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Professional paper

ASSESSMENT OF IMPACT ON ENVIRONMENT AND CONSTRUCTED FACILITIES OWING TO BLASTING AT OPEN PIT MINE "NEPRIČAVA"

PROCENA UTICAJA NA ŽIVOTNU SREDINU I GRAĐEVINSKE OBJEKTE USLED MINIRANJA NA PK „NEPRIČAVA“

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Abstract: This paper deals with problems related to adverse effects accompanying blast work. One of them is the occurrence of seismic effect and its impact on constructed facilities and the environment.
There is a growing problem of shock waves caused by blasting in the vicinity of the blast site. In addition to possible damage to constructed and mine facilities, those shock waves affect, adversely, people in them, namely the environment.
Lately considerable research in the world has been dedicated to the examination and numeric modelling of this phenomenon. Specific standards have been established defining the blast effect margin level of shock waves on facilities and human force there. Numerous numerical and empirical models have been developed to predict and monitor them. In Serbia, there are no standards for the assessment of blast effect of shock waves. This paper deals with the assessment of blast effect of an open pit mine and specific conclusions that have been drawn.

Key words: blasting, shock waves, measurement, environment, permissible limits, standards

Apstrakt: U ovom radu, obrađena je problematika vezana za negativne efekte koji prate minerske radove. Jedan od tih negativnih efekata koji prati minerske radove je pojava seizmičkog dejstva i njegovo delovanje na građevinske objekte i životnu sredinu.
Nastali potresi miniranjem izazivaju sve veći problem u okolini mesta izvođenja. Pored toga što mogu izazvati oštećenja na građevinskim i rudarskim objektima ti potresi deluju veoma nepovoljno na ljude u njima odnosno na životnu sredinu.
Poslednjih godina veliki broj istraživanja u svetu posvećen je ispitivanju i numeričkom modeliranju tog fenomena. Doneti su određeni standardi koji definišu dozvoljeni nivo potresa uticaja na građevinske objekte i ljudstvo u zgradama. Razvijeni su brojni numerički i empirijski modeli za predviđanje i praćenje istih. U Srbiji ne postoje standardi za ocenu uticaja dejstva potresa. U ovom radu izvršena je procena uticaja miniranja sa površinskog kopa „Nepričava“ – kod Lajkovca i izvedeni su određeni zaključci.

Ključne reči: miniranje, potresi, merenje, životna sredina, dozvoljene granice, standardi

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1. INTRODUCTION

Growing utilisation of blasting techniques in mining results from the fact that single blasting can replace the work of a number of workers and machines for the period of several months. The development in production capacity has caused the use of large amounts of explosive, which on the one hand results in the improvement of technico-economical indicators, and on the other hand in the increase of negative effects related to blast work.

By carrying out blast works, the potential energy of explosives converts into mechanical work. That energy, in the vicinity of the blasting area, breaks and crashes a rock mass further causing fractures and permanent deformations in the rock mass and even further it converts into elastic deformations. Seismic waves propagating through the rock mass induce the oscillation of soil and constructed facilities, impact the environment, etc.

The intensity of the seismic effect can be established if we measure one of basic dynamic parameters of the induced environment: oscillation velocity v, acceleration a or soil movement x. It is possible to make a connection among these parameters if we establish one instrumentally measurable parameter, which enables other parameters to be determined by calculating. One of the most common parameters used for the assessment of seismic intensity is the oscillation velocity of induced soil v.

2. EFFECTS OF BLASTING ON CONSTRUCTED FACILITIES

The intensity assessment of shock waves induced by blast work breaking a rock mass and its impact on construction facilities and an environment will be carried out on the basis of the following criteria:

1. Effects of blasting on constructed and mine facilities:

- Criterion according to the Institute of Physics of the Earth, Russian Academy of Sciences (IPERAS) scale;
- Criterion according to the standard DIN- 4150 and
- Criterion according to the Russian scale for mine facilities.

2. Effects of blasting on environment:

- Criterion according to the standard DIN- 4150.

2.1. Effects of blasting on constructed and mine facilities

The criterion according to the IPERAS scale. One of the most commonly used criteria with us for the assessment of shock wave intensity induced by blasting has been established by the Institute of Physics of the Earth, Russian Academy of Sciences. The Russian scale (Table 1) is of a descriptive type related to the ocsillation velocity of soil particles and the degree of seismic intensity and is given in the form of 12 seismic degrees.

Deformations on the facilities, as it can be seen in Table 1, occur if oscillation velocity owing to blasting exceeds the fourth degree of the seismic scale. The state of the facilities, soil characteristics, as well as the number and kinds of blasting activities should be taken into account for the assessment of blasting seismic effects on buildings and other constructed facilities (Slimak, 1996; Trajković et al. 2005).

Table 1 - IPERAS scale

Oscillation velocity v [mm/s]	Level of seismic intensity	Description of actions
< 2.0	I	Action is revealed only by instruments
2.0 - 4.0	II	Action is felt only in some cases when there is a complete silence
4.0 - 8.0	III	Action is felt by very few people or only those who are expecting it
8.0 - 15.0	IV	Action is felt by many people, the clink of the windowpane is heard
15.0 - 30.0	V	Plaster fall, damage on buildings in poor condition
30.0 - 60.0	VI	Air cracks in plaster, damage, damage to buildings that already have developed deformations
60.0 - 120.0	VII	Damage to buildings in good condition, cracks in plaster, parts of the plaster fall down, air cracks in walls, cracks in tile stoves, chimney wrecking
120.0 - 240.0	VIII	Considerable deformations on buildings, cracks in bearing structure and walls, bigger cracks in partition walls, wrecking of factory chimneys, fall of the ceiling
240.0 - 480.0	IX	Wrecking of buildings, bigger cracks in walls, exfoliation of walls, collapse of some parts of the walls
> 480.0	X - XII	Bigger destruction, collapse of complete structures etc.

