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DETERMINATION OF SAFETY DISTANCES DUE TO THE SEISMIC EARTHQUAKES DURING BLASTING AT THE OPEN PIT NORTH MINING DISTRICT OF THE MAJDANPEK COPPER MINE[**]

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Abstract

Majdanpek is located right next to the mine, so blasting at the Open Pit North Mining District could have an impact on the environment. If the intensity of that impact exceeds the prescribed limits, the harmful and dangerous consequences could be for people and facilities. In order to protect the environment from the harmful effects of blasting, the standards for protection and limits for the intensity of manifestation the certain effects of blasting at a certain distance are prescribed. This paper shows the determination of safety distances during blasting due to the seismic waves.

Keywords: *Open Pit North Mining District, blasting, seismic earthquakes, safety distance.*

1 INTRODUCTION

Excavation at the open pit North Mining District started in 1977, while the ore processing in the Flotation Plant began in 1989. By 2024, about 60 million tons of copper ore and about 200 million tons of waste were excavated

Discontinual excavation technology is applied at the open pit North Mining District. The excavation of waste is performed using the drilling - blasting works with vertical drill holes, loading with bucket excavators with and truck transport to the truck landfill of the North Mining District.

Drilling of exploitation blast holes, diameter 138 mm and 152 mm, is performed with the diesel drive drills, and loading of blasted rock mass is performed using the hydraulic backpack excavators of 5.6 m^3 and 8.0 m^3 on diesel drive. The waste and ore transport are performed with the load capacity trucks of 75 t and 85 t. The ore transport is to the primary crusher, located on the southeastern perimeter of the open pit, and waste to the truck landfill of the North Mining District, west of the open pit.

The designed floor level at the open pit is 15 m, while the designed roads of 7-8% are 15 m wide for one-way and 25 m for two-way roads. The roads of slope of 8-10%, were performed in the field. The current highest spot of the open pit is K + 770 m in the northeastern part of the open pit, while the bottom of the

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open pit is at K + 326 m. The planned annual capacity of ore excavation, based on internal long-term plans of the company, is 3.3 million tons of ore per year.

As the town of Majdanpek is located right next to the mine, blasting at the open pit North Mining District can have an impact on the environment. If the intensity of that impact exceeds the prescribed limits, it can have the harmful and dangerous consequences for people and objects. In order to protect the environment from the harmful effects of blasting, the protection standards and limits for the intensity of manifestation the certain effects of blasting at a certain distance are prescribed.

In recent years, an increasing number of experts in the field of blasting have been engaged in research related to the seismic earthquakes during blasting. Through research, conducting experiments and proposing measures, the authors try to reduce the negative impact of earthquakes on people and environment. The largest number of works in recent years is related to the prediction of earthquakes using the artificial intelligence methods [1-4]. In addition to research related to the application of artificial intelligence methods, a large number of authors are engaged in research on the impact of blasting parameters on the intensity of seismic earthquakes [5-7]. In this paper, a special care was taken to calculate and optimize the blasting parameters that affect the seismic earthquakes, all with the aim of reducing the negative effects of earthquakes.

2 BLASTING TECHNOLOGY

Blasting technology at the open pit North Mining District was processed through development the following blasting procedures: preparatory works, primary blasting, and oversize crushing / secondary blasting.

The works on drilling and blasting process needs to be planned, designed and optimized with a great care so that the effects and results are as good as possible. In addition to the positive effects, it is necessary to harmonize and reduce the negative effects such as disintegration of the rock massif, emission of harmful gases and seismic effects of blasting.

In order to achieve the designed capacity of a certain granulation while controlling the secondary effects of primary blasting, it is necessary to set and harmonize the three groups of parameters:

- The amount of explosive energy required for desired degree of rock mass crushing;
- Spatial distribution of energy in the mine field;
- The time scedule of communication the energy to the massif, defined by the initiation scheme and deceleration times.

In order to achieve the required effects of primary blasting, in addition to the properly selected explosive, it is also important to determine, i.e. adjustment of the blasting geometry parameters. The goal of determining the appropriate parameters is to maximize the use of explosion energy, and to reduce the negative effects of blasting, primarily the seismic effect. In the limited area intended for exploitation, in the engineering-geological sense, three units can be distinguished, the characteristics of which are shown in Table 1.

