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OPTIMIZATION OF THE IMPACT OF TECHNICAL SEISMICITY ON THE ROAD BRIDGE

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Abstract:

The implementation of blasting work in mining operations has both positive and negative consequences. Environmental protection laws, together with geological and mining laws, oblige the mining plant to protect its surroundings from the effects of mining activities. Blasting work is one of the basic technological processes. They help to dismantle the rock environment, which on the one hand represents a positive impact (obtaining rock debris with suitable fragmentation) and on the other hand causes a negative impact, because the surrounding buildings, the environment but also the population living in buildings near the quarry are endangered. For this reason, it is necessary to constantly deal with the optimization of blasting work.

This research was performed in order to find the optimal parameters of blasting works in the Gombasek quarry (CARMEUSE SLOVAKIA Ltd.) in the Slovak Republic. The research was focused on determining the maximum allowable charge per one timing stage depending on the distance in the Gombasek quarry so as to maintain the safety requirements for the road bridge (designation - M1714). The results of the research are presented in the article, where the maximum allowed charges for one timing stage were determined depending on the distance of blasting works in the Gombasek quarry per building object (bridge). Optimization of blasting parameters will make it possible to repeat aperture blasts in the Gombasek quarry.

Key words:
mining, optimization, blasting in quarries, seismic effects, building, maximum allowable charge per timing stage

INTRODUCTION

Extraction of minerals is one of the main activities of the world economy involved in creating social goods. However, this activity causes environmental damage. Experts (mining companies) around the world are addressing this issue and are looking for appropriate solutions and methods for environmental safety in extraction industries. Mining activity is mostly represented by these four main operations: drilling, blasting, loading and hauling. For a proper mine planning and design, all of these operations need to be carefully planned in such a manner that can prevent extra loads such as operating costs, environmental footprints, etc. Drilling and blasting are the two most significant operations in open pit mines that play a crucial role in downstream stages. Nowadays, the application of explosives to break rocks is a very common way of extracting rocks. The blasting technique has to have as minimal impact as possible on civil properties in the surrounding area. This is a crucial requirement how to reduce the damage to the buildings and citizens' health [1–4].

Blasting operations were used exclusively for mining. Recently, they are gaining wider application in bother branches of industry, i.e. in building industry, forestry, metallurgy, demolition of buildings, combating natural disasters, etc. Besides their positive effects they also have negative ones, that depend on a distance, which can endanger the objects situated close enough to the blasting. The bigger the explosive load the higher the intensity of seismic waves propagating in rock environment and gradually excite individual elements of the rock environment. If the intensity of vibration is high enough, it can lead to the damage of a construction and eventually to its destruction. Nowadays identifications of these negative effects and seismic safety assessment are very actual problems. An economical solution that, on one hand would prevent damage of object and on the other hand would assure the highest possible efficiency of the blasting, should be found [5–7].

To optimize the seismic effects of blasting, it is necessary to know the structural properties of the rock environment in which the blasting is carried out. Determination of structural properties of a rock mass is most often performed using seismic methods. This provides basic information on the spatial distribution and the intensity of the disturbance of the rock environment in which the blasting work is carried out. The seismic wave passing through the rock environment from blasting to receptors carries information about the structural properties of the rock environment. Dynamic characteristics of seismic waves - speed and frequency - are important for optimizing the seismic effects of blasting [8-9].

Previous research on the effects of blasting [10-12] shows that several factors need to be taken into account in aperture blasting, namely:

- recognition of types of objects around the quarry,
- define the degree of threat to objects in the vicinity of the quarry,
- identify objects, their number and purpose (industrial buildings, residential and utility buildings, sheltered buildings),
- frequency of blasting works and their parameters,
- blasting parameters (diameter of boreholes, slope of boreholes, depth of boreholes, spacing of boreholes, engagement, weight of charge in one borehole, total charge, timing of individual charges during blasting).

The article describes the results of research carried out in the Gombasek quarry and its surroundings. The aim of the research was to determine the law of attenuation of seismic waves from blasting to receptors, based on the propagation speed and frequency of seismic waves in the rock environment and to reduce the seismic effects of blasting (vibration) to an optimal value, which will not cause damage to surrounding buildings or the environment in the vicinity of the Gombasek quarry during blasting work.