Criterion according to standard DIN-4150. In the Federal Republic of Germany, maximal tolerable limits for the values of soil oscillation velocity are regulated in dependence on the significance and the state of facilities for the frequency span from 5 to 100 Hz. Tolerable limits for the values of the soil oscillation velocity according to DIN- 4150 are presented in Table 2 (Rakić, 2005).

Table 2 - Standard DIN-4150

Row	Type of the structure	Approximate values of vibration velocity v [mm/s]			
		Foundation			Top floor ceilings
		Frequency [Hz]			All frequencies
		< 10	10 - 50	50 - 100	
1	Structures used for craftsmanship, industrial and similar structural structures	20	20 - 40	40 - 50	40
2	Dwelling buildings and structures similar in construction or function	5	5 - 15	15 - 20	15
3	Structures that because of their particular sensitivity to vibrations do not fall into groups 1 and 2 and are essential for conservation (for inst. as cultural-historical monuments)	3	3 - 8	8 - 10	8

Criteria according to Russian scale for mine facilities. The level of rock mass deformation plays an important role in the protection of mine facilities constructed in a rock massif such as shafts, drifts, tunnels, rise headings, dip headings, chambers, stopes, sublevel posts, hydro-engineering tunnels, bench slopes, etc. Deformation characteristics of a rock massif have an essential impact while determining the threshold of deformations for facilities constructed in the rock massif. On the basis of experimental measurements, there have been established oscillation velocities of the rock massif in varied mining-geological and mining-engineering conditions whose values (Russian standards) are presented in Table 3 (Фокин, 2004; Medvedev, 1965).

Table 3 - Russian standards

Description of occurrences in rock massif induced by seismic wave	Oscilation velocity [cm/s]
There are no damages	< 20
The occurrence of insignificant development of fissures induced by previous blasting; locally, falling out of single pieces along previously weakened surfaces	20 - 50
Intensive development of existing fissures followed by minor caving of rock pieces with the dimensions to 0.2 x 0.2 x 0.2 m; the occurrence of cracks in tectonically weaker material filled fissures; the caving of bench slopes along tectonic deformations	50 - 100
The development of tectonic fissures and the caving of rock pieces with the dimensions 0.5 x 0.5 x 0.5 m	100 - 150
Caving from sides and roof of underground chambers along tectonic fissures, the formation of new fissures in undamaged part of the rock mass, collapse of safety pillars and benches	150 - 300
Complete damage of sides and roof of chambers followed by large blocks with dimensions of 1 x 1 x 1 m and filling up to the half of constructed surface; caving of hard rock slopes	300 - 400
Complete demolition of rock mass, the caving of large blocks bigger than 1 x 1 x 1 m and covering up more than a half of the chamber	> 400

In Table 4, according to Russian literature, relative thresholds of rock deformations are recommended depending on the category of facilities in them (Фокин, 2004; Trajković et al. 2005).

Table 4 - Allowed relative deformation of the soil

Facility class	Characteristics of mine facilities and period of their exploitation	Relative deformation margin ε_o
I	Especially significant facilities with a long period of exploitation (more than 10 - 15 years); hydro-engineering tunnels, shafts, capital chambers (walls, galleries, etc.), ore chutes, etc.	0.0001
II	Significant facilities with the 5 - 10 year period of exploitation; drainage and haulage tunnels, hydro-engineering facilities, safety pillars, walls and other mine chambers, bench slopes, etc.	0.0002
III	Underground facilities lasting for a shorter period (1 - 5 years): chambers, rises, walls etc.	0.0003
IV	Facilities of minor significance with the period of exploitation of one year: working space, rises, horizontal boards, working slope of open pit mines, etc.	0.0005

In Table 4 it can be concluded that a shock wave, if of high intensity, causes such stress in a rock mass that its deformations exceed the elasticity margin, thus delayed deformations occur. Bearing this in mind, it is necessary, for the stability of a facility in the rock at repeated blasting, to pay attention to so-called threshold of deformation, which at the elastic behaviour of rocks, must not exceed the value of $0.0002 \div 0.0005$ (Trajković et al. 2005; Medvedev, 1965).

The margin level of oscillation rate according to classes of facilities and of a rock mass they occur in, are presented in Table 5.

Table 5 - The margin level of oscillation rate according to rock mass

Characteristics of massif	**Coefficient of strength *f***	**Velocity of longitudinal waves C_p [km/s]**	**Tolerable limit of oscillation velocity of facilities by categories [cm/s]**			
			I	**II**	**III**	**IV**
Cohesionless rounded pebbles and alluvium	$0.5 \div 1$	1 - 2	4.08	8.2	12.2	20.4
Highly fissured rocks with clay and high porosity	$1 \div 3$	2 - 3	6.80	13.6	20.3	34.0
Significantly fissured bedding rocks	$3 \div 5$	3 - 4	9.50	19.0	28.4	47.5
Significantly homogenous rocks with single cracks and interstices	$5 \div 9$	4 - 5	12.2	24.4	36.7	60.0
Poorly fissured monolithic rocks	$9 \div 14$	5 - 6	14.9	29.8	44.6	74.5
Highly firm and monolithic rocks, without cracks	$14 \div 20$	6 - 7	17.8	35.6	53.3	89.0

2.2. Effects of blasting on environment

Effects on people in constructed facilities (buildings) according to DIN criteria. It is possible to evaluate any periodical and a-periodical oscillations by the assessment procedure. In the standard, there are stated requirements and approximate stress values of people in flats and rooms used for similar purposes (Ravilić, 2012).