Table 1 *Charging scheme of blast holes*

Medium	1. Gneiss	2. Limestone	3. Andesite
Volume mass (g/cm^3)	2.7	2.7	2.66
Pressure strength (MPa)	38.8	44	24.5
Spreading speed of longitudinal wave (m/s)	2,800-4,600	5,100-5,900	3,800-4,200

The maximum size of blasted mass is determined on the basis of bucket volume of the loading means 5.6 m^3 and 8.0 m^3:

- Oversize when loading with an excavator: $D\_max \leq 0.75 \cdot \sqrt[3]{5.6} = 1.33$ m
- Mean mass diameter $D\_sr = (0.15\text{-}0.20) \cdot \sqrt[3]{E} = 0.35$ m

During the calculation of blasting parameters, a special attention was paid to the following blasting parameters, which significantly affect the seismic earthquakes:

1. Selection of explosive and its quantity, both total and quantity per deceleration interval.
2. Initiation scheme and deceleration time between the mine charges.
3. The application of split charging was considered.
4. Alignment with the current blasting technology was also carried out.

Selection of explosives: Based on a long-term experience in the application of ANFO and emulsion explosive mixtures and positive effects, achieved by the use of these explosives for the primary blasting at the open pit North Mining District, the use of ANFO J.1 and emulsion explosive (Detolit) was adopted.

The amount of explosives per deceleration interval: By reducing the amount of explosives per deceleration interval, the seismic effects during blasting are reduced.

Initiation scheme: With an appropriate initiation scheme, the amount of explosives in connected charges can be reduced by reducing the number of charges that are initiated in the same time interval [8]. The appropriate initiation scheme achieves the management of explosion effect, and thus the reduction of seismic effect [9].

The initiation of explosive charges will be carried out by the NONEL Dual Delay system, which is already successfully applied at the open pits of the Majdanpek Copper Mine. The Nonel system provides the adequate safety during initiation, reduction the seismic effects of blasting, combination of different magnitudes of deceleration, use in the aquatic environment, etc.

The use of separated charges in the borehole can reduce the earthquakes. Separation of charging is done by intermediate plugs, the dimensions of which must be adequately calculated so that the impulses between charges are not transferred and initiated at the same time. The intermediate plugs vary from 0.4 m for 34-36 mm boreholes, up to 2 m for a 150 mm diameter borehole [8].

Drilling and blasting technology is harmonized to a large extent with the previous experiences at the open pit, which gave the good results in terms of obtaining the necessary granulation, safety and achieving the optimal costs in the exploitation phase.

Calculation of the primary blasting parameters was made for a floor height of 15 m, different environments, vertical boreholes and different explosives. For different environments, the calculation took into account different physical-mechanical parameters of the present engineering-geological environments. Different explosives are used in dry and wet environments, where the ANFO mixtures are used in dry environments, and the Detolit emulsion explosives in wet environments. The mining technical characteristics are given in Table 2. The blasting parameters were calculated, wherever possible, on the basis of several patterns taken from the literature and frequently used in the mining practice [10, 11].

Table 2 *Blasting - technical characteristics of explosives*

Characteristic	ANFO J.1	DETOLIT
Density (g/cm^3)	0.85-0.95	1.1-1.25
Detonation speed (m/s)	2.000	4.000
Gas volume (dm^3/kg)	1045	1090
Oxygen balance (%)	Balanced	Balanced
Explosion heat (kJ/kg)	3872	2805
Explosion temperature (K)	2544	
Min. usage diameter, mm	50	100
Initiation	Min. pentolite enhancer 250g	Min.pentolite enhancer 500g

Calculation was made according to the characteristics of three different engineering-geological environments (gneiss, limestone and andesite) and for explosives of the characteristics of explosives ANFO J.1 and Detolit (6 variants). Figure 1 shows the structural elements of the mine charge for one of the six variants [13].

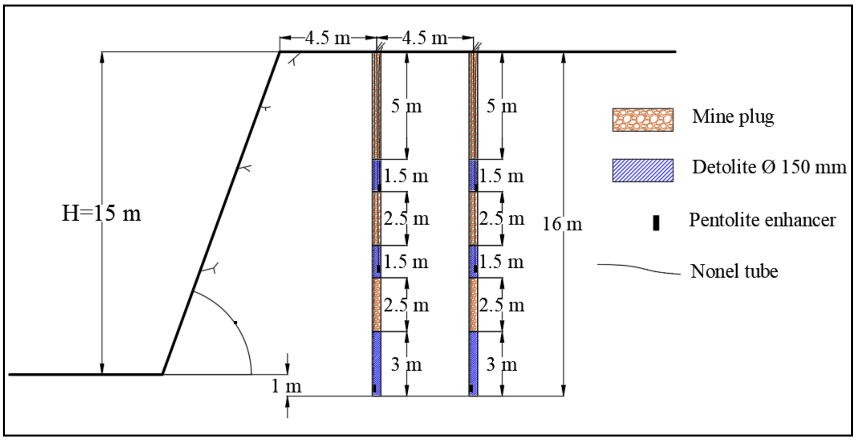


Figure 1 *Construction of blasting charge – 1 middle - gneiss (Detolit explosive)*