1 MATERIALS AND METHODS

1.1 Geological construction of the rock environment in the surrounding of quarry Gombasek

The Gombasek quarry is located at the southern edge of the Plesivec plain in the Kosice region, which is part of the East Slovakian region, belongs to the Roznava district and is in the cadastre of the municipalities of Slavec, Vidova and Plesivec. The Gombasek quarry is located approximately 10 kilometres southwest of the town of Roznava towards Rimavska Sobota (Fig. 1). The area is located at an altitude of 230 m above sea level up to about 600 m above sea level as far as the mining area. The Gombasek quarry is engaged in the production and supply of limestone. It is a high-capacity Wetterstein limestone [13].

Fig.1*Position of Gombasek quarry,*
Source: authors

Wetterstein-type limestones are arranged in a plate-like to bench shape with a thickness of approx. 0.3 to 1.5 meters. The transition of the slope of the stratification was found mostly in the direction northeast - southwest, with a slight slope of 10 - 20 ° (monoclinic) to the northwest. Tectonically disturbed layered surfaces are in many places and have fretted features. Sediments formed in karst cavities (quaternaries) are formed mainly from weatherings, represented by claystones (red to ocher), which are perforated by irregular fragments of limestone of the Wetterstein type (Fig. 2) [13].

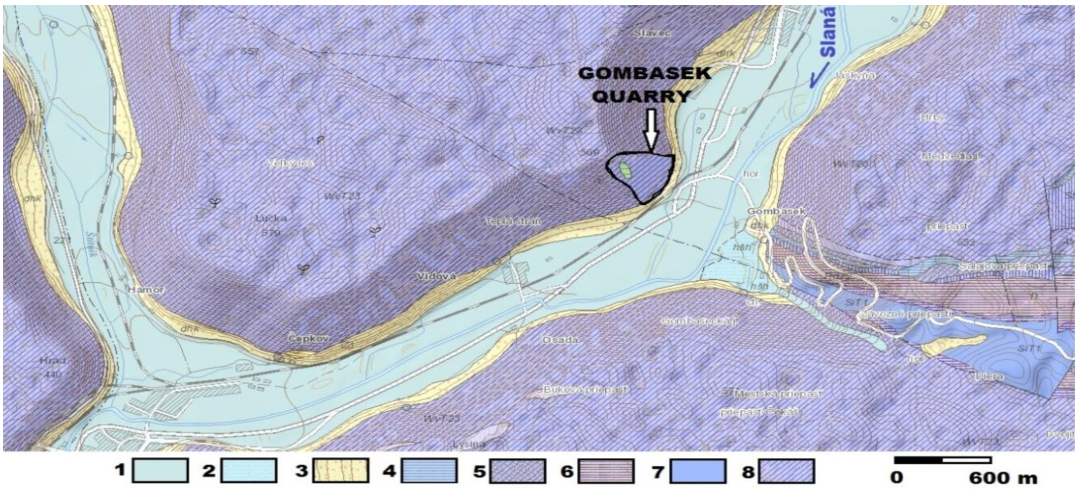

Fig.2 *Geological map of the surroundings of the Gombasek quarry*
Source: Mello, et al., 1996

Description of the legend of figure no. 2:

- Quaternary: 1. fluvial sediments: lithofacial unstructured alluvial clays, or sandy to gravelly clays of valley floodplains and floodplains of mountain streams, 2. proluvial sediments: mostly clays and sandy clays with rock fragments and clayey gravels in alluvial alluvial cones, 3. deluvial sediments: mostly dirty gravel (loamy sand) hill debris,
- Mesozoic: 4. Schreyeralm limestones: pink limestones, 5. Wetterstein limestones: light gray organodetritic and organogenic massive bedding, reef limestones, 6. Ramsau dolomites: gray layered dolomites, 7. Sinské layers: shales, limestones, dolomites, positions of organodetritic limestones, rauvacs; “Kampilian layers: silty and sandy shales, limestones, 8. Reiflin and Pseudoreiflin limestones: gray layered limestones with lime-silicate horstone [14].

1.2 Positions of measurement and apparatus used for measuring technical seismicity

The following digital vibrographs were used to measure and graphically record the seismic effects of blasting work at the mentioned measuring stations (Fig. 3):

- UVS 1504 vibrograph and geophones from the Swedish company ABEM,,
- ABEM Vibraloc vibrograph and geophones from the Swedish company ABEM.

