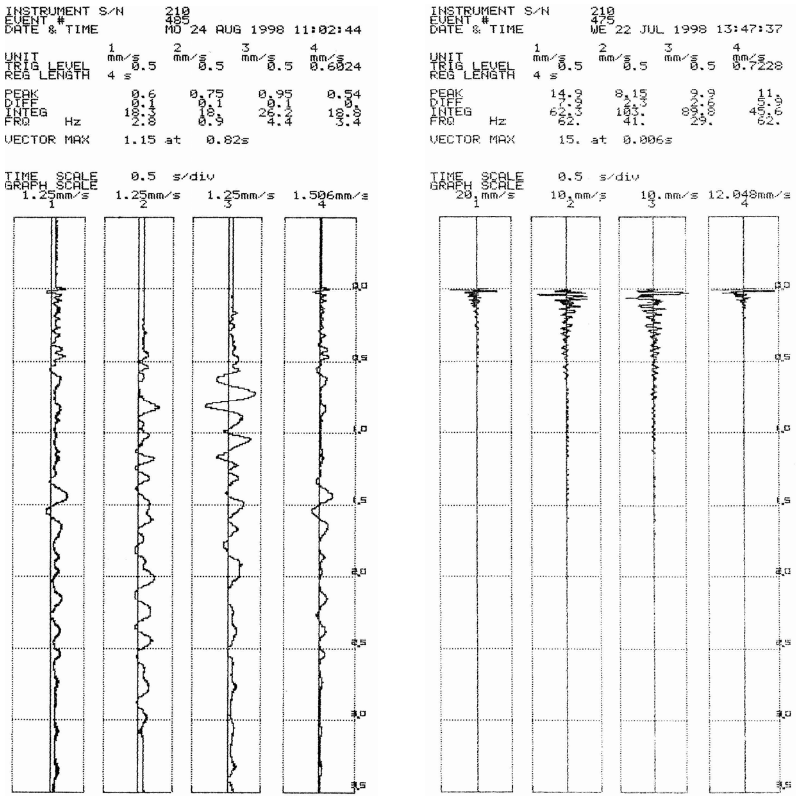

Fig. 2 Left graphical recording of the 4. blasting – bench blasting Nr. 2285, v = f (t), right graphical recording of millisecond blasting, v = f (t), at small-scale rock blasting: vibrations are activated by blasting - Včeláre quarry (after Dojčár and Pandula, 1998).

66 pieces of M_s 42/4.8$_M$, 30 pieces of detonators M_s 17/4.8$_M$, 2 pieces of M_s 25/4.8$_M$, 2 pieces of M_s 0/4.8$_M$. The borehole distribution scheme and blasting are shown in Figures 3 and 4.

The next blasting focused on monitoring the seismic impact on diorit porphyrite bearing in the Maglovec quarry was a bench blasting Nr. 336 (Pandula et al., 2009a).

There were 63 boreholes drilled 20 m deep under angle up to10^o. The maximum charge in one borehole was 105 kg. The total charge contained 6 452 kg of Centragold explosive (Titan 7000). The scheme of rock blasts timing and borehole distribution is shown in Figure 5. The maximum charge for one time stage was 420 kg. The timing method was proposed in order to straighten the quarry wall.

The analysis of grafical recordings presenting particular blastings in the Maglovec quarry has proved that there were not recorded any significantly higher particle velocity values in blastings carried out in 50 millisecond interval up to the value of interval 500 ms. On the contrary in both all blastings and particle velocity components in the vibrograms from the initial value up to the value of 50 millisecond (it demonstrates the grafical recording of self-detonation at rock blast timing), there were recorded the lowest values of particle velocity. Similar measurements were carried out in the Dubina quarry near Poprad (Pandula et al., 2009b). In bench blasting Nr. 20 there were 20 boreholes drilled. Electrical ignition was used and the detonators were DeM-S. Total charge of explosives in bench blasting Nr. 20 was 1 980 kg. The composition of detonators in each borehole is shown in Table 2.