Jeopardizing of people by shock waves depends on the following factors: shock wave intensity (strength), frequency, duration of shock waves, frequent recurrence and the period of a day when they occur, the sort and way of work of a shock wave source, individual characteristics and situational circumstances, health state (physical psychical), activity during shock wave stress, the level of becoming used to them.

The assessment procedure of vibrations is taken on the basis of unweighted signals expressed by the vibration intensity KB_F. During assessment the maximal weighted vibration intensity KB_{Fmax}, is determined and if necessary the vibration intensity during assessment KB_{FTr} which are compared with approximate values.

An unweighted vibration signal is a signal limited by the span and proportional to the vibration velocity in the operating frequency range from 1 to 80 Hz.

A frequently weighted signal of vibrations is obtained from an unweighted vibration signal by filtration. The obtained signal is weighted by the calculating procedure according to the relation:

$$\left|H_{KB}\left(f\right)\right|=\frac{1}{\sqrt{1+\left(\frac{f_o}{f}\right)^2}} \tag{1}$$

where there is:
f - frequency in Hz;
f_o = 5.6 Hz (threshold frequency of high permeability filter).

On the basis of the obtained weighted signal, the *KB* value with time constant τ = 125 ms is calculated based on the relation:

$$KB_\tau\left(t\right)=\sqrt{\frac{1}{\tau}\int_{\xi=0}^{\xi-t} e^{-\frac{t-\tau}{\tau}} KB^2\left(\xi\right)\cdot d\xi} \tag{2}$$

While determining weighted *KB* values, as experience shows, the aberration of 15% occurs.

The measurement of oscillation values must be carried out in the vertical direction (z) with two horizontal directions being at the right angle (x and y).

The assessment of obtained results according to DIN 4150 is carried out on the basis of two *KB* values:

- KB_{Fmax} - maximal weighted vibration intensity (maximal KBt value);
- KB_{FTr} - maximal effective value in time interval.

The effective value of maximal values in time intervals KB_{FTr} is determined via the relation:

$$KB_{FTm}=\sqrt{\frac{1}{N}\sum_{i=1}^{N} KB_{FTr}^2} \tag{3}$$

Both values (KB_{Fmax} and KB_{FTr}) are determined separately for all three components in x, y (horizontal) and z (vertical) directions. The assessment is carried out on the basis of that component which is the highest.

Values for assessment should be compared with approximate values: A_u - lower margin, A_o - upper margin and A_r - resulting value, in Table 6 under the following conditions:

- if KB_{Fmax} value is lower than (upper) approximate value A_o or the same, then requirements according to this standard are met;
- if KB_{Fmax} is higher than (upper) approximate value A_o then requirements according to this standard are not met;
- for momentary activities which rarely occur, the requirement according to the standard is met if KB_{Fmax} is lower than A_o;
- for more frequent activities, where KB_{Fmax} is higher than A_u but lower than A_o, another step of investigation is required in special cases, namely the determination of the vibration intensity for the assessment of KB_{FTr}. If KB_{FTr} is not higher than the approximate value A_r, according to the Table 6, then the requirements according to the standard are also met;
- the criterion A_r serves for the assessment of highly variable or only momentarily acting variations whose value KB_{Fmax} is higher than A_u, but lower than A_o.

Table 6 - Approximate values

Row	Workplace	Day			Night		
		A_u	A_o	A_r	A_u	A_o	A_r
1	A workplace where, in the vicinity, there are only industrial plants and possibly flats for owners, managers and monitorial staff and workers on duty (see industrial regions Article 9 Bau NVO, (Land Use Ordinance)	0.40	6.0	0.20	0.30	0.60	0.15
2	A workplace where, in the vicinity, there are predominantly located handicraft facilities (see craft fields Article 8 Bau NVO-(Land Use Ordinance)	0.30	6.0	0.15	0.20	0.40	0.10
3	A workplace where, in the vicinity, there are neither predominantly located industrial plants nor flats (see central areas Article 6 Bau NVO, rural areas Article 5 Bau NVO-Land Use Ordinance)	0.20	5.0	0.10	0.15	0.30	0.07
4	A workplace where, in the vicinity, there are predominantly or exclusively residential areas (see pure residential areas Article 3 Bau NVO, general residential areas Article 4 Bau NVO, small settlement areas Article 2 Bau NVO)	0.15	3.0	0.07	0.10	0.20	0.05
5	A workplace work requiring special protection, for example in hospitals, spa resorts, as well as special areas denoted for that purpose	0.10	3.0	0.05	0.10	0.15	0.05

Determining of the KB_{Fmax} value for blasting carried out at the OPM Nepričava in the vicinity of the town of Lajkovac will be conducted according to the program marked MR-2012[*].

3. GEOLOGIC-TECHNOLOGICAL CHARACTERISTICS OF DEPOSIT

The limestone deposit Nepričava is situated at the distance of about 7 km southwest of the town of Lajkovac. The limestone open pit is situated closely along the Lajkovac-Valjevo road and there is also the Belgrade-Bar railway in the immediate vicinity. The River Kolubara runs in the vicinity of the limestone mine as well (Ravilić, 2012; Trajković and Lutovac, 2006).