Fig.3_Used instruments for measuring technical seismicity (left - UVS 1504; right - ABEM Vibraloc)_
Source: authors

Vibrographs provide digital and graphical recording of all three components of the oscillation velocity of environmental particles, horizontal longitudinal - $\mathbf{v_x}$, horizontal transverse - $\mathbf{v_y}$, vertical –$\mathbf{v_z}$**.** The UVS 1500 and ABEM Vibraloc vibrographs work autonomously, automatically performing channel tests without the intervention and influence of the operator on the measured and registered vibration characteristics. The UVS 1500 and ABEM Vibraloc seismographs have an AD converter with an automatic 14-bit dynamic range, which corresponds to $0.05 \div 250$ mm.s^{-1} [15-16].

Three-component electrotro dynamic geophones with a frequency range of $2 \div 250$ Hz and a sensitivity of 10 mV / mm.s-1 from Nitro Consult, a three-component geophone with a frequency range of $1 \div 1000$ Hz and a sensitivity of 10 mV / mm.s^{-1} were used for these measurements and geophones from Instantel. The geophones were placed on a special pad with steel sharp points, which ensured continuous contact with the ground [15-16].

The measuring stations were located, namely:

- location directly in the quarry (S1),
- building (bridge) (S2)

All these locations (S1, S2) can be seen in (Fig. 4).

Fig.4 *Positions and distances from aperture blasting in the Gombasek quarry in relation to measuring stations (S1, S2),*
Source: authors

To determine the law of attenuation in the transmission environment between the source blasting (hereinafter CO) and the receptors (building - bridge), the measuring position S1 was located 18 m from the initiation well in the Gombasek quarry in order to determine the attenuation law for the transmission environment as accurately as possible.

An ABEM Vibraloc digital four-channel vibrograph was used to measure seismic effects at station S1 (Fig. 5).

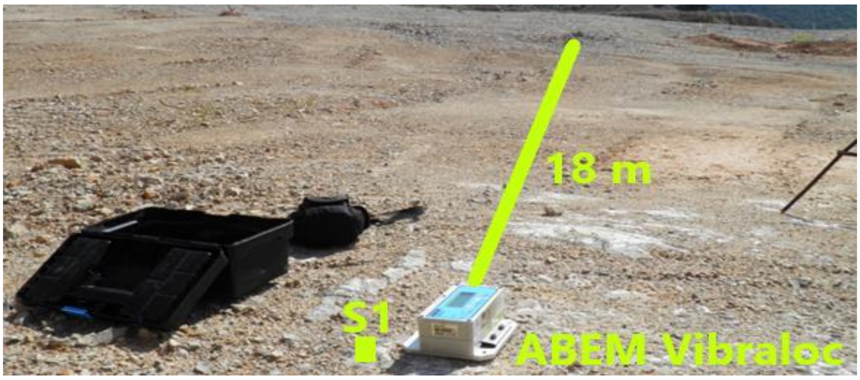

Fig.5*Measuring station S1 (used measuring apparatus ABEM Vibraloc),*
Source: authors

To assess the seismic effects on the building (bridge), the measuring position S2 was situated on the concrete base of the bridge (left side of the bridge). A UVS 1504 vibrograph was placed at station S2. The sensors were located on the concrete base of the bridge. 6).

Fig.6 *Measuring station S2 (used measuring apparatus UVS 1504),*
Source: authors

1.3 Source of shocks in technical seismicity research

The source of seismic effects was aperture blasting no. 574 (hereinafter "CO 574") on a limestone deposit located 755 meters from the building (road bridge). The shot was located in the left part II. storeys on the western edge of the Gombasek quarry. The positions and distances from CO 574 in the Gombasek quarry in relation to the measuring stations (S1, S2) can be seen in Fig. 4 [13].

Parameters of CO 574 in the Gombasek quarry: 16 vertical boreholes with a diameter of 105 mm, a length of 23.5 m, a working width of 2.5 to 5.2 m and a borehole spacing of 3.5 to 4.6 m were drilled. The total charge in these wells was 1743 kg of explosives, of which the maximum charge per time step was 160 kg. Furthermore, 31 heel wells were drilled with a total load of 398 kg. The total charge was 2665 kg of explosives. Non-electric ignition was used for aperture blasting. Timing was used for the shot (25 ms, 17 ms, 9 ms) and the pattern of the shot can be seen in Fig. 7 [13].