The investigation of particular blasting grafical recording in the Dubina quarry showed similar correlation as they were in previous measurements. There were not recorded any significantly higher values particle velocity in blastings carried out in 50 millisecond interval up to the value of 500 ms interval. In bench blasting Nr. 20 the vibrations were attenued to 75 millisecond. It proves that the charge capacity applied in blasting was not sufficient to activate reflection of seismic waves from seismic boundary.

Figure 7 demonstrates the scheme of delayed blast monitored in the Dolinka-Hradište pod Vrátnom quarry (Pandula and Kondela, 2009). This blasting was different because the measured particle velocity were much larger than we expected when the sizes of

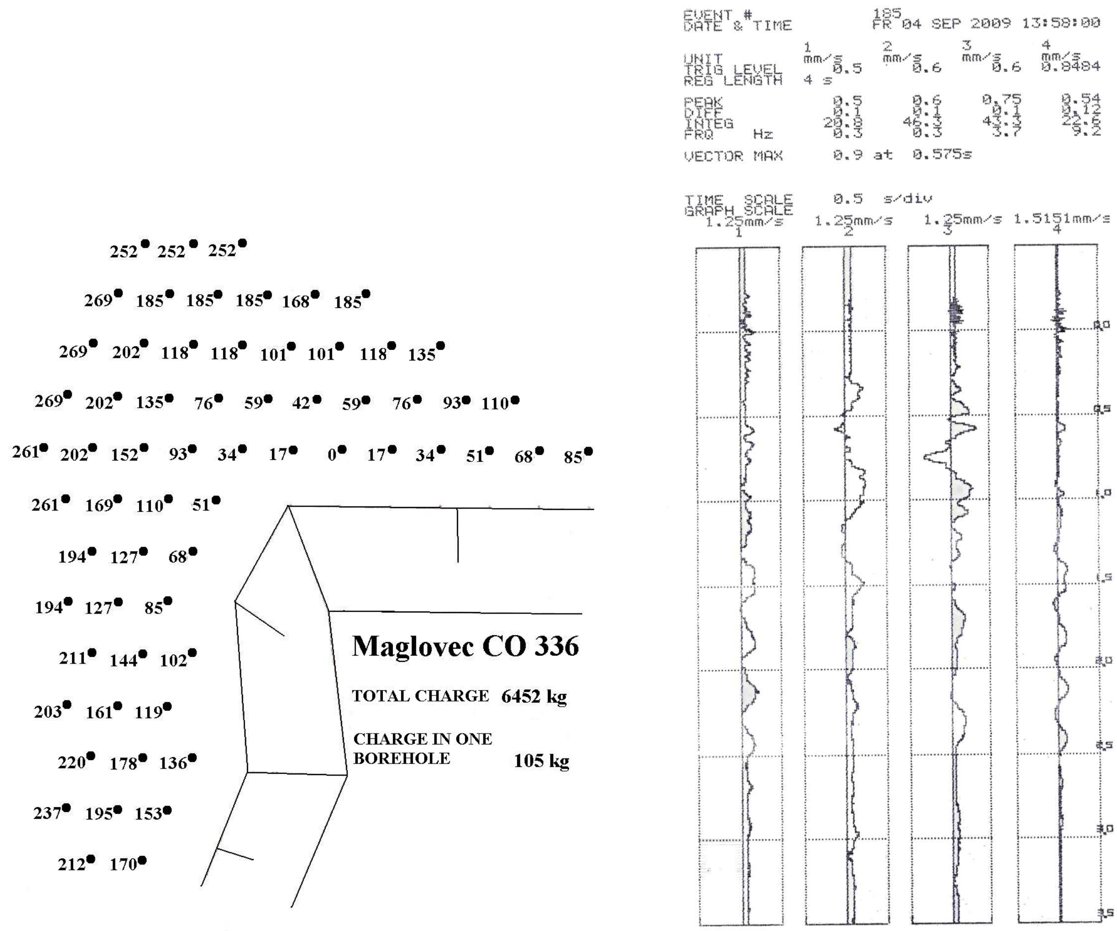

Fig. 5 Millisecond timing scheme bench blasting Nr. 336 and the final grafical recording of measured blasting (Pandula et al., 2009a).