The blasting charge in boreholes H_e = 15 m, that is, for the borehole length of 16 m, consists of separate (lower-main and two upper-separated) charges with a proportional ratio of 50%:25%:25%. The maximum mass of explosives in one blasting borehole is 137 kg for all six variants.

Initiation of explosive charges is carried out by the NONEL Dual Delay system, which is successfully applied at the open pits of the Majdanpek Copper Mine. The Nonel system ensures the adequate safety during initiation, reduction of seismic effects of blasting, combination of different sizes of deceleration, use in the aquatic environment [10,11,13].

During planning and execution of blasting at the work site, the initiation schemes with such deceleration values must be calculated, as well as carried out, in order to minimize the possible harmful effects of seismic waves on the natural environment and existing buildings. The initiation scheme should ensure, in addition to reducing the seismic effect, an increase in degree of rock crushing, as well as obtaining the required shape of a pile of blasted material.

When blasting on floors 15 m high (H_e = 15 m), the initiation scheme is with the split charge. Initiation of blasting series is done depending on the situation on the ground, i.e. from the needs in relation to the increase in a degree of rock crushing or reduction the seismic effect. When planning and carrying out the connection of blasting charges, it is necessary to take into account the length of blasting of the rock mass.

For all variants, the drilling geometry of the blasting series is 4.5 x 4.5 m. The deceleration is 25 ms between the boreholes in a row and 42 ms between rows [13].

Scheme of initiation is shown in Figure 2.

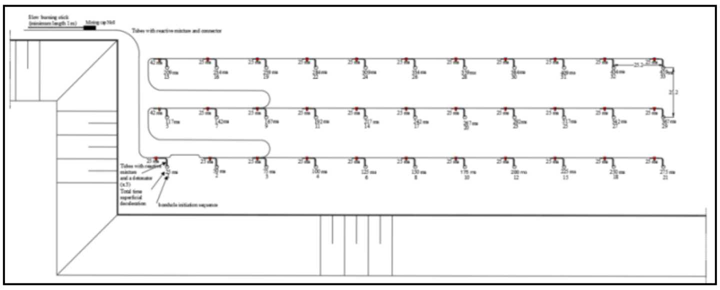


Figure 2 *Scheme of blasting field initiation with separated charge for floors H = 15 m*

3 PERIMETER BLASTING

Perimeter blasting has the task of crushing the rock mass in the peripheral parts of the floor, while ensuring:

- Preservation the stability of the open pit sides,
- Proper cutting of the floor slope according to the design, i.e. to the given floor contour.

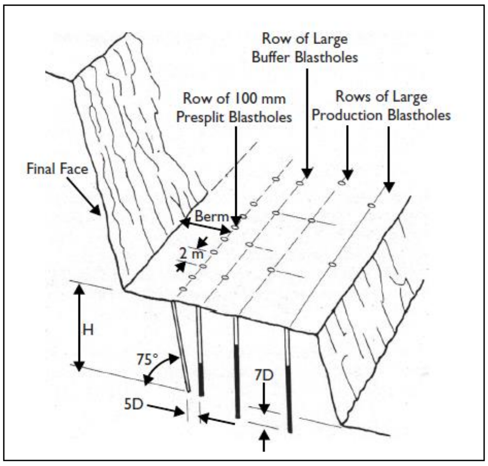


Figure 3 *Example of perimeter blasting [14]*

These effects are achieved by controlling the level of shaking the open pit sides and by appropriate blasting along the contour in order to cut it off properly. [10, 11]. At the same time, two different blasting methods or techniques are most often applied at the same time:

- Buffer blasting,
- Contour blasting.

In the specific case, the so-called smooth blasting technique will be performed when the contours of boreholes are activated as the last row in the series, what is typical for preserving the surface stability. This blasting is applied in the zone of final slope in order to preserve it [10,11].