Within the mine site there has been built an industrial area with processing plants and the administrative building. In addition to limestone processing in the plant of the mine, the limestone is also processed in the Ćelije plant being about 9 km away.

As far as values of physico-mechanical characteristics of limestone and technological process of production and lime production are concerned there have been conducted adequate examinations of samples taken within the deposit as well as of the samples taken by core. Values obtained by the examination are the following:

Comprehensive strength (mean values):	21.1 - 93.0 Mpa
Volume mass with interstices:	26.3 - 27.1 kN/cm^3
Porosity:	0.0004 - 0.026
Water suction:	0.217%

[*] MR 2012 programme was first applied to assess the impact of blasting on the environment (in Serbia) in the master thesis of M. Ravilic with the title *Analysis of blasting on constructed facilities and environment.*

The measurement of seismic effects, namely of the of soil oscillation velocity *v* has been carried out by instruments of the Vibraloc type, manufactured by the Swedish firm ABEM. The oscillation detector contains three seismometers placed in the mutual housing oriented in the directions of X, Y and Z axes of the orthogonal coordinate system. The seismograph is designed thus that it can record the oscillation velocity *v*, whereby acceleration *a* and soil movement *x*, as well as the frequency value are calculated. Shock waves can be recorded on the fourth channel by using a microphone connected to an outer connector.

The Vibraloc is equipped with the 8 megabyte memory for measurement and can keep about 1000 measurements which are memorized according to the time sequence. The oldest measurements are automatically replaced by the latest ones. The length of recording can be adjusted to 1, 2, 3, 4, 5, 10, 20, 30, …100 seconds. It is possible to read oscillation velocities on the spot in three basic directions.

The measuring of seismic effects, namely the oscillation velocity of soil particles *v* induced by blasting was carried out by a measuring device of Vibralok type, a product of the Swedish Company ABEM. Basic characteristics of the seismograph Vibraloc are the following:

Manufacturer:	ABEM, Sweden
Measurement possibilities:	velocity, acceleration, motion and air impacts
Number of components:	lateral, vertical, longitudinal
Frequency range:	2 - 250 Hz
Sampling:	1000; 2000 or 4000 Hz
Trigger levels:	0.1 - 200 mm/s
Trigger levels of the canal A (air):	2 - 150 Pa
Recording length:	1 - 100 s or automatic length
Site location possibilities:	flat floors, plates, foundations, soil, etc.
Data transfer and analysis:	UVSZ software; UVSZA software

Measurement points were located at the following locations (Ravilić, 2012):

Measurement point MM-1:	constructed facility - a house
Measurement point MM-2:	constructed facility - a house
Measurement point MM-3:	constructed facility - a house
Measurement point MM-4:	mine plateau
Measurement point MM-5:	mine plateau

3.1. Data on conducted blasting and measuring No.I

Data on blasting. The following means were used for this blasting (Trajković and Lutovac, 2006):

Overall number of boreholes:	$N_{uk} = 9$
Overall depth of boreholes:	$L_{uk} = 82.0$ m
Amount of explosive - Balkanit 60/1000:	$Q_1 = 80.0$ kg
Amount of explosive - Videksil 65/2000:	$Q_2 = 72.0$ kg
Overall amount of explosive:	$Q_{uk} = 152.0$ kg

Max. amount of explosive per one interval: $Q_i = 37.0$ kg
Amount of detonating fuse, C-12: $L_{df} = 100.0$ m
Length of stemming: $L_{č} = 3.2 - 3.5$ m
Amount of slow-burning fuse: $L_{sf} = 1.0$ m
Decelerators of 20 ms: $N_u = 7$ pieces
Delay action cap, DK-8: $N_{DK} = 1$ piece

Instrumental observations. The recording of seismic waves was carried out with four to five instruments. In Table 7 there are presented results of measuring for each measurement point (Trajković and Lutovac, 2006).

Table 7 - The survey of blasting parameters and measurement results

Measuring point M.P.	Distance from blastin field to measuring point	Maximum quantity per one interval	Overall quantity of explosive	Maximum oscilation velocity per comp. [mm/s]			Maximum oscilation velocity per comp. v_r	Real resultat maximum oscillation velocity v_{st}	Evaluation of measurement results *Hz*		
	[m]	[kg]	[kg]	v_V	v_T	v_L	[mm/s]	[mm/s]	*V*	*T*	*L*
MM-1	153.87	37.0	152.0	5.09	3.03	2.15	6.301	5.33	51.3	51.6	36.6
MM-2	130.52	37.0	152.0	6.70	6.80	4.15	10.41	6.98	34.7	30.9	37.8
MM-3	126.43	37.0	152.0	5.79	6.54	8.60	12.26	9.29	38.4	39.1	47.0
MM-4	71.24	37.0	152.0	16.9	12.2	7.24	22.06	17.61	30.0	40.2	36.0
MM-5	53.05	37.0	152.0	28.6	13.8	11.2	33.67	28.72	44.8	48.8	42.0

3.2. Data on conducted blasting and measuring No.II

Data on blasting. The following means were used for this blasting (Trajković and Lutovac, 2006):

Overall number of boreholes: $N_{uk} = 6$
Overall depth of boreholes: $L_{uk} = 40.0$ m
Amount of explosive - Balkanit 60/1000: $Q_1 = 53.0$ kg
Amount of explosive - Videksil 65/2000: $Q_2 = 48.0$ kg
Overall amount of explosive: $Q_{uk} = 101.0$ kg
Max. amount of explosive per one interval: $Q_i = 41.0$ kg
Amount of detonating fuse, C-12: $L_{df} = 60.0$ m
Length of stemming: $L_{č} = 3.0 - 3.2$ m
Amount of slow-burning fuse: $L_{sf} = 3.0$ m
Decelerators of 20 ms: $N_u = 2$ pieces
Delay action cap, DK-8: $N_{DK} = 1$ piece

Instrumental observations. The recording of seismic waves was carried out with four to five instruments. In Table 8 there are presented results of measuring for each measurement point (Trajković and Lutovac, 2006).