Table 2 Composition of explosives in boreholes at bench blasting Nr. 20.

Boreholes number	DAP 4 [kg]	POLONIT E [kg]	DANUBIT 2 [kg]	Total charge of explosives [kg/borehole]
1-20	50	24	25	99

charge. When we study the detailed diagram of delayed blasting, we found what is the reason. The charge capacity in particular time steps did not meet the requirements on timed blasting. The biggest charge of the applied explosives was used in the last delayed section as a consequence the activated seismic waves could not be attenuated by charge explosion in further time steps.Therefore, the seismic effects initiated by blasting were much bigger than compared with the cases when the biggest charges were timed in the first time steps.

CONCLUSION

The presented evaluation method of seismic effects proves again the fact that the issue of safety measures of blasting has not been solved yet.

The analysis of recordings of particular blastings showed that it is requirable to carry out blastings in accordance with the principle of millisecond blast timing. These timed blastings proved in recordings the lowest values of particle velocity.

To achieve maximum reduction of the seismic effects in millisecond timing it is necessary to deal with the following issues:

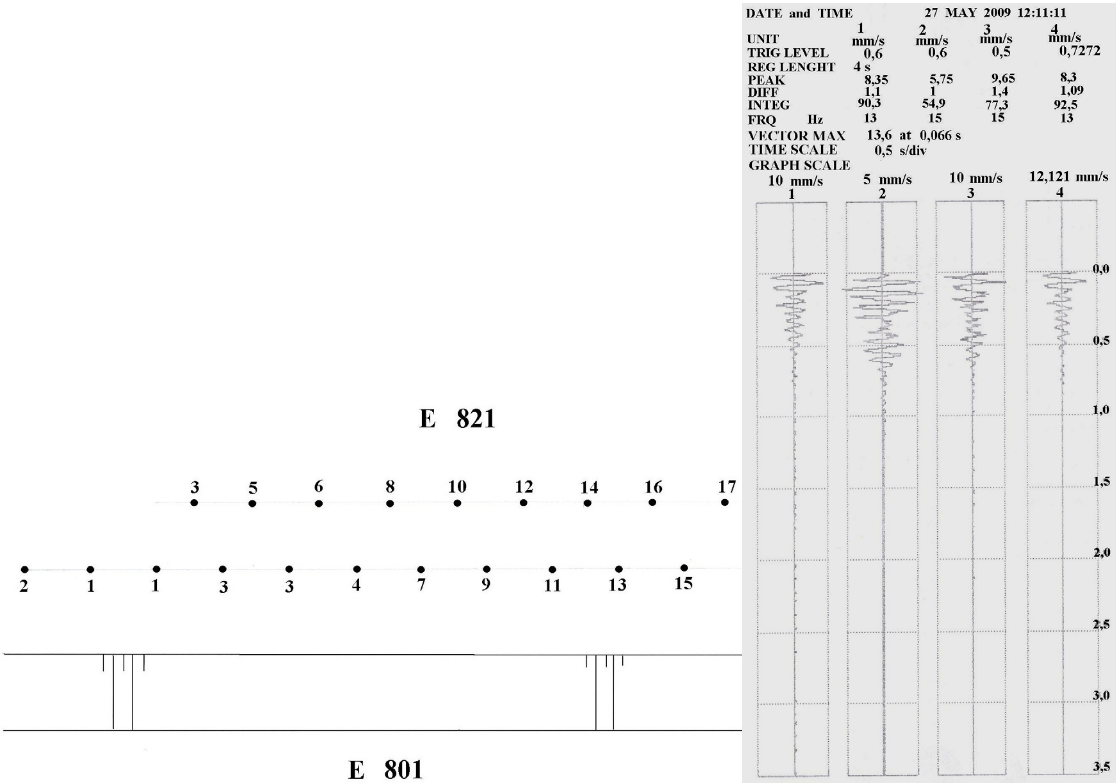

Fig. 6 Millisecond timing scheme bench blasting Nr. 20 in the Dubina quarry near Poprad and the final grafical recording of measured blasting (Pandula. et al., 2009b).