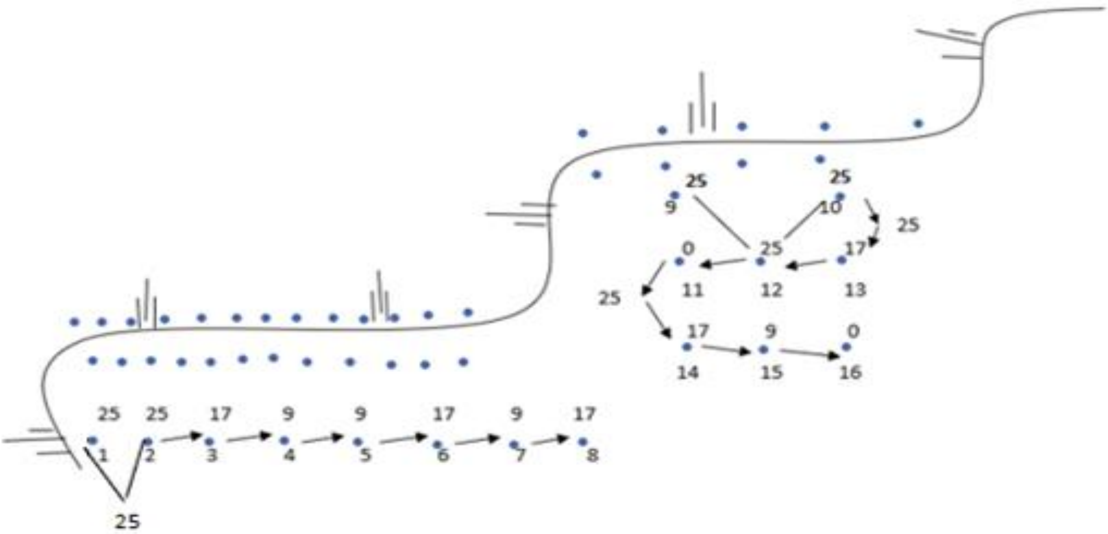

Fig.7 *Timing scheme and location of boreholes during aperture blasting in the Gombasek quarry*
Source: authors

2 MEASURED VALUES AND RESULTS

The instruments stored on the stands were calibrated before the measurement and their sensitivity was checked. Graphical waveforms of individual components of seismic waves at CO were recorded on the measuring stations.

At the measuring station S1 in the Gombasek quarry, where the ABEM Vibraloc apparatus was used, the components on the channels (channel No. 1 - component z, channel No. 2 - component x, channel No. 3 - component y) were measured and the effects of seismic waves were recorded 18 m from the initiation well in the Gombasek quarry (Fig. 4 and 5).

At the measuring station S2 bridge, the UVS 1504 apparatus was used, the components on the channels (channel no. 1 - component z, channel no. 2 - component y, channel no. 3 - component x) were measured and the effects of seismic waves 775 m from CO Gombasek quarry (Fig. 4 and 6).

The vibrographs were placed on the measuring stations so that it was possible to assess the influence of the excited technical seismicity on the assessed objects. The measured values at the individual measuring stations are given in Table 1.

Tab. 1*Measured maximum values of vibration velocities and frequency of individual stations during aperture shooting*

Opinion	Total charge weight per delay [kg]	Distance	v_x **[mm. s^{-1}]**	v_y **[mm. s^{-1}]**	v_z **[mm. s^{-1}]**	f_x **[Hz]**	f_y **[Hz]**	f_z **[Hz]**
S1 - Gombasek quarry	142.25	18 m	324,4	88,6	75,9	6,54	27,6	86,1
S2 - Building object (bridge),		755 m	0,75	0,65	0,5	2,9	0,9	2,3

Source: authors

Description of the legend of table no. : v_x - Maximum oscillation speed of particles in the environment (horizontal / longitudinal), v_y - Maximum oscillation speed of particles in the environment (horizontal / transverse), v_z - Maximum oscillation speed of particles in the environment (vertical), f_x - Maximum frequency (horizontal / longitudinal), f_y - Maximum frequency (horizontal / transverse), f_z - Maximum frequency (vertical).