Table 8 - The survey of blasting parameters and measurement results

Measuring point M.P.	Distance from blastin field to measuring point [m]	Maximum quantity per one interval [kg]	Overall quantity of explosive [kg]	Maximum oscilation velocity per comp. [mm/s]			Maximum oscilation velocity per comp. v_r [mm/s]	Real resultat maximum oscillation velocity v_{st} [mm/s]	Evaluation of measurement results *Hz*		
				v_V	v_T	v_L			*V*	*T*	*L*
MM-1	422.11	41.0	101.0	-	-	-	-	-	-	-	-
MM-2	406.79	41.0	101.0	0.49	1.10	0.67	1.378	1.10	32.3	26.7	22.1
MM-3	400.29	41.0	101.0	0.25	1.25	0.83	1.521	1.27	18.9	25.0	28.3
MM-4	326.39	41.0	101.0	1.03	2.18	0.91	2.577	2.39	28.4	22.6	20.8
MM-5	212.39	41.0	101.0	2.28	2.63	1.18	3.675	2.97	26.0	20.8	4.54

3.3. Data on conducted blasting and measuring No.III

Data on blasting. The following means were used for this blasting (Trajković and Lutovac, 2006):

Overall number of boreholes:	$N_{uk} = 8$
Overall depth of boreholes:	$L_{uk} = 80.0$ m
Overall amount of explosive - Balkanit 60/1000:	$Q_{uk} = 185.0$ kg
Max. amount of explosive per one interval:	$Q_i = 26.0$ kg
Amount of detonating fuse, C-12:	$L_{df} = 110.0$ m
Length of stemming:	$L_{č} = 3.0 - 3.2$ m
Amount of slow-burning fuse:	$L_{sf} = 3.0$ m
Decelerators of 20 ms:	$N_u = 7$ pieces
Delay action cap, DK-8:	$N_{DK} = 1$ piece

Instrumental observations. The recording of seismic waves was carried out with four to five instruments. In Table 9 there are presented results of measuring for each measurement point (Trajković and Lutovac, 2006).

Table 9 - The survey of blasting parameters and measurement results

Measuring point M.P.	Distance from blastin field to measuring point [m]	Maximum quantity per one interval [kg]	Overall quantity of explosive [kg]	Maximum oscilation velocity per comp. [mm/s]			Maximum oscilation velocity per comp. v_r [mm/s]	Real resultat maximum oscillation velocity v_{st} [mm/s]	Evaluation of measurement results *Hz*		
				v_V	v_T	v_L			*V*	*T*	*L*
MM-1	256,90	26,0	185,0	1,17	1,36	1,10	1,17	1,36	54,6	19,0	33,3
MM-2	220,81	26,0	185,0	1,99	2,96	2,27	1,99	2,96	37,5	28,2	24,2
MM-3	224,58	26,0	185,0	1,74	3,13	1,60	1,74	3,13	39,5	31,3	37,7
MM-4	161,78	26,0	185,0	2,67	4,17	2,37	2,67	4,17	30,8	26,6	37.3
MM-5	179,10	26,0	185,0	2,17	2,11	1,24	2,17	2,11	24,7	23,1	9,92

3.4. Data on conducted blasting and measuring No.IV

Data on blasting. The following means were used for this blasting (Trajković and Lutovac, 2006):

Overall number of boreholes:	$N_{uk} = 7$
Overall depth of boreholes:	$L_{uk} = 70.0$ m
Overall amount of explosive, Balkanit + Videksit:	$Q_{uk} = 135.0$ kg
Max. amount of explosive per one interval:	$Q_i = 20.0$ kg
Amount of detonating fuse, C-12:	$L_{df} = 90.0$ m
Length of stemming:	$L_{č} = 3.0 - 3.2$ m
Amount of slow-burning fuse:	$L_{sf} = 3.0$ m
Decelerators of 20 ms:	$N_u = 6$ pieces
Delay action cap, DK-8:	$N_{DK} = 2$ pieces

Instrumental observations. The recording of seismic waves was carried out with four to five instruments. In Table 10 there are presented results of measuring for each measurement point (Trajković and Lutovac, 2006).