The last row of boreholes is drilled at an inclination of 70° (floor inclination). The diameter of boreholes, as well as for the primary blasting, is adopted as 150 mm. The last row of boreholes is drilled without piercing. In addition to the contour boreholes according to the intended geometry, the contour boreholes without explosives are also drilled at a half of distance between the boreholes (the role of these contour boreholes is to form a line of weakened resistance along which a crack will be formed during blasting). Each row of boreholes is drilled at a certain angle. The borehole scheme for the smooth blasting method is shown in Figure 4.

The layout of the blasting charge construction for the ANFO explosive for the first middle in the floor contour for the smooth blasting method is given in Figure 5 [13].

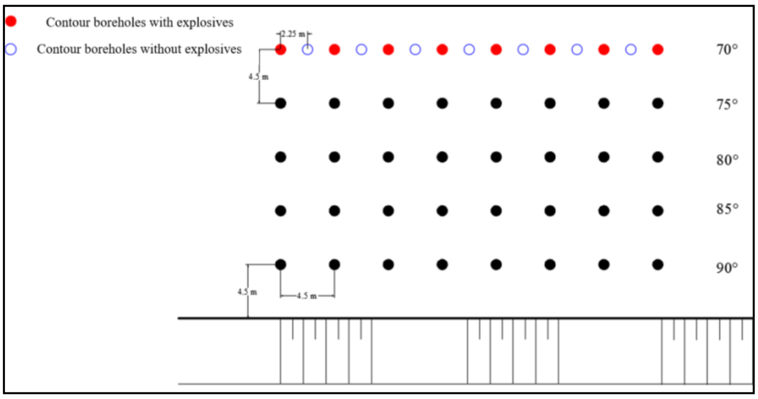


Figure 4 *Scheme of boreholes for the smooth blasting method*

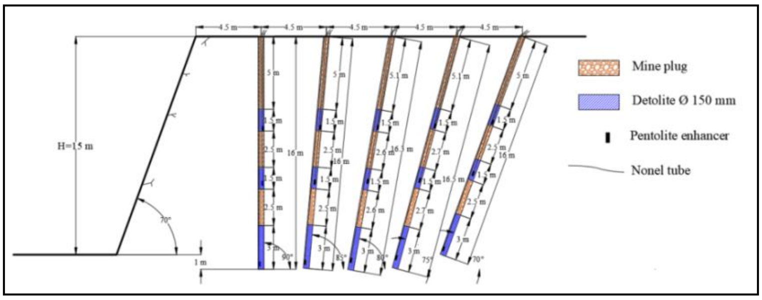


Figure 5 *Layout of the construction of the ANFO explosive charge for the first middle in the floor contour (for the smooth blasting method)*

4 DETERMINATION OF SAFETY DISTANCES DUE TO THE SEISMIC EARTHQUAKES

Determination of safety distances when performing the blasting works refers to:

- Determination of safety distances due to the seismic earthquakes;
- Determination of safety distances from flying pieces during blasting;
- Determination of safety distances due to the effect of air shock waves;
- Determination the gas hazard zone.

The shock wave, which moves through the rock mass from the blast site, gradually loses energy on its way - it weakens (causes less and less strain in the rock) until it is completely attenuated, that is, lost at a certain distance from the blasting site.

In the vicinity of the explosion site, the shock wave has such energy that it causes the compressive strains greater than the compressive strength of the rock mass, then due to the loss of energy from a certain distance it can cause only tensile stresses greater than the tensile strength of the rock, and finally only the elastic deformations in the rock mass until it disappears. In the area where it causes the creation of cracks in the rock mass, the wave has a destructive character, and beyond that it causes only elastic deformations of the rock mass and has the character of a seismic wave, so it is called that.

The seismic ground oscillations, caused by blasting, are very similar to the oscillations caused by an earthquake, and the difference between them is manifested mainly in duration and length of oscillation time. During earthquakes, the oscillations occur that last a long time and in which the length of oscillation period is from 0.5 to 5 s, while during blasting, the duration of oscillations is significantly shorter and ranges from 0.004 to 0.25 s. As a rule, the blasting is carried out frequently, so the object affected by seismic tremors is significantly exposed to their influence. That is why, depending on the condition of the object, during blasting, the permissible tremors are usually one to two degrees lower than in the case of earthquakes.

When a seismic wave hits a soil particle, it throws it out of equilibrium at that point, whereupon it begins to oscillate around its equilibrium position for a certain time until it completely settles. The oscillation of particles of the rock mass (terrain or soil) is what manifests itself or is felt as an earthquake, that is, the ground.