- to distribute the total charge of blasting into maximum number of delayed sections, i.e. the larger number of them the lower the seismic effect of the blasting will be,
- the total load divided by the time shooting step (boreholess, groups) evenly so that the weight variation of charges attributable to the time step did not exceed 10 to 15 %,
- the direction of the blast ignition has to be oriented beyond the protected objects,
- to orientate the rock massif against the protected object by its narrower side,
- pay attention to the careful selection of ignition scheme.

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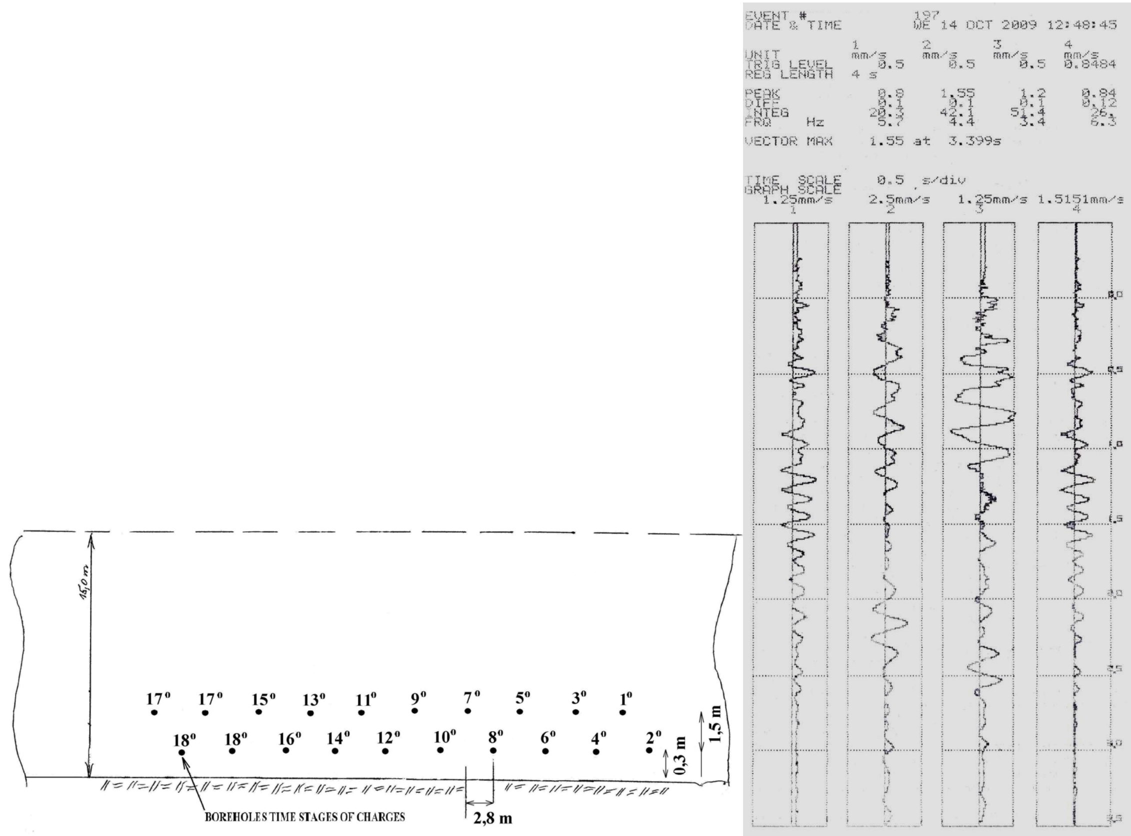

Fig. 7 Millisecond timing scheme bench blasting Nr. 191 in the Dolinka-Hradište pod Vrátnom quarry and the final grafical recording of measured blasting (after Pandula and Kondela, 2009).