Table 10 - The survey of blasting parameters and measurement results

Measuring point M.P.	Distance from blastin field to measuring point [m]	Maximum quantity per one interval [kg]	Overall quantity of explosive [kg]	Maximum oscilation velocity per comp. [mm/s] v_V	v_T	v_L	Maximum oscilation velocity per comp. v_r [mm/s]	Real resultat maximum oscillation velocity v_{st} [mm/s]	Evaluation of measurement results *Hz* *V*	*T*	*L*
MM-1	184,41	20,0	135,0	1,95	1,71	1,10	2,82	2,66	41,5	46,6	58,8
MM-2	151,52	20,0	135,0	3,41	2,76	2,53	5,06	4,51	41,2	32,1	33,1
MM-3	152,79	20,0	135,0	3,72	4,66	2,21	6,36	5,04	38,0	38,5	31,6
MM-4	87,57	20,0	135,0	11,7	8,21	6,15	15,56	11,95	40,2	43,2	29,9
MM-5	99,91	20,0	135,0	3,70	4,80	3,04	6,78	5,56	36,6	26,6	34,9

3.5. Data on conducted blasting and measuring No.V

Data on blasting. The following means were used for this blasting (Trajković and Lutovac, 2006):

Overall number of boreholes:	$N_{uk} = 7$
Overall depth of boreholes:	$L_{uk} = 70.0$ m
Overall amount of explosive, Balkanit + Videksit:	$Q_{uk} = 105.0$ kg
Max. amount of explosive per one interval:	$Q_i = 19.0$ kg
Amount of detonating fuse, C-12:	$L_{df} = 90.0$ m
Length of stemming:	$L_{č} = 3.0 - 3.2$ m
Amount of slow-burning fuse:	$L_{sf} = 3.0$ m
Decelerators of 20 ms:	$N_u = 6$ pieces
Delay action cap, DK-8:	$N_{DK} = 2$ pieces

Instrumental observations. The recording of seismic waves was carried out with four to five instruments. In Table 11 there are presented results of measuring for each measurement point (Trajković and Lutovac, 2006).

Table 11 - The survey of blasting parameters and measurement results

Measuring point M.P.	Distance from blastin field to measuring point [m]	Maximum quantity per one interval [kg]	Overall quantity of explosive [kg]	Maximum oscilation velocity per comp. [mm/s]			Maximum oscilation velocity per comp. v_r [mm/s]	Real resultat maximum oscillation velocity v_{st} [mm/s]	Evaluation of measurement results *Hz*		
				v_V	v_T	v_L			*V*	*T*	*L*
MM-1	160,27	19,0	105,0	1,23	1,43	0,77	2,04	1,46	86,2	40,0	28,6
MM-2	137,43	19,0	105,0	2,85	2,54	1,80	4,22	2,99	43,3	27,5	20,6
MM-3	137,33	19,0	105,0	3,00	3,76	2,46	5,40	4,19	46,0	31,9	33,3
MM-4	72,09	19,0	105,0	10,3	5,65	3,39	12,23	10,44	68,8	81,4	72,4
MM-5	77,99	19,0	105,0	3,37	2,56	3,15	5,27	4,01	35,4	32,0	35,3

4. ASSESMENT OF MEASUREMENT RESULTS

The assesment of intensity of shock waves induced by blasting on breaking rock mass and its impact on surrounding facilities and environment, will be conducted on the basis of the following criteria:

A. Effects of blasting on constructed and mine facilities:

- criterion according to Institute of Physics of the Earth, Russian Academy of Sciences (IPERAS) scale;
- criterion according to the standard DIN-4150;
- criteria according to the Russian scale for mine facilities.

B. Effects of blasting on environment:

- criterion according to the standard DIN-4150.

In order to conduct the assessment of induced shock waves by these three criteria, in Table 12, there have been given recorded values of velocity by components, resulting maximal oscillation velocity, frequency by components, as well as the KB calculated value whose values will be compared with the values presented in Tables 1, 2, 3, 4, 5 and 6.

To assess the shock wave intensity the following marks were used to fill in Table 12.

A. Effects of blasting on constructed and mine facilities:

- the criterion according to the IPERAS scale (facilities of the third class according to Table 1 taken into account):
  - A - it meets requirements within thresholds of oscillation velocity;
  - B - it does not meet requirements, above thresholds of oscillation velocity;
- the criterion according to DIN 4150 standard (facilities of the second class according to Table 2 taken into account):
  - C - it meets requirements within thresholds of oscillation velocity;
  - D - it does not meet requirements, above thresholds of oscillation velocity;

Table 12 - Results of blasting and measuring conducted at the open pit Nepričava in the vicinity of the town Lajkovac