While the seismic waves travel at significantly higher speeds through the rock mass, provoking the oscillations of particles at points found on their path of propagation, the oscillation of material particles of the mass around its equilibrium position is at much lower speeds, on the order of mm/s - cm/s.

In seismic earthquakes, two types of waves are distinguished:

- Volume
- Superficial

There are two basic types of volume waves. The first is longitudinal, under the influence of which the particles move forward - back along the line that determines the direction of wave propagation. Considering that in this way the elastic deformations are transmitted by the shortest path and that longitudinal elastic waves reach the measuring point first, these waves are also called the primary waves and are denoted by (P). The propagation speed of longitudinal elastic waves [10,11] on sample can be determined from the ratio:

$$V_u = \sqrt{\frac{E \cdot g}{\gamma}}, \quad \text{m/s}$$

where:

V_u - propagation speed of longitudinal waves, m/s

E - modulus of elasticity, dN/cm^2

g - acceleration of the earth's gravity, cm/s^2

γ - volumetric weight, g/cm^3

When the longitudinal wave reaches the free surface or boundary of the layer with other physical and mechanical properties, then at an angle of incidence of 90^o it is reflected back, forming a transverse wave in which the particles of the excited medium oscillate in a plane perpendicular to the direction of wave propagation. maintaining a mutual distance and thereby causing the elastic deformations that are parallel to the direction of wave movement. Due to this property, the transverse elastic waves are also called the shear waves. Their speed of propagation is lower than that of longitudinal waves, and they reach the measuring point later, so they are sometimes called the secondary waves and are denoted by (S). The ratio of the speeds of longitudinal and transverse waves is:

$$V_u = \sqrt{3} \cdot V_p$$

The propagation speed of elastic waves in the rock depends on the elastic properties of rock and its density, shown in Table 4.

Table 4 *Propagation speeds of longitudinal elastic waves for some media*

Type of rock	**V_u (m/s)**
Granite	5.000 – 5.700
Limestones, Sandstones	2.500 – 4.500
Marl, Gypsum	1.700 – 2.300
Gravel	900 – 1.100
Sandy soil	600 – 1.600
Clay soil	500 -1.500
Loose soil	200 - 500
Water	1 430
Air	340

The speed of transverse wave propagation [1, 2] can be determined from the relationship:

$$V_p = \sqrt{\frac{E \cdot g}{2 \cdot \gamma \cdot (1+\mu)}}, \text{ m/s}$$

where:

V_u - propagation speed of longitudinal waves, m/s

E - modulus of elasticity, dN/cm^2

g - acceleration of the earth's gravity, cm/s^2

μ - Poisson's ratio, which most often ranges from 0.20 - 0.40.

While the longitudinal elastic waves (P) propagate through the solid, liquid and gaseous media, the transverse waves travel only through the solid media.

The surface waves got their name from the layer thickness over which they spread, which is approximately equal to their wavelength and in most cases is 100 - 200 m, so that at a depth of twice the wavelength, the wave oscillation is practically not felt. There are several types of surface waves depending on the trajectory of movement the medium particles:

1. Type (R) waves - in this type of wave, the oscillation of material soil particles is carried out along an elliptical path, the main axis of which is vertical. In the upper part of ellipse, the particles move in a source direction, and in the lower part, away from the source of explosion.
2. Type (Q) waves - in this type of surface waves, the particles move perpendicular to the direction of wave propagation, where the movement takes place in the horizontal plane.
3. Waves of type (C) - this wave is created by combination of (R) and (Q) waves and material particles move along a diagonal path.

The (C) waves usually arrive at the measuring point first, then the (Q) and finally the (R) waves. From the aspect of seismic earthquakes, the surface waves are more interesting because they lead to the damage of objects that are one or more wavelengths away from the site of explosion.

There are three important factors that determine the intensity of earthquakes during blasting [8]:

1. Characteristics of the rock massif
2. Distance from the blasting site
3. The amount of explosives initiated

In addition to obtaining the loose rock mass of required granulation that is the subject to further technological processing, the most important task in the process of primary blasting is the need to preserve the residential buildings in the vicinity of the open pit North Mining District from the seismic impact. Therefore, it is necessary to determine the law of ground oscillation for directions towards the critical objects, and then to define the zones with precisely determined amounts of explosives per deceleration interval, which must not be exceeded under any circumstances.