We used the following formulas to process the maximum measured values in the Gombasek quarry (Tab. 2 and 3). The first is to calculate the Q value:

$$v = \left(\frac{L}{Q^{0,5}}\right) = K\left[\frac{L}{Q^{0,5}}\right]^n \quad , (1)$$

where: v - is the maximum vibration velocity (maximum component of the vibration velocity) generated by the blast [mm / s],

$L/Q^{0,5}$ - is the so-called reduced distance [$m/_{kg}{}^{0,5}$],

L - s the shortest distance of the source of shocks from their receptor [m],

Q - is the mass charge of the time step [kg],

K - the factor depends on the firing conditions, the properties of the transmission environment, the type of explosive, etc.,

N - is an indicator of seismic wave attenuation [6].

The second formula is for calculation maximum permissible charge per one time step depending on the distance for repeated aperture blasting in the Gombasek quarry:

$Q_{vmax} = L^2/L_R^2$, (2)

where:L - distance,

L_R - safety value, according to the law of attenuation of seismic waves. [6].

The individual graphic recordings are four seconds (Fig. 8 and 9). The individual measuring apparatuses were placed on the measuring stations so that it was possible to assess the influence of the excited technical seismicity on the measured object. During this measurement, we placed the ABEM Vibraloc measuring apparatus and the Gombasek quarry near the borehole boreholes, which made it possible to obtain values of the vibration velocity for a very accurate determination of the law of attenuation of seismic waves from blasting to receptors.

Channel	1	Channel	2	Channel	3
Input	Geo	Input	Geo	Input	Geo
Unit	mm/s	Unit	mm/s	Unit	mm/s
Trig level	0,15	Trig level	0,3	Trig level	0,3
Pk	324,364	Pk	95,219	Pk	88,602
Diff m/s2	227	Diff m/s2	27,5	Diff m/s2	32,8
Integ um	51,40	Integ um	2730	Integ um	15000
Frq(zx) Hz	86,1	Frq(zx) Hz	6,54	Frq(zx) Hz	27,6

S	- 400 0 400	- 400 0 400	- 400 0 400

Fig.8 *Graphic recording of individual wave components (vert-z, rad-x, trans-y) at the MS1 station - Gombasek quarry at a distance of 18 from the CO initialization well*
Source: authors

UNIT	1 mm/s	2 mm/s	3 mm/s	4 mm/s
TRIG LEVEL	0,4	0,4	0,4	OFF
REG LENGTH	4 s			
PEAK	0,5	0,65	0,75	0,48
DIFF	0,1	0,1	0,1	0
INTEG	16,4	19,3	25	12,1
FRQ Hz	2,3	0,9	2,9	2,7
VECTOR MAX	0,85 at 0,227 s			
TIME SCALE	0,5 s/div			
GRAPH SCALE	1,25 mm/s 1	1,25 mm/s 2	1,25 mm/s 3	1,506 mm/s 4