Blasting No.	Measur. point M.P.	Distance from blastin field to M.P.	Max. quantity per one inter. [kg]	Overall quantity of exp. [kg]	Max. oscilation velocity per comp. [mm/s]			Res.max. oscilation velocity [mm/s]	KB_{fm}	Frequency per components [Hz]			Evaluation of measurement results			
					v_V	v_T	v_L			V	T	L	IFZA	DIN	Russ stan.	DIN KB_{fm}
I	MM-1	153.87	37.0	152.0	5.09	3.03	2.15	6.301	1.292	51.3	51.6	36.6	A	C	-	G
	MM-2	130.52	37.0	152.0	6.70	6.80	4.15	10.41	2.150	34.7	30.9	37.8	A	C	-	G
	MM-3	126.43	37.0	152.0	5.79	6.54	8.60	12.26	2.593	38.4	39.1	47.0	A	C	-	G
	MM-4	71.240	37.0	152.0	16.9	12.2	7.24	22.06	5.500	30.0	40.2	36.0	-	-	E	-
	MM-5	53.050	37.0	152.0	28.6	13.8	11.2	33.67	9.205	44.8	48.8	42.0	-	-	E	-
II	MM-1	422.11	41.0	101.0	-	-	-	-	-	-	-	-	A	C	-	G
	MM-2	406.79	41.0	101.0	0.49	1.10	0.67	1.378	0.502	32.3	26.7	22.1	A	C	-	G
	MM-3	400.29	41.0	101.0	0.25	1.25	0.83	1.521	0.469	18.9	25.0	28.3	A	C	-	G
	MM-4	326.39	41.0	101.0	1.03	2.18	0.91	2.577	0.888	28.4	22.6	20.8	-	-	E	-
	MM-5	212.39	41.0	101.0	2.28	2.63	1.18	3.675	0.381	26.0	20.8	4.54	-	-	E	-
III	MM-1	256.90	26.0	185.0	1.17	1.36	1.10	1.170	0.334	54.6	19.0	33.3	A	C	-	G
	MM-2	220.81	26.0	185.0	1.99	2.96	2.27	1.990	0.992	37.5	28.2	24.2	A	C	-	G
	MM-3	224.58	26.0	185.0	1.74	3.13	1.60	1.740	1.031	39.5	31.3	37.7	A	C	-	G
	MM-4	161.78	26.0	185.0	2.67	4.17	2.37	2.670	1.293	30.8	26.6	37.3	-	-	E	-
	MM-5	179.10	26.0	185.0	2.17	2.11	1.24	2.170	0.951	24.7	23.1	9.92	-	-	E	-
IV	MM-1	184.41	20.0	135.0	1.95	1.71	1.10	2.820	0.759	41.5	46.6	58.8	A	C	-	G
	MM-2	151.52	20.0	135.0	3.41	2.76	2.53	5.060	1.365	41.2	32.1	33.1	A	C	-	G
	MM-3	152.79	20.0	135.0	3.72	4.66	2.21	6.360	1.869	38.0	38.5	31.6	A	C	-	G
	MM-4	87.570	20.0	135.0	11.7	8.21	6.15	15.56	3.804	40.2	43.2	29.9	-	-	E	-
	MM-5	99.910	20.0	135.0	3.70	4.80	3.04	6.780	0.396	36.6	26.6	34.9	-	-	E	-
V	MM-1	160.27	19.0	105.0	1.23	1.43	0.77	2.040	0.400	86.2	40.0	28.6	A	C	-	G
	MM-2	137.43	19.0	105.0	2.85	2.54	1.80	4.220	1.072	43.3	27.5	20.6	A	C	-	G
	MM-3	137.33	19.0	105.0	3.00	3.76	2.46	5.400	1.536	46.0	31.9	33.3	A	C	-	G
	MM-4	72.090	19.0	105.0	10.3	5.65	3.39	12.23	2.372	68.8	81.4	72.4	-	-	E	-
	MM-5	77.990	19.0	105.0	3.37	2.56	3.15	5.270	1.140	35.4	32.0	35.3	-	-	E	-

- the criteria according to Russian scale for mine facilities (facilities of the first category according to Table 3, 4 and 5 taken into account):
    - E - it meets requirements within threshold values;
    - F - it does not meet requirements, above threshold values.

B. Effects of blasting on environment according to DIN standard (Table 6)

- G - it meets requirements within threshold values;
- H - it does not meet requirements, above threshold values.

In Figure 1 - 4 there is shown the value of wave component as well as the KB_{fm}. value.