The protection of buildings against earthquakes is carried out with limitation the amount of explosives that is initiated in one time interval, whereby the time interval must not be shorter than 8 ms, taking into account the possible deviation of deceleration time from the nominal retarder times.

The earthquake protection comes down to limiting the speed of soil oscillation and with it the foundations of residential buildings. The permitted oscillation speeds for certain types of objects are regulated by the standards. Since there is no such standard in Serbia, the German standard DIN 4150-3 is most often used, Figure 6. The maximum permissible ground oscillation speeds according to the DIN 4150-3 are given in Table 5.

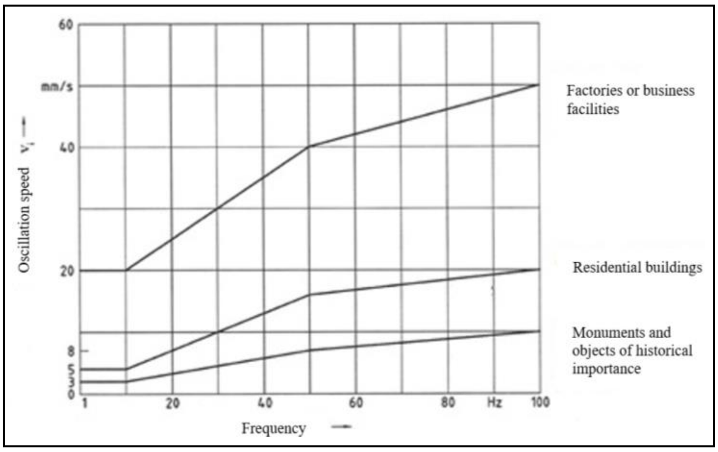


Figure 6 *Maximum permissible oscillation speeds according to DIN 4150-3 [8]*

Table 5 *Oscillation speed size limits in mm/s according to the DIN standard 4150 [8]*

Type of Buildings/site measurement	**Foundations**			**Floors on the highest floor of building**
	<10 Hz	**10-50 Hz**	**50-100 Hz**	**all frequencies**
1. Factories or business facilities	20	20-40	40-50	40
2. Residential buildings	5	5-15	15-20	15
3. Monuments or objects of historical importance	3	3-8	8-10	8
Vibrations in the frequency range higher than 100Hz can have a higher value				

A real-time monitoring system was introduced at the open pits South and North Mining District in order to monitor and realistically assess the impact of seismic earthquakes during blasting and determine the laws of soil oscillation.

After looking at the measurement results of the ground oscillation speeds as the blasting results at the open pits North and South Mining District [12], the following was concluded:

1. Measuring points were placed on the outskirts of the city, and the vast majority of blasting was carried out at relatively long distances (700 and more meters).
2. The maximum oscillating speeds (and the used maximum speeds in all

three directions x, y and z) are small (< 2 mm/s).

3. The laws of soil oscillation, obtained on the basis of performed measurements have a low correlation with the measurements themselves due to the large deviations of the measured values from the mean value. In the submitted analyses, the laws of oscillation are given for 50% and 95% reliability and the total amount of explosives that are simultaneously initiated and initiated in a time interval of 8 ms. Taking into account the dispersion of the measured values for practical application, the ground oscillation law would be acceptable for a reliability of 95% and the amount of explosives that is initiated in an interval of 8 ms.

In order to see the analysis results specifically for the North Mining District, the results of measurements during blasting in the North Mining District and for the closest measured places (MM-5 and MM-6) were used in the course of 2023, i.e. in the reports for January, February and March. In February, there was only one blasting in the North Mining District, and it was carried out in an uncharacteristic place, and due to this reason, it was not considered. A significantly larger number of blasting in these reports was carried out in the South Mining District, but the general conclusions about the oscillation speeds as a function of the amount of explosives that are simultaneously initiated and the distance are similar, that is, the low oscillation speeds were measured at the measuring points.

Based on all of the above, the dependence of distance on the amount of explosives that is initiated from 8 ms, based on the given law of oscillation in the aforementioned Report was not given, but the safety distance due to the effect of seismic earthquakes was determined on the basis of literature [10].

The Mercalli-Cancani-Seiberg (MSC) scale, which contains 12 seismic degrees, is most often used to assess the seismic effect, and is used to assess the earthquakes. The Mercalli-Cancani-Seiberg (MSC) scale provides the modified Mercalli scale intensities, commonly observed at locations near the earthquake epicenters, Table 6.