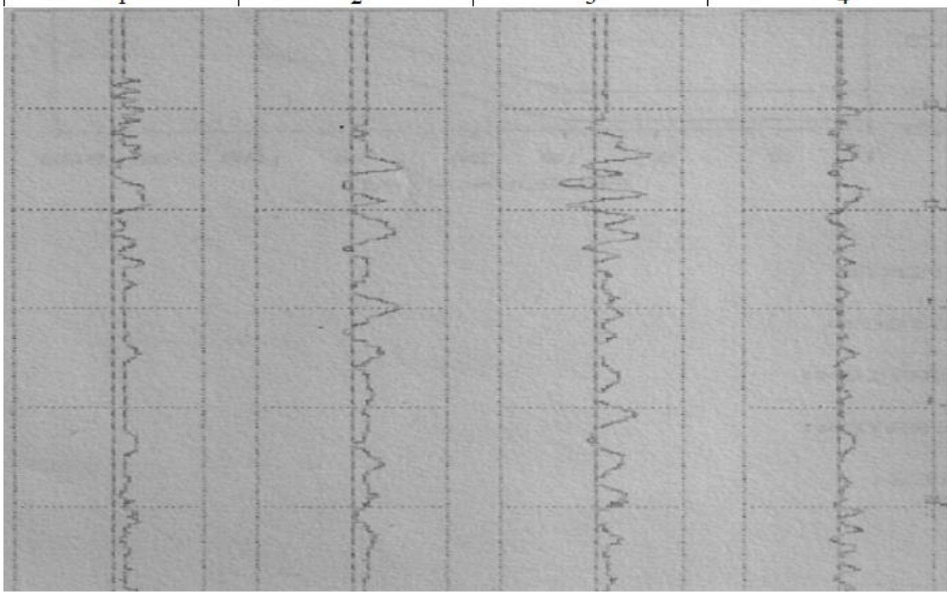

Fig.9 *Graphic recording of individual wave components (1-z, 2-x, 3-y) at the S2 stand - bridge at a distance of 755 m from the initial borehole in the Gombasek quarry*
Source: authors

3 CONCLUSIONS

Based on research conducted in the Gombasek quarry, it was found that the measured values from the measurement of seismic effects of CO, which was performed in the Gombasek quarry, confirmed that the measured values (see Tab. 1) did not exceed the values set by the valid Slovak technical standard STN EN 1998-1 / NA / Z1 (Seismic load of building structures) namely: vd <3 mm / s for frequencies less than 10 Hz and for foundation soil type "b" (see Tab. 2) [17].

Tab. 2 *Measured maximum values of the components of the oscillation velocity of the aperture*

Maximum particle velocities for the frequency area			Level of damage	Class of resistance of an object	Type of foundation
f_k< 10 Hz	10 Hz <f_k< 50 Hz	f_k> 50 Hz			
Up to 3	3 to 6	6 to 5	0	A	a
3 to 6	6 to 12	12 to 20	0	A	b,c
				B	a

Source: authors

Description of the legend of table no. 2:

- Legend class of building resistance: A - Old buildings not conforming with regulations, ruins, historical buildings from unworked stone or bricks with arches cross-beams, girders and flat arches above the premise of the ground floor and basement : stone and brick monuments and fountains, buildings with extensive moulding decorations, buildings with special preservation and conservation status. B - Conventional brick buildings detached or terraced houses with ground area up to 200m three storeys at the most.
- Legend class of soil: Category a - Includes rocks of all classes with the design strength Rdt ≤ 0,15 Mpa, underground water level at the constant depth of 1,0 to 3,0 m below the footing bottom. Category b - Includes rocks of all classes with design strength Rdt ≤ 0,15 Mpa, underground water level at the constant depth of more than 3,0 m. This category also includes rocks of all classes with design strength Rdt ≤ 0,15 Mpa if the underground water level is constantly at the depth of 1,0 to 3,0 m below the footing bottom, Category c - includes rocks of all classes with the design strength Rdt ≥ 0,15 Mpa, underground water level at the constant depth of more than 3,0 m below the footing bottom. This category also includes rocks of all classes with design strength Rdt ≤ 0,6 Mpa if the underground water level is constantly at the depth of more than 1,0 m [17].

The frequency analysis of the individual components of the vibration velocity at the measuring stations showed that the blasting energy acting on the object under consideration had a frequency of less than 10 Hz (Figs. 9 and 10). This means that when seismic waves pass through the ground of the object under consideration, these waves act on the object under consideration with greater energy than at frequencies above 10 Hz. This was the reason for determining the allowable oscillation speed of 3 $mm.s^{-1}$.

The measured maximum values of seismic effects generated by aperture blasting, which was performed in the Gombasek quarry, are in Table 3. These values served as a basis for determining the law of seismic wave attenuation in the Gombasek quarry [17-19].

Tab. 3 *Measured maximum values of the components of the oscillation velocity of the aperture*

L [m]	Q [kg]	$L_R = L/Q^{0,5}$ [m/kg^{0,5}]	v_x[mm/s]	v_y[mm/s]	v_z[mm/s]
29,6	142,25	2,46	324,4	88,6	75,9
755	142,25	62,9	0,75	0,65	0,5

Source: authors

Based on the data from Table 3, a graphical dependence of the maximum components of the oscillation velocity on the reduced distance LR for aperture blasts was constructed. The graph in FIG. 10 represents the so-called seismic wave attenuation law for the Gombasek quarry, in which the value Q was calculated from the formula 1.

From the law of attenuation of seismic waves, it is possible to determine the size of the charge for a particular receptor at a known distance, so that the maximum values of individual components of the oscillation velocity do not exceed the specified maximum oscillation velocities [18-19].