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Fig. 3 Blasting site at bench blasting Nr. 315 etage 390 - 415 meters above sea level (Pandula et al., 2009).

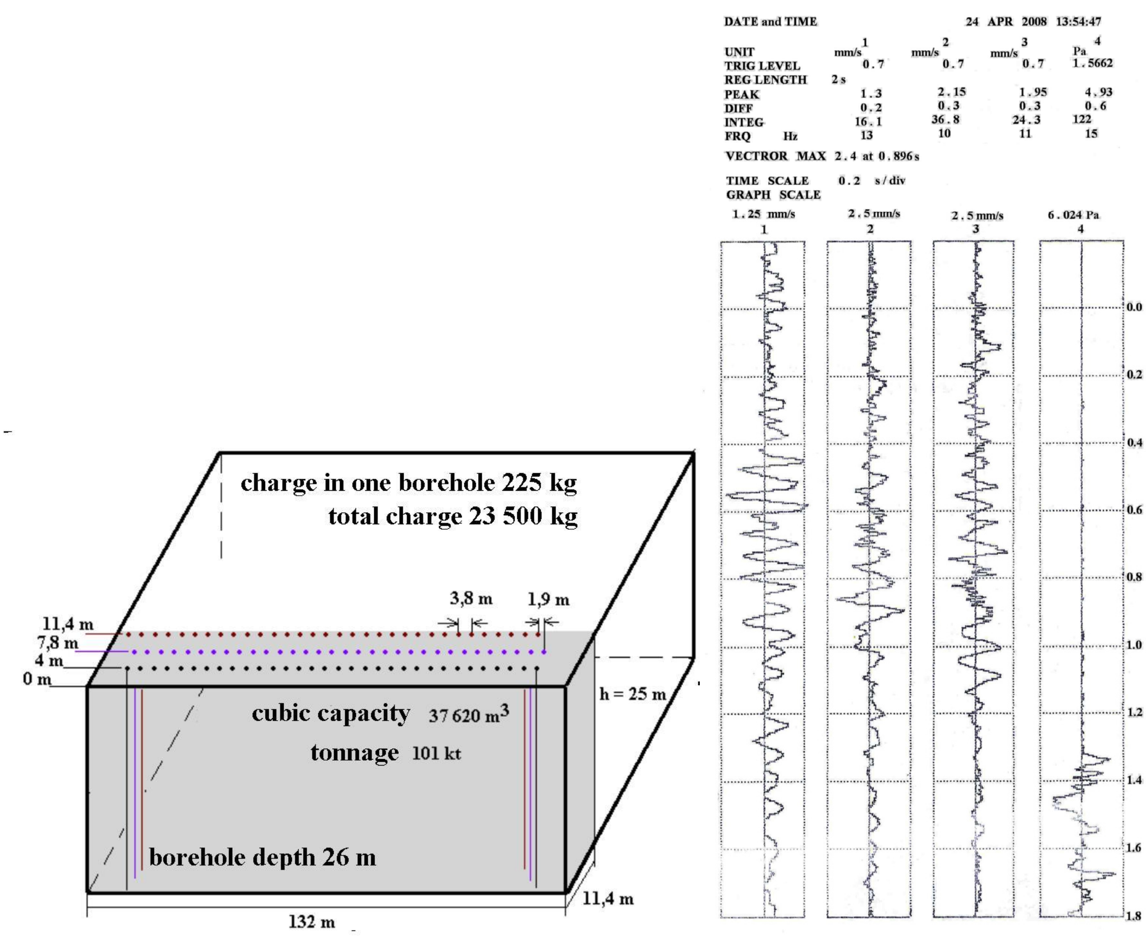

Fig. 4 Scheme of borehole distribution and parameters of explosive in bench blasting Nr. 315 at the etage 390 - 415 meters above sea level and the final grafical recording of blasting (Pandula et al., 2009).