Table 6 *Mercalli-Cancani-Seiberg (MSC) scale [8]*

Oscillation speed cm/s	Degree of seismic intensity (IFZ)	Description of effect
Up to 0.2	I	The earthquake is felt only by the instruments
0.2 – 0.4	II	The earthquake is felt only in some cases in complete silence
0.4 – 0.8	III	The earthquake is felt by very few people or only by those who expect it
0.8 – 1.5	IV	The earthquake is felt by many people, the clinking of window glass is heard
1.5 - 3	V	Lime shedding, damage to buildings in poor condition
3 - 6	VI	There are fine cracks in the plaster, damage to buildings that have already developed permanent deformations
6 - 12	VII	Damage to buildings in good condition, cracks in plaster, parts of plaster falling off, cracks in brick ovens, collapse of chimneys
12 - 24	VIII	Significant damage to buildings, larger cracks in the supporting structure and walls, falling factory chimneys, falling ceilings
24 - 48	IX	Demolition of buildings, larger cracks in walls, dismantling of walls
> 48	X - XII	Greater destruction, destruction of entire buildings

In terms of resistance to the earthquakes due to the blasting, the buildings can be divided into three basic categories:

1. Buildings made of rough stone, village buildings, buildings made of unbaked bricks and houses made of clay.
2. Ordinary brick buildings, large block buildings and buildings made of prefabricated materials, buildings with partially wooden construction, as well as buildings made of natural hewn stone.
3. Reinforced concrete buildings and ordinary wooden buildings.

The safety distance [10] can be determined from the relationship:

$$r_s = K_b * K_p * K_z * R_{red} * Q^{1/3}$$

where:

r_s – danger zone radius due to the effect of seismic waves

K_s – coefficient calculated as: $K_s = K_b * K_p * K_z$

K_b – coefficient depending on the condition of the object, Table 7

K_p – coefficient depending on the method of initiation the internal filling, Table 8

K_z - coefficient depending on the physical and mechanical characteristics of the working environment, Table 9

Table 7 *Coefficient Kb*

Building categorization	Building state	Seismic intensity degree (cm/s)	Coefficient K_b
A	Dilapidated building made of broken stone	4	2,5
B	Buildings built with brick blocks with previous deformations	5	1.6
C	Strong stable buildings made of reinforced concrete or wooden structures	6.7	1

Table 8 *Coefficient Kpb*

Initiation method						
Degree of seismic intensity cm/s	Currently			Milliseconds		
	Rk	Ri	Rp	Rk	Ri	Rp
1	100	91	72	80	83	63
2	63-100	68-91	46-72	50-80	82-83	50-63
3	40-63	37-58	29-46	32-50	34-52	25-16
4	25-40	23-37	12-18	13-20	13-21	10-16
5	16-25	15-23	12-18	13-20	13-21	10-16
6	10-16	9-15	7.3-12	8-13	8.3-13	6.3-10
7	6.3-10	5.8-9	4.6-7.3	5-8	5.2-8.3	4-6.3
8	4-6.3	3.7-5.8	2.9-4.6	3.2-5	3.4-5.2	2.5-4
9	2.5-4	2.3-3.7	1.8-2.9	2-3.2	2.1-3.4	1.6-2.5
10-12	2.5	2.3	1.8	2	2.1	1.6
K_p	1.0	0.91	0.72	0.8	0.83	0.63

Table 9 *Coefficient Kz*

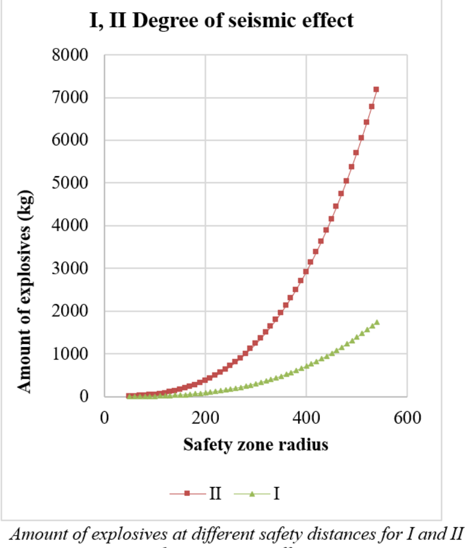
Soil type	K_z
Solid rock	0.5
Solid cracked rock	0.7
Semi-solid rock (gypsum, marl, sandstone)	0.8
Gravel soil	0.9
Sandy clay soil with water at a depth of 10m and more	1
Sandy clay soil with water at a depth of 5-10m	1.2
Sandy soil and clay with water up to a depth of 5m	1.4
Muddy soil	1.8