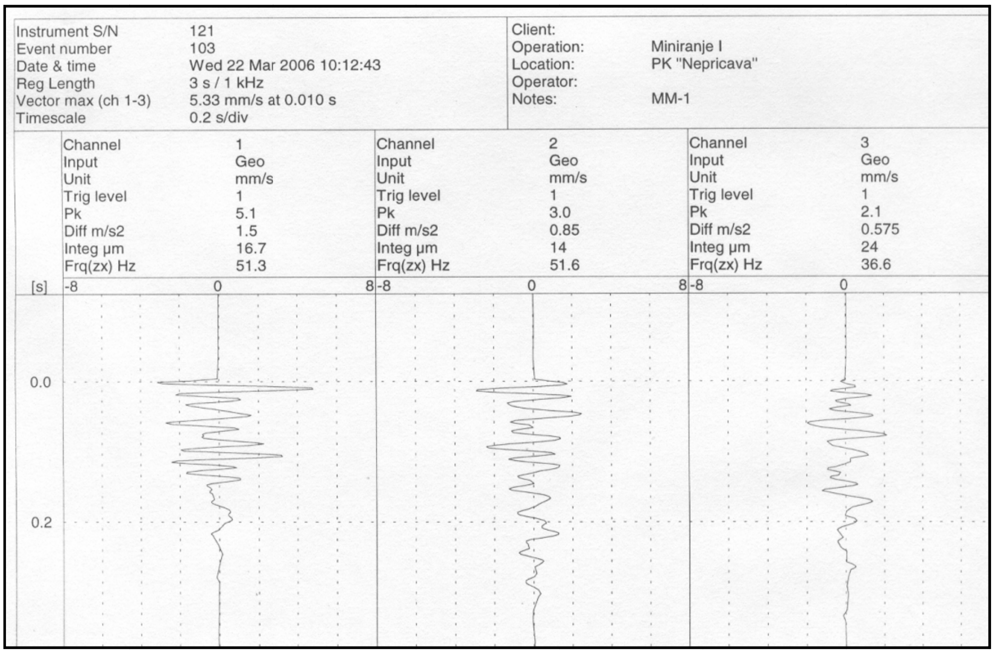

Figure 1 - Velosity shot for blasting No.I, measurement point MM-1

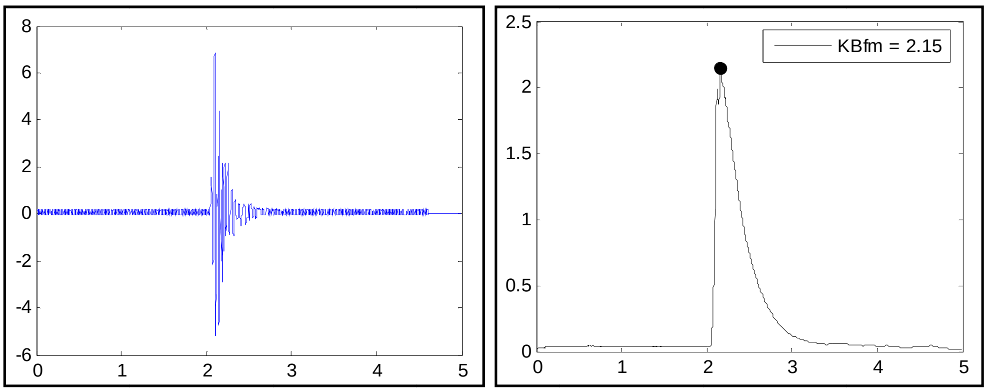

Figure 2 - Value of v_v and KB_{fm} components. Blasting No.I, measurement point MM-2

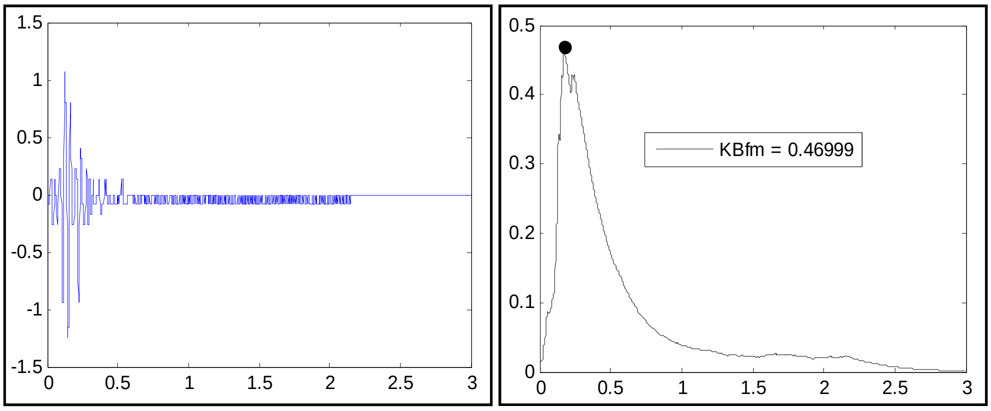

Figure 3 - Value of v_T and KB_{fm} components. Blasting No.II, measurement point MM-3

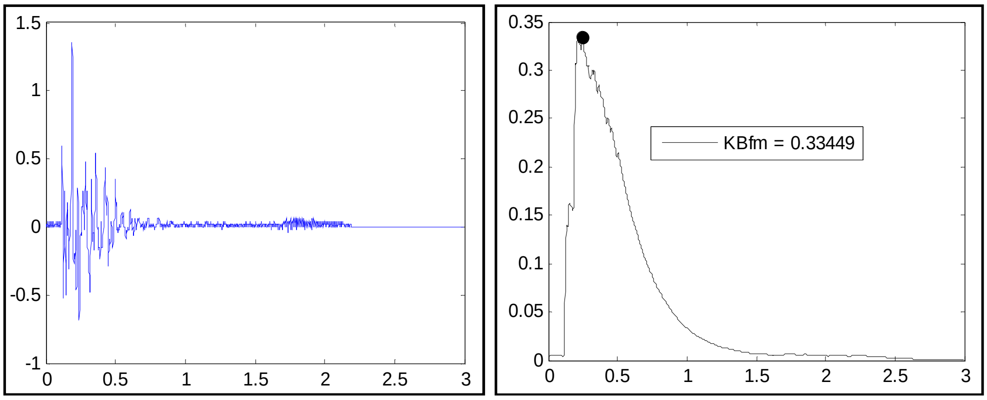

Figure 4 - Value of v_v and KB_{fm} components. Blasting No.III, measurement point MM-1

5. CONCLUSION

The estimate of shock wave effects on constructed facilities and the environment, while carrying out blasting activities at the open pit "Nepričava", was made at surrounding constructed facilities according to the criteria of IPERAS, Russian standards for mine facilities and DIN-4150. On the basis of the carried out measurements it can be concluded:

- the recorded values of oscillation velocity in the vicinity of the mine (the measurement points: MM-1, MM-2 and MM-3), meet requirements within threshold values, thus *do not affect constructed facilities*;
- the recorded values of oscillation velocity at measurement points being within the quarry (the measurement point MM-4 and MM-5), are within threshold values, which according to tables 3, 4 and 5 *do not affect facilities in the mine*;
- predominant frequencies range from 30.0 - 40.0 Hz, thus do not affect people in the surrounding facilities;

- for more detailed perception of blasting effects on constructed facilities, it is necessary to establish the state of constructed facilities (the way of constructing, the resistance of facilities, the age of facilities, etc.), as well as to monitor occasionally shock waves in the vicinity of the mine;
- in addition to determining of blasting effects on constructed facilities, the KB_{fm} values, namely the impact of rock mass oscillation velocity on environment, were also determined. The KB_{fm} values according to the results presented in Table 12 with constructed facilities where measurements were conducted do not exceed threshold values according to.

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