On the graph (Fig. 10) the measured values of vibration velocities in the Gombasek quarry (points on the left side) and on the bridge structure in the vicinity of the Gombasek quarry at CO (points on the right side) are plotted in blue. The red line represents the limit of the maximum permitted vibration speeds for the foundation soil type "b" (the groundwater level is more than 3 m below the surface level).

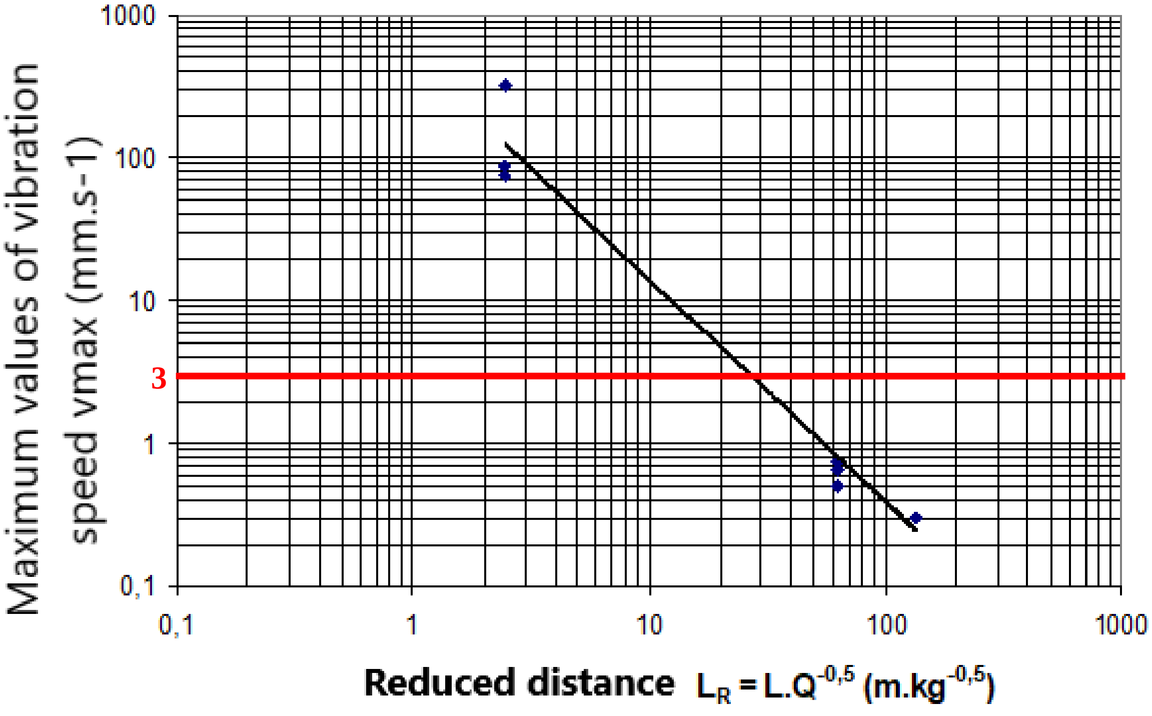

Fig.10 *Graphical dependence of the maximum components of the oscillation velocity on the reduced distance during aperture blasting in the Gombasek quarry - the law of attenuation of seismic waves. The red line indicates the maximum safe allowed vibration speed for the vicinity of the Gombasek quarry*

Source: authors

These measured values are safe from the point of view of seismic safety for the building. Based on the measured and calculated values during operational blasting in the Gombasek quarry, the law of seismic wave attenuation was determined, on the basis of which it is possible to use the maximum permissible charge per timing step depending on the distance for repeated aperture blasts in the Gombasek quarry (see Tab. No. 4). For calculation maximum permissible charge per one time step depending on the distance for repeated aperture blasting in the Gombasek quarry, we used formula 2.

Tab. 4 *Use of the maximum permissible charge per one time step depending on the distance for repeated aperture blasting in the Gombasek quarry*

Distance	**L**	**L_R**	**Maximum allowed charge per timing stage**
500 m	500	40	156 kg
600 m	600	40	225 kg
700 m	700	40	306,25 kg
750 m	750	40	351 kg
800 m	800	40	400 kg
900 m	900	40	506,25 kg
1000 m	1000	40	625 kg

Source: authors

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