- The adopted values: K_b-1, K_p-0.8, K_z- 0.7
- R_{red} – reduced distance for various degrees of earthquakes at current and millisecond blasting
- Q – quantity of used explosive (kg)

For an individual assessment of the object resistance to earthquakes due to blas-ting, it is necessary to determine which level of seismic intensity is dangerous for a given object, and then what is the seismic intensity of the observed earthquake. Table 10 presents the safety distances and permitted quantities of explosives for the I, II and III degrees of seismic effect.

Table 10 *Amount of explosives (kg) at different safety distances for the I, II and III degrees of seismic effect*

R, Safety distance m	Degree of seismic effect III	II	I
50	22	6	1
60	38	10	2
70	60	16	4
80	89	23	6
90	127	33	8
100	174	46	11
110	231	61	15
120	300	79	19
130	382	100	24
140	477	125	31
150	586	154	38
160	712	187	46
170	854	224	55
180	1013	266	65
190	1192	312	76
200	1390	364	89
210	1609	422	103
220	1850	485	118
230	2114	554	135
240	2402	630	154
250	2715	712	174
260	3054	801	195



Amount of explosives at different safety distances for I and II degree seismic effects

The nearest residential buildings, which represent the most threatened buildings from the perspective of blasting operations at the North Mining District, are over 250 m away from the nearest blasting site. In order to determine the maximum amount of explosives that can be initiated simultaneously, a distance of 240 m was adopted, and the mentioned objects should be located in the zone of the first or second degree of seismic effects [13].

Based on a large number of measurements of earthquakes during floor blasting on different terrains, the USA Bureau of Mining determined the average law of soil oscillation, which could also be used in our country for the first approximation, whose constants are k=750 and n=-1.67. that is, it reads [11]:

$$V_o = 750 \cdot R_{r.8ms}{}^{-1,67}$$

The width of the zone of seismic impact of blasting (R_{gr}) can be determined by the expression:

$$R_{gr} = \sqrt{Q_{8ms.sr}} \cdot \left(\frac{k}{V_{doz}}\right)^{\frac{1}{n}}$$

For the maximum permissible speed of ground oscillations $V_{doz} = 5\, mm/s$ and average value of the maximum masses of explosives that were initiated within the time interval of 8 ms $Q_{8ms.sr} = 137\, kg$ of explosives, the zone width of seismic impact of blasting at the open pit North Mining District [4], amounts to:

$$R_{gr} = \sqrt{137} \cdot \left(\frac{750}{5}\right)^{\frac{1}{1,67}} = 234\, m$$

CONCLUSION

In this paper, it was repeatedly emphasized that blasting can have an impact on the environment if the intensity of that impact exceeds the prescribed limits, which can have the harmful consequences for people and environment.

The main effects of blasting, from which people and objects should be protected, are:

- Seismic earthquakes;
- Pieces flying apart;
- Air shock waves;
- Gases.

Earthquakes are the primary impact of blasting on the environment because they cause the sudden vibrations of ground and structures. In case of inadequate control, the earthquakes can cause serious damage of buildings and installations. The use of mass blasting increases the problems related to the earthquakes. Due to this reason, the open pits must have an earthquake control system in order to avoid the aforementioned damages.

In order to control the impact of blasting on the environment, it is necessary to determine the law of ground oscillation for directions towards the critical objects, and define the zones with determined amounts of explosives per deceleration interval. Earthquake protection is reduced to limiting the speed of ground oscillation and with it the foundations of residential buildings according to the standards.

Since there is already a real-time seismic effects monitoring system with six measuring points, it is recommended to introduce one or more measuring points (aligned with the designed position of the works) into the monitoring system. The introduction of one or more measuring points will improve the already existing real-time monitoring system.

The authors would like to point out that after each blasting, it is necessary to analyze the obtained results and effect of blasting. Based on the obtained results and phenomena that follow the blasting, further activity must be planned in advance in order to prevent any bad effects of blasting.

At the open pit North Minng District, the calculation of explosive amount by boreholes and series, as well as the deceleration and initiation intervals, were done so that all blasting influence zones are below the object distance limit. Blasting is carried out according to the calculated parameters with the application of special protective measures, i.e. placing the protective coverings on minefields.

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